Rebekado !

Chapter 1

Bipolar Junction Transistors

A transistor is a semiconductor device used to amplify and switch electronic signals and power. It is composed of a semiconducting material with at least 3 terminals for connection to an external circuit. A voltage (or current) applied to one pair of terminals Charges the current flowing through another pair of terminals As a result, the controlled (output) power of a transistor can be much more than the (input) power. Hence the transistor can amplify an input signal

Broadly speaking, there are two types of transistors.

1. Bipolar junction transistors (BJT)
2. Field-effect transistors

BJT was developed by Dr William Shockley and his team in 1947 at Bell laboratories

A BJT consists of two PN junctions. The junction are formed by switching either P-type or N type semiconductor layers between a pair of opposite types as shown in fig 1

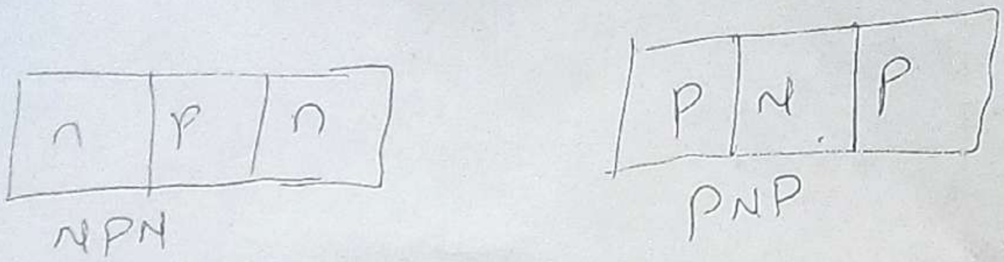

fig 1.1 BJT

The BJT has essentially three region know as emitter, base, and collector. These three region are provided with terminals that are labelled E (emmitter), B (base) and C (collector).

i Emitter: This is a region situated in one side of transistor, which supplies charge carriers (h-le-ele) to the other two regions. The emitter is a heavily doped region

ii Base. It is the middle region that forms two PN junctions in the transistor. The base of transistor is thin, ~~and~~ as compared to the emitter and is a lightly doped region.

iii. Collector This is the region ~~that forms t~~ situated in the other side of transistor The collector of ~~a~~ transistor is always larger than the emitter and base of a transistor. The doping level is always intermediate betw the heavily doped emmitter and lightly dope base ~~of the BJT~~

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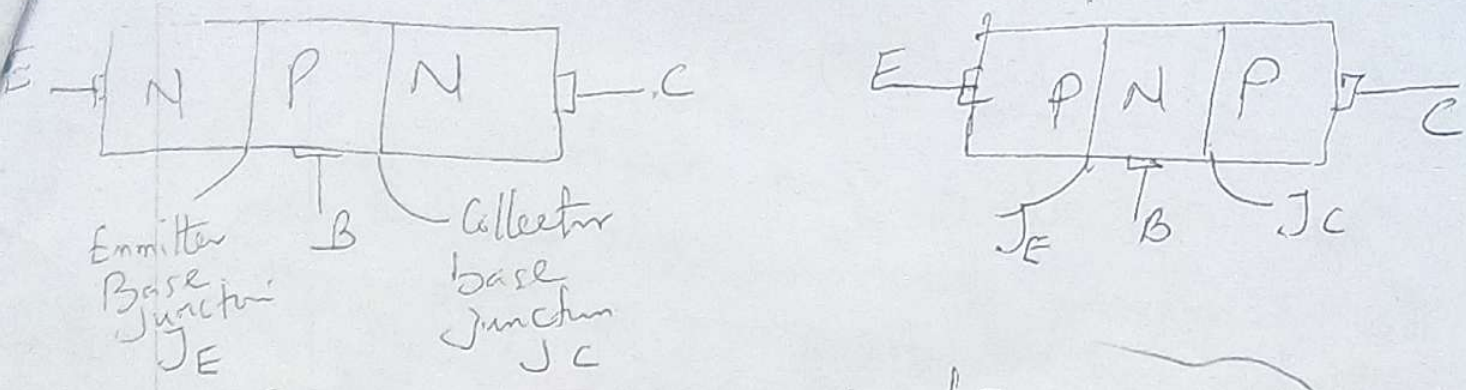


fig 2 : BJT Construction

BJT Symbols

Fig 3 shows the circuit symbol of NPN and PNP transistors.

The PNP transistor is a complement of the NPN transistor. Thus in NPN transistor, the major carriers are free electrons, while in PNP transistor these are holes.

1.2 BJT Biasing

The application of a suitable dc voltages, across the transistor terminals, are called biasing. Each junction of a transistor may be forward biased or reverse biased independently. The following are the three differents ways of biasing a transistor

i. Forward active: In this mode, the emmitter base junction of the BJT is forward biase and the collector base junction is reverse biased. In this situation, the -ve terminal of a battery is connected to N side and positive terminal to P-side

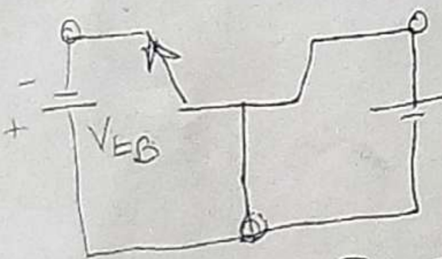


fig 1.3. Forward Active

ii Saturation: In this mode, both the emmitter base and the collector base junctions of a transistors are forward biased. In this case, the transistor has a very large value of current. The transistor is operated in this mode when it is used as a closed switch

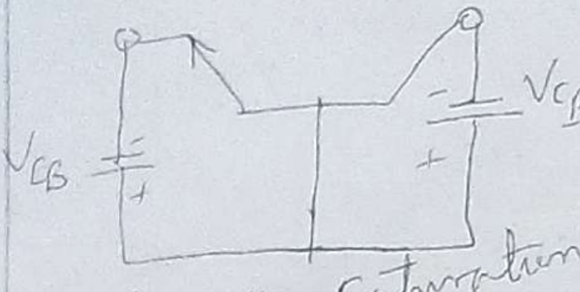
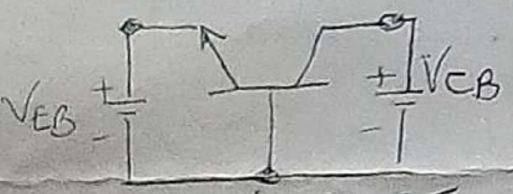


fig 1.4 Saturation region

iii) <u>Cut off R</u> In this mode, both the emitter-base and the collector base junction are reversed biased. In this case the transistor has practically zero current. The transistor is operated in this mode, when it is used as an open switch



cut off ~~reg~~

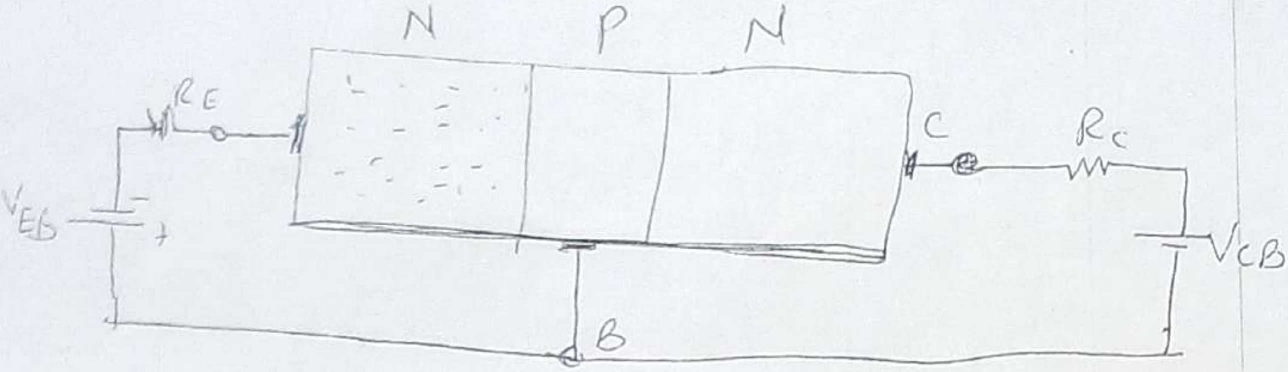
fig 1.5 cutt off

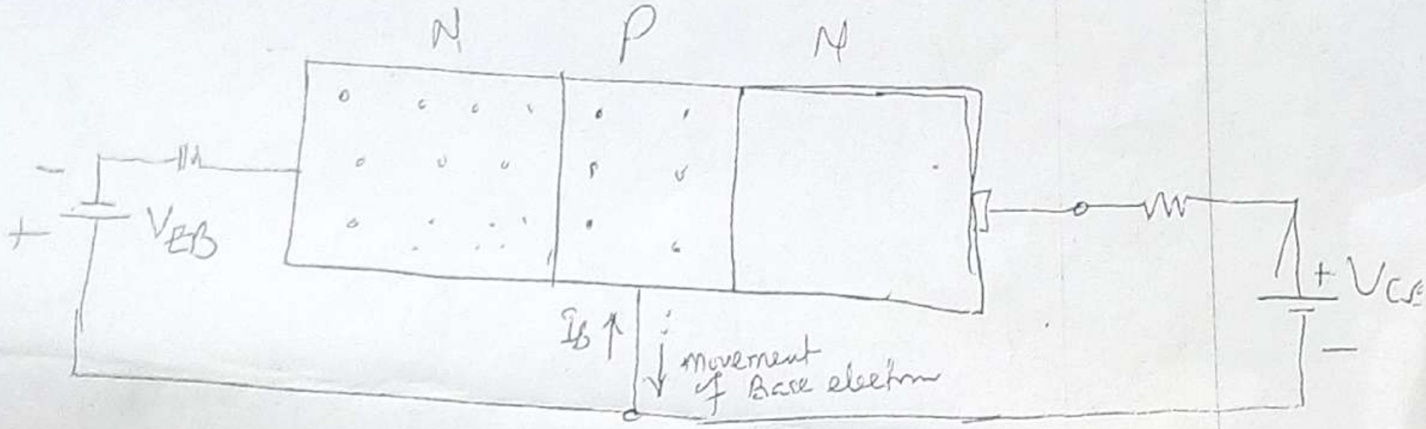
	mode	Junction Biasing Emitter Base	Collector Base
1	Active	Forward	Reverse
2	Saturation	Forward	Forward
3	Cut-off	Reverse	Reverse

1.3 <u>Operation of NPN BJT</u>

The figure below (Fig 1.6) shows an NPN transistor in the active mode. The EB is forward biased only if V_{EB} is greater than barrier

barrier potential which is 0.7V for silicon, and 0.3V for germanium transistors.





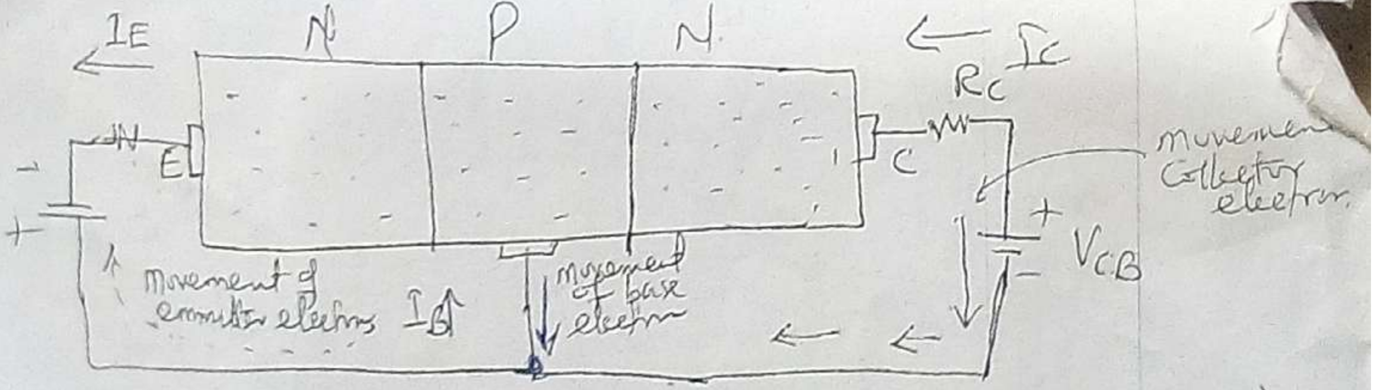


Fig 1.6 Movement of electrons in forward biased NPN transistor

The forward bias on the EB junction causes free electrons in the N-type emmitter to flows towards the base region. This constitute the emmitter current. Electron upon getting to the base region, combine with the holes in the base to constitute base current Ib. However, because the base is thin compared with the the emmitter and also less doped, not all the electron will have holes to combine with. Thus, most of the electrons will diffuse to the collector region and constitute the collector current(I_c). This collector current is also call injected current because this current is produced due to electrons injected from the emmitter region

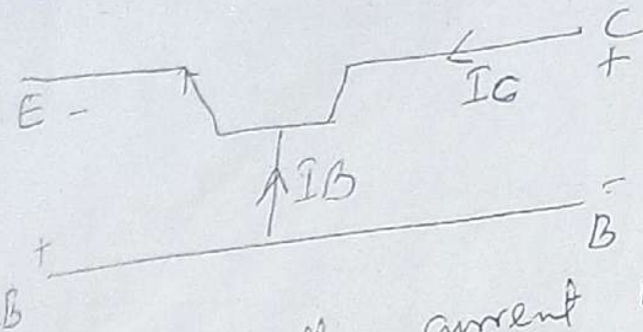
It is interesting to know that there is another component of collector current due to the thermally generated carriers. This is called the reversed saturation current and quite small

~~It~~ The following however should be noted.

~~Ie~~ i The emmitter current of a transistor consist of two components i.e the base current and collector current. The base current is about 2% of the emmitter current, while collector current is about 98% of the emmitter current

ii The collector current is mainly due to the electron injected from the emmitter. However, there is another small component of collector current due to thermally generated carriers.

~~iii~~



The emmitter current is the sum of the collector and base currents.

$I_E = I_B + I_C$.

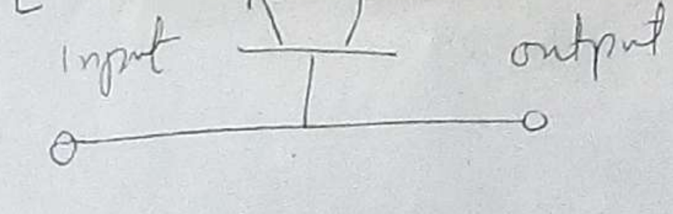
Since the base current is very small, therefore

$I_E \simeq I_C$.

1.4 BJT Circuit configuration

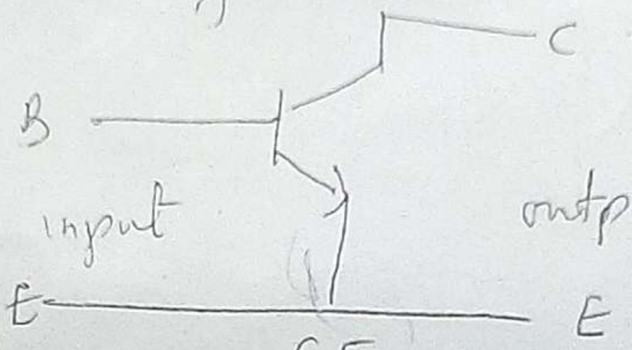
The transistor has three terminals. However, when connected in ~~the~~ a circuit, we require four terminals two for input and two for output. This difficulty is overcome by using one of the three terminals as common terminals. This leads to three different configurations.

