DEPARTMENT OF ELECTRICAL ENGINEERING

ANALOG ELECTRONICS & OP-AMP

4TH SEMESTER

GOVERNMENT POLYTECHNIC SONEPUR

PREPARED BY

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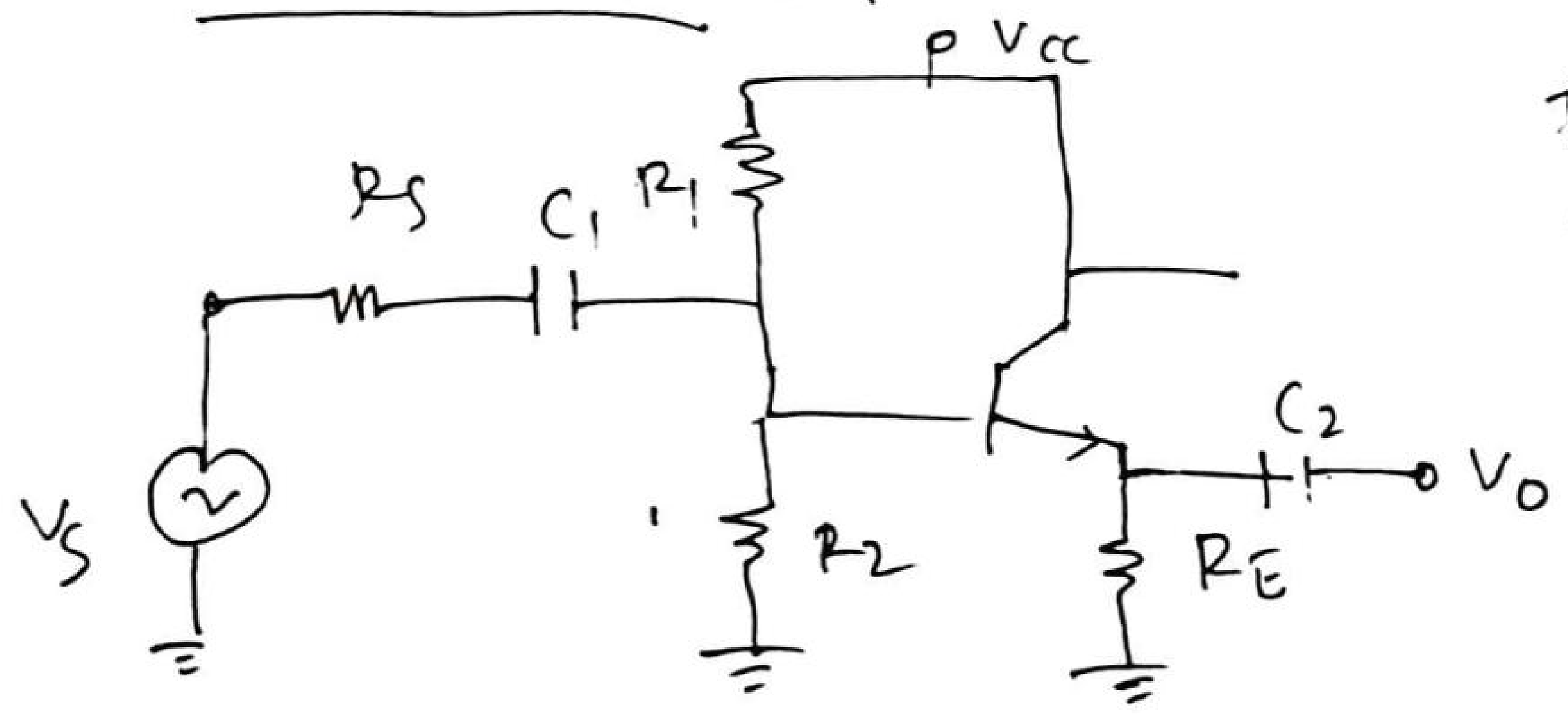
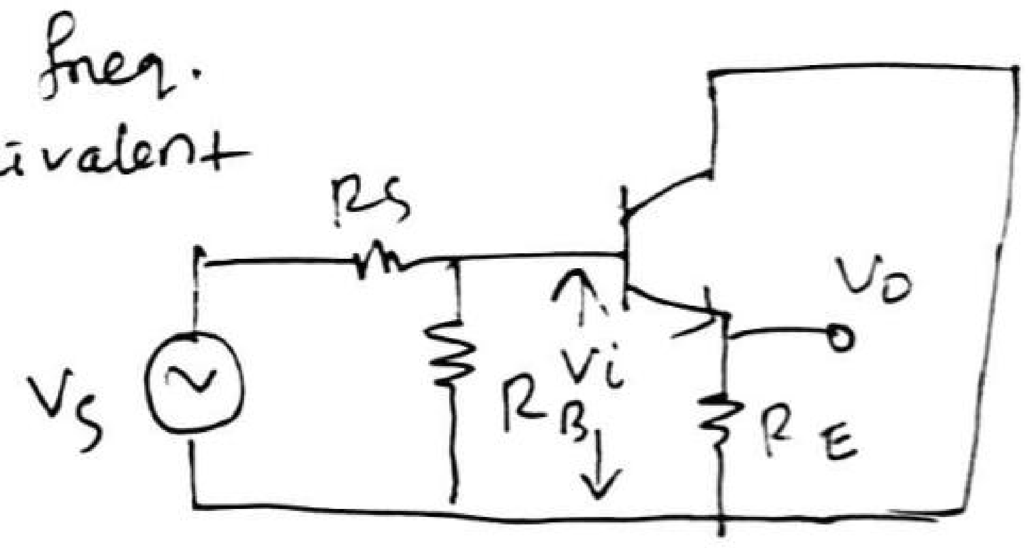
LECTURER IN ELECTRONICS

Common collector Amplifier



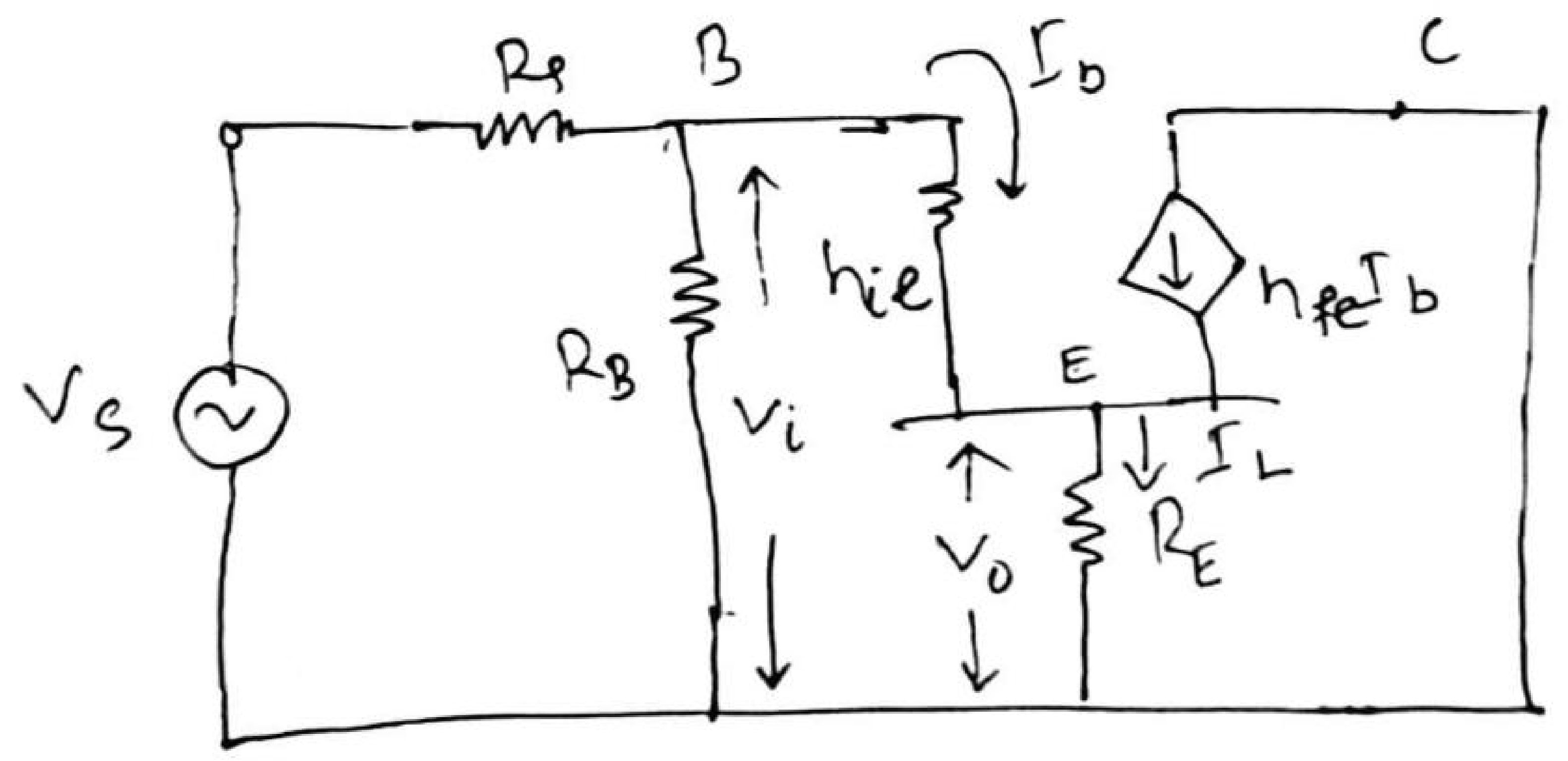
Medium freq.
AC equivalent

≡



$R_B = R_1 // R_2$

Replace BJT with approximate CE parameter model & neglect hoe



① Current Gain

$$A_I = \frac{I_L}{I_b} = \frac{I_b + h_{fe} I_b}{I_b} \Rightarrow \boxed{A_I = 1 + h_{fe}}$$

② Input Resistance

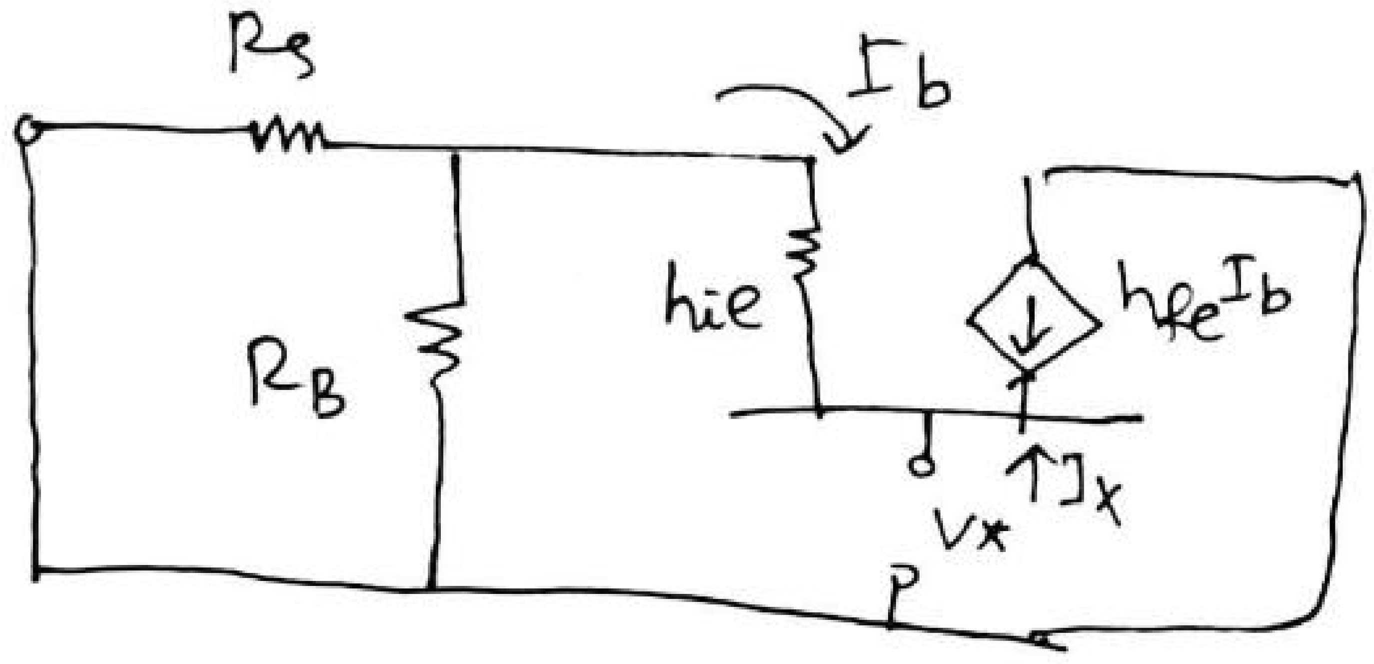
$$R_i = \frac{V_i}{I_b} = \frac{I_b h_{ie} + I_L R_E}{I_b} = \frac{I_b h_{ie} + (I_b + h_{fe} I_b) R_E}{I_b} = h_{ie} + (1 + h_{fe}) R_E$$

③ Voltage Gain

$$A_V = \frac{V_o}{V_i} = \frac{I_L R_E}{I_b h_{ie} + (I_b + I_b h_{fe}) R_E} = \frac{I_b (1 + h_{fe}) R_E}{I_b (h_{ie} + (1 + h_{fe}) R_E)}$$

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

④ Output Resistance

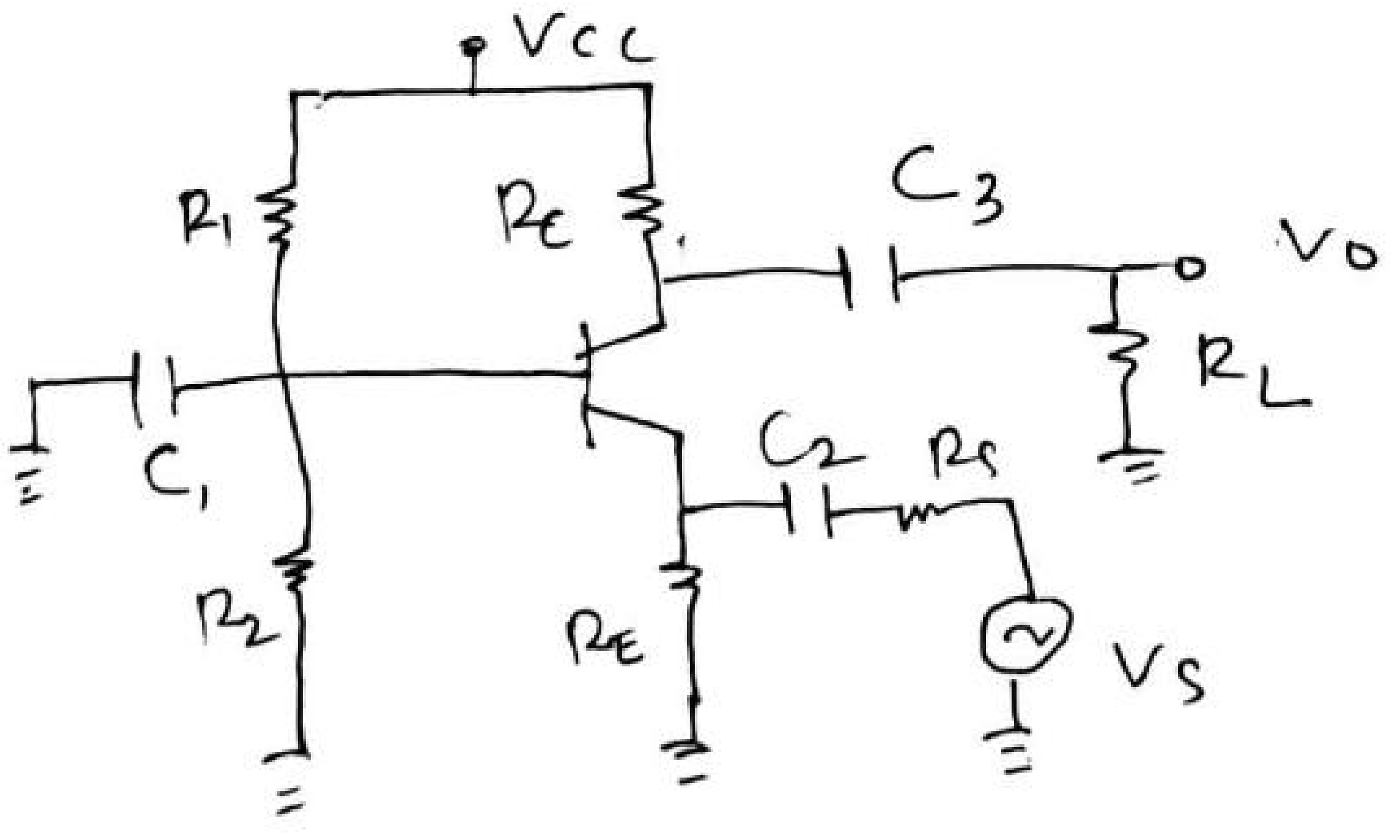


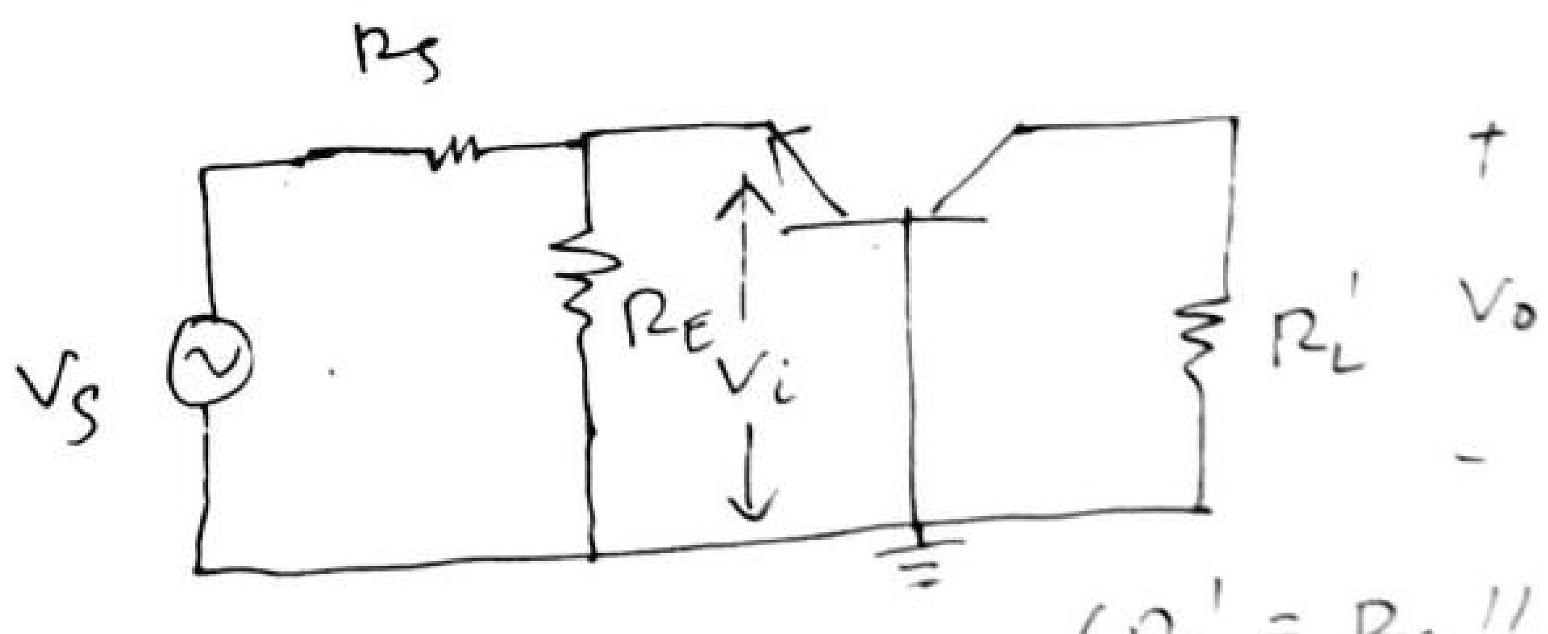
$$I_b R_s' + I_b h_{ie} + V_x = 0 \quad \Rightarrow \quad V_x = -I_b (R_s' + h_{ie})$$

$$I_b + I_x + h_{fe} I_b = 0 \quad \Rightarrow \quad I_x = -I_b (1 + h_{fe})$$

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

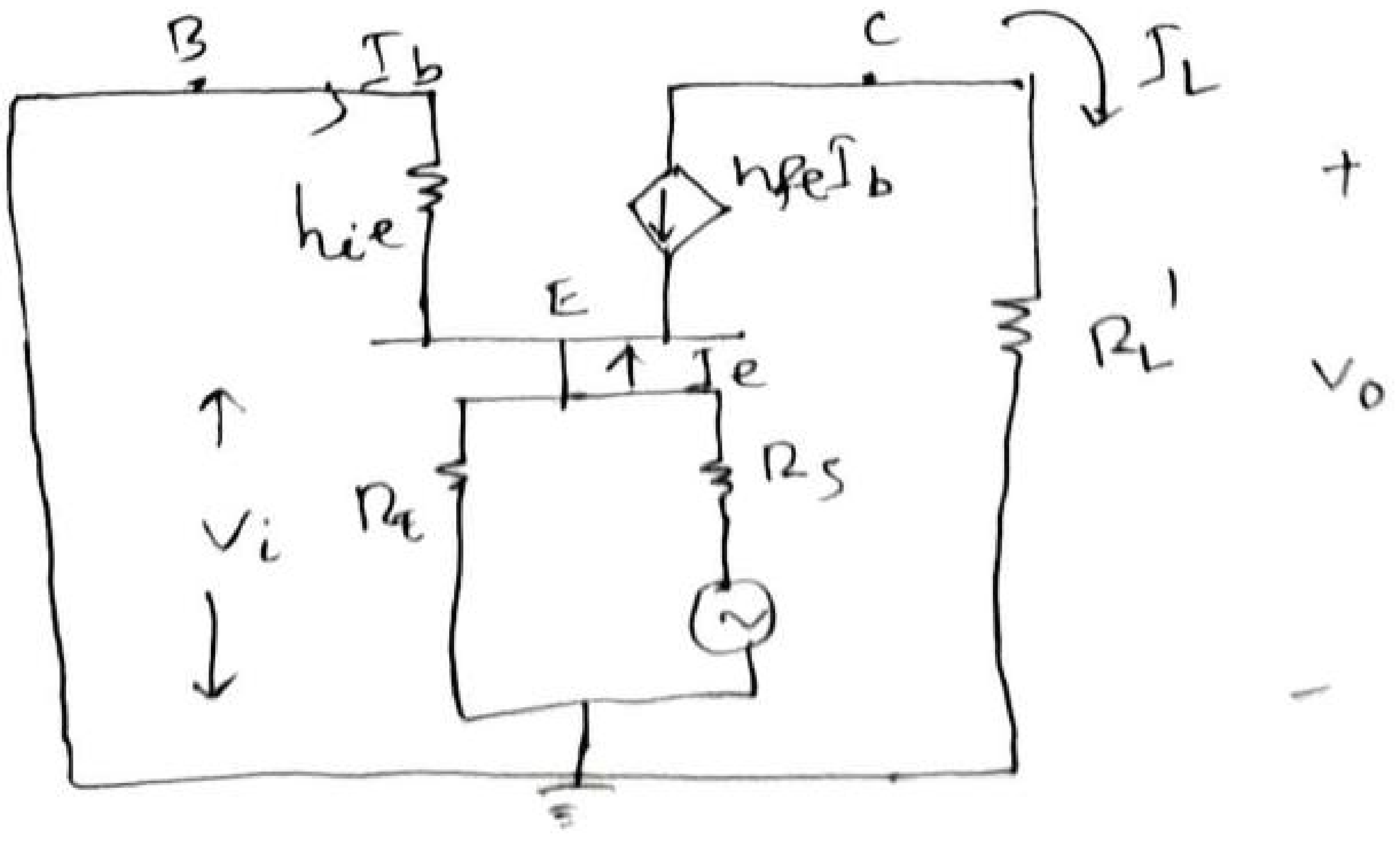
Common Base Amplifier





$(R_L' = R_C \| R_L)$

Replace BJT with approx CE parameter & neglect h_{oe}



① Current Gain

$$A_I = \frac{I_L}{I_e} = \frac{-h_{fe} I_b}{-I_b - h_{fe} I_b} = \frac{h_{fe}}{1+h_{fe}}$$