1. Common-base (CB) connection. In this configuration, the transistor is connected with the base as a common terminal.



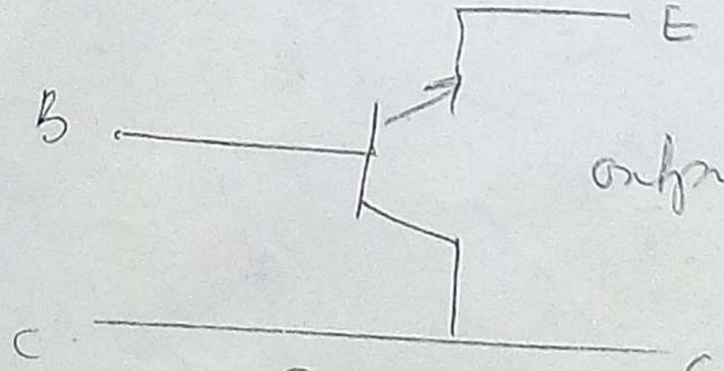
② Common emmitter connection

In this configuration, the transistor is connect with the emmitter as a common terminal. This is one of the most commonly used connections of a transistor.



CE

③ Common collector (CC). In this configuration, the transistor is connected with collector as a common terminal. The input is applied between the base and collector terminals



CC connection

1.5 Current Gain of BJT in CB configuration

For a transistor in ~~NPN~~ a CB Configuration the emitter current is the input current and the collector current is the output current. The ratio of the transistor output current to the input current is the current gain of a transistor.

(a) Common base dc current gain (α) (h_{FB}) This is the ratio of collector current I_C to emitter I_E

$$\alpha = I_C / I_E \quad \text{and} \quad I_C = \alpha I_E$$

$$I_E = I_B + I_C$$

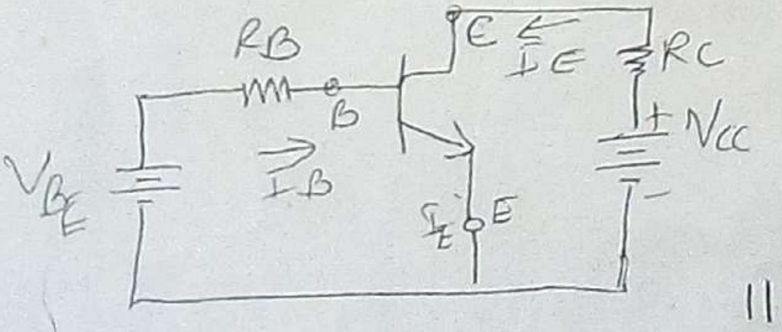
$$I_B = I_E - I_C = I_E - \alpha I_E = (1-\alpha) I_E$$

(b) Common base a.c current gain (α_0).

This is the defined as the ratio of small change in collector current (ΔI_C) to a small change in emitter in emitter current ΔI_E for a constant V_{CB}

$$\alpha_0 = \Delta I_C / \Delta I_E$$

1.6 Current Gain of BJT in CE mode



i Common-emitter dc current gain (β).

This is the ration of collector current I_c to the base current I_B and des-pnoted as β, β_{dc}, h_{FE}

$$\beta = I_C / I_B$$

ii Common emitter ac current gain β_o: This is the ration of small change in collector current ΔI_C to the small change in base current ΔI_B for a constant collector-to-emitter voltage V_{CE}

$$\beta_o = \Delta I_C / \Delta I_B$$

1.7 Relationship between current gain α & β.

$$I_E = I_B + I_C$$

Divide by I_C.

$$I_E / I_C = I_B / I_C + 1$$

Since $I_C / I_E = \alpha$ and $I_C / I_B = \beta$, therefore

$$\frac{1}{\alpha} = 1/\beta + 1 = \frac{1+\beta}{\beta}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

Also, $\alpha(\beta+1) = \beta$

$$\alpha \cdot \beta + \alpha = \beta$$

$$\alpha = \beta - \alpha \cdot \beta = \beta(1-\alpha)$$

$$\beta = \alpha / 1-\alpha$$

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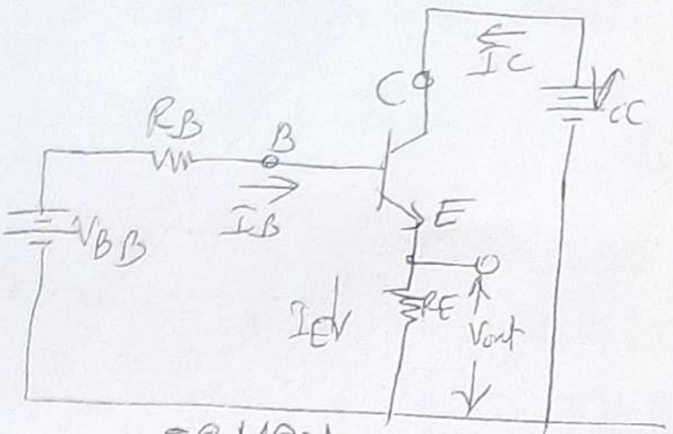
1.8 Current Gain of a Bipolar Junction Tr... in CC configuration.



CC NPN

The V_{BB} forward-biases the emitter-base jn and V_{CC} reverse-biases the CB junction of the transistor. Here the collector is not at dc ground. But it is at ac ground. It is due to the fact, that the voltage of dc supply source (V_{CC}) has zero resistance to an a-c signal. An external resistor R_E is connected from the emitter to ground. The o/p of the circuit is taken across the resistor R_E.

It may be noted that in a common-collector transistor circuit, the input current is the base current (I_B) and the o/p current is the emitter current (I_E)

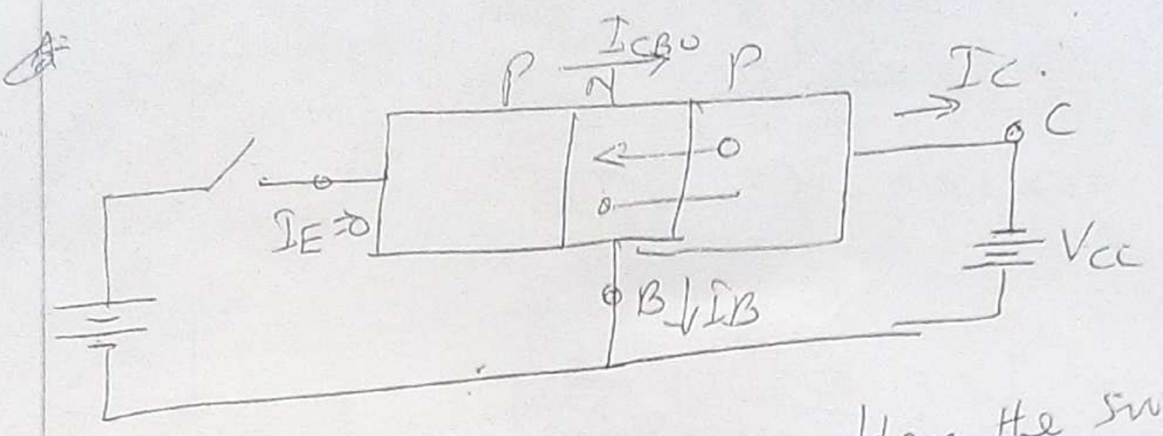
$\therefore$ Common-collector current gain is given by the relation

$$= \frac{I_E}{I_B} = \frac{I_E}{I_C} \times \frac{I_C}{I_B} = \frac{1}{\alpha} * \beta$$

Since $\alpha = \beta/1+\beta$.

$$= \frac{\beta}{\beta/(1+\beta)} = 1+\beta$$

1.9 Leakage Current in a Common-Base BJT



Consider the figure above when the switch is closed, V_{EE} will inject the holes to the base region and the V_{CC} will attract the majority of the hole to constitute collector current.

when the switch is opened, the emitter is disconnect from the base and no emitter current, no base current & no collector current. It may however be noted that the CBJ is forward biased due to the thermally generated minority carriers. The minority carriers diffuse across the CB junction and hence produce a certain value of current known as leakage current. This current is called the leakage current from collector to base with emitter open and is designated by I_{CBO}. It is also known as the reverse saturation current I_{CO}.

therefore the total current in a transistor consist of

1. The injected current αI_E
2. The reverse saturation current I_{CO}

therefore $I_C = \alpha I_E + I_{CO}$.

$$\alpha = \frac{I_C - I_{CO}}{I_E}$$

Since $I_E = I_B + I_C$

we have $\alpha = \frac{I_C - I_{CO}}{I_B + I_C}$

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}$$

For the case of BJT in CE configuration,

we have $I_{CEO} = I_{CO} + \beta \cdot I_{CO} = (1+\beta) I_{CO}$

The total current $I_C = \beta I_B + I_{CEO} = \beta I_B + (1+\beta) I_{CO}$

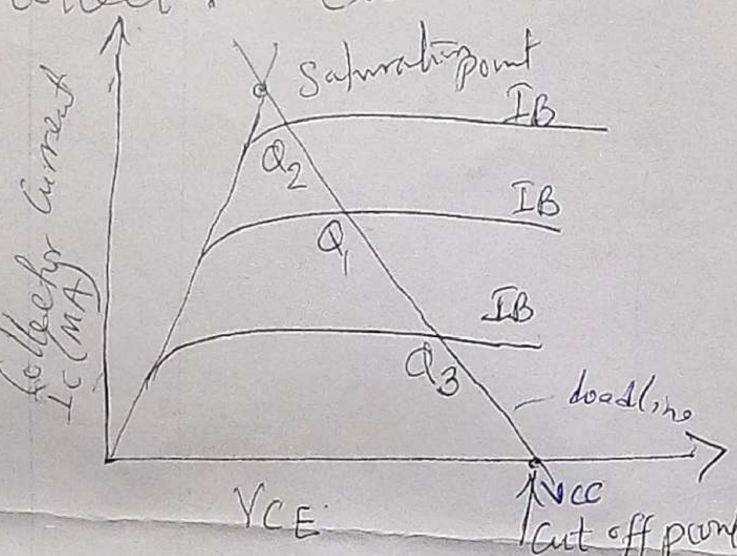
1.10 BJT Biasing & stabilization

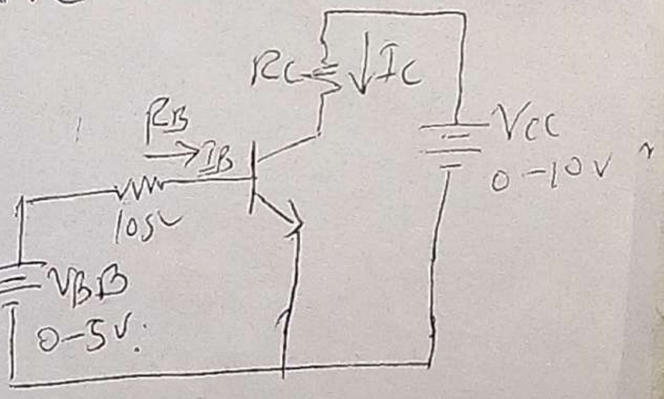
BJT biasing deals with setting a fixed level of the current which should flow through the transistor with a desired fixed voltage drop across the transistor. Usually, the ~~collector current~~, base current, collector-to-emitter voltage and the base-to-emitter voltage are the currents & voltages, which are require to be set by the biasing circuit. The proper setting of these allow a transistor to amplify the weak signal faithfully

II The D.C Operating Point and load line

The DC operating point of BJT are the value of currents and voltages at which the transistor operate normally.

The DC load line is usually obtained from the collector characteristic curve.





The dc load line gives information about two important points

① The load line intersects the horizontal axis at a point marked Vcc. This is a point called transistor cut off point or lower end of the load line. At this end, the value of base current is zero and also the value of the collector current.

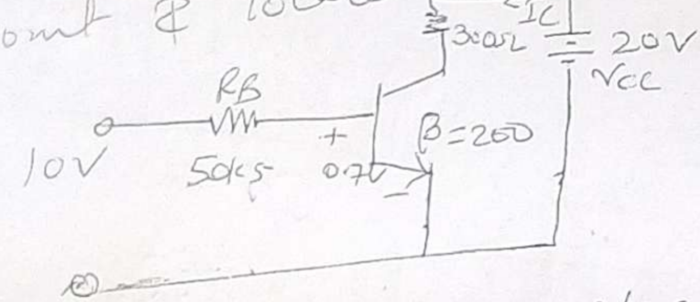
The load line intersect the vertical axis at a point marked Ic which is called the transistor saturation point or upper end of the load line. Here the ~~too~~ Ic is maximum and VCE is very small.

The DC load line can be drawn by calculating $I_{C\,saturation}$ and V_{CE} cut off as

$$I_{Csat} = V_{CC}/R_C \quad \text{and} \quad V_{CEsat} = V_{CC}$$

Example 1.0

Find the upper & lower ends of the d.c load line for the circuit shown below. Also find the Q point & locate it on the dc load line.



$V_{CC} = 20V$, $R_C = 300\Omega$, $V_{BB} = 10V$, $R_B = 50k\Omega$

$$I_{Csat} = V_{CC}/R_C = 20/300 = 66.7\,mA$$

$$\cancel{V_{CEsat}} \; V_{CE(cutoff)} = V_{CC} = 20V$$

Apply KVL to the base loop we have

$$I_B R_B + 0.7 = 10V$$

$$I_B = \frac{10 - 0.7}{50 \times 10^3} = 0.186 \times 10^{-3} A$$

$$I_C = \beta I_B = 200 \times 0.186 \times 10^{-3} A = 37.2 \times 10^{-3} A$$

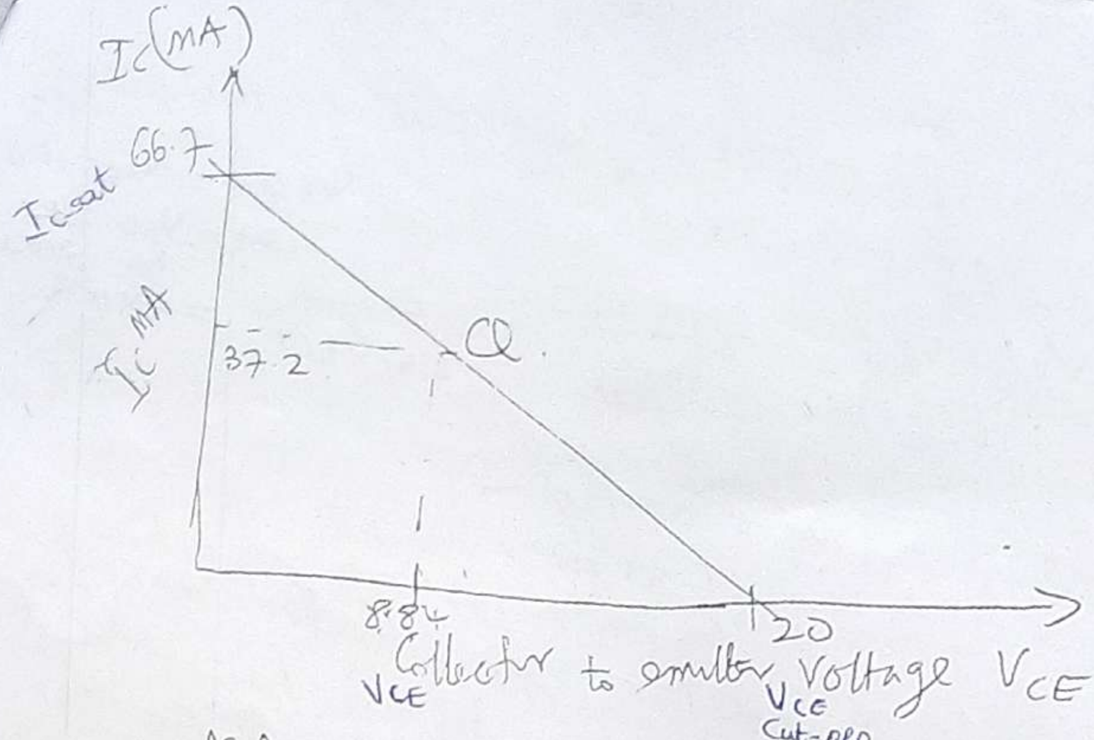
$$V_{CC} = I_C R_C + V_{CE}$$

$$\therefore V_{CE} = V_{CC} - I_C R_C$$

$$= 20 - 37.2 \times 10^{-3} \times 300$$

$$= 20 - 11.16 = 8.84\,V$$

Example
22.8
22.12
22.13
22.20



Stability factor.

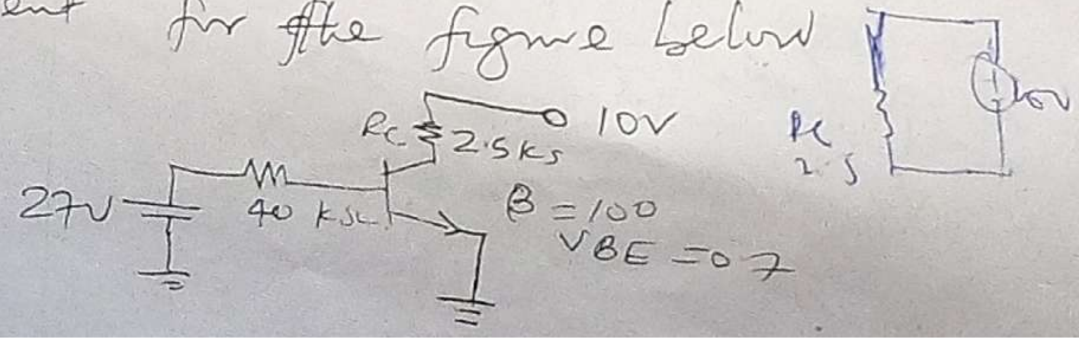
This is the rate of change of collector cur with respect to the reverse saturation current keep-p the common-emitter current gain β and base current I_B as constant

$$S = \frac{dI_C}{dI_{CO}}$$

For BJT at CB configuration, the stability factor is 1 while for CE configurat

$$S = 1 + \beta$$

Example Calculate the value of collect current for the figure below



$V_{BB} = 2.7V$, $R_B = 40k\Omega$, $V_{CC} = 10V$, $R_C = 2.5k$

$\beta = 100$, $V_{BE} = 0.7V$

$V_{CE(cut\,off)} = V_{CC} = 10V$

$I_{Csat} = \frac{V_{CC}}{R_C} = \frac{10}{2.5k\Omega}$
$= 4 \times 10^{-3}$

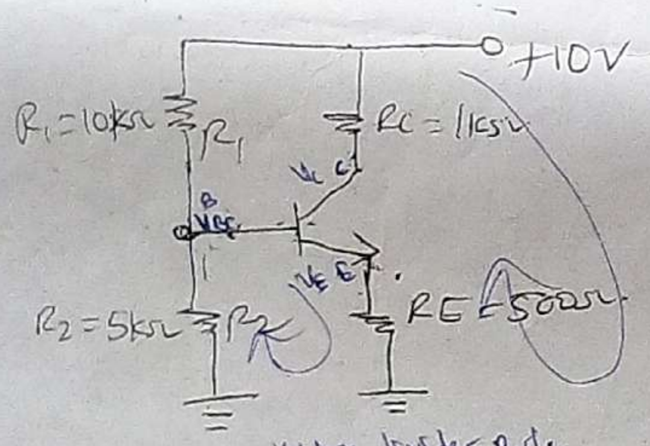
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{27 - 0.7}{40K} = \cancel{50\mu A} \; 6.57 \times 10^{-4}$$

$$I_C = \beta I_B = \cancel{8} = \cancel{5mA} \; 6.57 \times 10^{-2}$$

Example

Determine the value of collector current and V_{CE} for the voltage divider bias circuit shown below. Assume $V_{BE} = 0.7V$ & $\beta = 100$

$V_{CC} = 10V$, $R_C = 1k\Omega$, $R_1 = 10k\Omega$, $R_2 = 5k\Omega$,
$R_E = 500\Omega$ $V_{BE} = 0.7$, $\beta = 100$.



voltage divider Rule

$$V_B = V_{CC}\left(\frac{R_2}{R_1 + R_2}\right) = 10\left(\frac{5}{10+5}\right) = 3.33$$

$$V_E = V_B - V_{BE} = 3.33 - 0.7 = 2.63$$

$$I_E = V_E/R_E = \frac{2.63}{500} = 5.26 \times 10^{-3} A$$

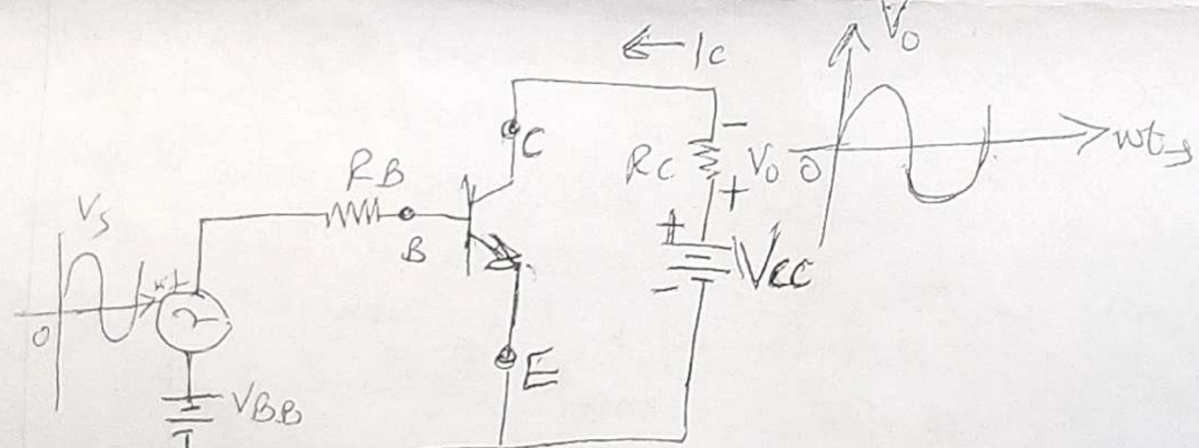
$$I_C \cong I_E = 5.26mA$$

$$V_{CE} = V_{CC} - I_E(R_C + R_E) \left\{ V_{CC} - I_C R_C - I_E R_E \right)$$
$$= 10 - 5.26 \times 10^{-3}(10^3 + 500) = 2.11V$$

CHAPTER 2: Single Stage BJT Amplifiers

An amplifier can be defined as a device which produces a larger electrical output characteristic than that of the input parameters. The amplifier in which the instantaneous output supply is directly proportional to the corresponding input signal, is called a linear amplifier. On the other hand, an amplifier in which the output is not directly proportional to the input is called a non-linear amplifier.

Transistor as an Amplifier



Consider the NPN transistor above acting as an amplifier. Let us assume there is no a.c supply source. Under this condition a d.c collector flows through the collector load (RC). This is called zero signal current or quiescent current. Now, let an a.c signal be applied between the EB junction. During the period of the +ve half cycle of the input signal, the forward-bias across the emitter base junction is increased. More electrons are injected into the base, & reach the collector, which increase the current. The increased I_C produced greater voltage drop across R_C. During the negative half cycle, the forward-bias across the EB junction reduced. Due to this, the collector-current decreases which in turn reduce voltage drop across R_C.

<u>Different mode of Transistor Amplifier</u>

2.1. Common-Emitter Transistor Amplifier

The figure below shows a CE amplifier. The input ac signal is applied across the base-emitter terminals and the output across the collector-emitter. The EB junction of a transistor is biased by V_{BB}. The CB junct reversed biased by V_{CC}. The output is determined by the V_{CC} supply along side R_B and R_C. The capacitor are called blocking capacitors. Each acting like a switch. Because of this, a blocking capacitor block d.c & pass a.c. This isolate d.c bias from a.c signal in the circuit. ~~The~~ C_1 connect the a.c signal source to the circuit of the amp. C_2 connect circuit to its load resistance

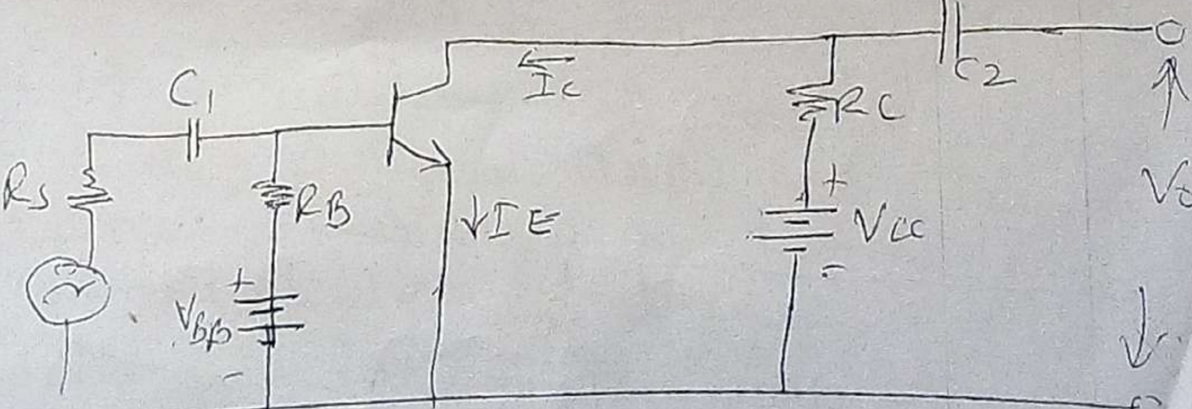


Fig 2.1

All the voltages and currents of a transistor are indicated by the instantaneous total (i.e dc+ac)

Thus

$$i_B = I_B + i_b \quad , \quad i_C = I_C + i_c$$

$$v_{BE} = V_{BE} + v_{be} \quad , \quad v_{CE} = V_{CE} + v_{ce}.$$

Study - Analysis of Transistor Amplifier

~~There~~ we analysis transistor in order to determ the a.c and d.c currents, voltage, input and output resistance of an amplifier. To do this, we adopt two ways

i D.C Analysis:-

In DC analysis, first, all the a.c sources are reduced to zero, i.e voltage source is replaced by a short circuit and a current source replaced by an open circuit

All ~~op~~ capacitor are also open as they block dc. The remain circuit is called d.c equivalent circuit that can be used to determ d.c parameters.

ii AC analysis.

In doing this, all d.c sources are reduced to zero and all capacitors are shorted. Then the transistor is replaced by ~~the~~ its small signal equivalent circuit.

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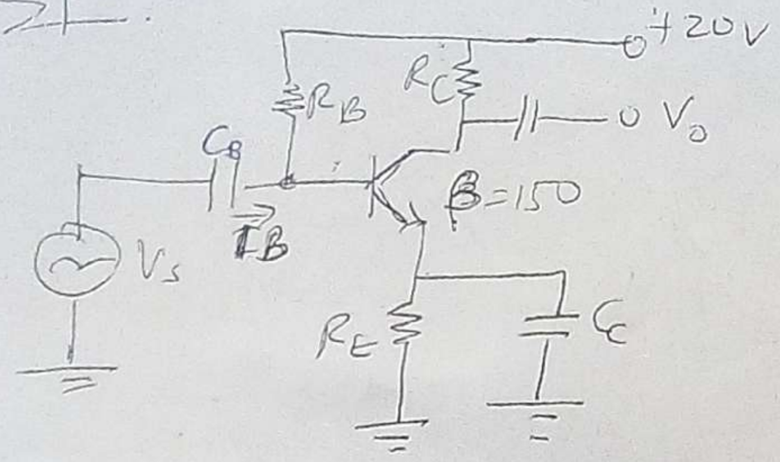
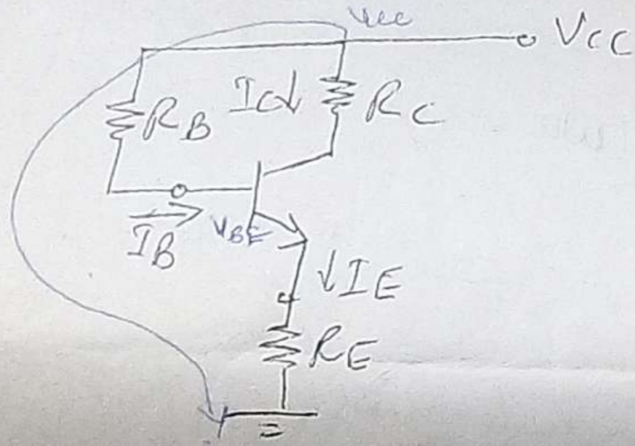
Example.

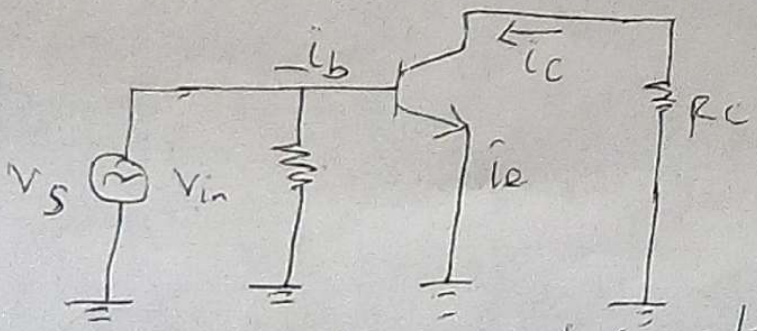


⇒ DC equivalent cc



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = V_{CC}/R_B.$$

$$I_C = \beta I_B \quad , \quad I_E \simeq \beta \cdot I_B$$



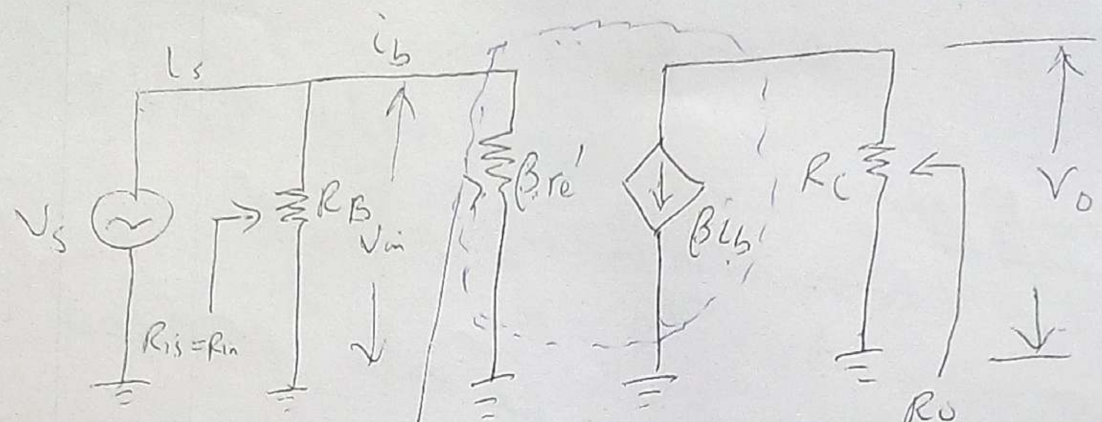
AC equivalent cct

Preliminary.