② Input Resistance

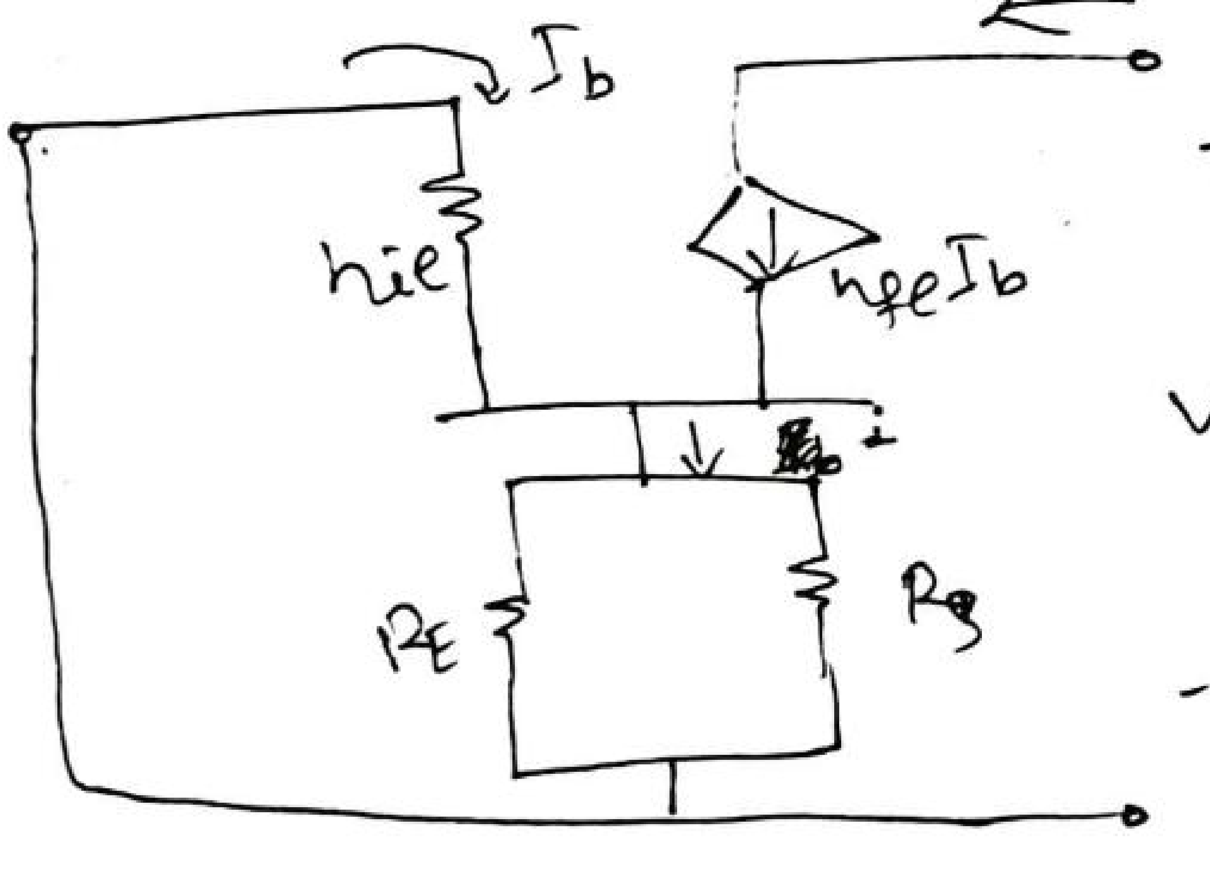
$$R_i = \frac{V_i}{I_e} \qquad I_b h_{ie} + V_i = 0 \implies V_i = -I_b h_{ie}$$

$$\frac{V_i}{I_e} = \frac{-I_b h_{ie}}{-I_b - h_{fe} I_b} = \frac{h_{ie}}{1+h_{fe}}$$

③ Output Resistance

$$A_V = \frac{V_o}{V_i} = \frac{I_L R_L'}{V_i} = \frac{-h_{fe} I_b R_L'}{-I_b h_{ie}} = \frac{h_{fe} R_L'}{h_{ie}}$$

④ Output Resistance



$$R_o = \frac{V_x}{I_x} \qquad (R_s' = R_E \,||\, R_s)$$

$$I_b h_{ie} + (I_b + h_{fe} I_b) R_s' = 0 \implies I_b = 0$$

$$I_x = h_{fe} I_b = 0$$

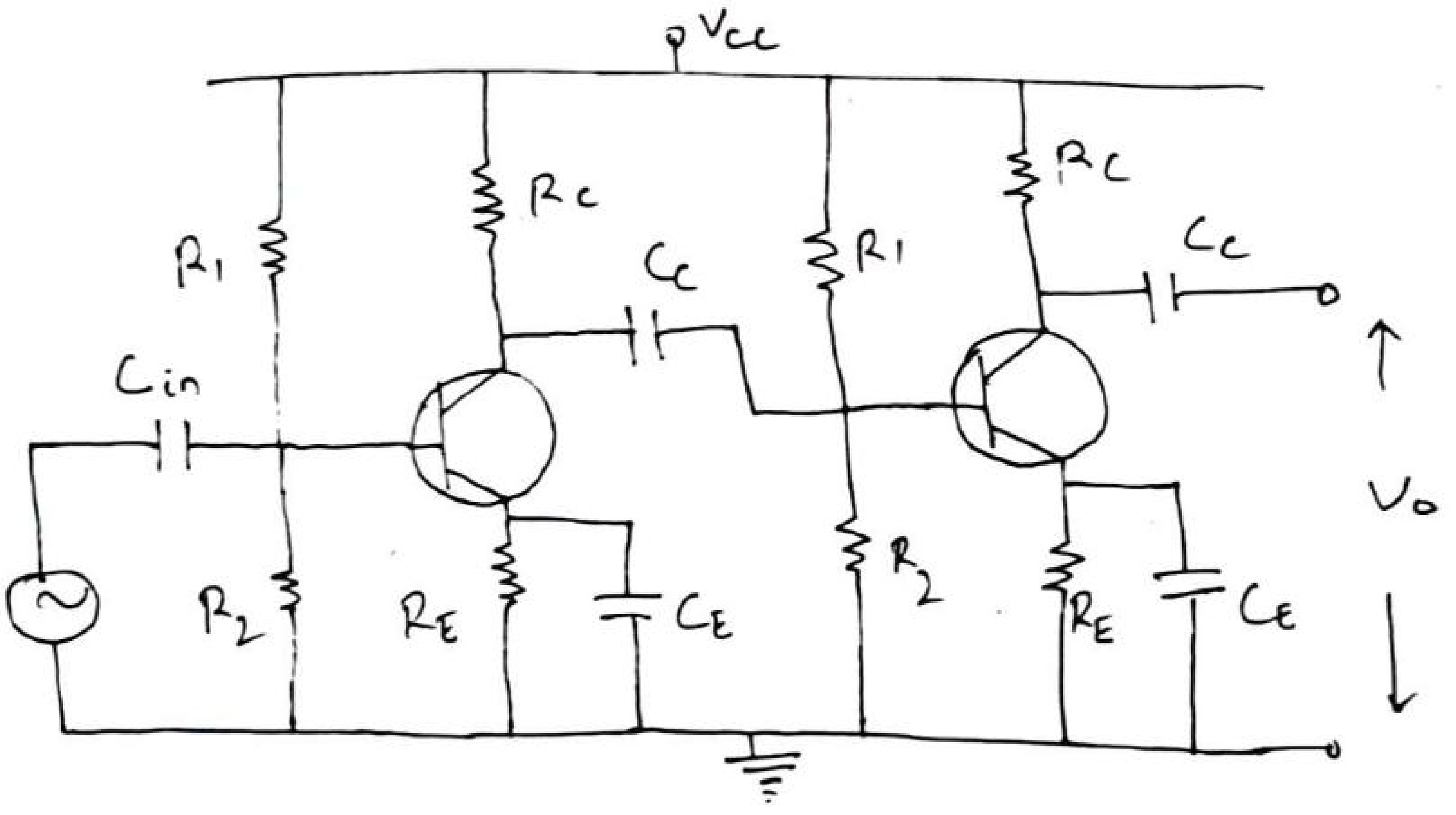
$$\implies R_o = \frac{V_x}{0} = \infty$$

CE	CB	CC
- Large current gain	- Unity current gain	- Large current gain
- Large voltage gain	- Large voltage gain	- Unity voltage gain
- Medium input resistance	- Small input resistance	- Large input resistance
- Medium output resistance	- Large output resistance	- Small output resistance

Multistage Transistor Amplifier

- Multistage amplifier is used to improve gain or amplification.
- A transistor circuit containing more than one stage of amplification is known as multistage transistor amplifier.
- In a multistage amplifier, a number of single amplifiers are connected in cascade arrangement i.e output of 1st stage is connected to the input of the second stage through a suitable coupling device.

RC coupled transistor amplifier



- A coupling capacitor C_c is used to connect the output of first stage to the base of the 2nd stage
- As the coupling from one stage to next is achived by a coupling capacitor followed by a connection to a shunt resistor, therefore such amplifiers are called Resistance-Capacitance coupled amplifiers or RC coupled amplifier.
- The coupling capacitor C_i transmits AC signal but blocks DC.
- 1st stage amplifier amplify the input signal & the amplified signal is fed to 2nd stage & further amplification takes place in the 2nd stage. Hence overall amplification is improved.

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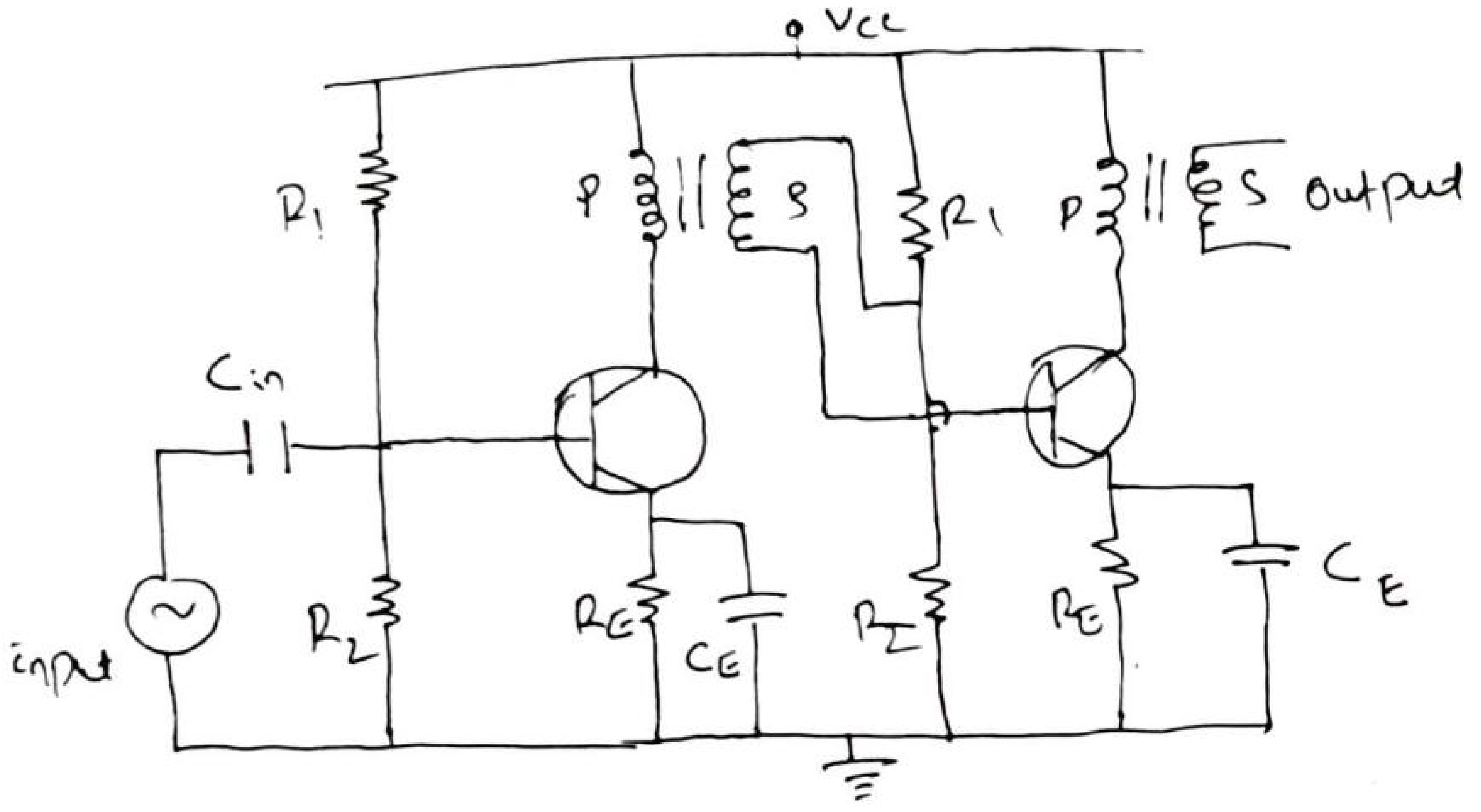
Transformer Coupled transistor amplifier



P - Primary
S - Secondary.

- In transformer coupled amplifier output stage is connected to input stage through a transformer i.e output of 1st stage is fed to the input of 2nd stage using transformer as a coupling device.

Power Amplifier

- It is a large signal amplifier.
- Due to large signal variation it has large AC o/p current & voltage. Hence it can supply large AC signal power to the load.
- In power amplifier, a power transistor is used which is operated at a greater I_C & V_{CE}. I_C in Ampere & V_{CE} in 10's of volt (20, 30 ...).
- Performance of power amplifier is measured interms of conversion efficiency & figure of merit.
- A power amplifier supplies large AC power to load because it internally convert a part of DC power drawn from biasing supply into AC power.

Conversion efficiency

Conversion efficiency describes the ability of power amplifier to convert DC power to AC power.

Mathematically,

$$\eta = \frac{\text{AC signal power supplied to load}}{\text{DC power drawn from biasing supply}}$$

Figure of merit

It is the ratio of maximum power dissipation in the transistor & maximum AC signal power which can be supplied to load.

$$F = \frac{P_{Dmax}}{P_{ACmax}}$$

- Power dissipation in transistor is undesired. Therefore figure of merit should be smaller.

Classification of power amplifiers

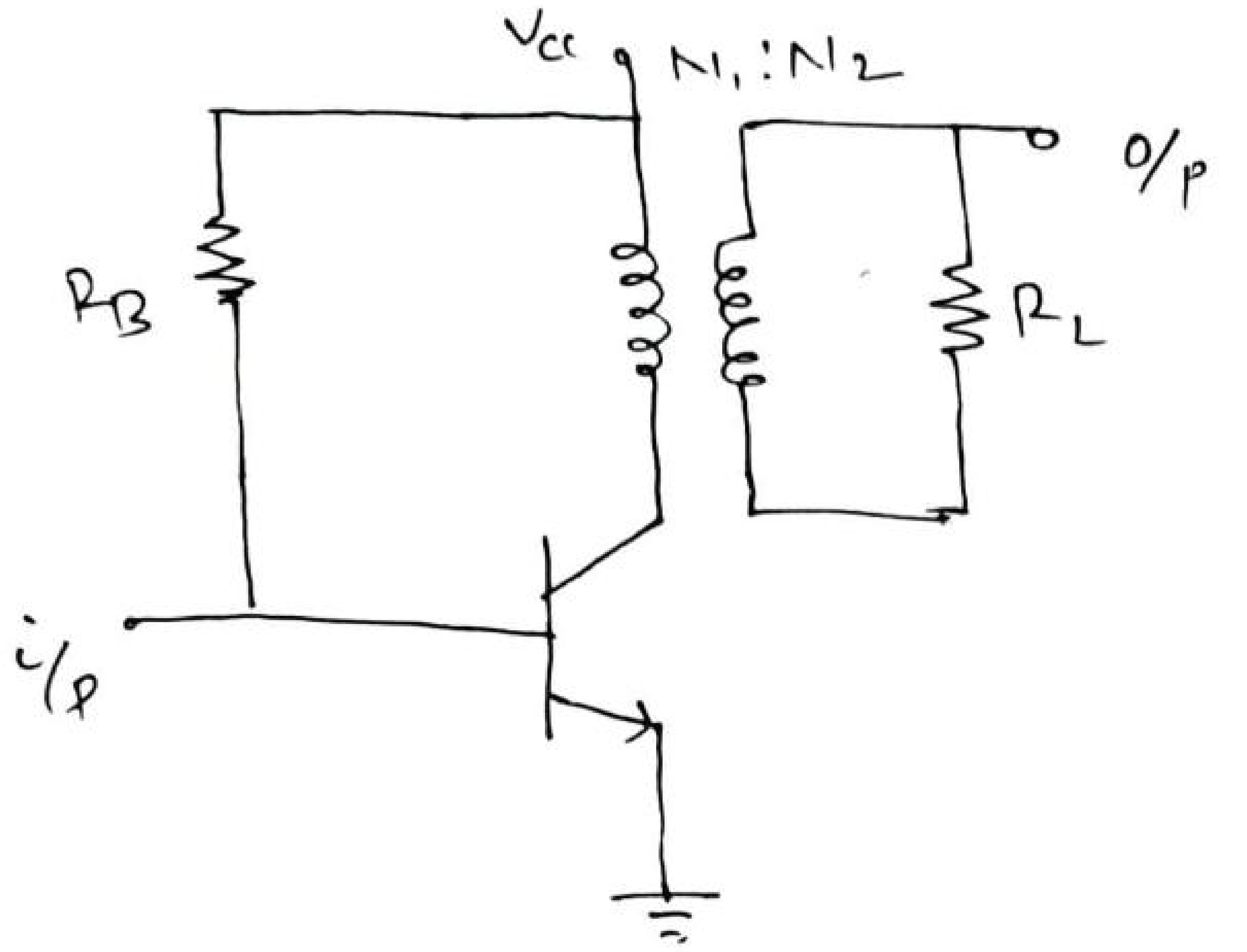
According to position of operating point on loadline, amplifiers are divided in 4 types i.e.