~~Amplifier~~

This equivalent circuit is used to analyse the amplifier

CE amplifier parameter



$R_i = R_{in}(\text{base})$.

study

Input Resistance: This is the resistance look-in directly into the base and is given by the ratio of base voltage to base current. Therefore

Input resistance

r_e = AC resistance $= \frac{25}{I_E}$

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

$$V_{in} = \beta \cdot r'e \cdot i_b$$

$$\therefore \quad R_i = \frac{\beta \cdot r'e \cdot i_b}{i_b} = \beta \cdot r'e$$

and the input resistance of the amplifier stage

$$R_{is} = R_B // (\beta \cdot r'e)$$

$$R_B >> \beta \cdot r'e$$

$$\therefore \quad R_{is} = \beta \cdot r'e = R_i$$

r_e – emitter resistance

It is a constant

~~22~~ 24

output resistance: This is the resistance, look into collector, and is approximately equal to the collector resistance (R_C).

$$R_o = R_C$$

Current gain: This is the ratio of collector current i_c to the base current (i_b).

$$A_i = i_c/i_b = \beta$$

voltage gain: This is the ratio of output voltage v_o to the input voltage (v_{in}) - since the output voltage is the same as collector voltage and input voltage is the same as base voltage, ∴ it is known as voltage gain from base to collector

$$A_V = \frac{v_o}{v_{in}}$$

we also know that the input voltage

$$v_{in} = i_b \cdot \beta \cdot r_e'$$

& the output voltage

$$v_o = i_c \cdot R_C = \beta \cdot i_b \cdot R_C$$

voltage again,

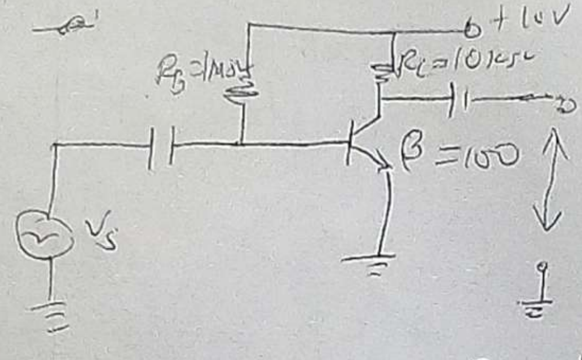
$$A_V = \frac{\beta \cdot i_b \cdot R_C}{i_b \cdot \beta r_e'} = \frac{R_C}{r_e'}$$

Power gain: It is product of current gain (A_i) and voltage gain (A_V)

Power gain $= A_p = A_i \cdot A_V = \beta \cdot R_C/r_e'$

in decibels $G_p = 10 \log_{10} A_p$

Example: The figure below shows a common emitter amplifier with a base-bias arrangement. Determine the values of (a) input resistance looking into the base (b) input resistance of the stage (c) output resistance and (d) voltage gain



$V_{CC} = 10V$, $R_C = 10k\Omega$, $R_B = 1M\Omega$, $\beta = 100$

(a) Input resistance looking into the base

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{1 \times 10^6} = 9.3 \times 10^{-6} A$$

$$I_C = \beta I_B = 100 \times 9.3 \times 10^{-6}$$
$$= 0.93 mA$$

$$\therefore I_E \simeq I_C = 0.93 mA$$

a.c resistance of emitter diode

$$r'_e = \frac{25}{I_E} = \frac{25}{0.93} = 26.9\Omega.$$

$$\therefore R_i = \beta \cdot r'_e = 100 \times 26.9 = 2.69k\Omega$$

(b) Input resistance of the stage

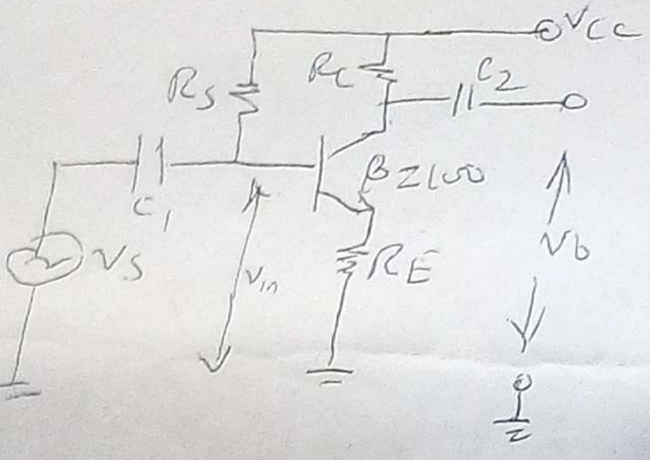
$$R_{is} = R_B // (\beta \cdot r'_e) = 1 \times 10^6 // 2.69 \times 10^3$$
$$= 2.69 k\Omega$$

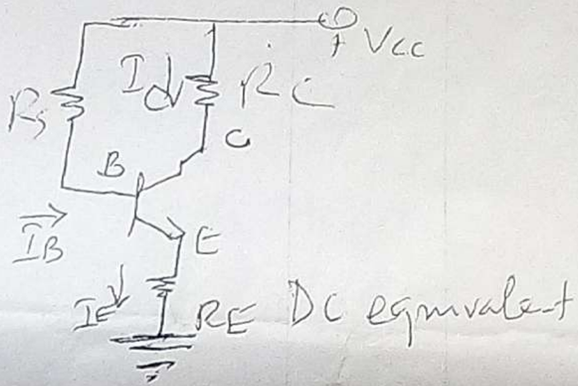
Ouput resistance

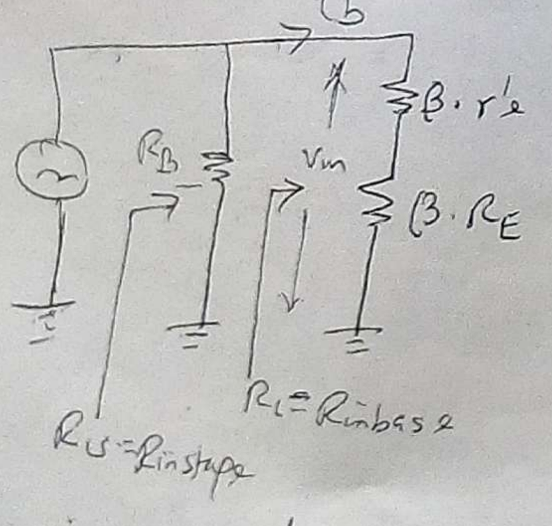
$$R_o = R_C = 10\,k\Omega.$$

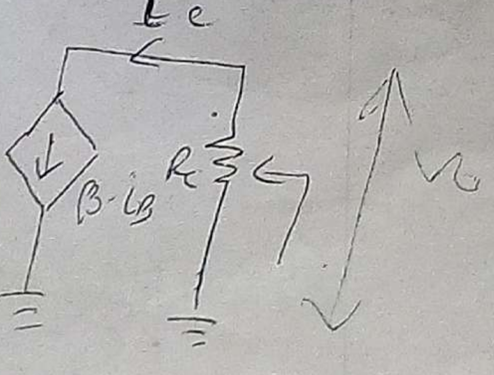
Voltage gain $A_v = \frac{R_C}{r_e'} = \frac{10\times10^3}{26.9} = 372.$

<u>Effect</u> of emitter feedback resistor on common Emitter Amplifier parameter









for the figure above,

$$I_C = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta} = \frac{V_{CC}}{R_E + R_E/\beta}$$

$R_i = \beta(r_e' + R_E)$

If $R_E >> r_e'$, then $R_i \simeq \beta R_E$

$R_{is} = R_B \| (\beta \cdot R_E) = R_B \| R_i$

$v_{in} = i_b \cdot \beta(r_e' + R_E) = i_b \cdot \beta \cdot R_E$

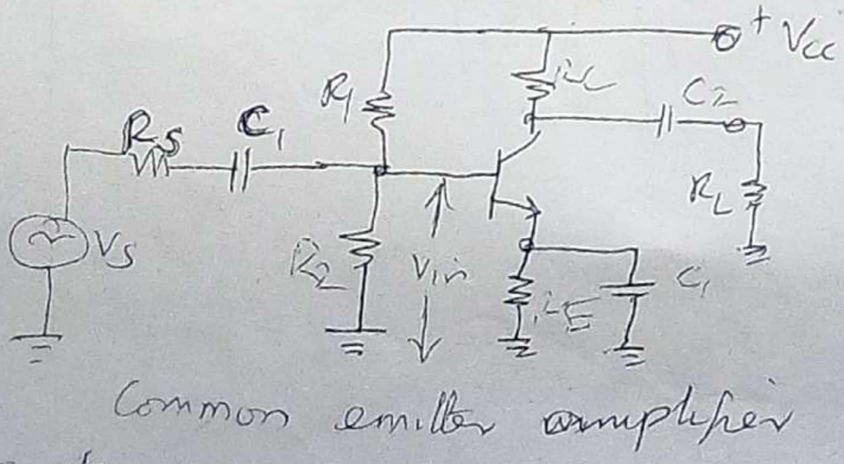
$v_o = i_c \cdot R_c = \beta \cdot i_b \cdot R_C$

$A_v = V_o / V_{in} = \dfrac{\beta \cdot i_b \cdot R_C}{i_b \cdot \beta \cdot (r_e' + R_E)} = \dfrac{R_C}{r_e' + R_E}$

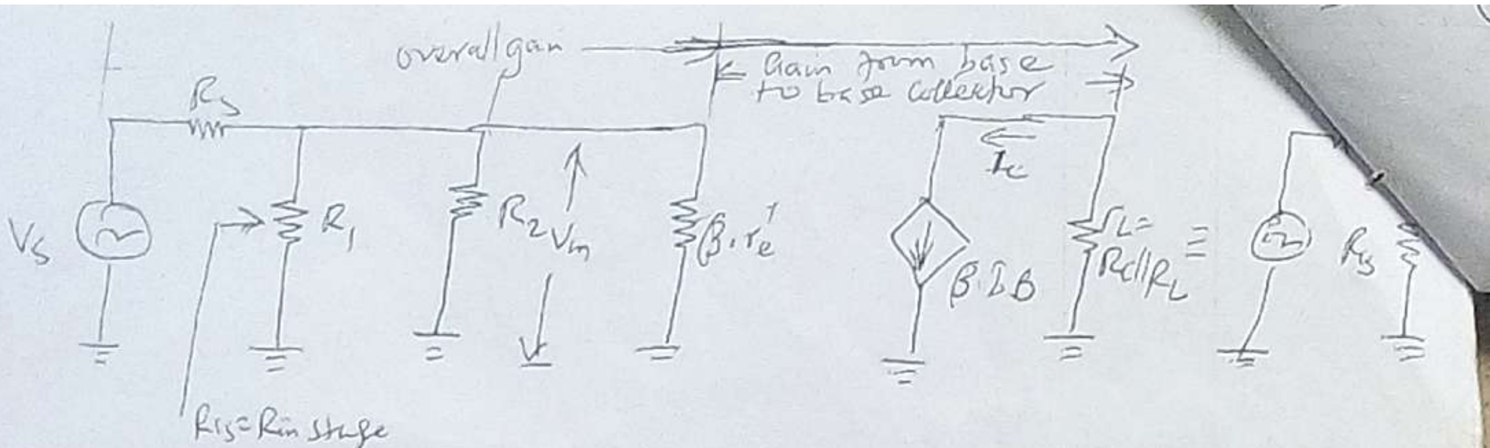
$= R_C / R_E$

$A_V = \dfrac{R_C}{R_E}$ ...

Effect of signal source Resistance on Common Emitter Amplifier parameter



Common emitter amplifier with signal source resistance



$$R_{is} = (R_1 \| R_2 \| (\beta \cdot r'_e))$$

$$V_{in} = \left(\frac{R_{is}}{R_s + R_{is}}\right) V_s$$

If $R_{is} >> R_s$

$$V_{in} = V_s$$

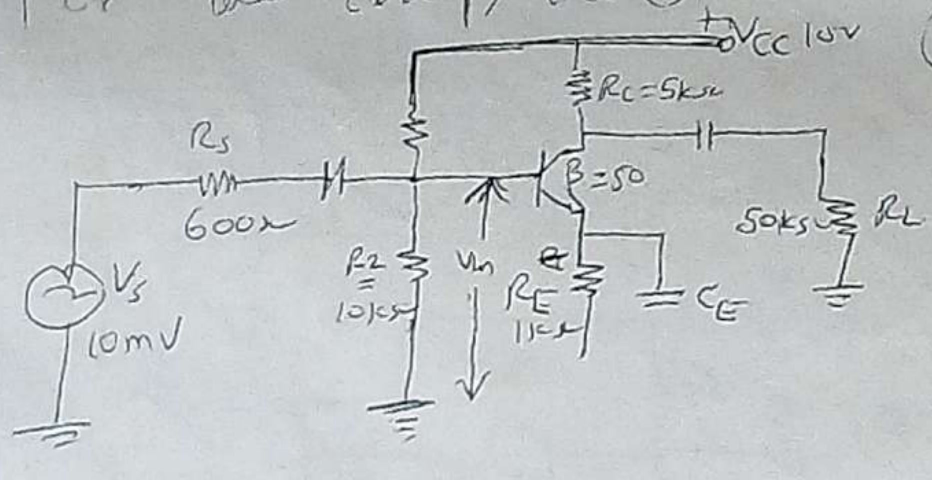
$$A_v = \frac{r_c}{r'_e} = \frac{R_C \| R_L}{r'_e}$$

overall gain

$$A_{v_s} = A_v \cdot \frac{V_{in}}{V_s}$$

Exam

For the amp, determine (a) output voltage (b) the overall voltage gain



$V_{CC} = 10V$, $R_C = 5k\Omega$, $R_E = 1k\Omega$, $R_1 = 50k\Omega$
$R_2 = 10k\Omega$ $R_s = 600\Omega$, $R_L = 50k\Omega$
$\beta = 50$ & $V_s = 10mV$

$$V_{TH} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) = 10\left(\frac{10}{50+10}\right) = 1.67\,V$$

$$R_{Th} = R_1 \| R_2 = (R_1 \cdot R_2)/R_1+R_2$$
$$= 8.3\times10^3\,\Omega$$

$$I_E = \frac{V_{Th}-V_{BE}}{R_E+\frac{R_{TH}}{\beta}} = \frac{1.67-0.7}{1000+\frac{8.3\times10^3}{50}}$$

$$= 0.83\,mA$$

Ac resistance $r'_e = 25/I_E = \frac{25}{0.83} = 30\,\Omega$

$$R_{is} = (R_1 \| R_2) \| (\beta \cdot r'_e) = R_{TH} \| (\beta \cdot r'_e)$$
$$= 1270\,\Omega$$

$$R_L = R_C \| R_L = 5 \| 50 = 4.545\,k\Omega$$

$$A_V = \frac{r_L}{r'_e} = \frac{4.545\times10^3}{30} = 151.5$$

$$V_{in} = V_s\left(\frac{R_{is}}{R_{is}+R_s}\right) = 10\left(\frac{1270}{1270+600}\right)$$
$$= 6.79\,mV$$

$I_C = \frac{V_{BB}-V_{BE}}{R_B}$

$I_B = V_{CC}$

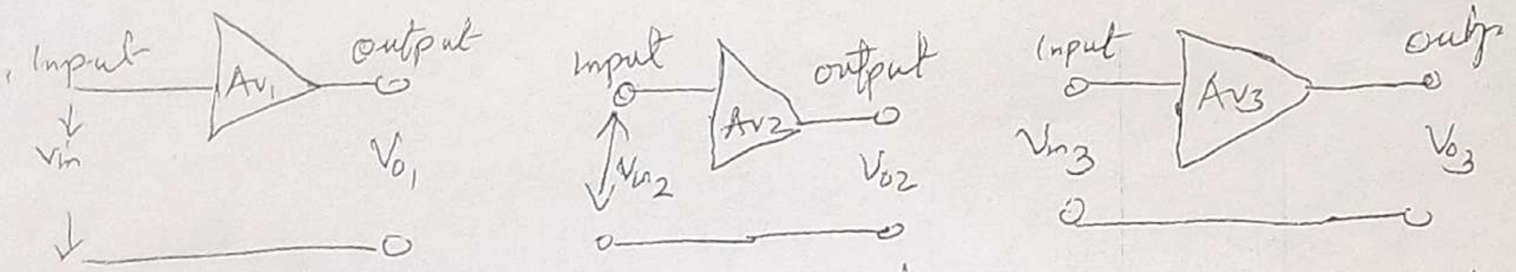
$$V_o = A_V \times V_{in} = 151.5\times6.79 = 1.029\,V$$

(b) Overall Voltage gain

$$A_{VS} = A_V \times \frac{V_{in}}{V_s} = 151.5\times\frac{6.79}{10}$$
$$= 102.9$$

Multi stage BJT Amplifiers

A multistage BJT amp uses more than one stage of amplification to achieve greater voltage and power gain.



Taken that the individual stage gains respectively are A_{v_1}, A_{v_2} and A_{v_3}, the total voltage gain

voltage gain

$A_v = A_{v_1} \times A_{v_2} \times A_{v_3}$

while in decibel, the gain

voltage gain in decibel dB

$G_v = G_{v_1} \times G_{v_2} \times G_{v_3}$

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

$= 20\log_{10} A_v.$

Current gain z $A_i = A_{i_1} * A_{i_2} \times A_{i_3}$

overall power gain Linear power gain.

$A_p = A_v * A_i$

in decibel

$G_p = 10\log_{10} A_p$

power gain in decibel

Example

Three amp stages are work-e in cascade with 0.05V peak to peak input ~~and~~ produceing 150V peak to peak output. If the voltage gain of the first ~~S~~stage is 20 and input to the third stage is 15v peak to peak, determine

(a) the over all gain (b) voltage gain of 2nd & 3rd stage

(c) input voltage off the 2nd stage

Sol^n

Overall gain $A_v = \frac{V_{out\,3}}{V_{in\,1}} = \frac{150}{0.05} = 3000$

~~V_{in_3}~~ $A_{v_3} = \frac{V_{out_3}}{V_{in\,3}} = \frac{150}{15} = 10$ //

~~A~~

$A_V = A_{v_1} \cdot A_{v_2} \cdot A_{v_3}$

$3000 = 10 \times 20 \times A_{v_2}$

$A_{v_2} = \frac{3000}{200} = 15$ //

V_{in_2}

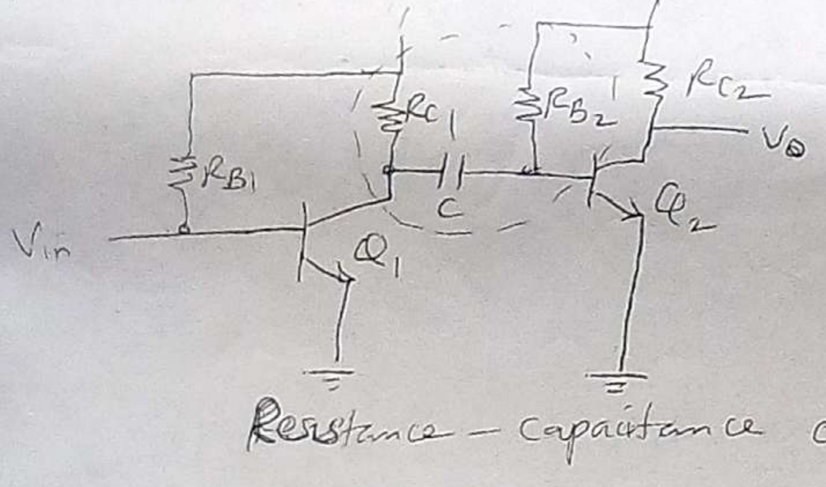
~~15~~ $A_{v_2} = \frac{(V_{out})_2}{V_{in\,2}} = \frac{(V_{in})_3}{(V_{in})_2} = \frac{15}{(V_{in})_2} = 15$

$(V_{in})_2 = \frac{15}{15} = 1$ //

Coupling in multistage Amplifiers

Different types of coupling schemes are employed in multistage amplifiers.

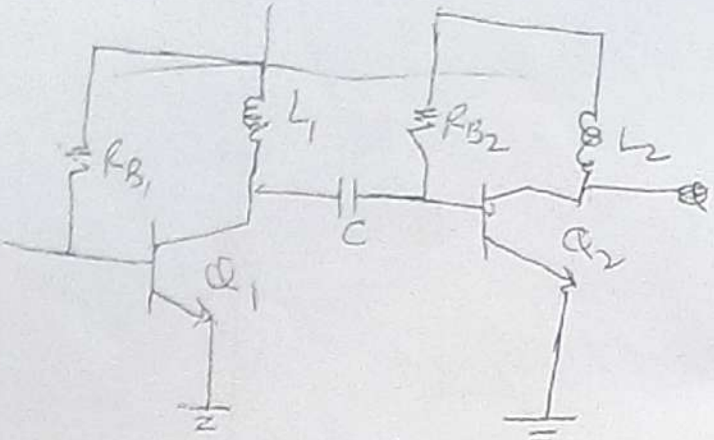
1 Resistance - capacitance (RC) coupling This is the most important method of coupling used in multi-stage amplifier. In this method, the signal developed in the collector of each stage is coupled through capacitor into the base of the next stage. The signal is amplified in each stage and the overall gain of the amplifier is equal to the product of individual gain



Resistance - capacitance coupling

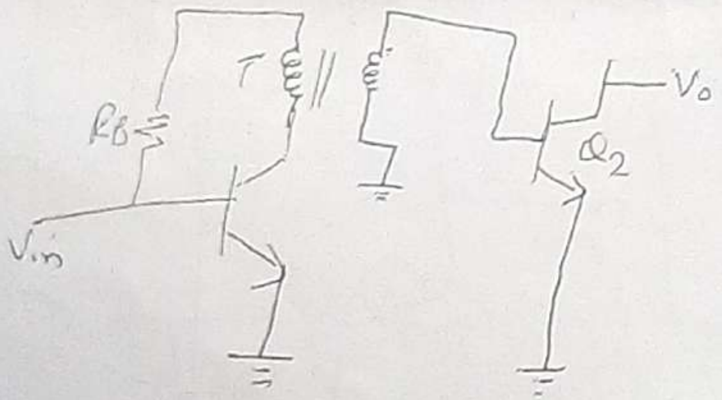
II Impedance coupling

This type of coupling scheme employs, resistor, capacitor and inductor. As the frequency increases, inductive reactance approaches infinity and each inductor appears open. That is, the inductor allow direct current but block alternating current (AC)

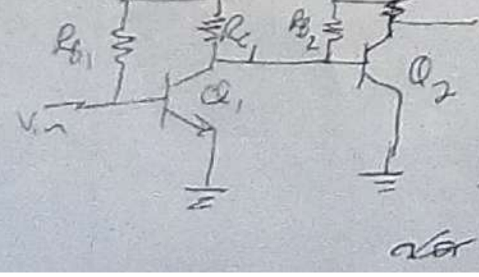


Impedance Coupling

(3) ~~...~~ Transformer Coupling: This coupling employs a transformer as a coupler. The primary winding of the transformer acts as a collector load while the secondary winding convey the a.c output directly to the base of the next stage. In this system, there is no need of coupling capacitor.



(4) Direct-Coupling: In this scheme, the ac output sig is feed directly to the next stage. This type of con is used where low frequency signal are to be amp



Direct coupling

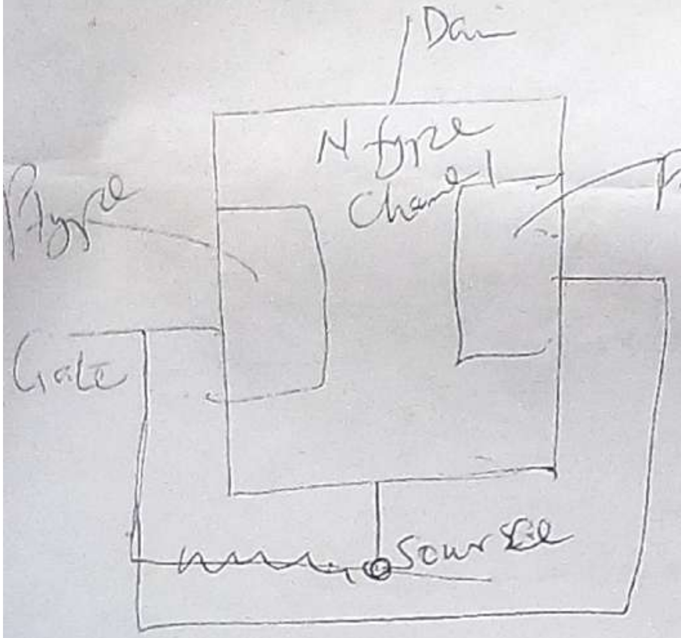
vor 2-4

FET

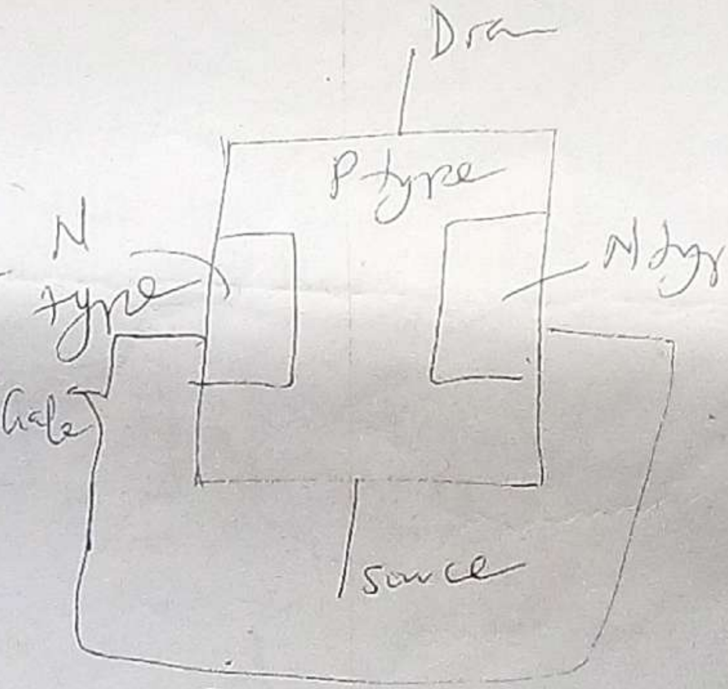
Types =

① JFET
② MOSFET

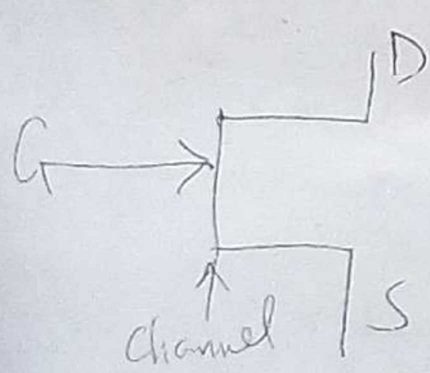
① JFET
There are two types N-channel and the P channel.

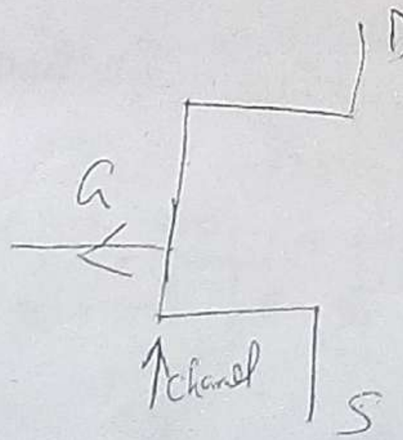


N Channel

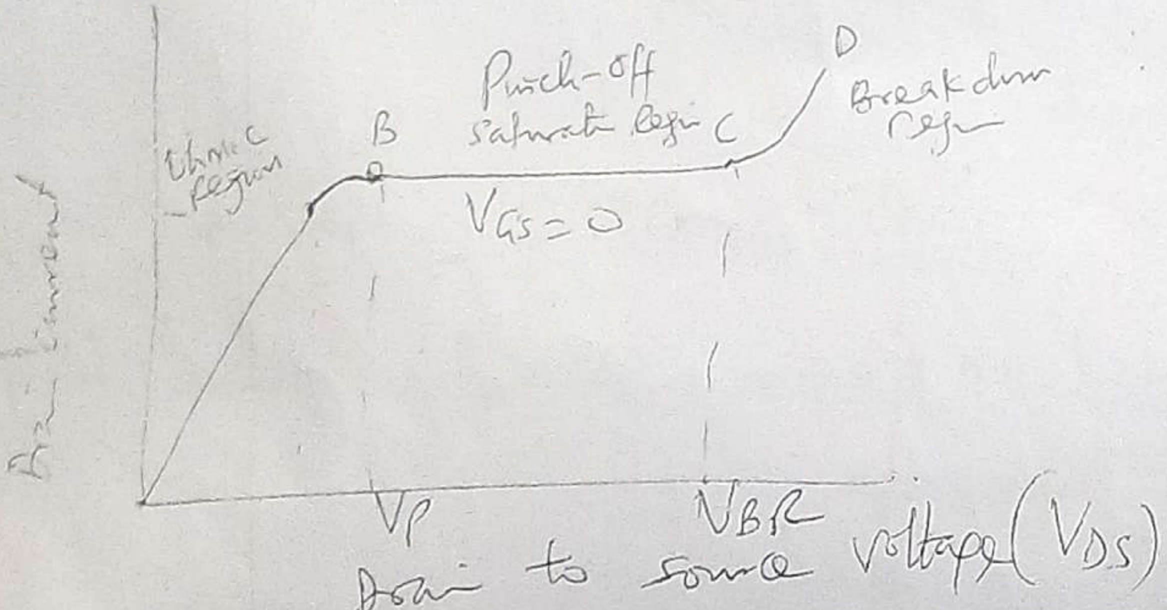


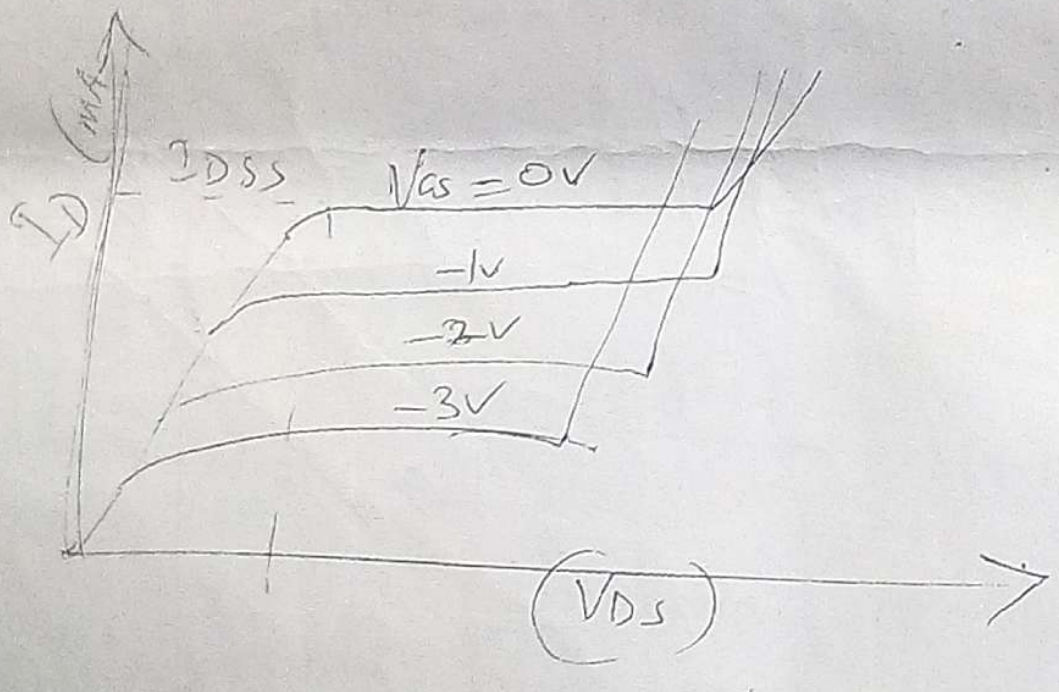
P type





Drain characteristic of JFET with V_{GS} = 0 volt





1. Ohmic Region, the drain current increases linearly with the increase in drain to source voltage

2. Curve AB: the Drain current increase at the reverse square law rate with increase in drain to source voltage

③ Pinch off region: The drain current remains constant at its maximum value I_{DSS}. The drain current in the pinch off region depends upon the gate to source voltage and is given by

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = \text{Shockley eqn}$$

④ Breakdown Region: The drain current increase rapidly as the drain to source voltage is also increased.