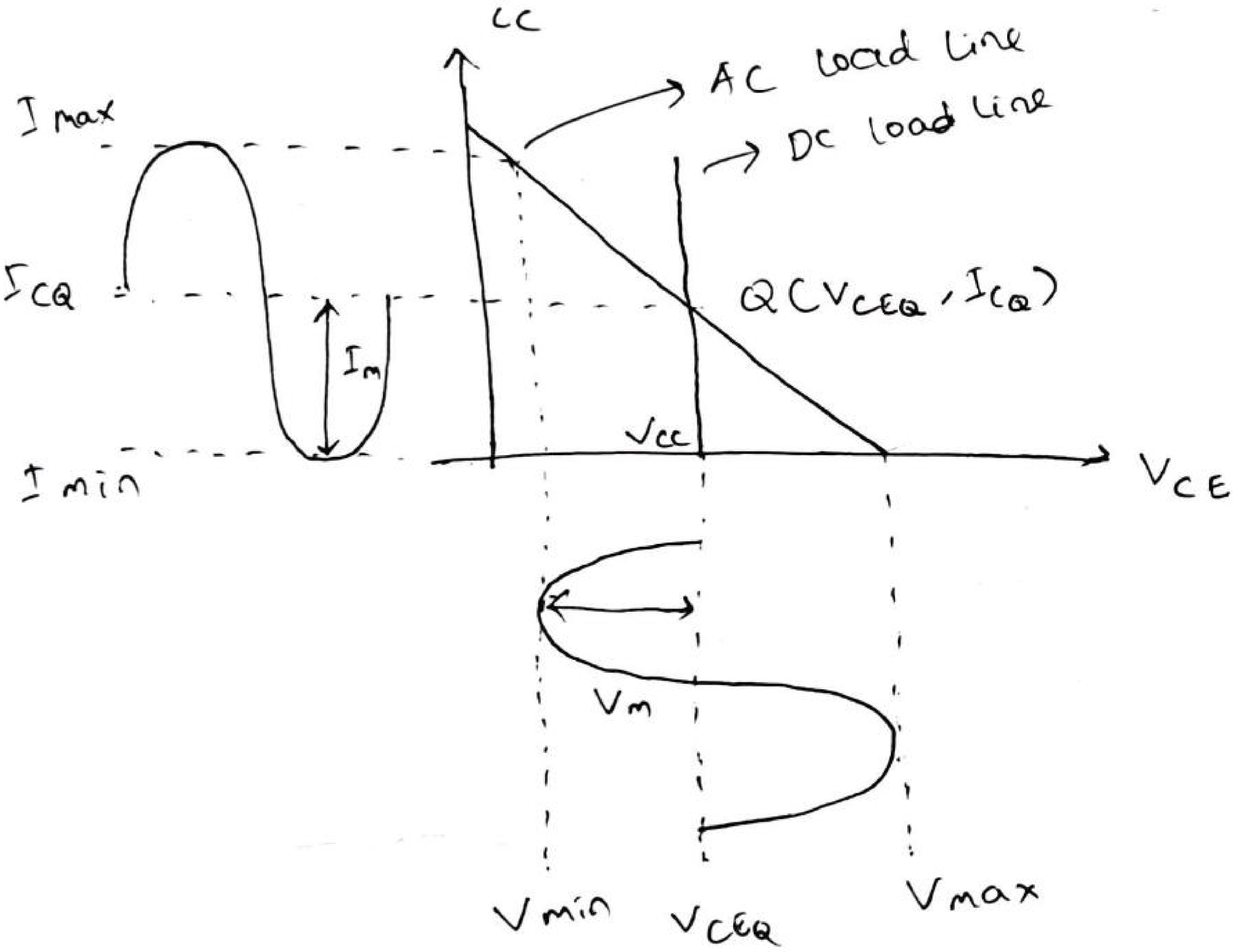
1. Class A
2. Class B
3. Class AB
4. Class C

Transformer Coupled class-A-power Amplifier

Transformer coupling is prefered in power amplifiers because -

1. It results in better efficiency.
2. maximum power can be transfered to load due to impedance matching property of transformer.
3. It provides DC isolation betn amplifier & load.





Conversion efficiency

$$\%\eta = \frac{P_{AC}}{P_{DC}} \times 100\%$$

$$P_{AC} = V_{rms} \times I_{rms} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = \frac{V_m I_m}{2}$$

$$P_{AC} = \frac{(V_{cc} - V_{min}) I_{CQ}}{2}$$ $[V_m = V_{cc} - V_{min},\ I_m = I_{CQ}]$

$$P_{DC} = V_{cc}(I_{CQ})$$

$$\eta\% = \frac{\frac{(V_{cc} - V_{min}) I_{CQ}}{2}}{V_{cc} I_{CQ}} \times 100 = \frac{V_{cc} - V_{min}}{V_{cc}} \times 50\%$$

- If Q-point is exactly at centre & signal variation is maximum possible then $V_{min} = 0$ & efficiency of 50% can be achieved.

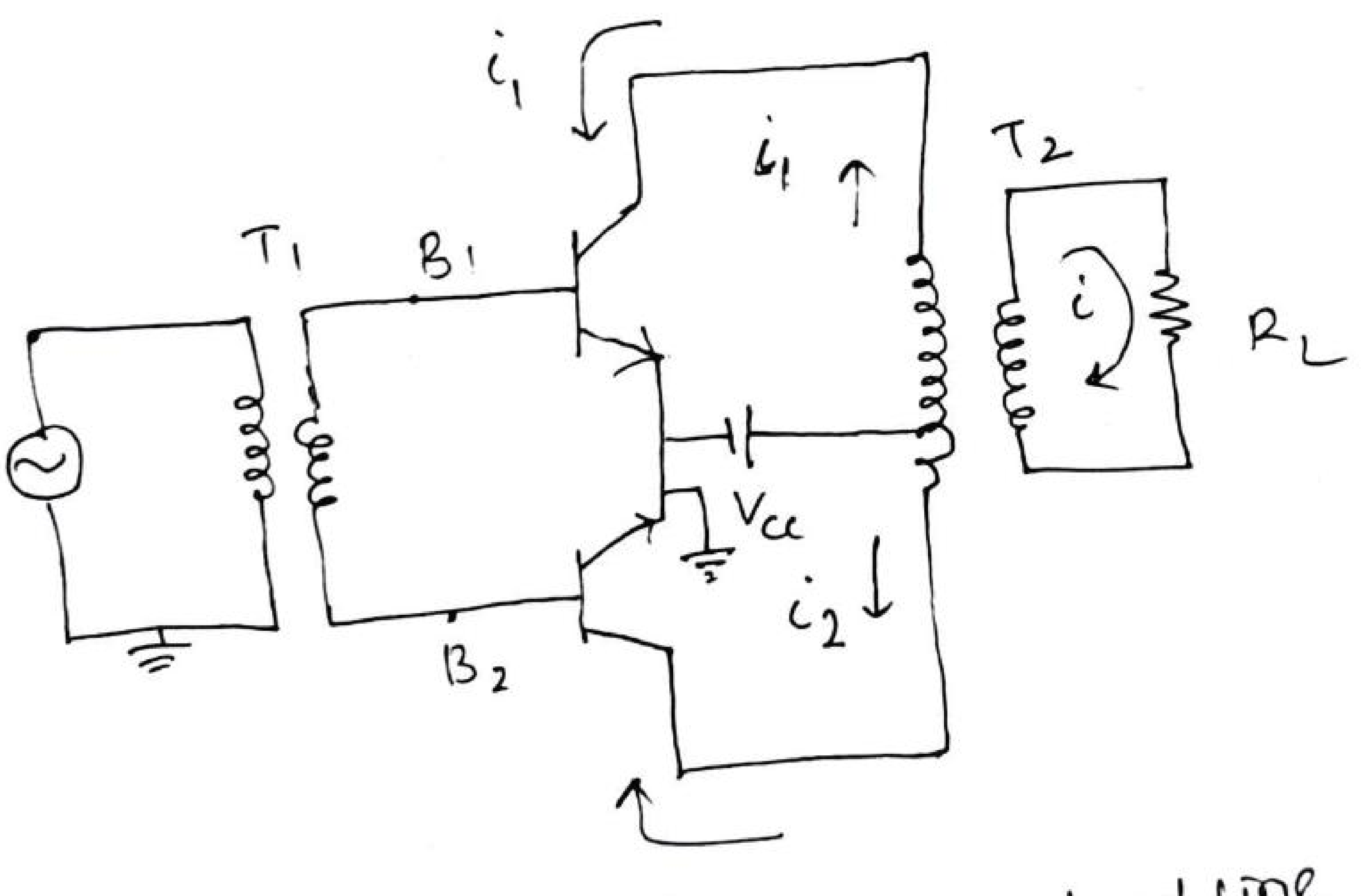
- Transformer coupling results in greater efficiency because -
  (i) power dissipation in primary winding is zero.
  (ii) DC power dissipation in load is zero.

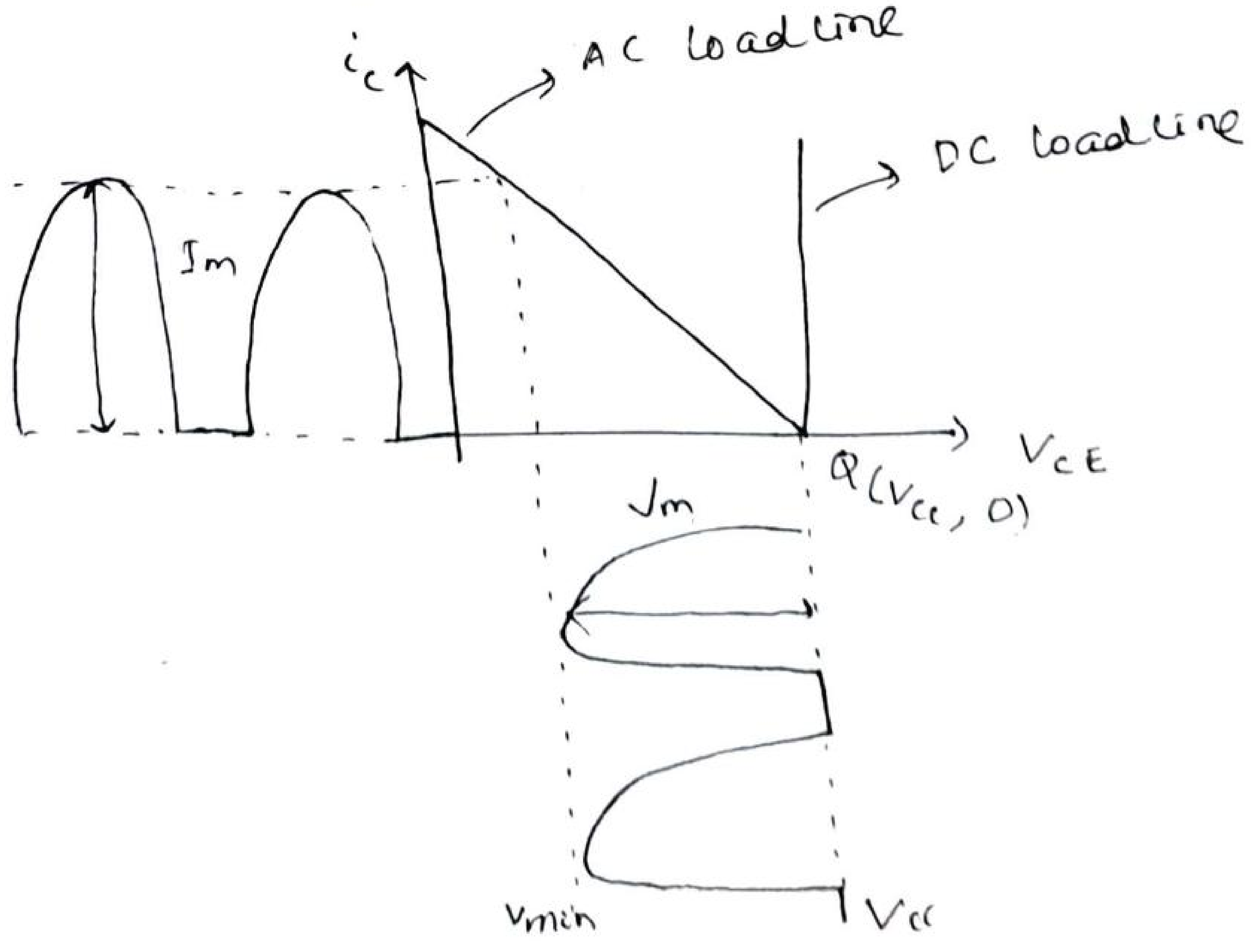
- Figure of merit is 2.

Application

- Class A transformer coupled amplifier is used as audio frequency power amplifier.

Class-B push-pull amplifier





- If signal variation is maximum possible then maximum efficiency of 78.5% is achieved.

- Figure of merit is 0.4.

Advantage

1. Full cycle of o/p is available over the entire full cycle of i/p
2. Loss of information is very less.
3. Harmonics are eliminated due to push pull configuration.

Disadvantage

1. Cross over distortion is present.
2. Two large centre tapped transformer are used which are complex & costly.

Feedback in Amplifier

- Feedback refers to mixing a part of the amplifier o/p with applied input.
- Feedback signal is proportional to o/p signal.

$$x_f \propto x_o \qquad (x_f \rightarrow \text{feedback signal}, X_o - \text{o/p signal})$$

$$X_f = \beta (X_o) \qquad (\beta \rightarrow \text{feedback factor})$$

$$\beta = \frac{x_f}{X_o}$$

- Positive feedback: If feedback signal gets added to applied input it is called +ve feedback.

$$x_i = x_s + x_f \qquad (x_s \rightarrow \text{applied i/p}, x_i \rightarrow \text{Net i/p})$$

- Positive feedback is used in oscillators to generate an ac waveform.

- Negative feedback:- If feedback signal is subtracted from the applied input it is called negative feedback.

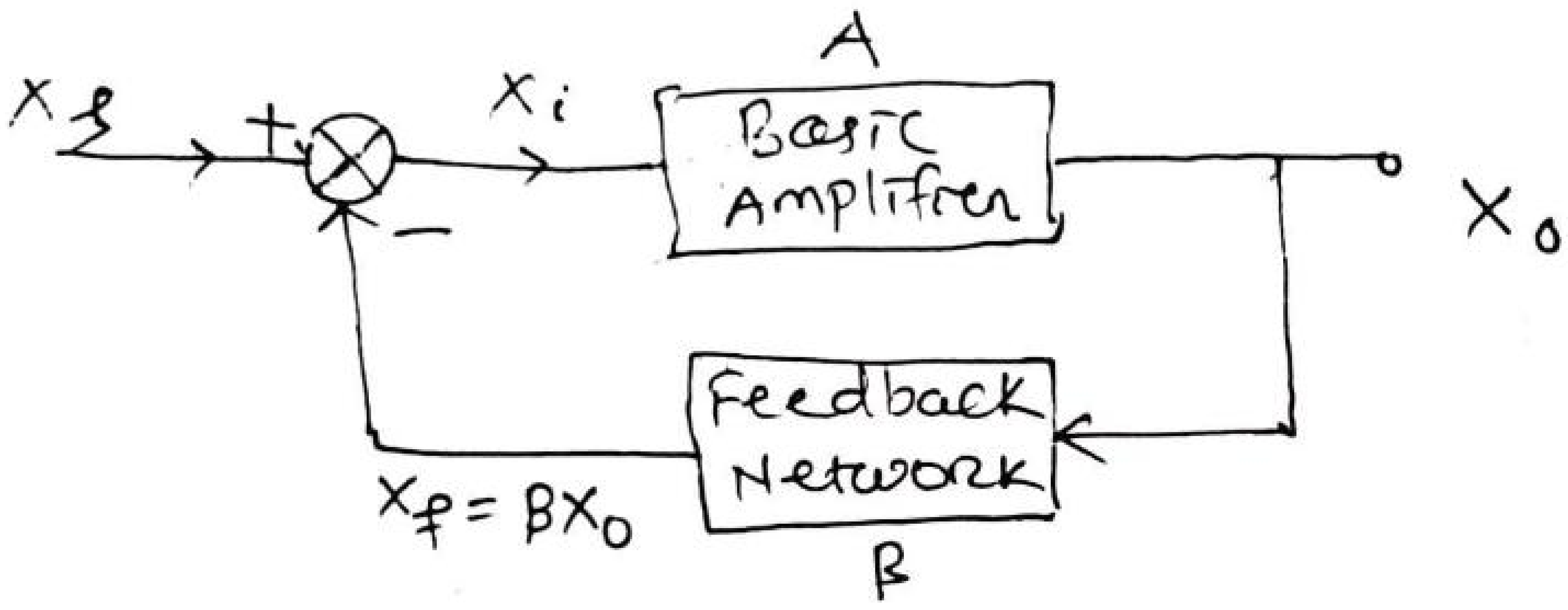
$$x_i = x_s - x_f$$

- In negative feedback applied i/p & feedback signal are out of phase.

Negative feedback is used in amplifier :-

1. To make the gain stable
2. To reduce distortion.
3. To obtain desired values of i/p & o/p impedances.
4. To increase Bandwidth.

Effects of Negative feedback ~~on character~~



- Basic amplifier is converted into feedback amplifier by connecting a feedback network.
- Feedback network is a passive network. It consists of resistors in -ve feedback & a combination of RLC in +ve feedback.

A → open loop gain / Gain of basic amplifier.

A_f → Gain of feedback amplifier / overall gain.

$$A = \frac{X_o}{X_i} \quad , \quad A_f = \frac{X_o}{X_s}$$

$$X_i = X_s - X_f \Rightarrow X_s = X_i + X_f$$

$$\Rightarrow X_s = X_i + \beta X_o$$

$$\Rightarrow X_s = X_i + A\beta X_i$$

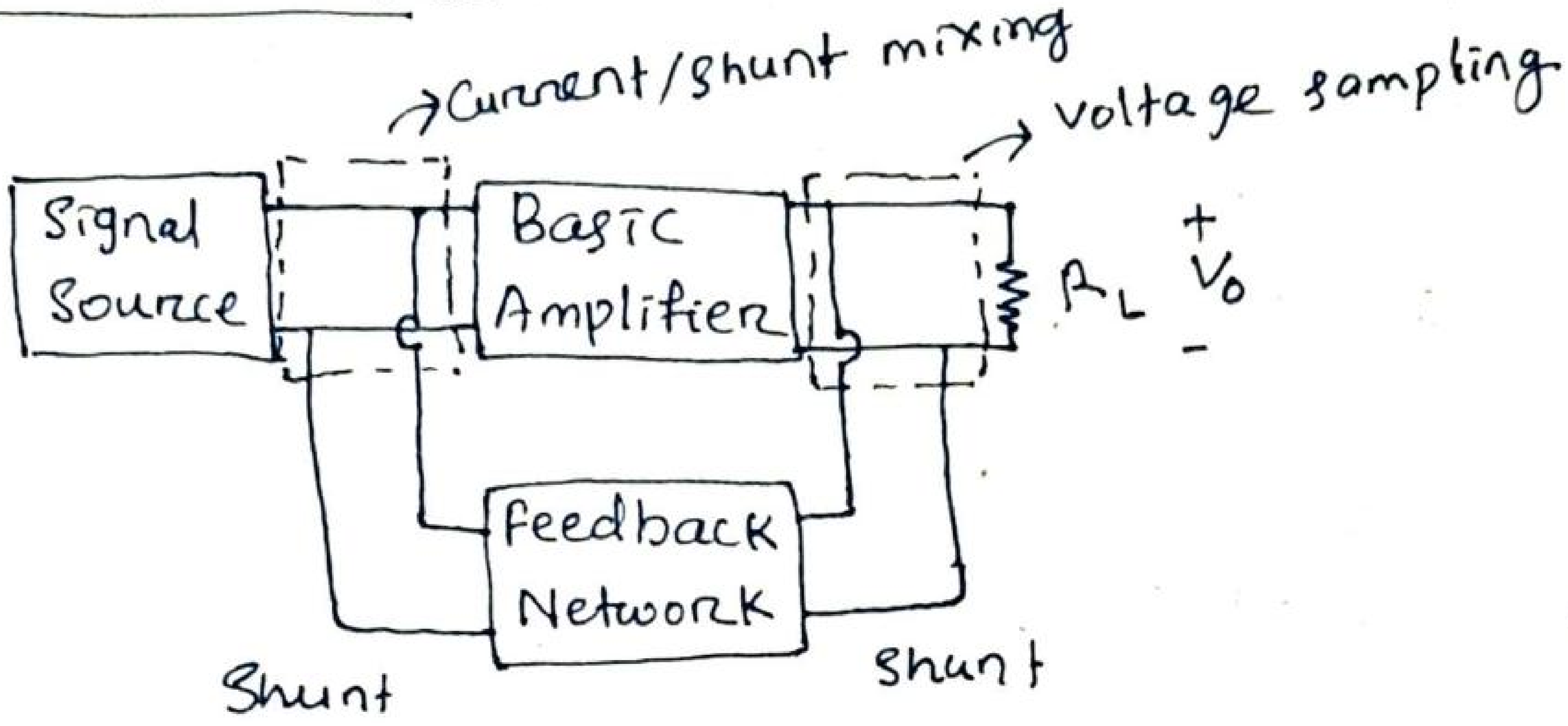
$$\Rightarrow X_s = X_i(1 + A\beta)$$

$$\Rightarrow \frac{X_i}{X_s} = \frac{1}{1 + A\beta}$$

$$A_f = \frac{X_o}{X_s} = \frac{X_o}{X_i} \times \frac{X_i}{X_s} = \frac{A}{1+A\beta} \Rightarrow \boxed{A_f = \frac{A}{1+A\beta}}$$