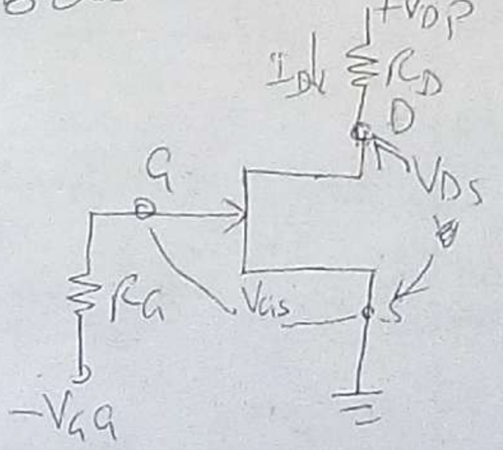
FET Amplifier

Biasing the JFET

The JFET can be biased through the following methods

① Gate bias ② self biase, and Source biase voltage divider bias

① Gate Biase



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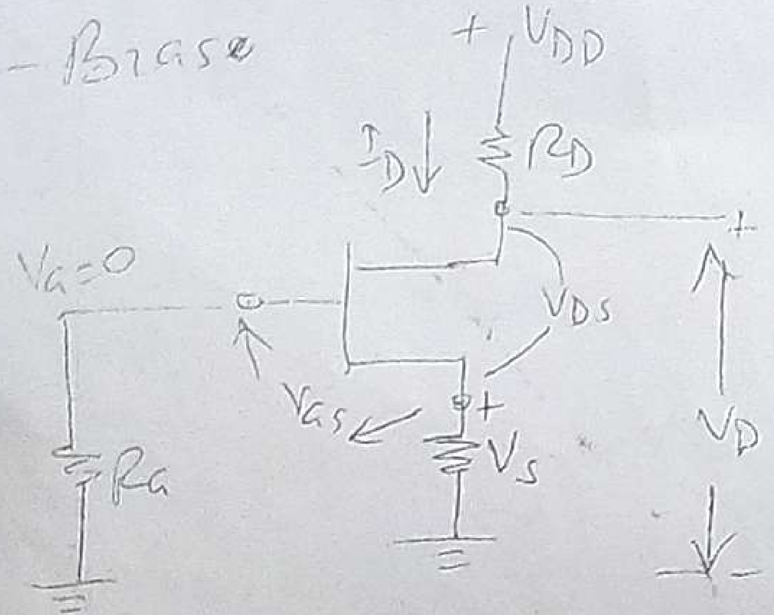
In the gate bias, V_{GG} is used to ensure that the gate - source junction is reverse biase.

Self-Biase



s^2+2s+5

$s^2+2s+ -5(s+1) \frac{A}{(s+1)} + \frac{B}{(s+1)^2}$

$\left(\frac{2}{2}\right)^2 = 1$

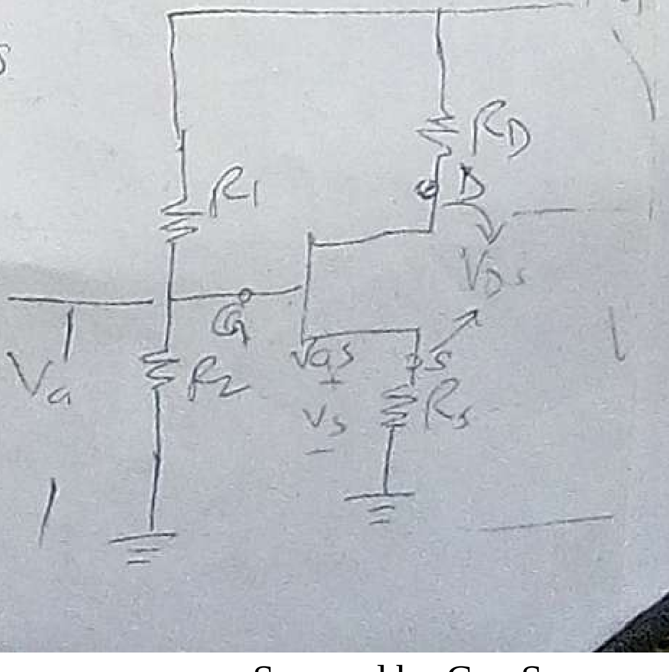
$s^2+2s+1 = -5+1$

$s^2+2s+1 = -4$

$\frac{8+1}{(s+1)^2+4}$

When the drain voltage is applied, a drain current flows even if there is no gate current (V_G). The drain current produces a voltage drop across ~~resistor~~ R_S. This voltage drop provides the gate to source ~~voltage~~ reverse voltage required for an FET operation.

3) Voltage Divider Bias



$$V_G = \left(\frac{R_2}{R_1+R_2}\right)V_{DD}$$

$$V_S = V_G - V_{GS}$$

$$I_D = V_S/R_S = \frac{V_G - V_{GS}}{R_S}$$

$$V_D = V_{DD} - I_D R_D$$

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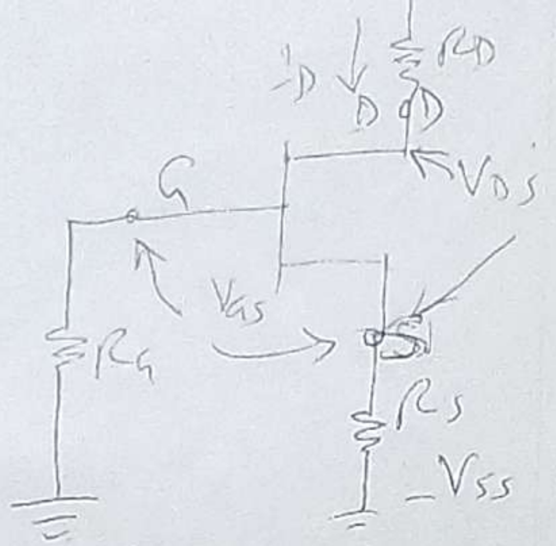
Source Bias



The value of the drain current is given by $I_D = \frac{V_{SS} - V_{GS}}{R_S}$.

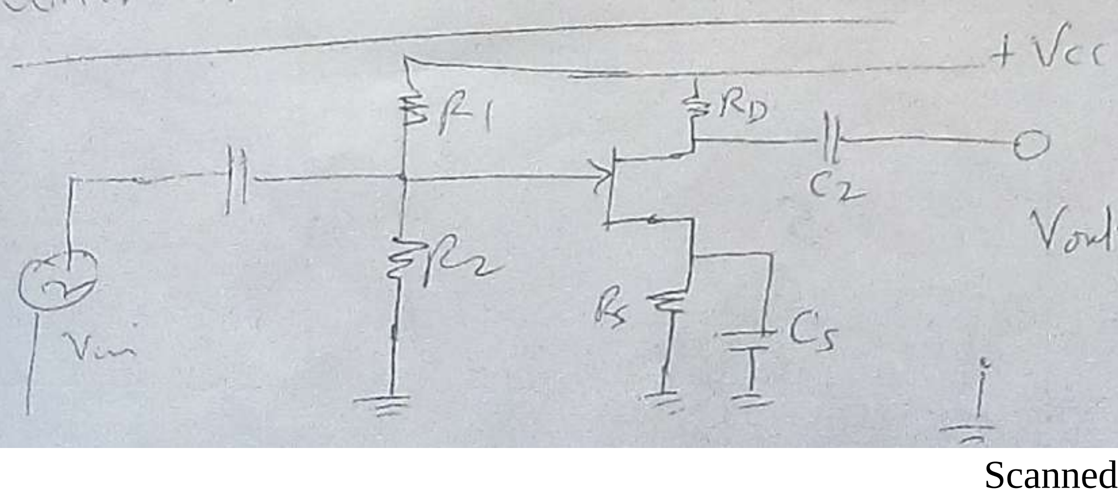
Since $V_{SS} >> V_{GS}$, the

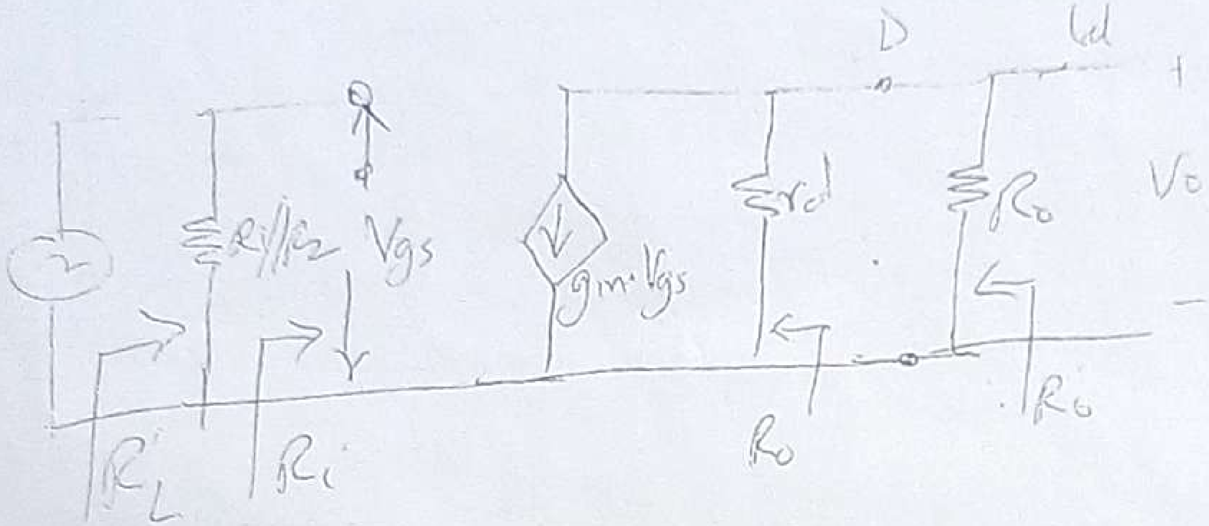
$$I_D \simeq \frac{V_{SS}}{R_S}$$

The FET Amp can be ~~call~~ connected

1. Common source amplifier
2. Common drain amplifier
3. Common gate amplifier

Common Source amplifier





<u>Voltage gain</u> = $A_v = V_o / V_{in}$

$$i_D = \frac{r_d}{R_D + r_d}(g_m \cdot V_{gs})$$

$$V_{out} = -i_d \times R_D = -\cancel{i_d}\, R_D \times \left(\frac{r_d}{R_D + r_d}\right)(g_m V_{gs})$$

$$V_{out} = -g_m\, r_L \times V_{in}$$

$$A_v = -g_m \cdot r_L$$

Input resistance

$$R_i = V_{in} / i_{in}$$

$$R_i' = R_1 || R_2$$

$$R_i' = R_G$$

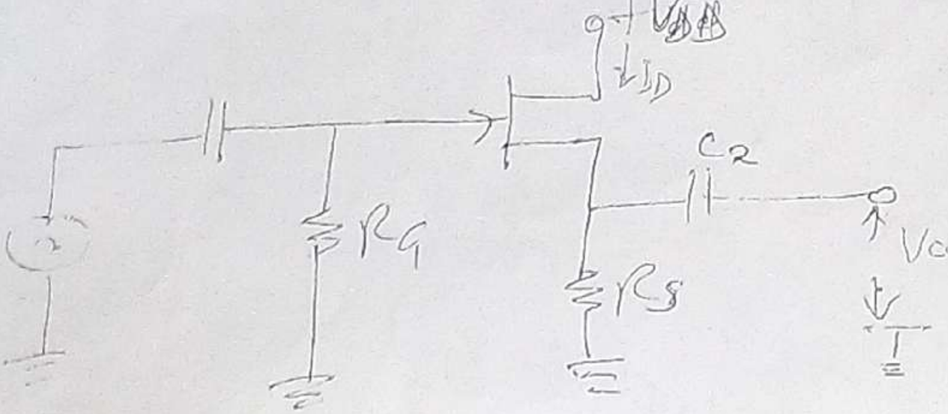
output resistance

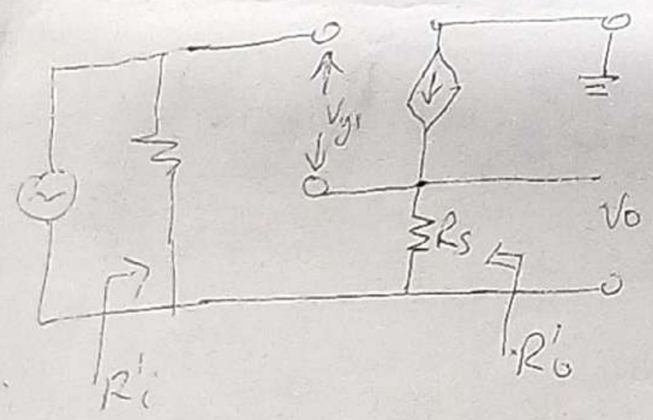
$R_o' = V_o / i_d$, $R_o' = R_D || r_D$

if $r_D >> R_D$ then $R_o = R_D$

Common drain Amplifier

This is similar to Common Collector - BJT. It uses self-bias. The input signal is applied to the gate through a coupling capacitor (C_1). The output is taken from the source terminal through a coupling capacitor.





$V_{in} = V_{gs} + i_d' R_s$

$V_o = i_d \times R_s$

$A_v = \dfrac{i_d R_s}{V_{gs} + i_d R_s}$, If $i_d = g_m V_{gs}$

$$A_v = \frac{R_s}{R_s + 1/g_m}$$

input Resistance

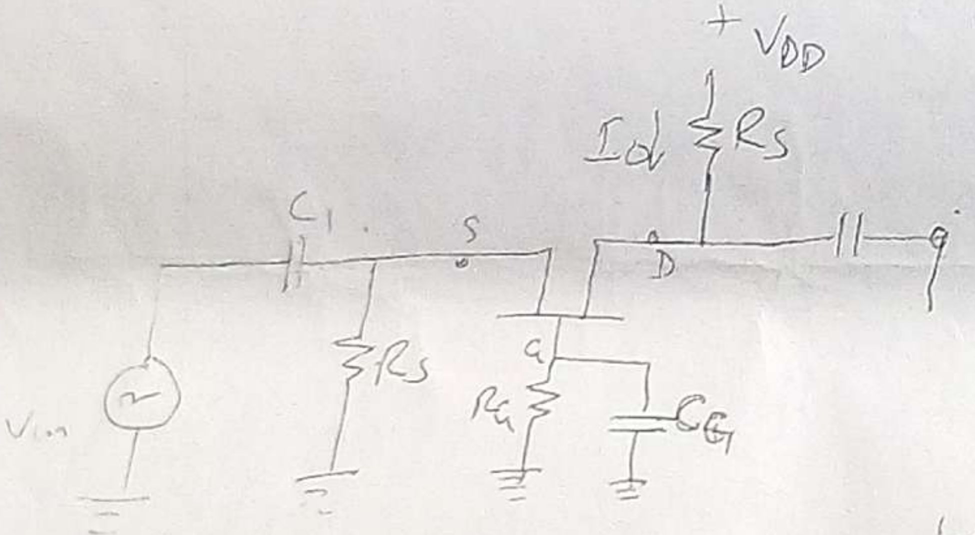
$$R_i' = R_G \| R_i$$ however R_i is extremely high

$$R_i' = R_G$$

$$R_o' = R_s \| \frac{1}{g_m}$$ if $R_s >> \frac{1}{g_m}$ then

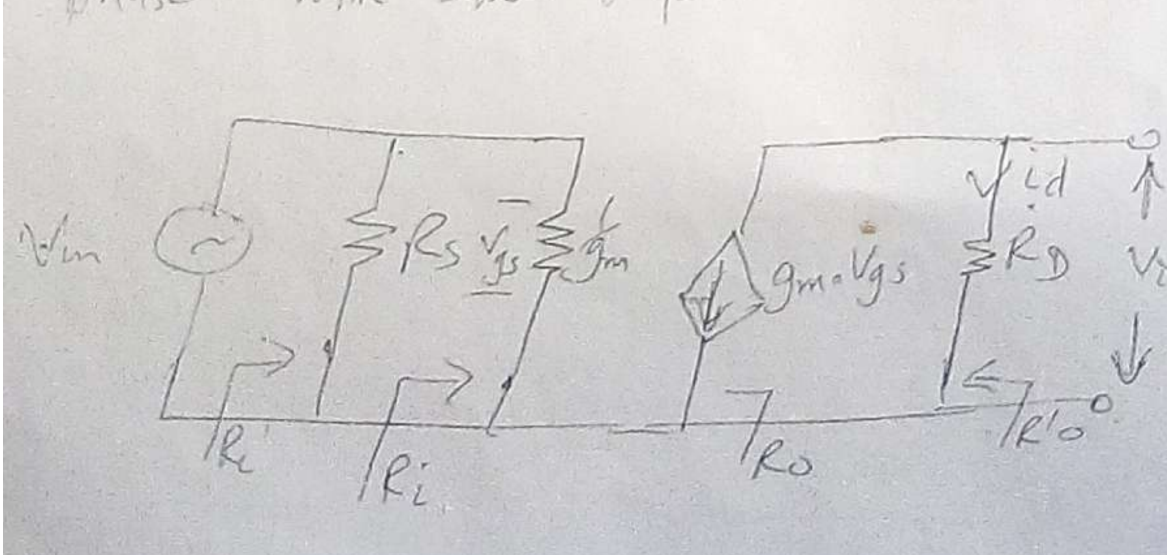
$$R_o' = \frac{1}{g_m}$$

Common gate Amplifier



This is ~~common to the~~ similar common base amplifier

Thus output voltage is common gate amplifier is in phase with the input voltage.



Voltage gain

$v_{in} = V_{gs}$, $V_o = i_d \cdot R_D$

$V_o = \frac{i_d \cdot R_D}{V_{gs}}$, $i_d = g_m \cdot V_{gs}$

$A_v = \frac{g_m \cdot V_{gs} \cdot R_D}{V_{gs}}$

$A_v = g_m (R_D \parallel R_L)$

Input Resistance

$R_i = 1/g_m$

$R_i' = R_S \parallel 1/g_m \simeq R_S$

Output Resistance

$R_o' = R_D \quad \left\{ \frac{v_o}{i_o} = \frac{i_d \cdot R_D}{i_d} \right.$

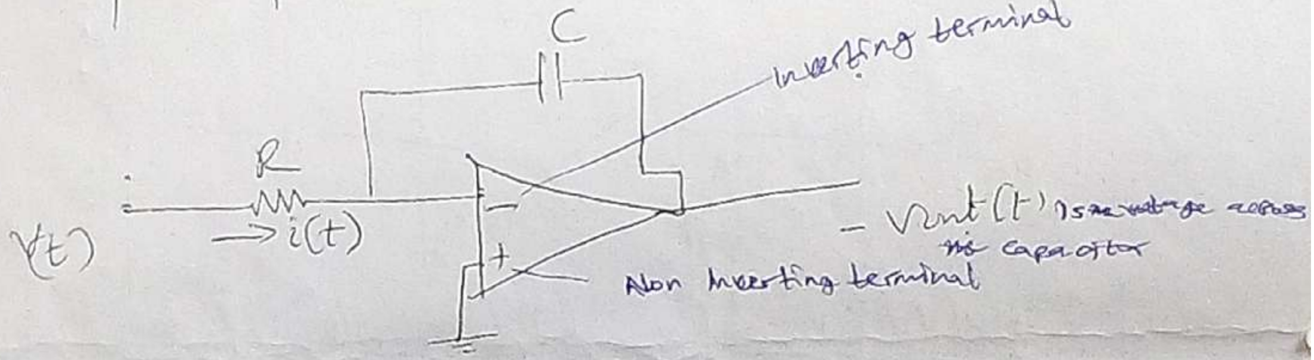
$R_o' = R_D \parallel R_L$

Applications of OP-Amps

Integrator

An integrator is a circuit whose output is proportional to the area of its input wave

The RC circuit act as a simple integrator, and the op amp linearize the cut.

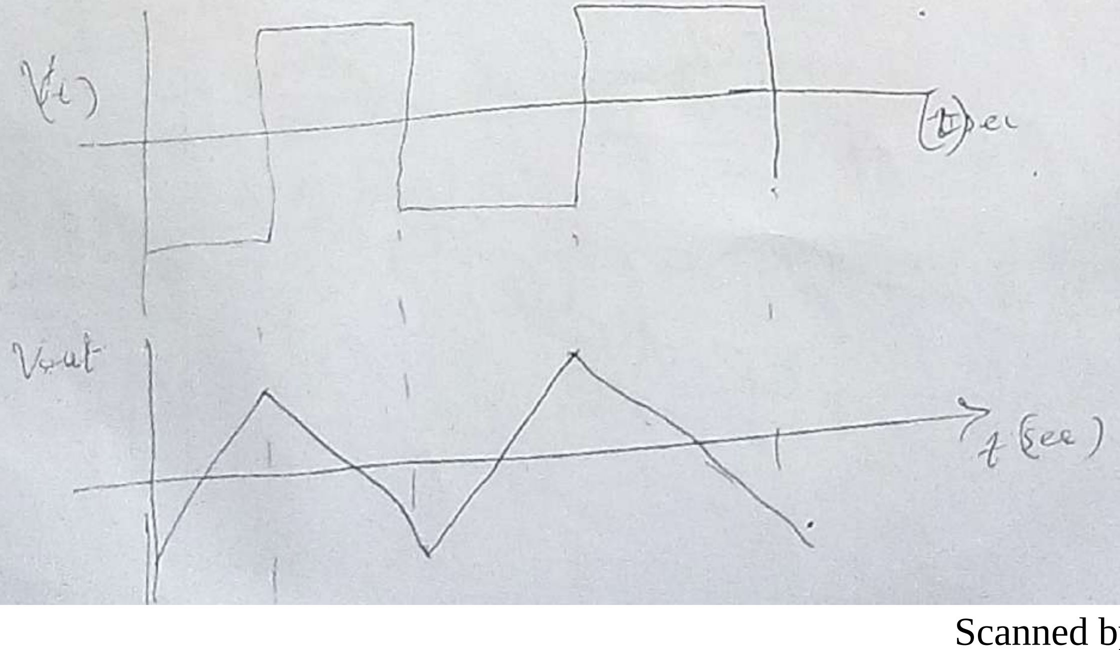


$$i(t) = \frac{V(t)}{R}$$

$$V_{out}(t) = -\frac{1}{C}\int i(t)\,dt$$

$$V_{out}(t) = -\frac{1}{C}\int \frac{V(t)}{R}\,dt$$

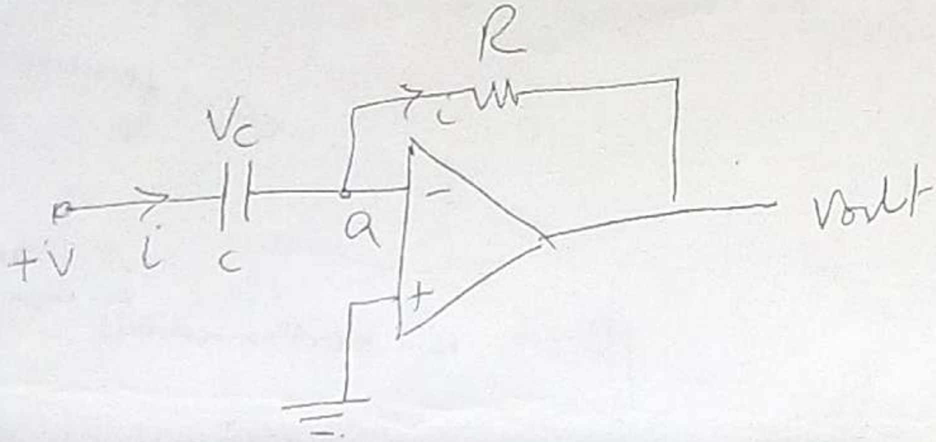
$$V_{out} = -\frac{1}{RC}\int V(t)\cdot dt + A$$



The cut off frequency of the integrator is given by

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

Differentiator



The differentiator is a circuit whose output is proportional to the rate of change of its input signal.

Let i be the rate of change of charge

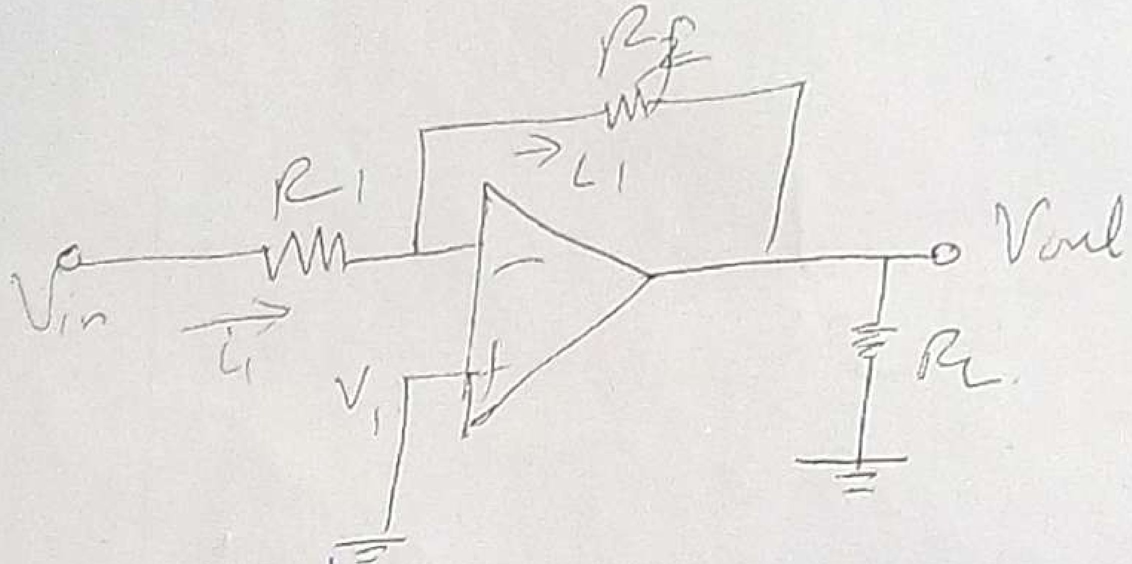
i.e. $i = dq/dt$

$$i = \frac{dq}{dt} = \frac{d\, CV_c}{dt} = C\frac{dV_c}{dt}$$

$$V_{out} = -iR = -\left[C\frac{dV_c}{dt}\right]R$$

$$V_{out} = -CR\frac{dV_c}{dt}$$

Inverting amplifier



$i_1 = i_1$

$A_V = 1 + \frac{R_f}{R_1}$

$$\frac{V_{in} - V_2}{R_1} = \frac{V_2 - V_{out}}{R_f}$$

$V_2 = 0$ because of virtual ground

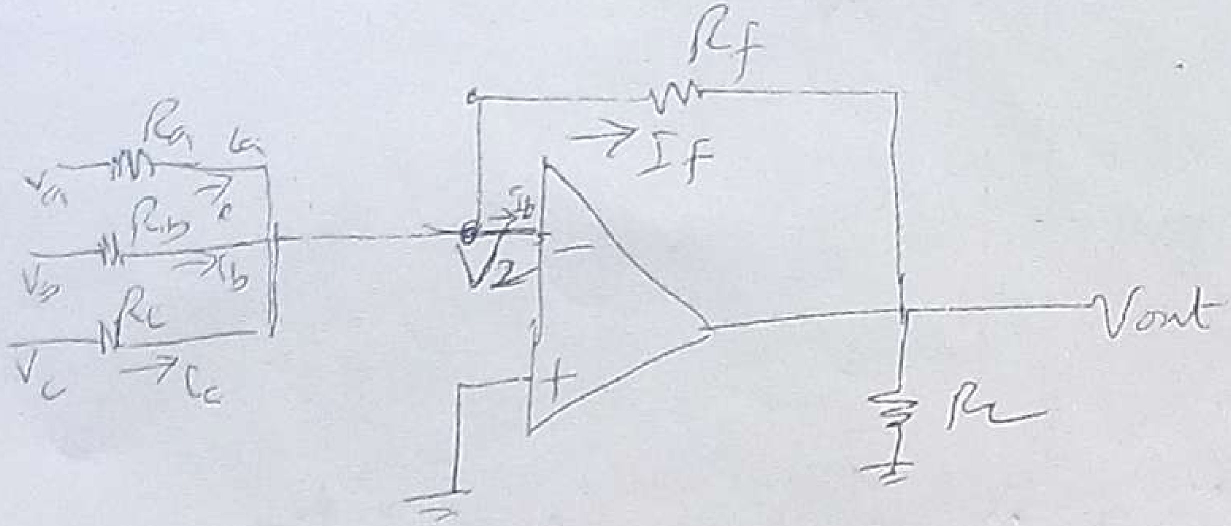
$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_f}$$

$$\frac{V_{out}}{V_{in}} = A_V = -\frac{R_f}{R_1}$$

$$V_{out} = -\frac{R_f}{R_1}(V_{in})$$

Summer

The output of a summer is equal to the negative sum of all the input times the gain of the circuit R_f/R



At node V_2,

$$i_a + i_b + i_b = i_f \quad \text{because } i_b = 0$$

$$i_a = V_a/R_a, \quad i_b = V_b/R_b, \quad i_c = V_c/R_c$$

$$V_a/R_a + V_b/R_b + V_c/R_c = -V_{out}/R_f$$

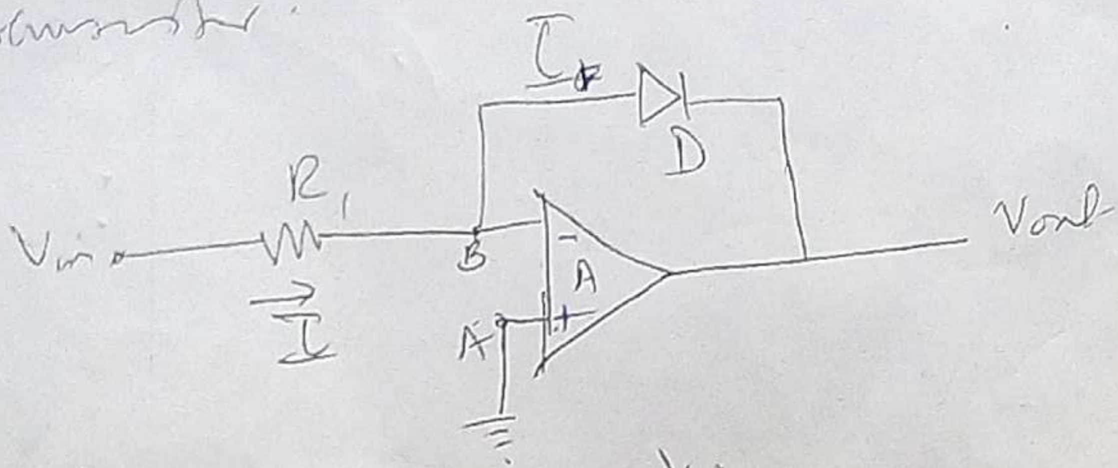
$$V_{out} = -R_f\left(V_a/R_a + V_b/R_b + V_c/R_c\right)$$

if $R_a = R_b = R_c = R$

Then $V_{out} = -\frac{R_f}{R_a}\left(V_a + V_b + V_c\right)$

log Amplifier

log Amp are non linear circuits in which the output voltage is proportional to the log of the input. It can be achieved using either a diode or transistor.