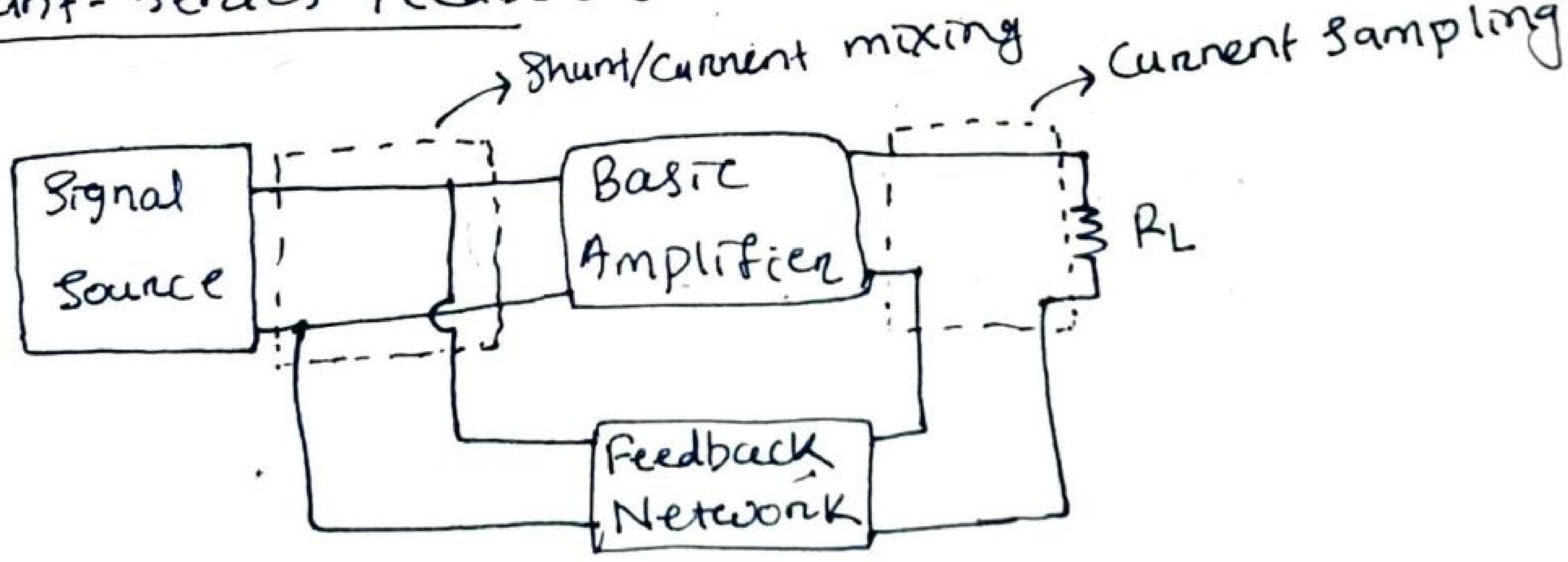
Types of Feedback

(I) Shunt-Shunt Feedback



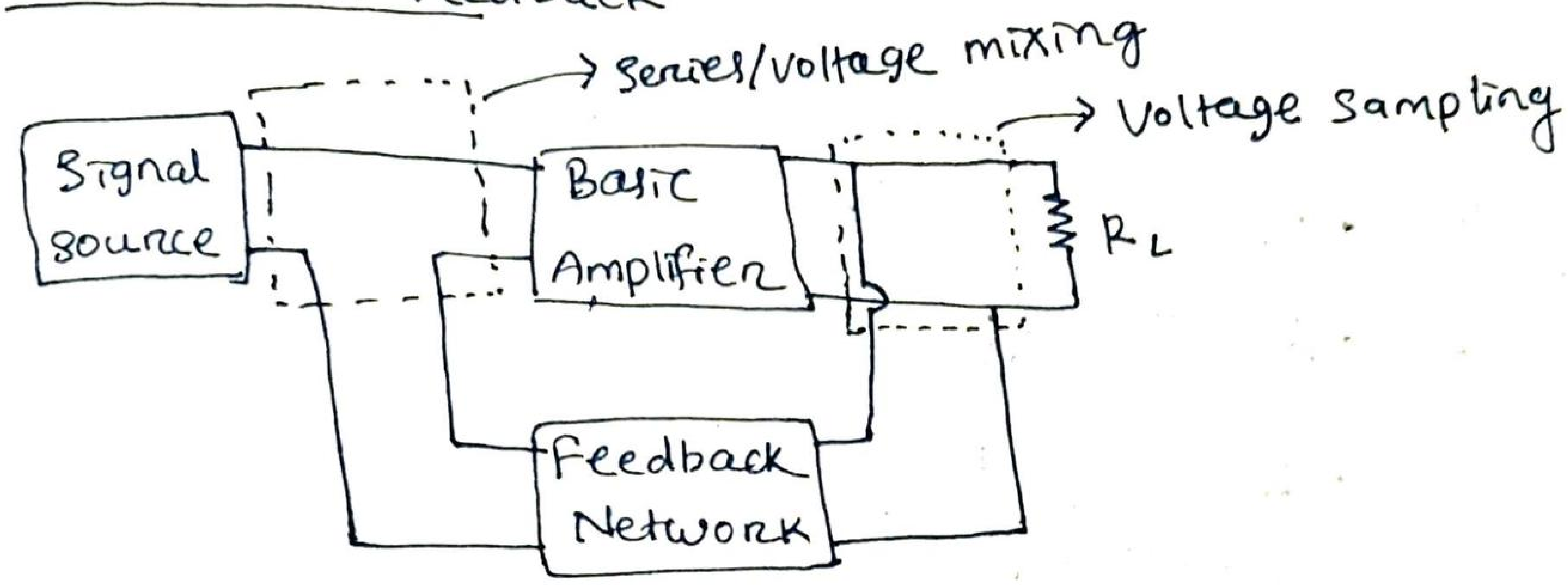
- If feedback network is connected in shunt with load resistor then o/p voltage Vo will appear as i/p to feedback network
- Shunt-shunt feedback is also called voltage-shunt feedback (voltage sampling & shunt mixing) or voltage-current feedback (voltage sampling & current mixing).
- Voltage shunt feedback is also called transconductance amplifier because input is current & o/p is voltage.

(II) Shunt-Series Feedback



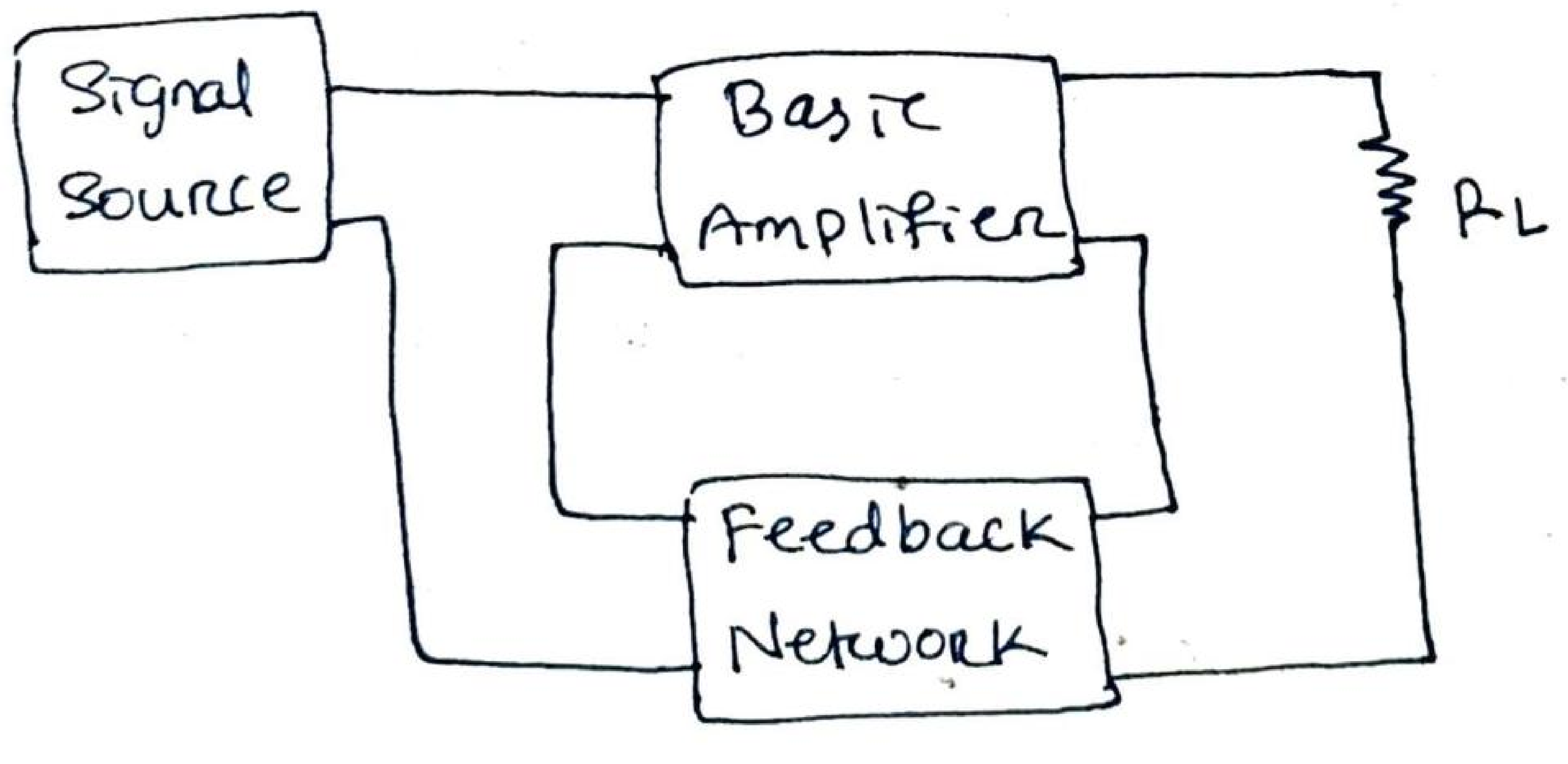
- If feedback network is in series with R_L then load current will appear as i/p to feedback network. This is called current sampling.
- Shunt series feedback is also called current-shunt feedback or current-current feedback.
- current-shunt feedback is a current feedback.

(III)- Series-Shunt feedback



- Series-Shunt feedback is voltage series feedback or voltage-voltage feedback or voltage feedback.
- It is a voltage amplifier.

(IV) Series-Series feedback



- It is current-series or current-voltage or transconductance amplifier.

oscillator

An electronic circuit which generates an AC waveform without using AC input.

Essentials of oscillator

① An electronic circuit with desired gain is required.

② positive feedback is required :- i.e the feedback signal should be in phase with the i/p terminals of the amplifier i.e the phase difference betn i/p terminal & the feedback signal should be either 0° or 360°, so that oscillations are initiated.

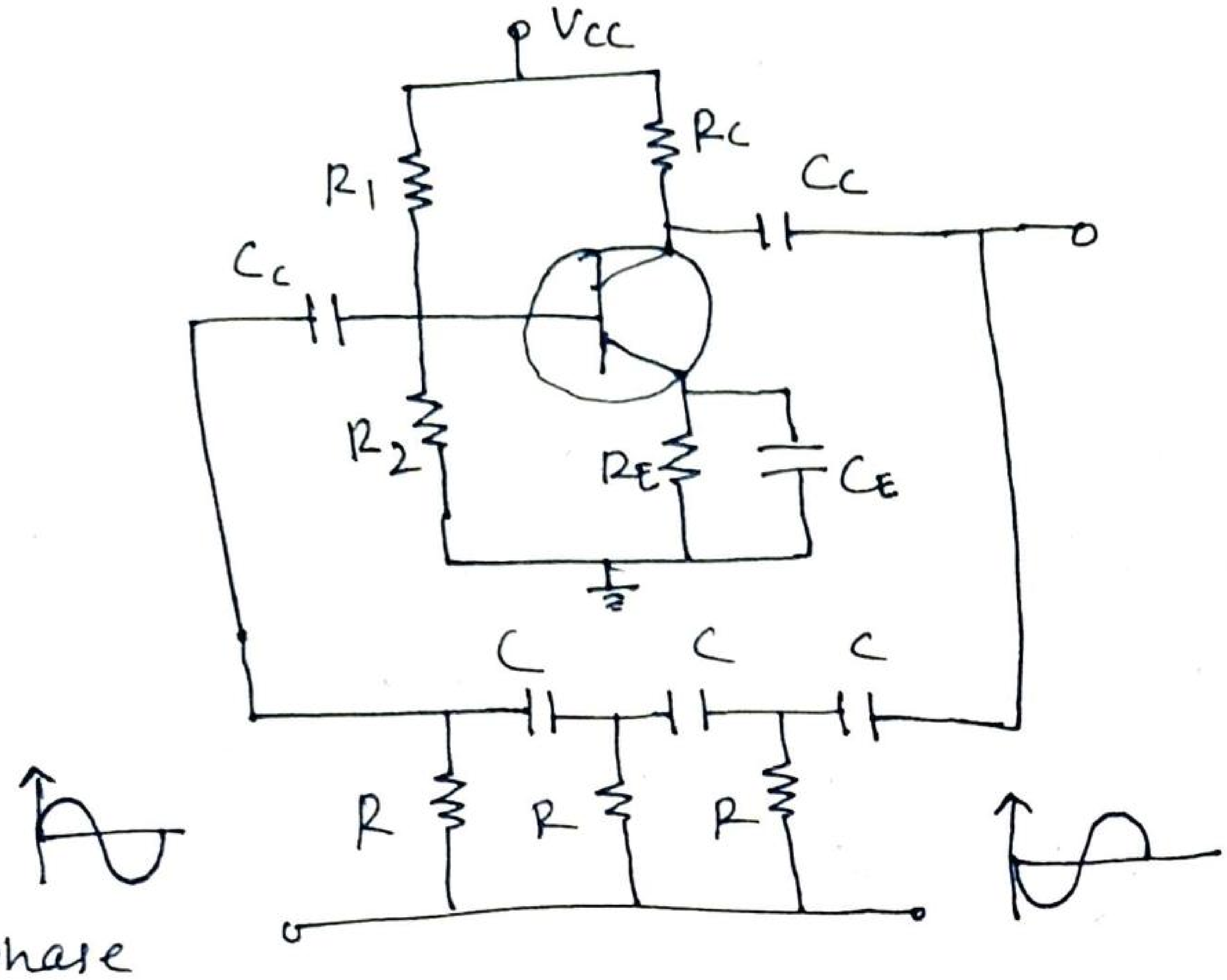
③ Bark-Hausen criterion is to be implemented :- i.e the loopgain of the system $\boxed{A\beta = 1}$, so that oscillations are sustained.

Types of oscillator

① Audio frequency oscillator (RC oscillator)
- RC phase shift
- wein Bridge

② Radio frequency oscillator (LC or high frequency)
- Hartley
- Colpitts
- Clapp
- crystal

RC phase shift oscillator



(phase shift by 180)

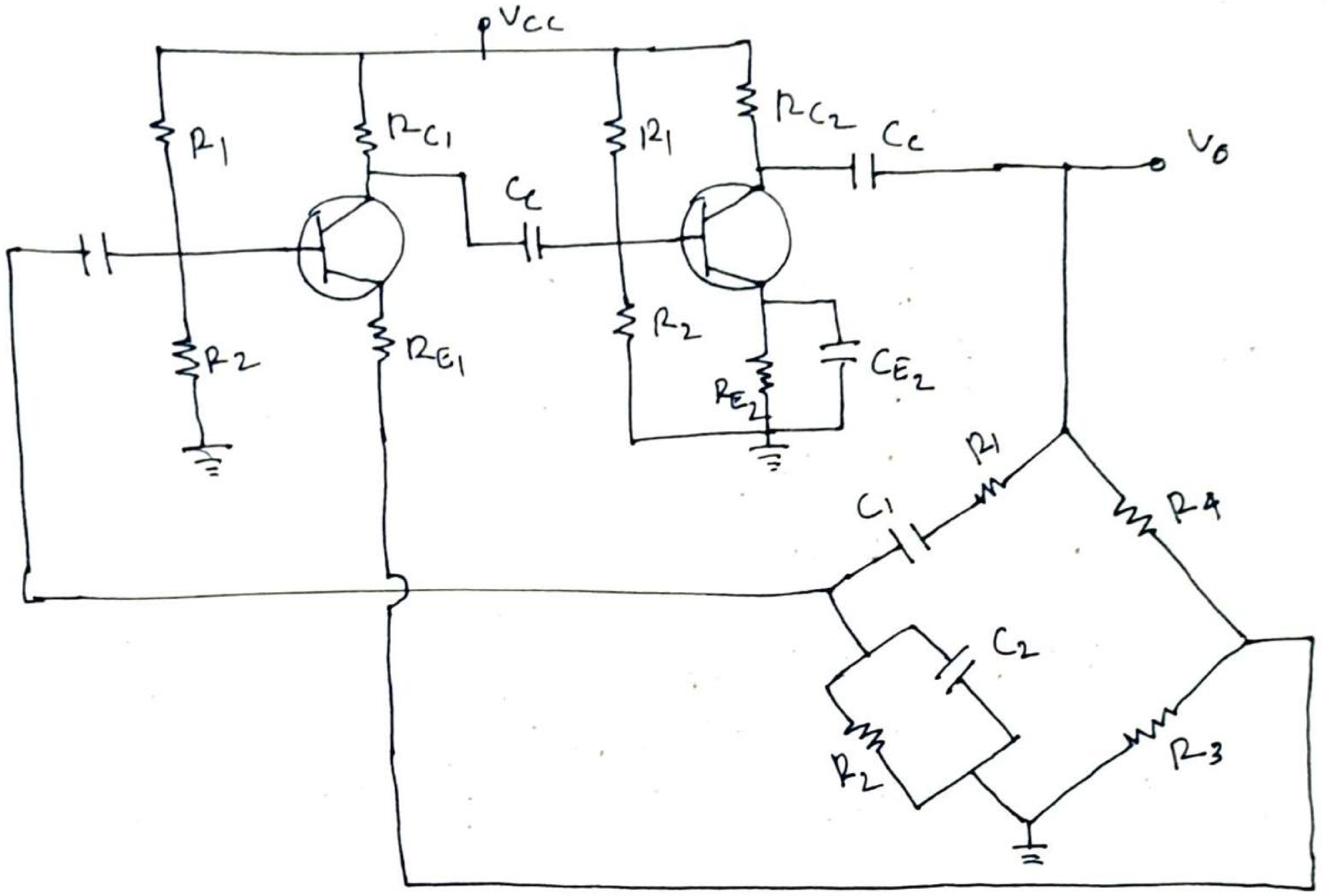
Advantage

- Suitable for oscillation in audio frequency range, preferably upto 1KHz.

Disadvantage

- Fixed frequency oscillation
- Since the system gain depends on feedback network elements which is undesirable & leads to amplitude unstability in the oscillation.
- Frequency unstability in the oscillation.
- Not suitable for high frequency or radio frequency oscillation.

wein-Bridge oscillator



Advantage

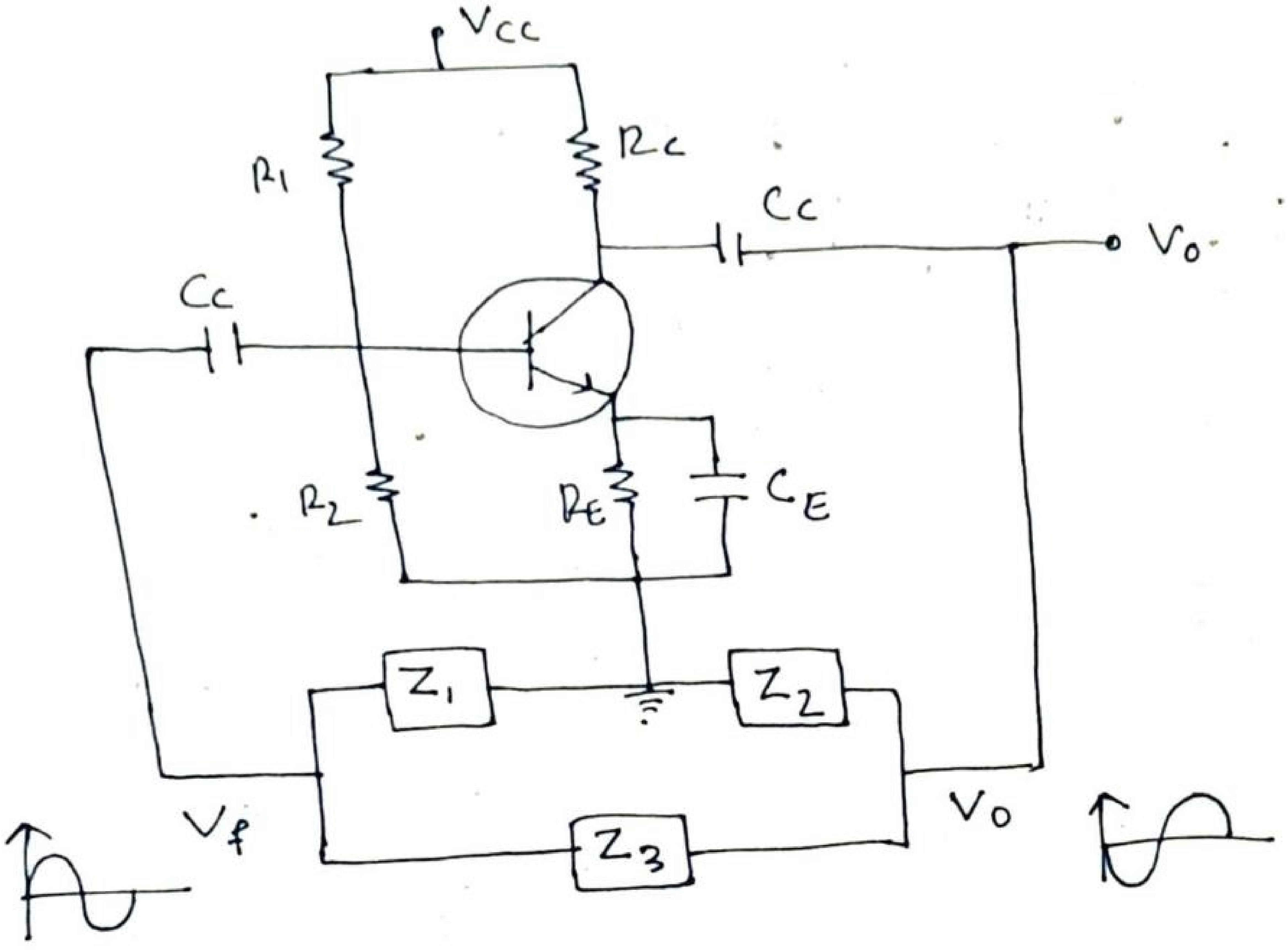
- Suitable for oscillation at audio frequency range, preferably upto 100KHZ.
- Variable frequency oscillator.
- System gain is independent of feedback network elements so amplitude stability in the oscillation.
- Frequency stability is improved in the oscillation by providing negative feedback along with positive feedback.