$V_{in} = IR$, $\quad I = V_{in}/R$

$I = I_f$,

$$I_f = I_0\left(e^{\frac{V_D}{\eta V_T}} - 1\right) = I_0\left(e^{\frac{V_D}{\eta V_T}}\right)$$

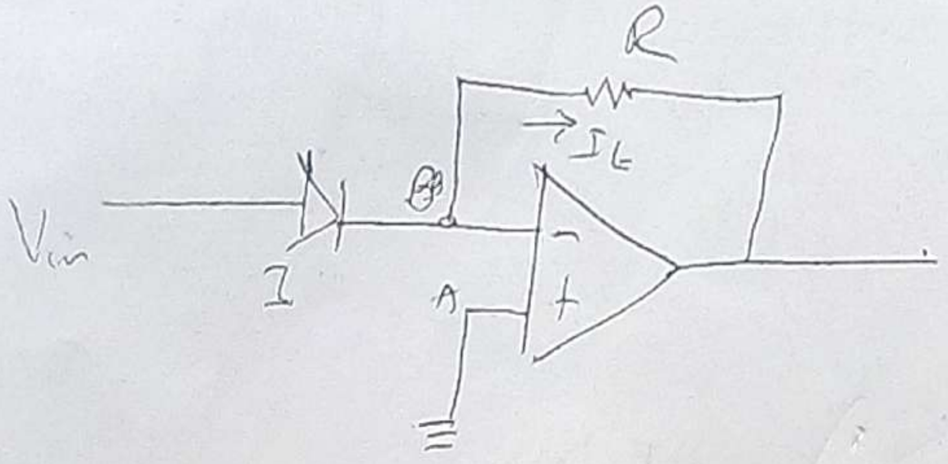
or $$\frac{V_D}{\eta V_T} = \ln\left(\frac{I_f}{I_0}\right)$$

$$V_D = \eta V_T \ln\left(\frac{I_f}{I_0}\right)$$

$V_0 = -V_D$ and $I = I_f = V_{in}/R$.

$$\therefore V_{out} = \eta V_T \ln\left(\frac{V_{in}}{R I_0}\right)$$

Antilog Amplifier



$$I = I_o\left(e^{\frac{V_D}{\eta V_T}} - 1\right) \simeq I_o e^{\frac{V_D}{\eta V_T}}$$

$$V_D = V_{in}$$

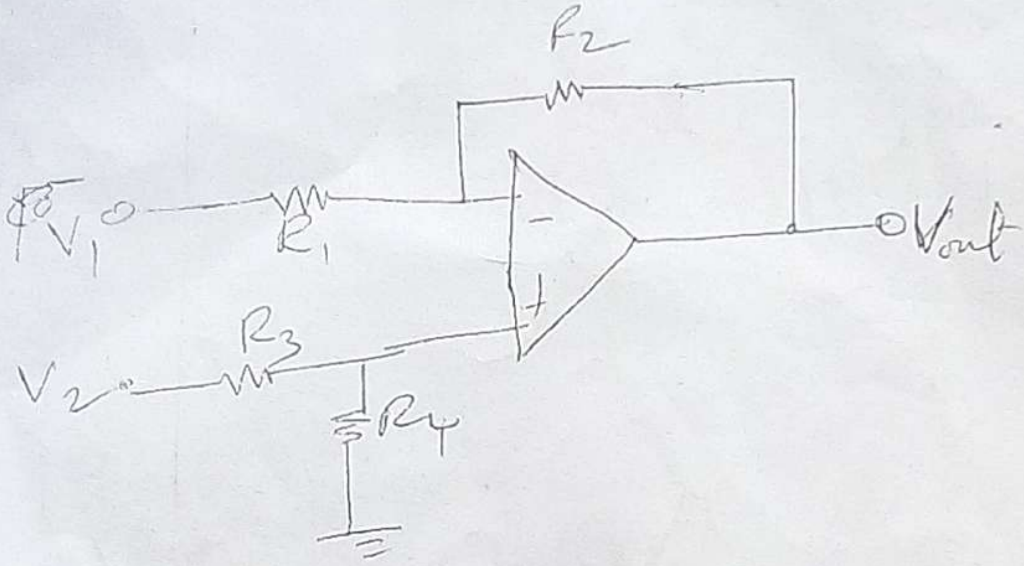
and $V_{out} = -I_f * R$

$$I_f = -V_o/R, \quad V_{out} = -I_f R$$

$$V_{out} = -R I_o e^{\left(\frac{V_{in}}{\eta V_T}\right)}$$

The output is exponential function of V_{in}

Differential Amplifier

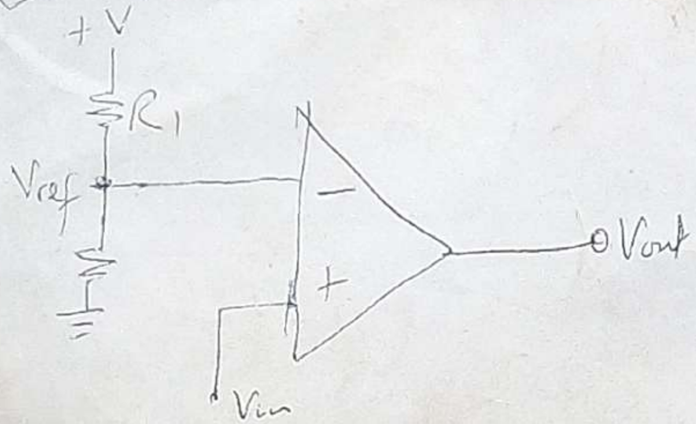


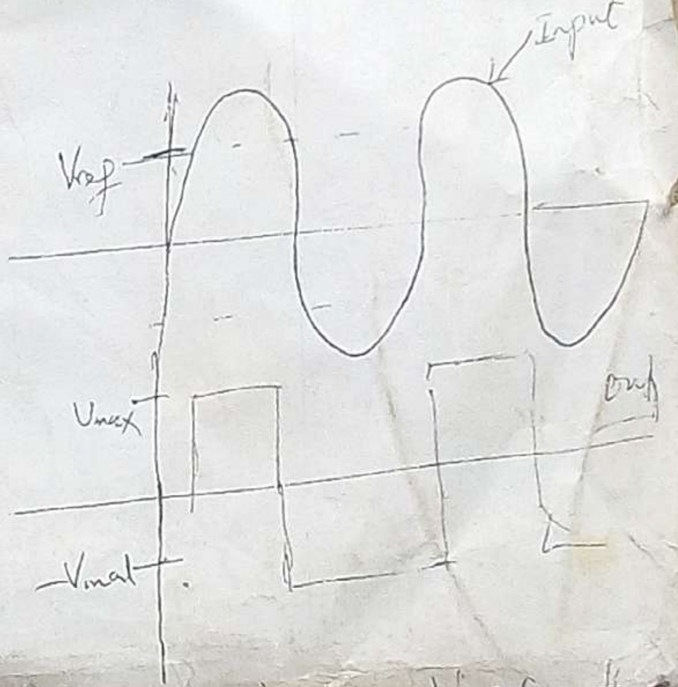
The output of the differential amplifier if $R_1 = R_3$ and $R_2 = R_4$

$$= V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

Comparator

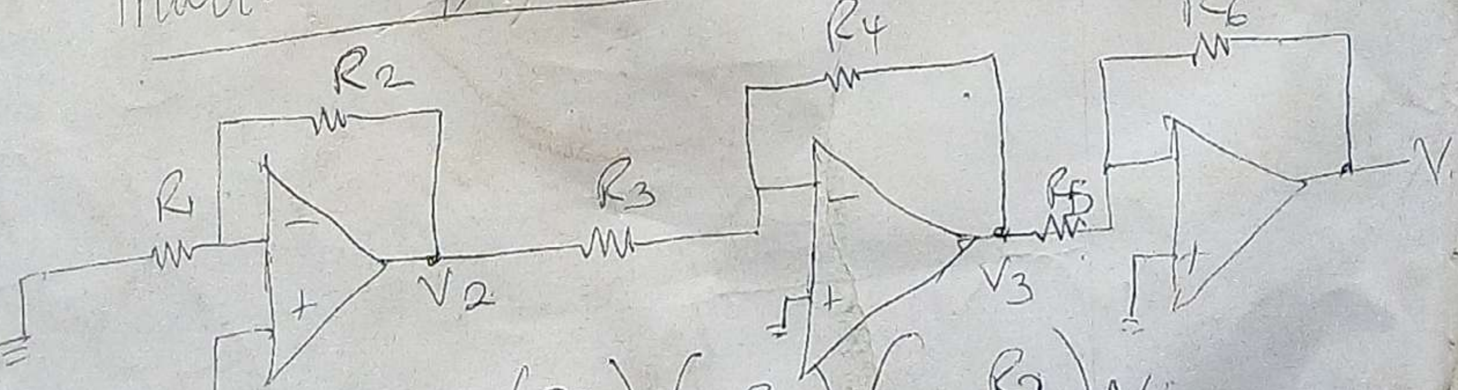
The Comparator is used to Compare two voltages and provide an output indicate the relationship between those two voltage





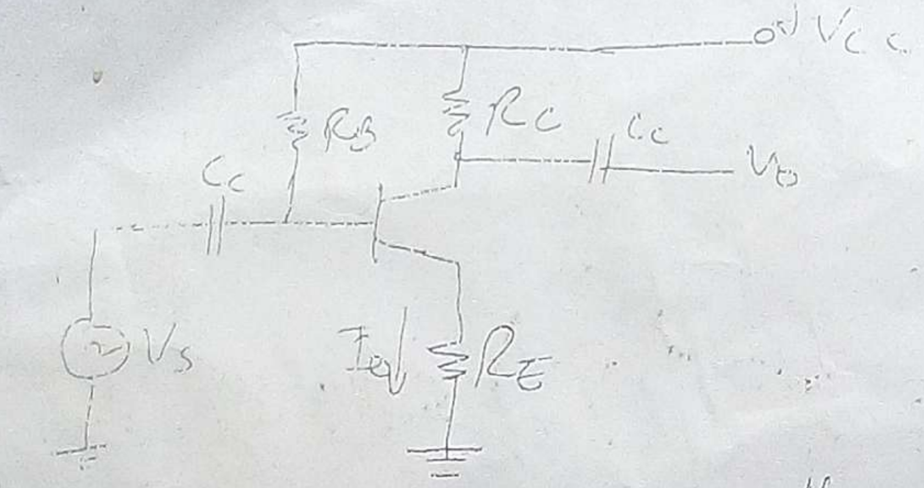
As long as the input voltage is below Vref, the comparator output is approximately $-V_{max}$ volt But if the input voltage equals or exceed Vref, the comparator output changes to $+V_{max}$ Volt.

Multi-Stage Gain Amplifier



$$V_{out} = -\left(\frac{R_6}{R_5}\right)\left(-\frac{R_4}{R_3}\right)\left(1+\frac{R_2}{R_1}\right)V_{in}$$

Common Emitter Amplifier

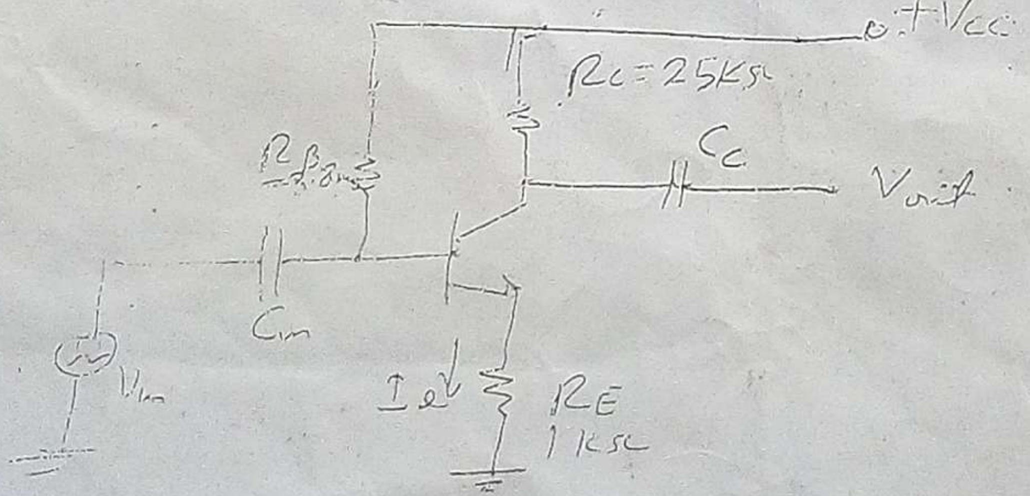


Voltage gain without feedback

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

$$A_v' = \frac{R_C}{(r_e' + R_E)}$$

$$\beta = \frac{R_E}{R_C}$$



$V_{CC} = 20V \quad R_B = 3.8M\Omega, \quad R_C = 25K\Omega$
$R_E = 1K\Omega, \quad \beta = 200$

$$I_E = \frac{V_{CC}}{(R_B/\beta) + R_E} = \frac{20}{\left(\frac{3.8 \times 10^6}{200}\right) + (1 \times 10^3)}$$

Feed back Amplifier

The feedback is a process of injecting some energy from the output and then return it back to the input input. Feedback is needed because practical amplifier will depart from the ideal in the midfrequency region.

There is positive feedback in which signal is applied in such a way that it is in phase with the input signal and thus increase the signal. We also have negative feedback in which the signal is out of phase with the input signal and thus decrease it.

The voltage gain for positive feed back amplifier

$$A_v' = \frac{A_v}{1-\beta \cdot A_v}$$

while for negative amplifier

$$A_v' = \frac{A_v}{1+\beta \cdot A_v}$$

Advantages of Negative amplifier

1. Increase stability
2. Increase bandwidth
3. Less amplitude & harmonic distortion