Disadvantage

- Not suitable for high frequency oscillation.

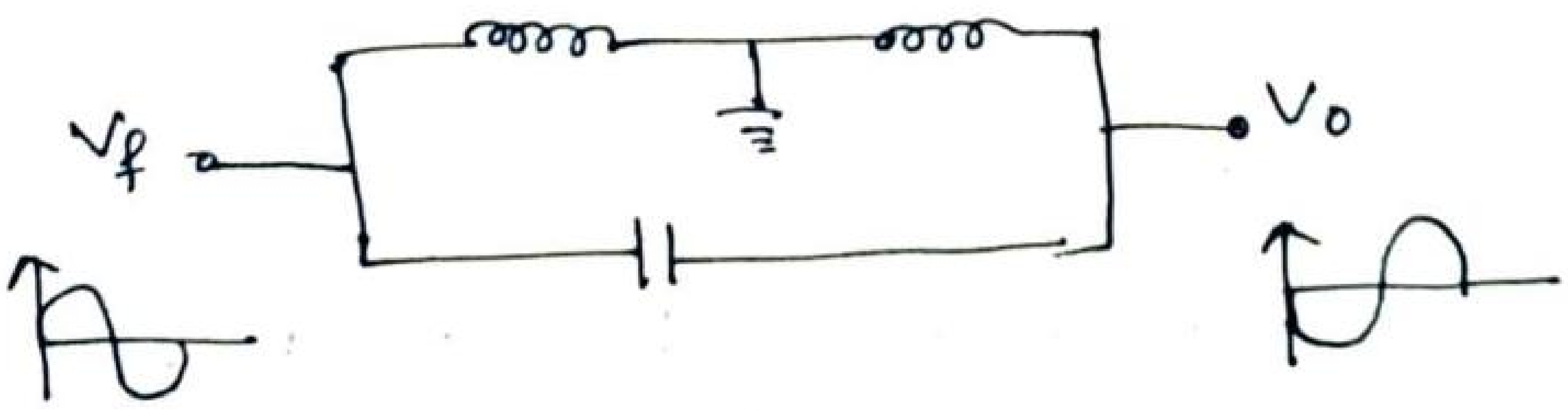
LC oscillators

General circuit



Hartley oscillator

- For hartley oscillator $Z_1 = L_1$, $Z_2 = L_2$, $Z_3 = C$.



Advantage

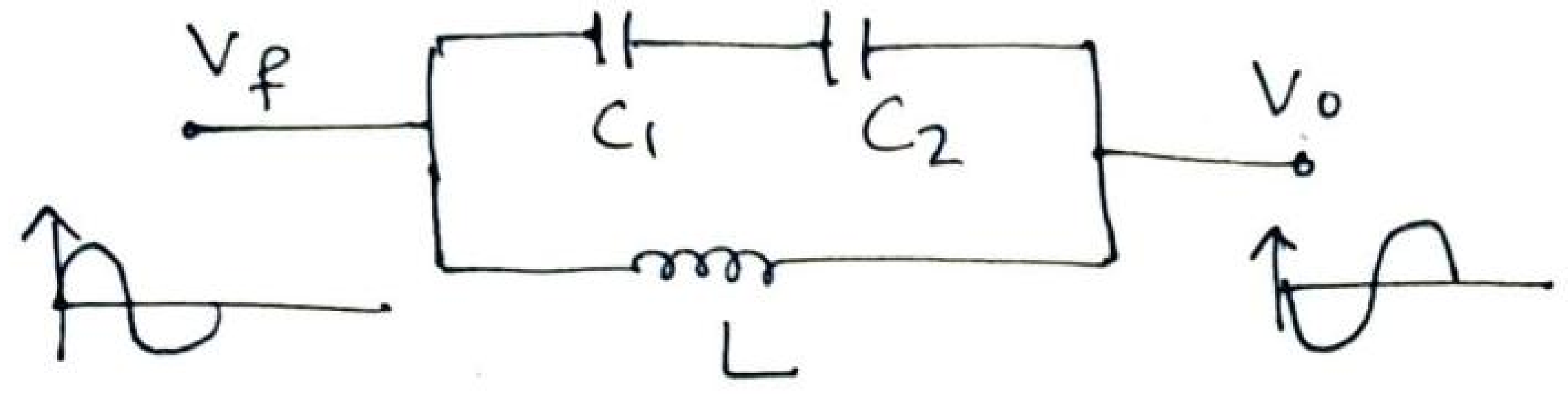
- Suitable for oscillation for radio frequency range or high frequency preferable upto 3MHz.

Disadvantage

- Fixed frequency oscillation.
- Amplitude unstability.
- Frequency unstability in the oscillation.
- mutual inductance is an additional problem.

Colpitts oscillator

- In colpitts oscillator, $Z_1 = C_1$, $Z_2 = C_2$, $Z_3 = L$



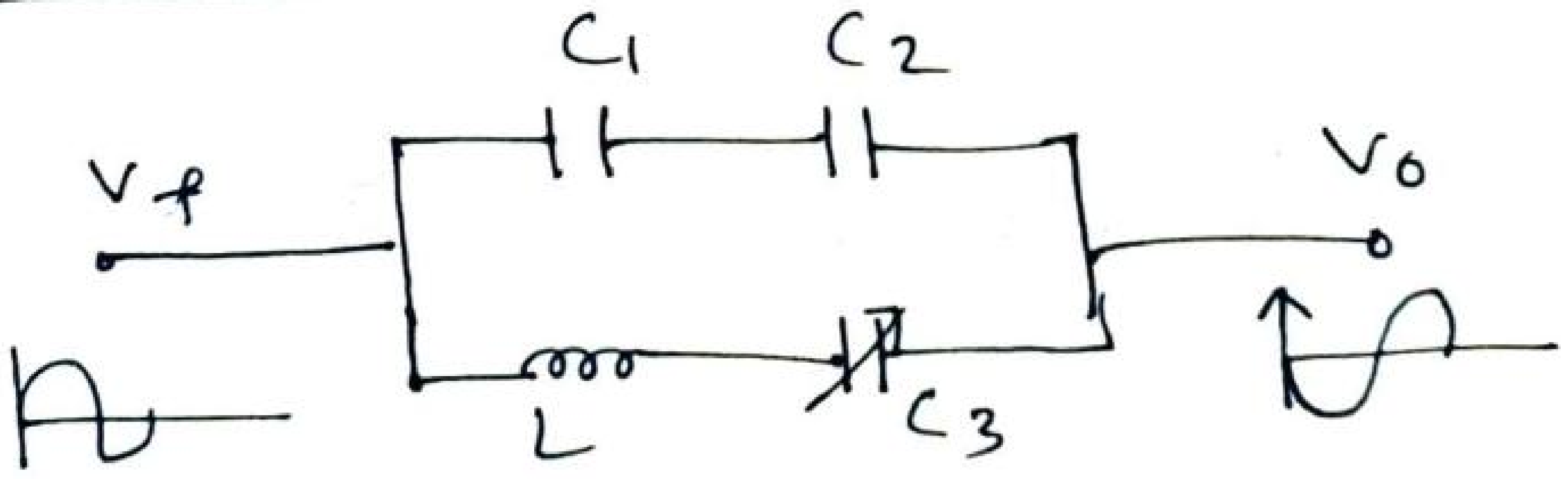
Advantage

- Suitable for high frequency oscillation in Radio frequency Range upto 30MHZ. (high frequency)
- Mutual inductance problem is avoided.

Disadvantage

- Fixed frequency oscillation.
- Amplitude unstability in the oscillation.
- Frequency unstability in the oscillation.

Clapp oscillator



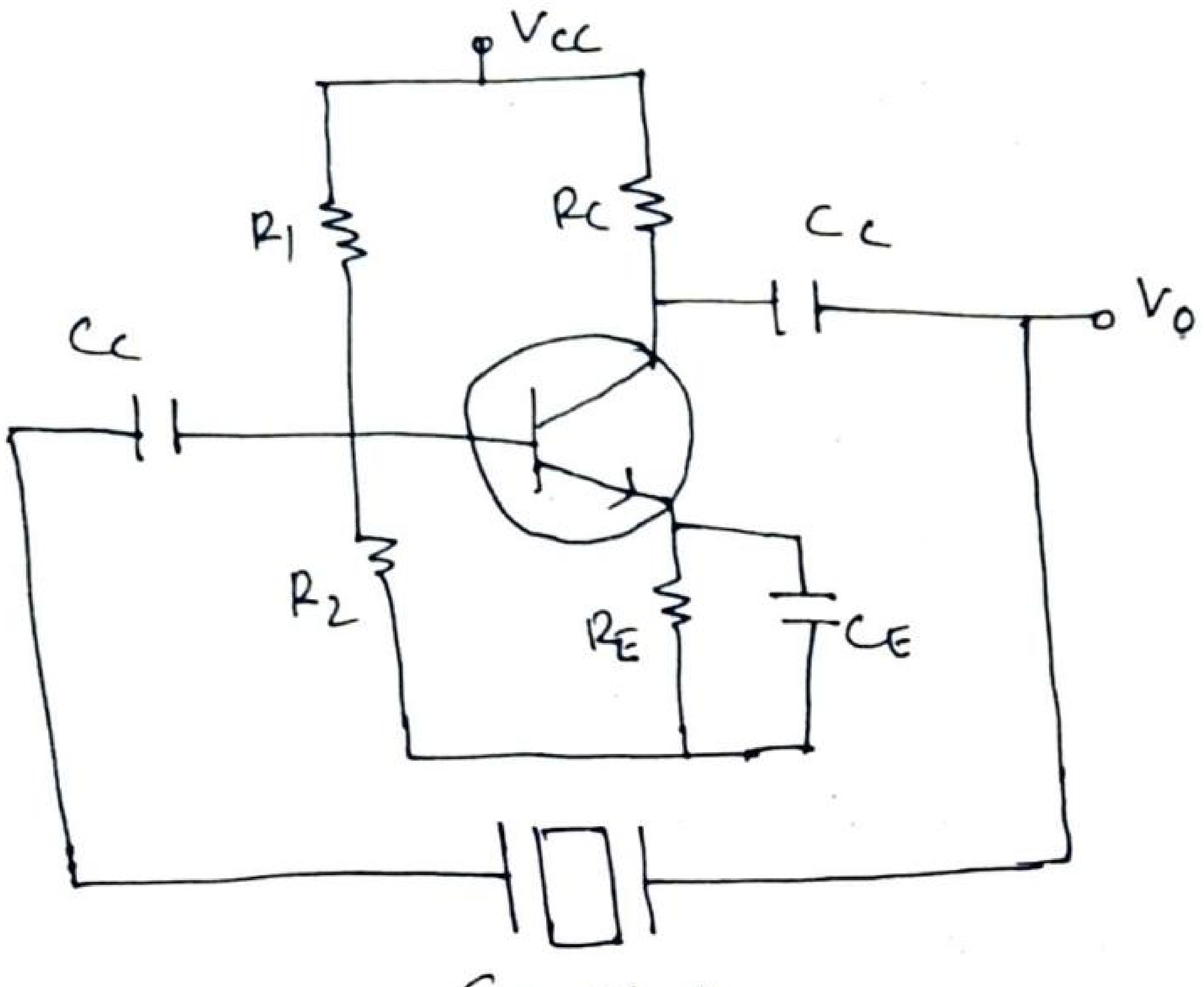
Advantage

- Suitable for high frequency oscillation in radio frequency range.
- variable frequency oscillation.
- No mutual inductance problem.

Disadvantage

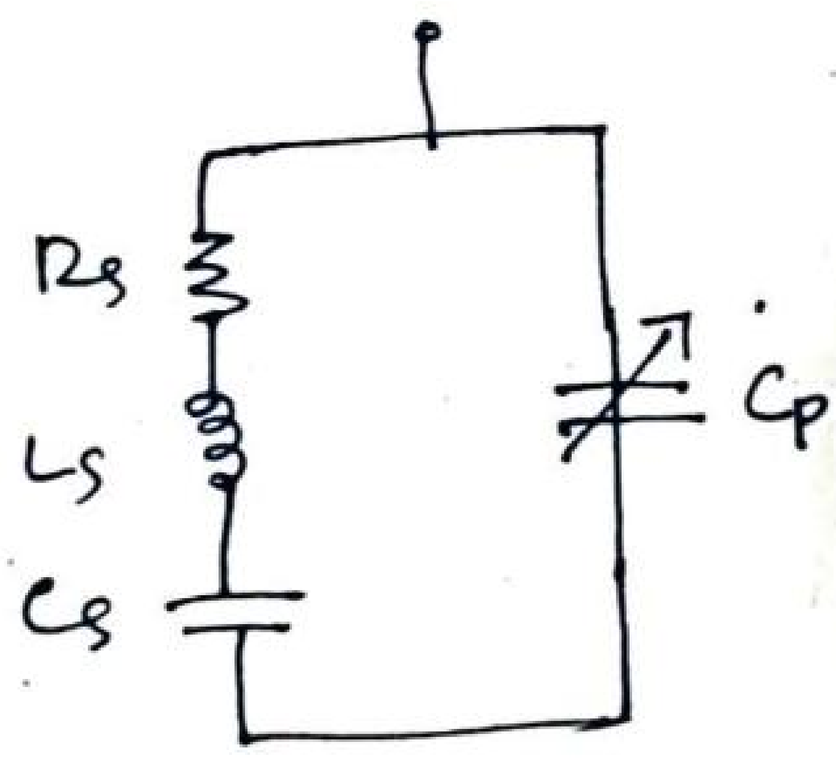
- Amplitude unstability in the oscillation.
- Frequency unstability in the oscillation.

Crystal oscillator



Symbol

Electrical equivalent



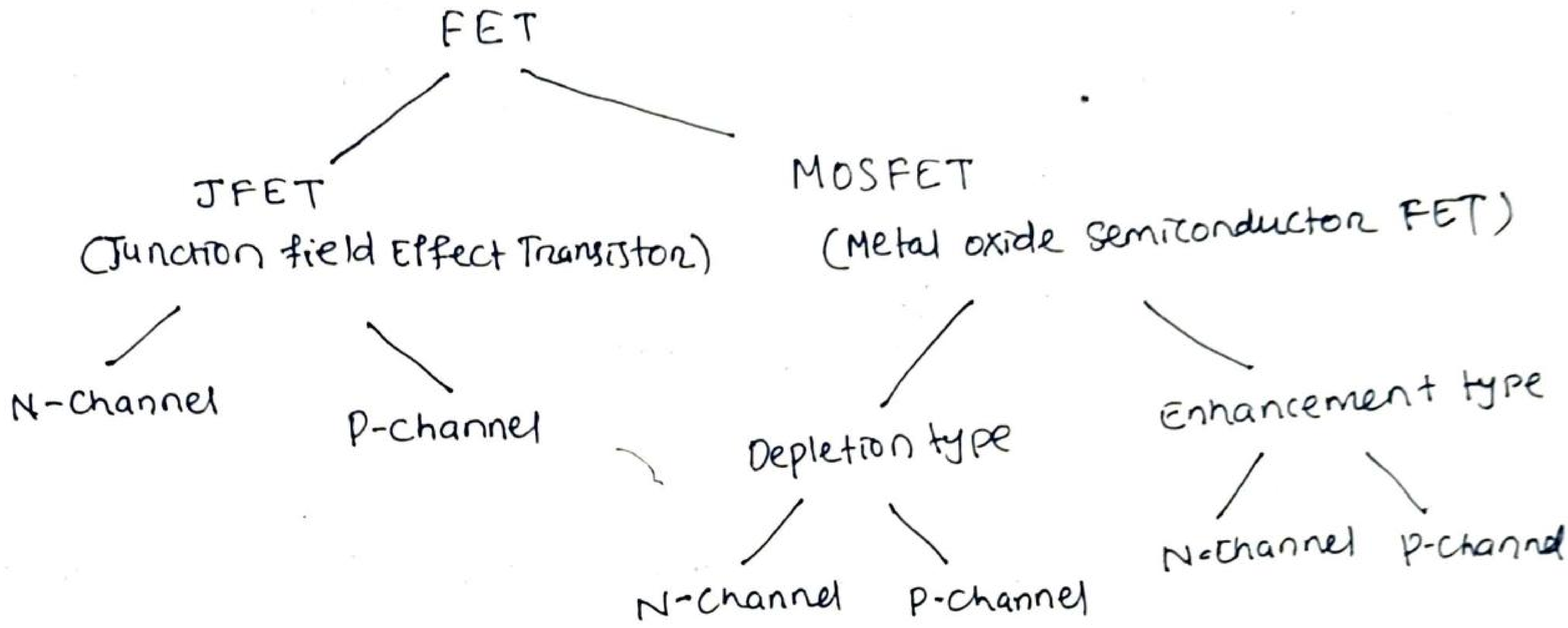
Advantages

- A crystal oscillator is suitable to provide oscillation in radio frequency range upto 30MHZ.
- Crystal oscillator can produce oscillation at 2 different frequencies namely series & parallel resonant frequency.
- Amplitude stability of oscillation is improved.
- Frequency stability of oscillation is improved.

Disadvantage

- crystal oscillator can't provide oscillation at any frequency.
- Costly.

Field Effect Transistor (FET)



Advantages of FET over BJT

- FET is simpler to fabricate & occupies less space in integrated form.
- It exhibits a high input resistance, typically many megohms.
- FET is less noisy than a BJT.
- It exhibits no offset voltage at zero drain current, and hence makes an exellent signal chopper.
- It has higher switching speed.
- It has longer life & high efficiency.

FET parameters

Drain dynamic Resistance (r_d)

The ratio of change in output voltage (∂V_{DS}) to the change in output current at a constant input voltage is called drain dynamic resistance.

$$r_d = \left[\frac{\partial V_{DS}}{\partial I_D}\right]_{V_{GS}\ \text{constant}}$$

Trans conductance (g_m)

The ratio of change in output current (∂I_D) to the change in input voltage (∂V_{GS}) at a constant output voltage is called as transconductance.

$$g_m = \left[\frac{\partial I_D}{\partial V_{GS}}\right]_{V_{DS}\ \text{constant}}$$

Amplification factor (μ)

The ratio of change in output voltage to the change in input voltage (∂V_{GS}) at a constant output current is called amplification factor.

$$\mu = \left[\frac{\partial V_{DS}}{\partial V_{GS}}\right]_{I_D\ \text{constant}}$$

Relation among the parameters of FET

we know,

$$\mu = \frac{\partial V_{DS}}{\partial V_{GS}} \quad \text{---} (1)$$

multiply & divide by ∂I_D in eq^n (1)

$$\mu = \frac{\partial V_{DS}}{\partial V_{GS}} \times \frac{\partial I_D}{\partial I_D}$$

$$= \frac{\partial V_{DS}}{\partial I_D} \times \frac{\partial I_D}{\partial V_{GS}}$$

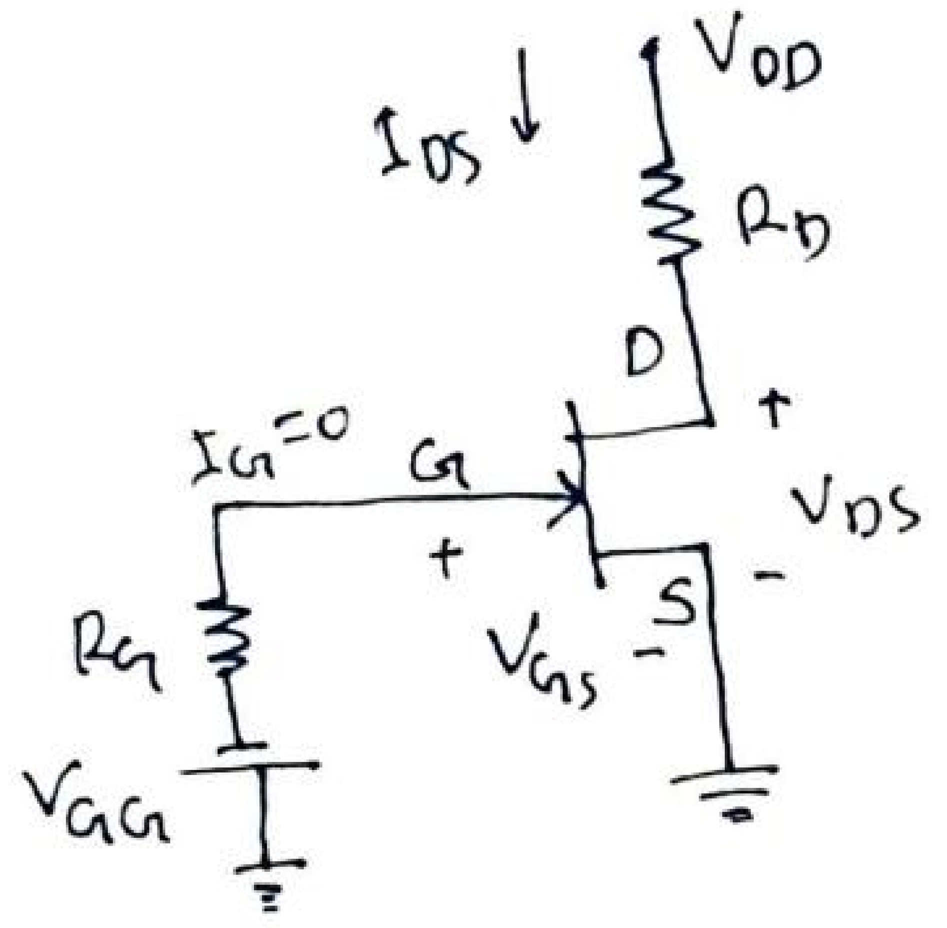
$$= R_d \times g_m$$

$$\boxed{\mu = R_d\, g_m}$$

→ FET is a 3 terminal device such as :- Gate
Source
Drain

JFET Biasing

① Gate Bias CKt



V_{DD} → Drain supply

V_{GG} → Gate supply

- Gate current is zero in JFET due to reverse biasing of gate channel junction. [$I_G = 0$]

Apply KVL at input loop :-

$$V_{GG} + I_G R_G + V_{GS} = 0$$

$$\boxed{G_{SS} = -V_{GG}} \qquad [\text{as } I_G = 0]$$

Apply KVL at output loop :-

$$-V_{DD} + I_{DS} R_D + V_{DS}$$

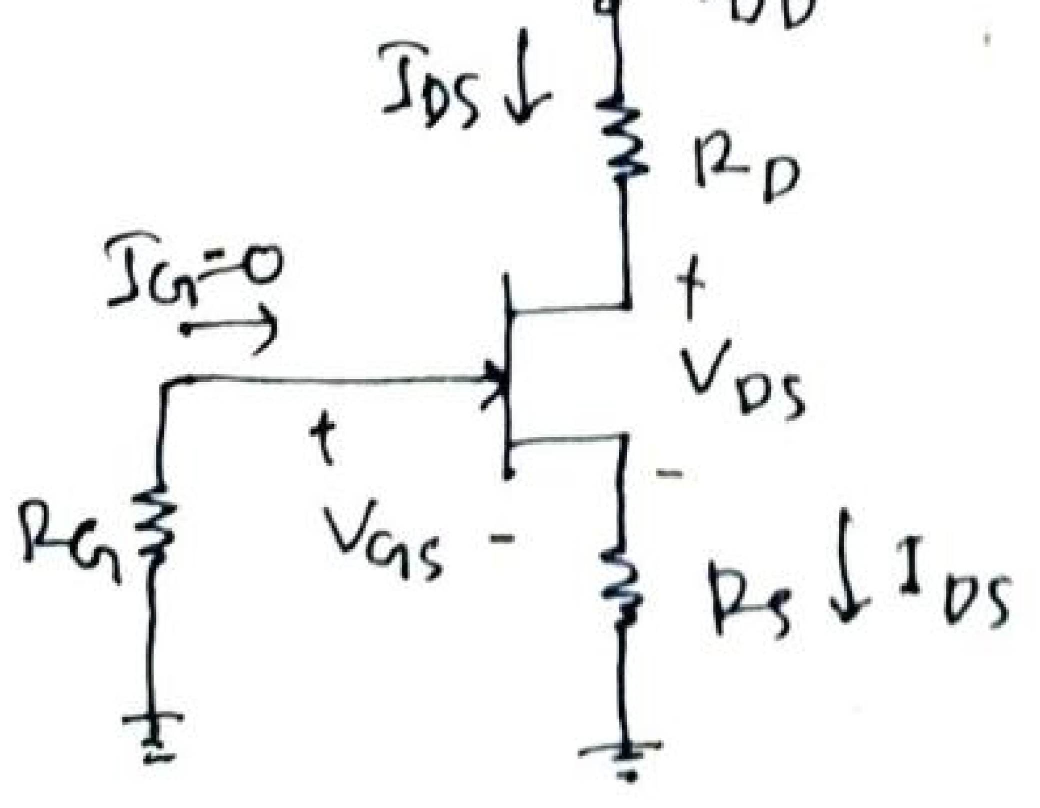
$$\boxed{V_{DS} = V_{DD} - I_{DS} R_D}$$

- R_D controls V_{DS}

Disadvantage

- Gate bias CKt require 2 biasing supply which are costlier.

② Source Self Bias CKt



I_{DS} → drain-source current.

R_S → Self bias resistor.

Apply KVL at input loop

$$I_G R_G + V_{GS} + I_{DS} R_S = 0$$

$$\Rightarrow \boxed{V_{GS} = -I_{DS} R_S} \qquad [I_G = 0]$$

Apply KVL at output loop

$$-V_{DD} + I_{DS} R_D + V_{DS} + I_{DS} R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_{DS} R_D - I_{DS} R_S$$

$$\boxed{V_{DS} = V_{DD} - I_{DS}(R_D + R_S)}$$

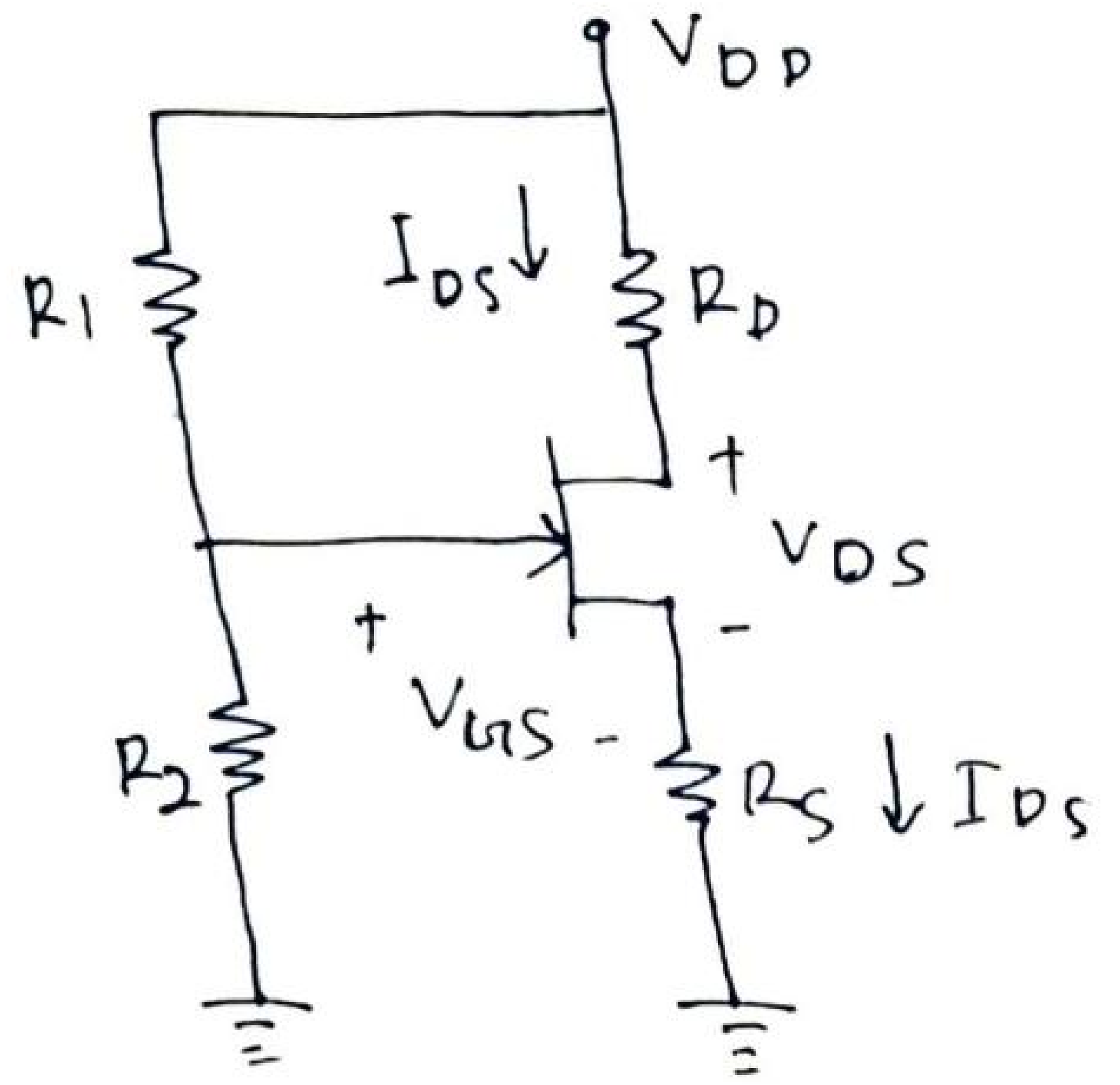
<u>Advantage</u>

- Single biasing supply is needed.
- Resistor R_S causes -ve feedback which helps in keeping the drain current stable.

<u>Disadvantage</u>

- Negative feedback reduces voltage gain.

Voltage Divider Bias ckt



R_1 & R_2 form voltage divider

Applying voltage division rule

$$V_G = \frac{V_{DD} \times R_2}{R_1 + R_2}$$

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

$$= \frac{V_{DD} R_2}{R_1 + R_2} - I_{DS} R_S \quad [V_S = I_{DS} R_S]$$

Applying KVL to output loop :-

$$-V_{DD} + I_{DS} R_D + V_{DS} + I_{DS} R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_{DS} R_D - I_{DS} R_S$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_{DS}(R_D + R_S)}$$

-) Advantages & disadvantage same as source self bias circuit.

- Drain current of FET has negative temp. coefficient i.e drain current decreases with increase in temp. due to decrease in carrier mobility.

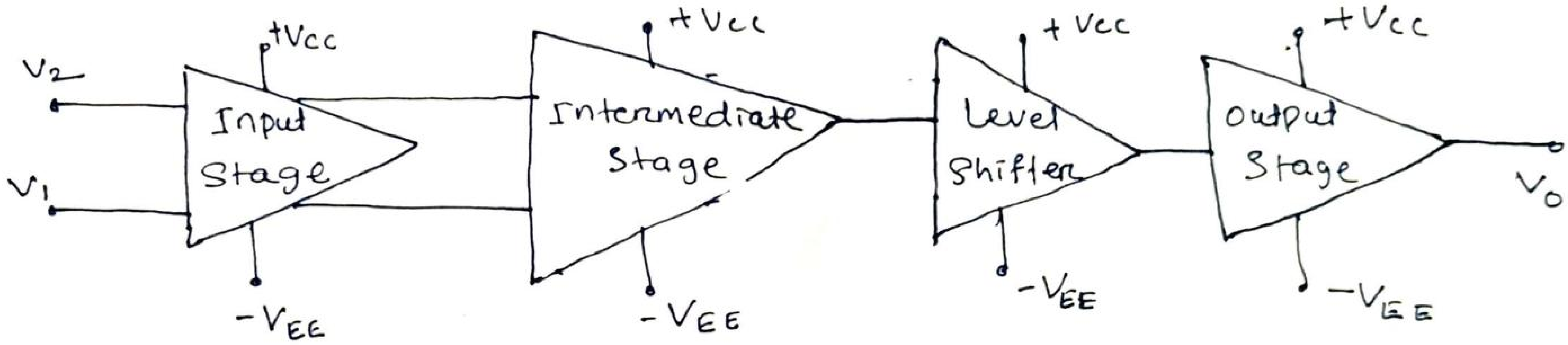
- Due to decrease in mobility thermal run away can not occure in FET. Hence FET is said to be thermally stable.

Operational Amplifier (OPAMP)

- It is a direct coupled amplifier having high voltage gain.
- It can be used to perform mathematical operations on analog signals. Hence it is called operational amplifier.
- OPAMP is available as IC 741 : General purpose OPAMP IC

Operational Amplifier Stages

- IC 741 internally consists of 4 stages.



- Input stage is dual input, balance output differential amplifier.
- Intermediate stage is dual input, unbalanced output differential amplifier.
- Two differential amplifier are used in the internal ckt of IC 741 to achieve high voltage gain & high CMRR.

CMRR

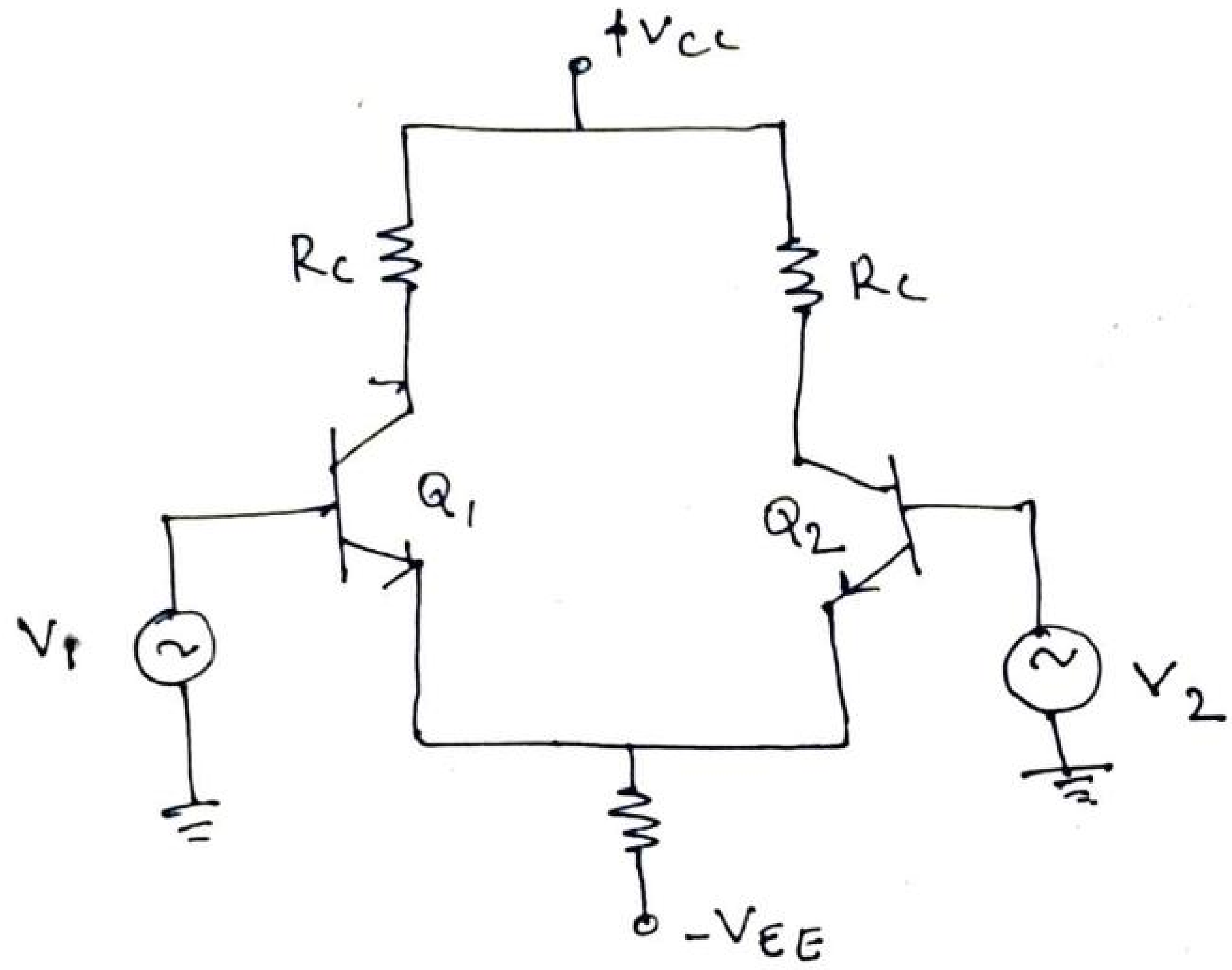
It is the ratio of diffential mode gain to common mode gain.

$$CMRR = \frac{A_{DM}}{A_{CM}}$$

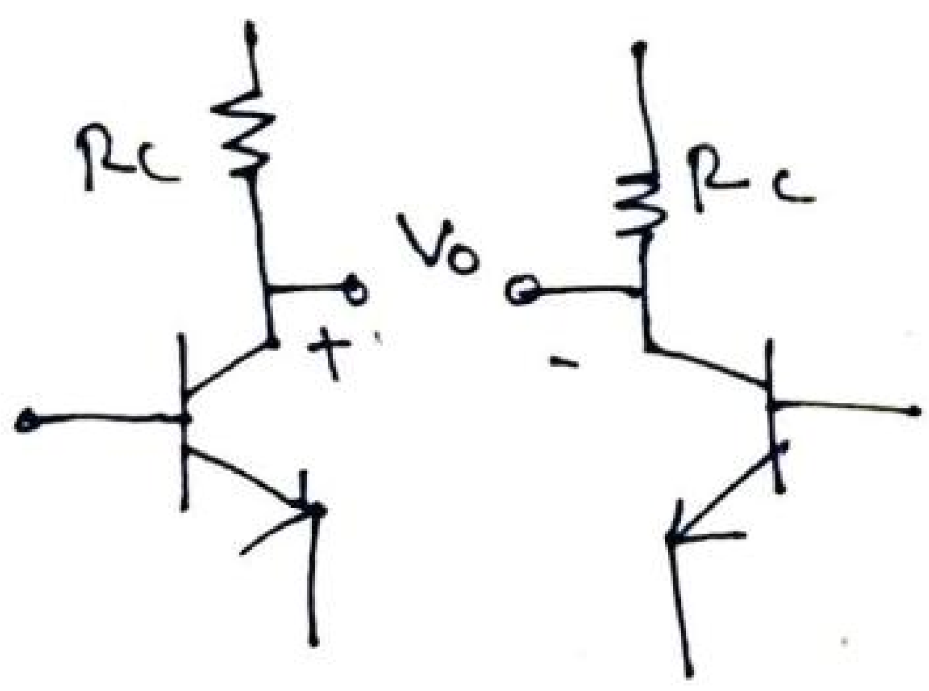
- A level shifter is used as 3rd stage to eliminate the DC bias voltage present in output of intermediate stage.
- Output stage is a complementary symmetry push pull power amplifier.

Differential Amplifier

- It is a circuit which amplify the difference of 2 input voltages.
- It should have 2 identical transistor
- 2 biasing supply +Vcc & -VEE are used to operate 2 transistor in active region.

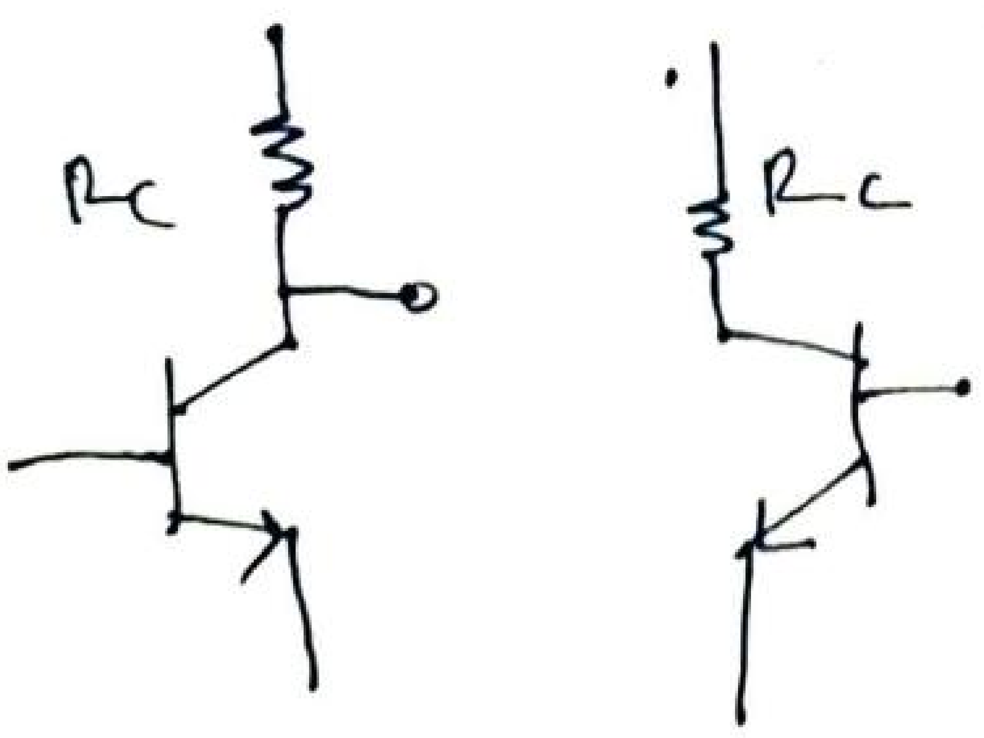


Balanced output



→ It is measured between 2 collector.

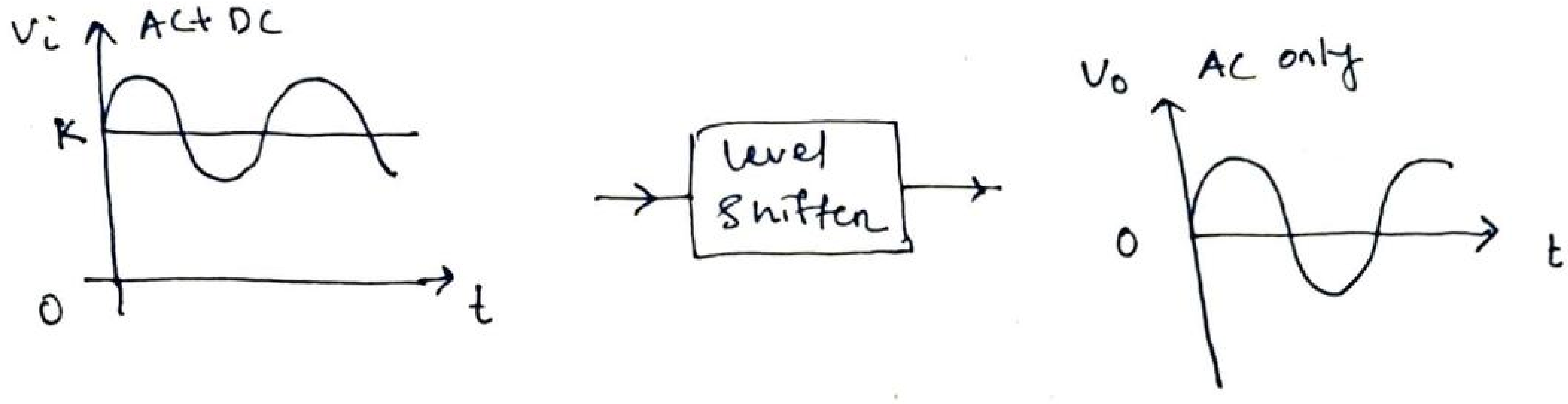
Unbalanced output



→ It is measured between one collector & ground.

Level shifter

A circuit which shifts the DC voltage level to 0 volt i.e it eliminates DC voltage from a signal



Properties of ideal OPAMP

1. Open loop voltage gain is ∞. ($A_{OL} = \infty$)
2. Input resistance is ∞ i.e currents are zero.
3. Output resistance is zero.
4. Bandwidth is ∞ i.e it can amplify signal of any frequency.
5. Common mode rejection ratio (CMRR) is ∞.
6. Slew rate is ∞

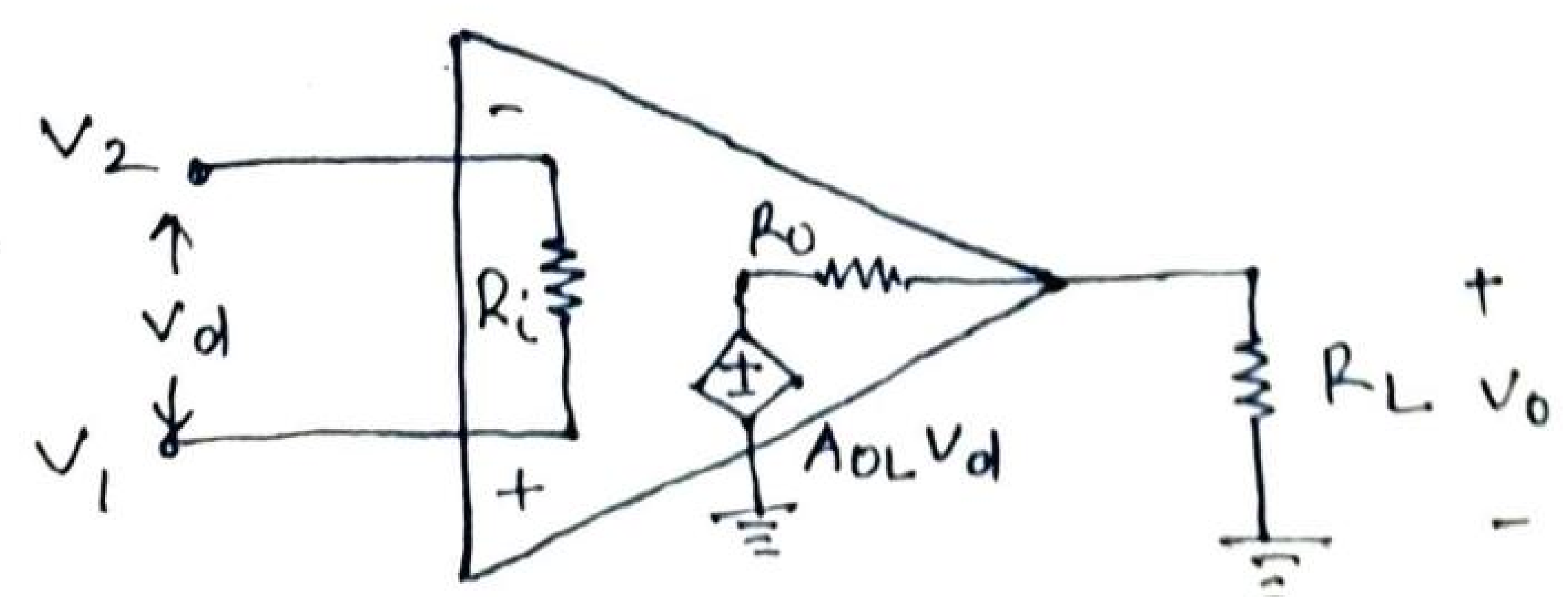
Slew rate

The maximum rate of change in the output of OPAMP is called as slew rate.

$$\text{Slew rate} = \left[\frac{dV_o}{dt}\right]_{max}$$ unit : volt/µsec

Equivalent circuit of OPAMP

According to the values of R_i & R_o, ideal OPAMP is ideal voltage amplifier or voltage dependent voltage source



Virtual Short circuit

when OPAMP is in linear region, differential input will be very small (μV) hence mathematically analysis such small value of Vd can be approximated to zero.

$$V_d \cong 0 \Rightarrow \boxed{V_1 = V_2}$$

- The 2 input terminal of OP-AMP will be aproximately at equal voltage without any physical short circuit between them. Hence the two input terminals are said to be virtually shorted.

Virtual Ground

- If virtual short circuit is present between two node A & B & if node B is physically ground then voltage at node A also becomes zero or node A gets virtualy grounded.
- If a node voltage become zero without physically ground it then it is called virtual ground.

Application of OPAMP

open-loop

- OPAMP when in open loop act as voltage comparator.
- Here OPAMP is used without feedback.

closed-loop

- Negative feedback : Amplifier, mathematical operation etc.
- Positive feedback : Schmitt trigger, waveform generator & oscillator.

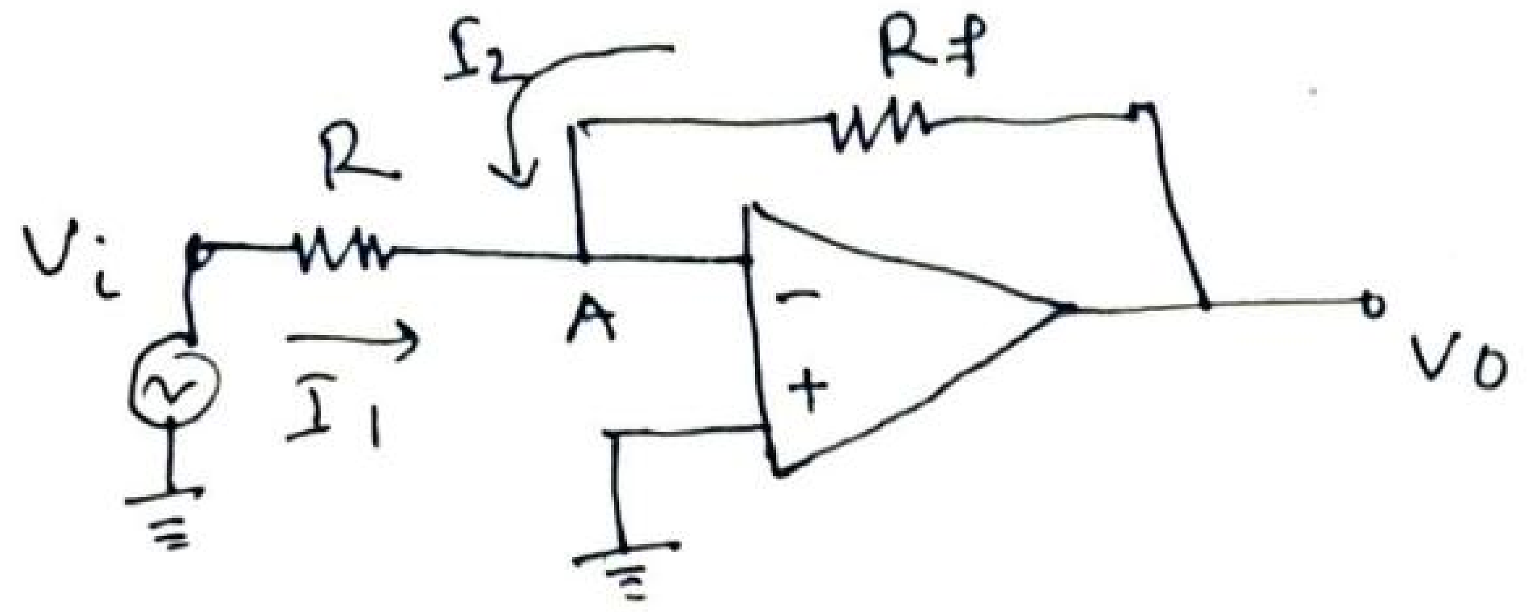
Negative feedback Application of OPAMP

- Assumptions used in the analysis of OPAMP in negative feedbak :-

① OPAMP is in linear region & hence 2 i/p terminal virtually shorted.

② The input current of OPAMP are negligible.

Inverting Amplifier



- In inverting OPAMP input is connected to negative terminal.

Apply KCL at node A

$$I_1 + I_2 = 0$$

$$\Rightarrow \frac{V_i - V_A}{R} + \frac{V_o - V_A}{R_f} = 0$$

According to virtual ground connection $V_A = 0$ (as other terminal is grounded)

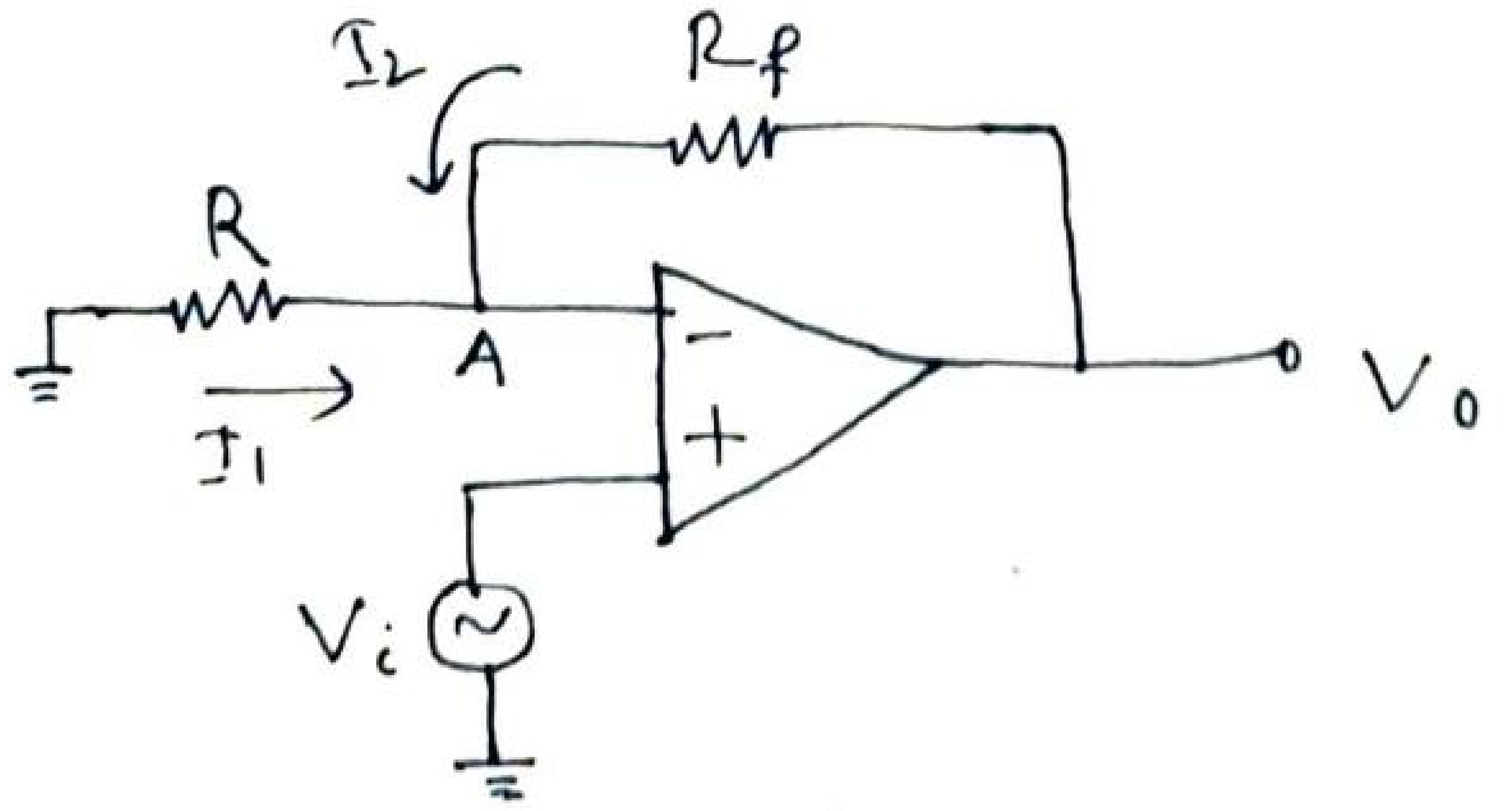
$$\Rightarrow \frac{V_i}{R} + \frac{V_o}{R_f} = 0$$

$$\Rightarrow \frac{V_o}{R_f} = -\frac{V_i}{R} \Rightarrow \boxed{V_o = \frac{-R_f}{R} V_i}$$

$$\Rightarrow \frac{V_o}{V_i} = -\frac{R_f}{R} \Rightarrow \boxed{A_f = \frac{-R_f}{R}}$$ ($A_f \rightarrow$ Gain)

Non Inverting OPAMP

- In non inverting OPAMP input is connected to positive terminal.



$V_A = V_i \rightarrow$ According to virtual ground connection.

Apply KCL at node A :-

$$I_1 + I_2 = 0$$

$$\Rightarrow \frac{0 - V_A}{R} + \frac{V_0 - V_A}{R_f} = 0$$

$$\Rightarrow -\frac{V_A}{R} + \frac{V_0}{R_f} - \frac{V_A}{R_f} = 0$$

$$\Rightarrow \frac{V_0}{R_f} = \frac{V_A}{R_f} + \frac{V_A}{R}$$

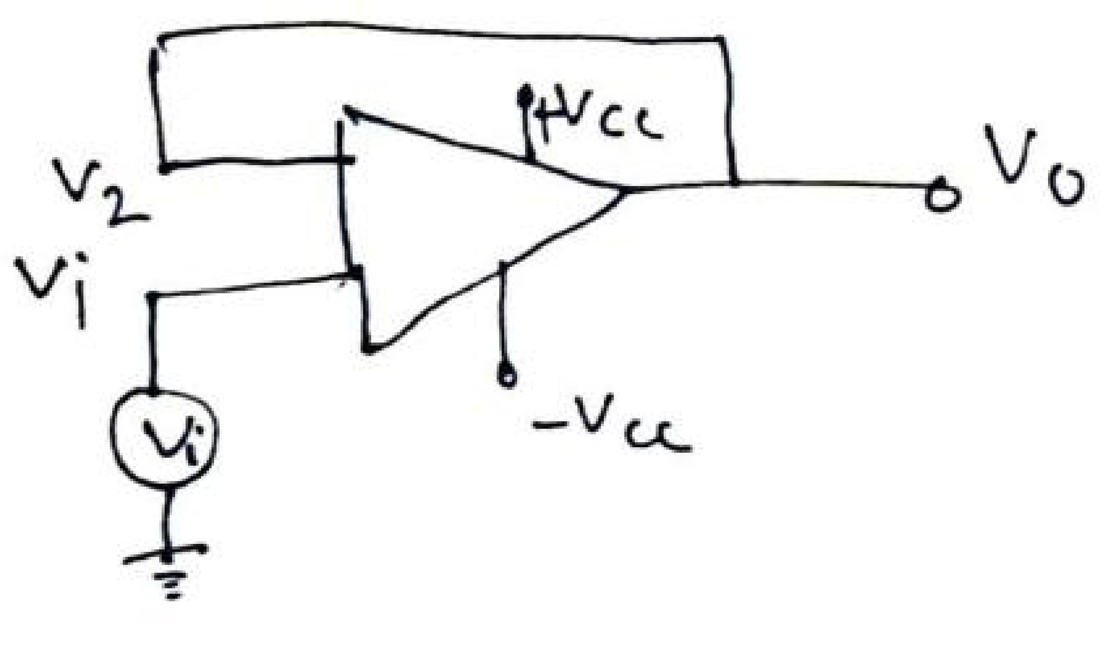
$$\Rightarrow \frac{V_0}{R_f} = V_A \left(\frac{1}{R_f} + \frac{1}{R} \right) = V_A \left(\frac{R + R_f}{R \cdot R_f} \right)$$

$$\Rightarrow V_0 = V_A \left(\frac{R + R_f}{R \cdot R_f} \right) \cdot R_f$$

$$\Rightarrow \boxed{V_0 = V_i \left(1 + \frac{R_f}{R} \right)} \quad (V_A = V_i)$$

$$\frac{V_0}{V_i} = 1 + \frac{R_f}{R} \Rightarrow \boxed{A_f = 1 + \frac{R_f}{R}}$$

<u>voltage follower</u>



$V_2 = V_0$ (output is short) — ①

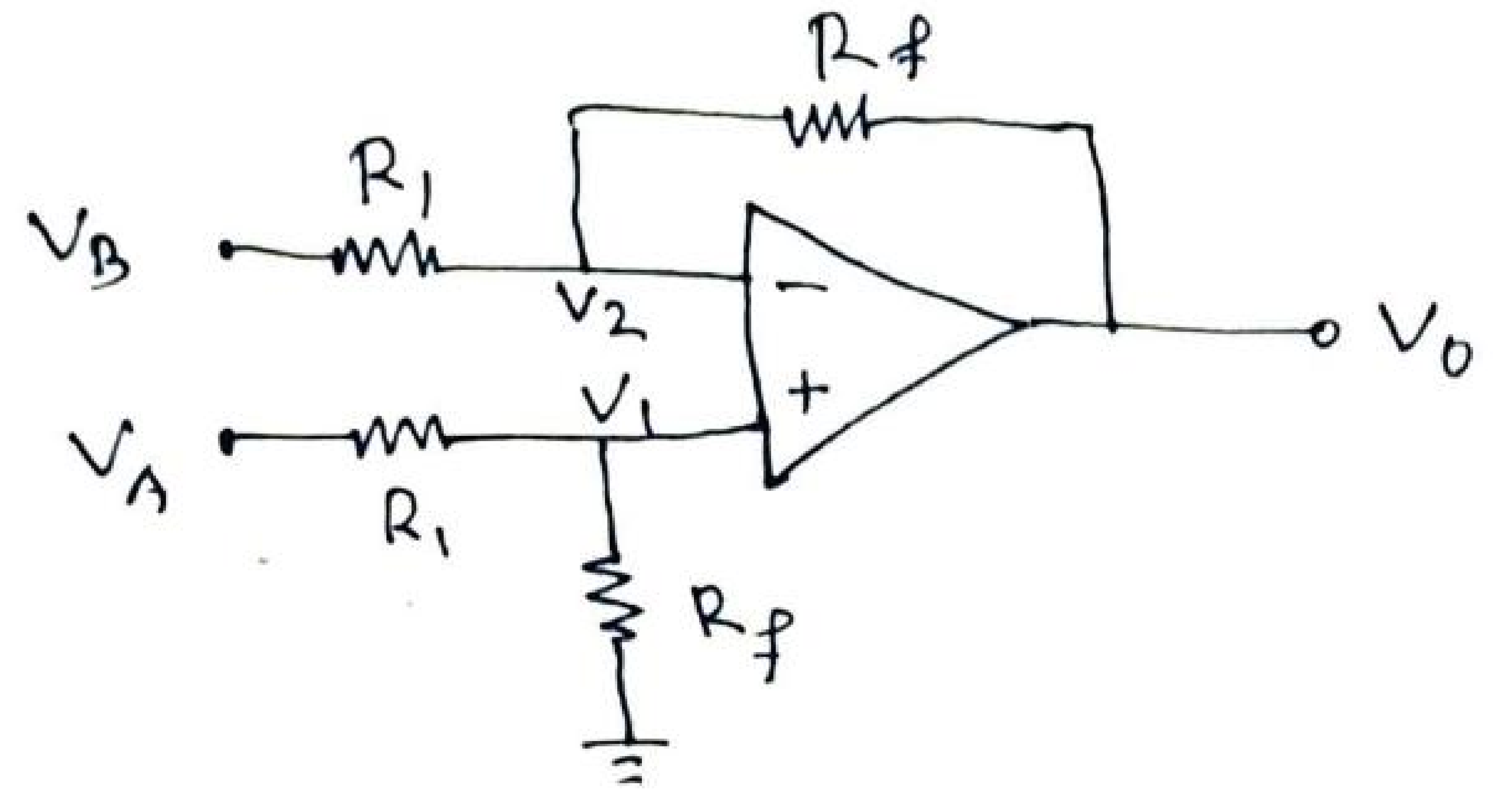
$V_i = V_2$ (According to virtual ground) — ②

from ① & ②

$$\boxed{V_0 = V_i}$$

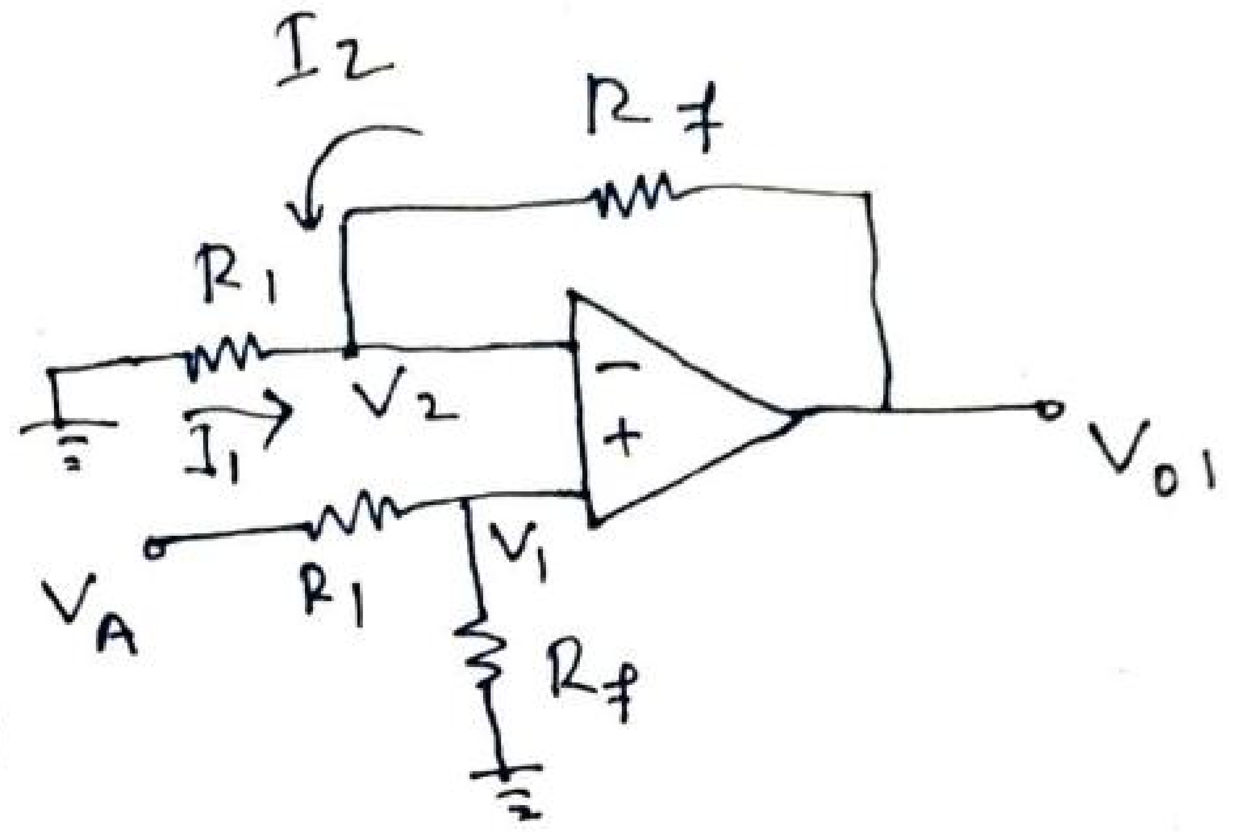
- It is known as voltage follower because output follows input i.e equal.
- It is used as a voltage buffer in the practical electronic circuit.

Differential Amplifier



Case-I : let $V_B = 0$

voltage division rule at V_1



$$V_1 = \frac{V_A R_f}{R_f + R_1}$$

$V_2 = V_1$ (According to virtual ground)

KCL at V_2 node :-

$$I_1 + I_2 = 0 \Rightarrow \frac{0 - V_2}{R_1} + \frac{V_{01} - V_2}{R_f} = 0$$

$$\Rightarrow -\frac{V_2}{R_1} - \frac{V_2}{R_f} + \frac{V_{01}}{R_f} = 0 \Rightarrow \frac{V_{01}}{R_f} = V_2\left(\frac{R_f + R_1}{R_f R_1}\right)$$

$$\Rightarrow V_{01} = V_2\left(\frac{R_f + R_1}{R_1}\right) \Rightarrow V_{01} = V_1\left(1 + \frac{R_f}{R_1}\right) \quad [V_2 = V_1)$$

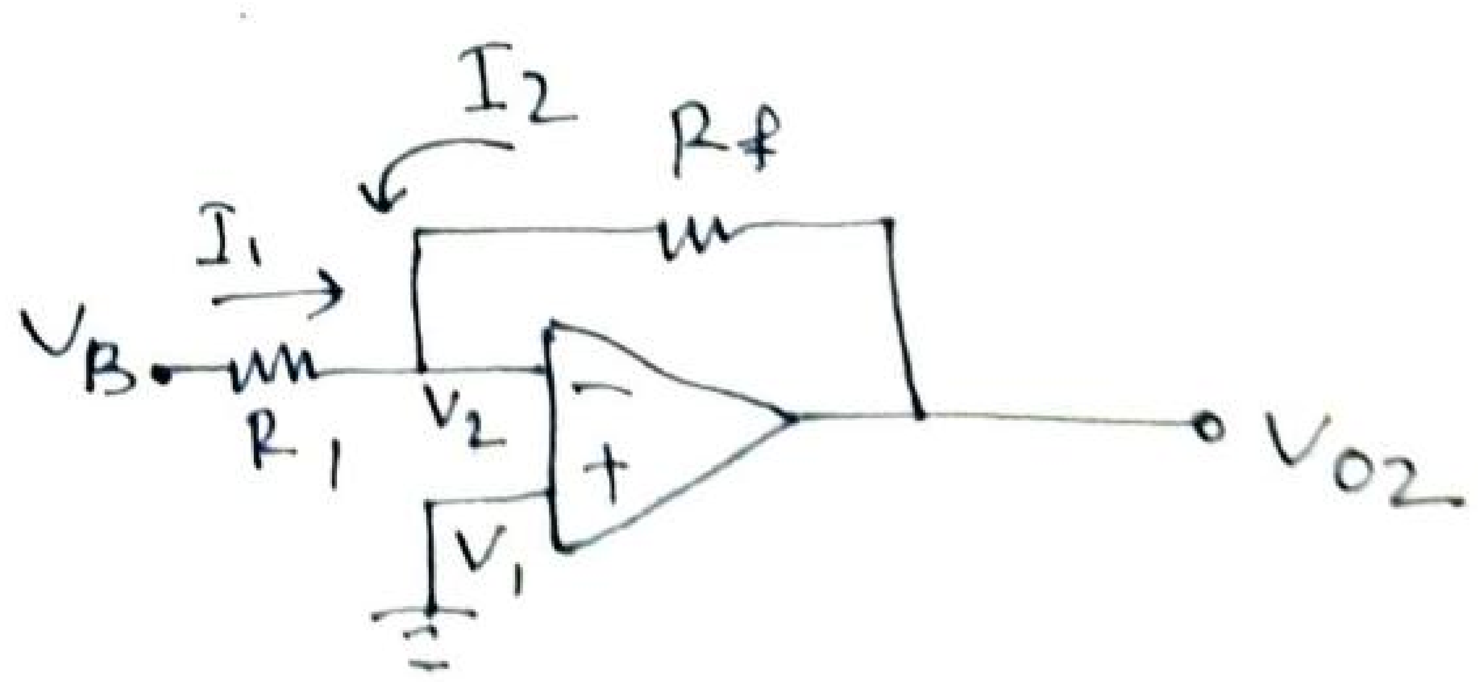
$$\Rightarrow V_{01} = V_A\left(\frac{R_f}{R_1 + R_f}\right)\left(\frac{R_1 + R_f}{R_1}\right)$$

$$\Rightarrow V_{01} = V_A \frac{R_f}{R_1} \quad \text{—— (1)}$$

Case-II : Let $V_A = 0$

$V_1 = V_2$ (virtual ground)

$\Rightarrow V_2 = 0$ (as $V_1 = 0$)



KCL at V_2 :-

$$I_1 + I_2 = 0$$

$$\Rightarrow \frac{V_B - V_2}{R_1} + \frac{V_{02} - V_2}{R_f} = 0 \Rightarrow \frac{V_B}{R_1} + \frac{V_{02}}{R_f} = 0$$

$$\frac{V_{o2}}{R_f} = -\frac{V_B}{R_1} \Rightarrow V_{o2} = -\frac{R_f}{R_1} V_B \quad \text{—— (2)}$$

$V_o = V_{o1} + V_{o2}$ (SUPERPOSITION)

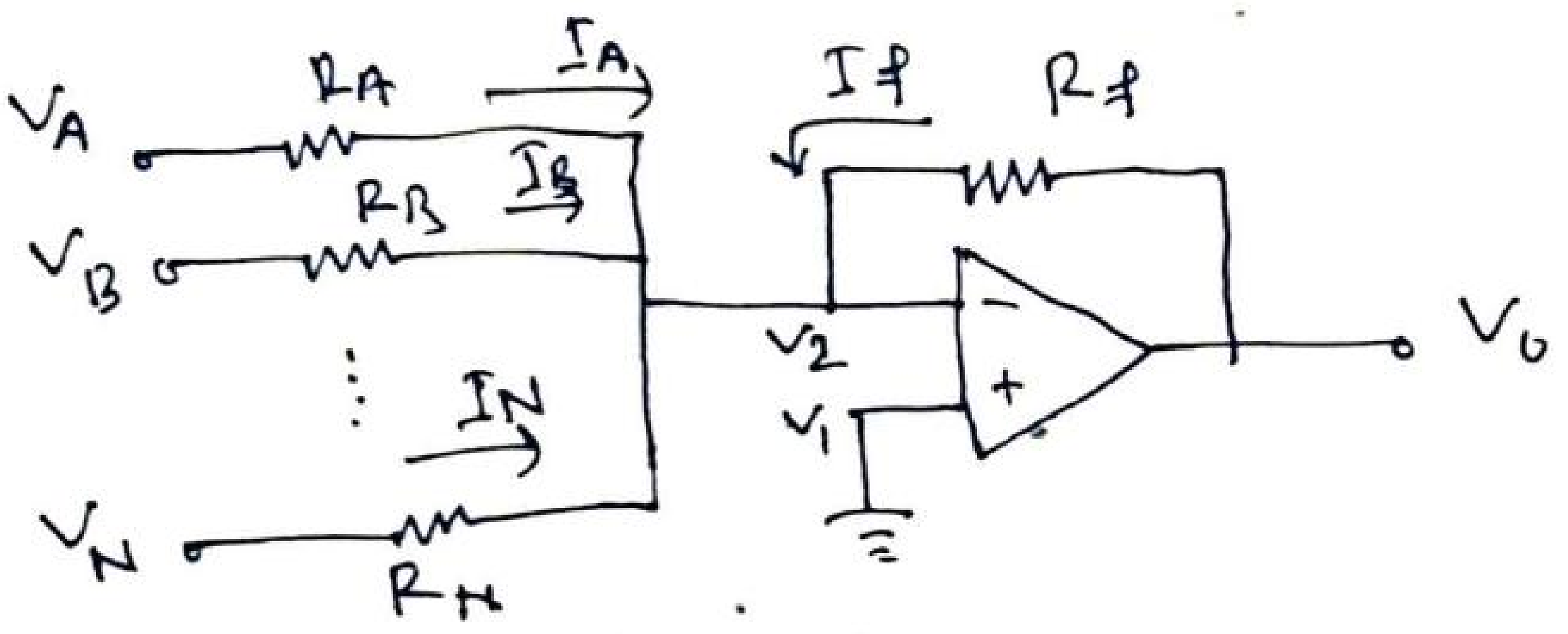
from (I) & (2)

$$V_o = \frac{R_f}{R_1} V_A - \frac{R_f}{R_1} V_B$$

$$V_o = \frac{R_f}{R_1}(V_A - V_B)$$

- If R_f & R_1 are equal then $V_o = V_A - V_B$, which is a subtractor.

Adder using OPAMP



$V_2 = V_1 = 0$ [virtual ground]

KCL at V_2 node :-

$$I_A + I_B + \dots + I_N + I_f = 0$$

$$\Rightarrow \frac{V_A}{R_A} + \frac{V_B}{R_B} + \dots + \frac{V_N}{R_N} + \frac{V_o}{R_f} = 0$$

$$\Rightarrow \frac{V_o}{R_f} = -\left(\frac{V_A}{R_A} + \frac{V_B}{R_B} + \dots \frac{V_N}{R_N}\right)$$

$$\Rightarrow V_o = -R_f\left[\frac{V_A}{R_A} + \frac{V_B}{R_B} + \dots + \frac{V_N}{R_N}\right]$$

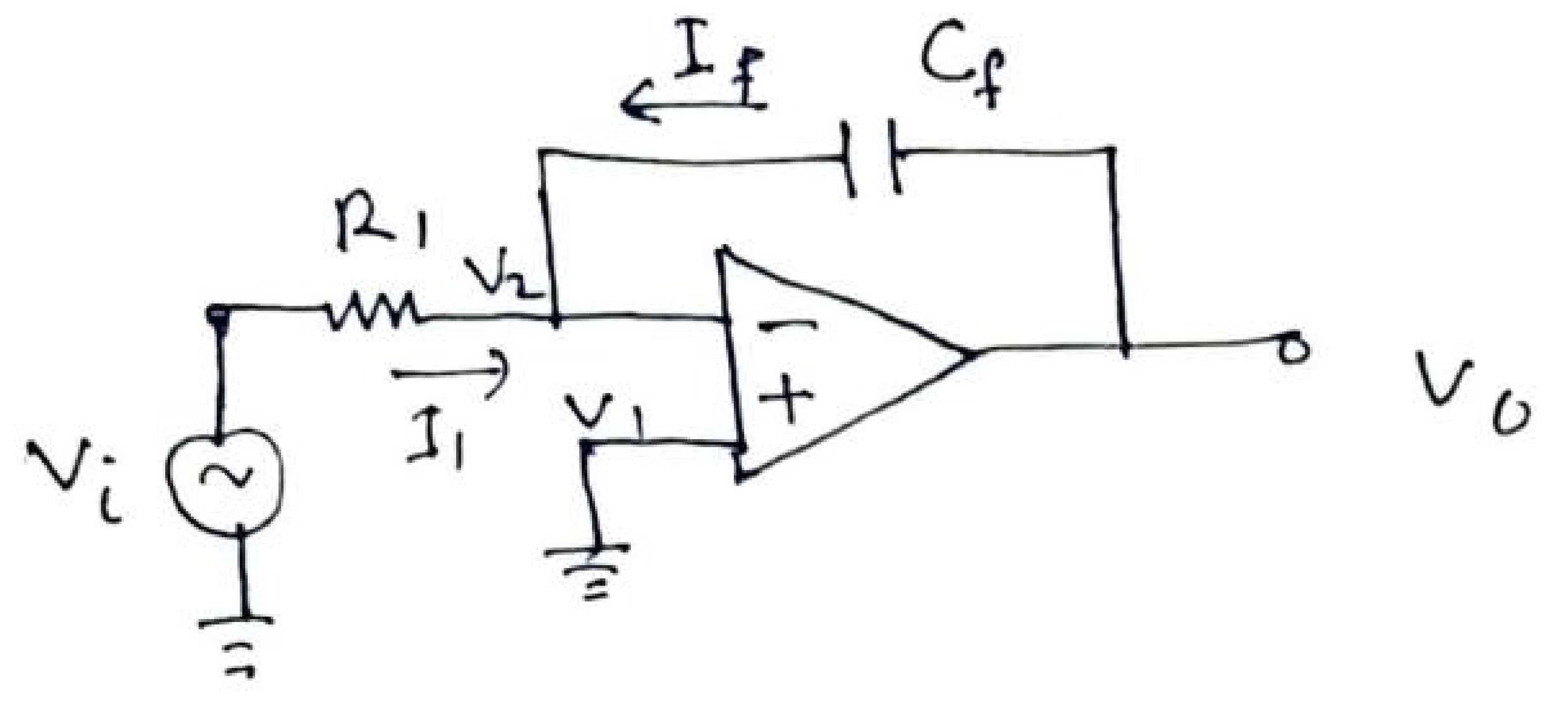
(I) If $R_A = R_B = \dots = R_N = R_f = R$

$$V_o = -[V_A + V_B + \dots + V_N] \rightarrow \text{ADDER}$$

(II) If $R_A = R_B = \dots R_N = R_f = KR$

$$V_o = -K[V_A + V_B + \dots + V_N] \rightarrow \text{SUMMING AMPLIFIER}$$

Integrator Using OPAMP



$V_2 = V_1 = 0$ [virtual short]

Apply KCL at V_2 node :-

$$I_1 + I_f = 0$$

$$\Rightarrow \frac{V_i - V_2}{R_1} + C_f \frac{d(V_0 - V_2)}{dt} = 0$$

[current across capacitor]
$$\left(i_c = C \frac{dV}{dt} \right)$$

$$\Rightarrow \frac{V_i}{R_1} + C_f \frac{dV_0}{dt} = 0$$

$$\Rightarrow C_f \frac{dV_0}{dt} = -\frac{V_i}{R_1}$$

$$\Rightarrow \frac{dV_0}{dt} = \frac{-1}{R_1 C_f} V_i \Rightarrow \boxed{V_0 = -\frac{1}{R_1 C_f} \int V_i \, dt}$$

- Output is integration of input signal. Hence it is known as Integrator.

Differentiator using OPAMP

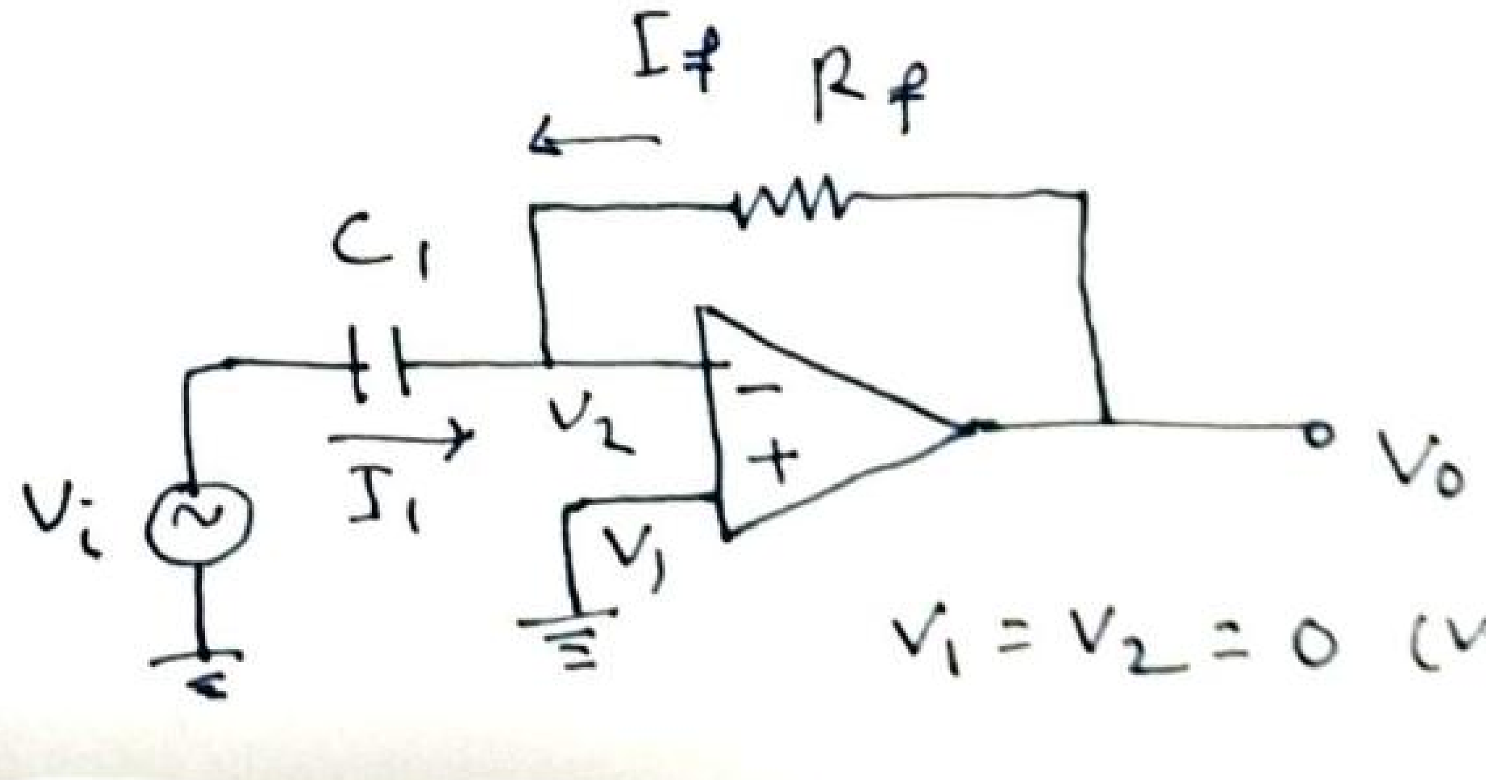
KCL at V_2 node :-

$$I_1 + I_f = 0$$

$$\Rightarrow C_1 \frac{dV_i}{dt} + \frac{V_0}{R_f} = 0$$

$$\Rightarrow C_1 \frac{dV_i}{dt} = -\frac{V_0}{R_f}$$

$$\Rightarrow \boxed{V_0 = -R_f C_1 \frac{dV_i}{dt}}$$



$V_1 = V_2 = 0$ (virtual ground)

- Output is derivative of input signal. Hence it is called Differentiator.