OPAMP
Lecture 13

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Tuned Collector Oscillator:

The output of the tuned tank circuit is magnetically coupled to a secondary windings. The voltage developed across the output is fed back to the input base load through a series resistor R_S. The Barkhausen Criterion must be satisfied as a condition for sustained oscillation is $A\beta = 1$. This can be written in form of

$$\frac{1}{A} - \beta = 0$$

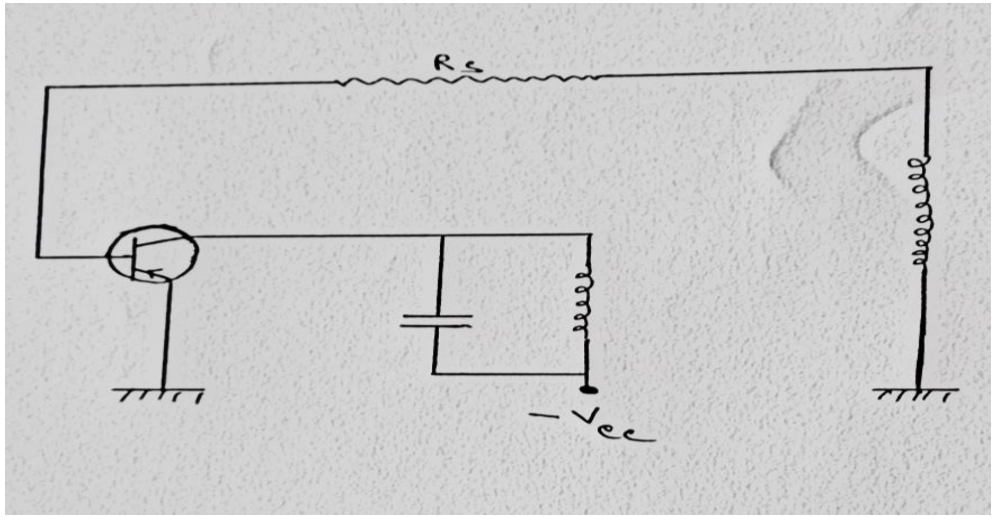

Fig 1

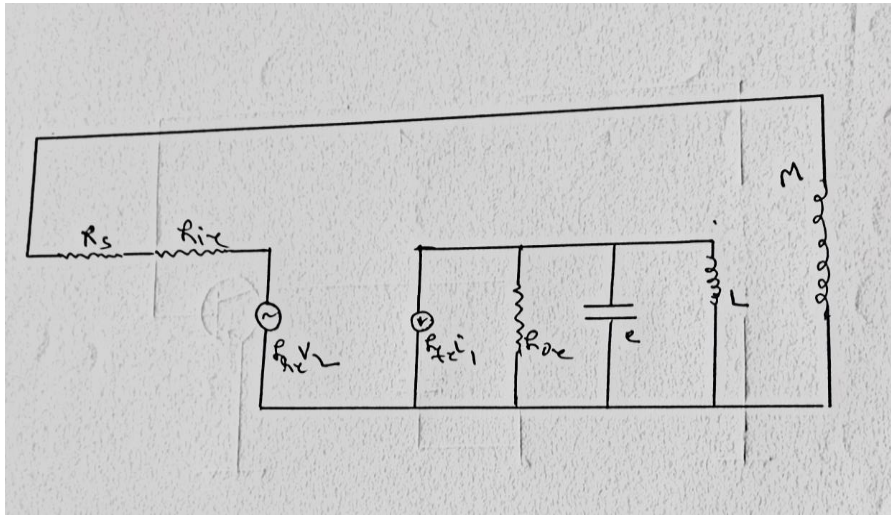

Fig 2

Now for CE transistor amplifier the equation for voltage gain with impedance load is given by

$$A_v = -\frac{h_{fe} Z_L}{h_{ie} + \Delta h_e Z_L}$$

Having satisfied the condition that R_P prevents loading the tank circuit, we can write to a good approximation.

$$\beta = \frac{-j\omega M i_1}{(R + J\omega L) i_1} = \frac{-j\omega M}{R + j\omega L}$$

Now from the above three equations we get

$$h_{ie}R\omega C + j(\omega^2 LC - 1)h_{ie} - j\Delta h_e R + \omega L \Delta h_e - \omega M h_{fe} = 0$$

Equating real and imaginary parts equal to zero we get

$$\omega^2 LC h_{ie} - h_{ie} - \Delta h_e R = 0$$

Now solving for ω we get

$$\omega = \frac{1}{\sqrt{LC}}\left[1 + \frac{\Delta h_e R}{h_{ie}}\right]^{1/2}$$

Thus we find that frequency of oscillation depends on tank circuit values and transistor parameter. Since Δh is small and also for a high $Q - value$, the coil resistance is small. So frequency of oscillation is close to the natural frequency of resonant circuit.

Again for real part

$$\omega\left(h_{ie}RC + L\Delta h_e - Mh_{fe}\right) = 0$$

Since $\omega \neq 0$, therefore

$$h_{ie}RC + L\Delta h_e - Mh_{fe} = 0$$

Therefore

$$M = \frac{h_{ie}RC}{h_{fe}} + \frac{L\Delta h_e}{h_{fe}}$$

This equation gives us a relation between the circuit and transistor values that should exist for oscillation to begin. Changes in transistor parameter and power supply voltage and in the passive circuit element cause in change from the required value. This change is called as drift.

OPAMP (Operational Amplifier):

The OPAMP is a direct coupled high gain differential input amplifier. OPAMP can perform mathematical operation such as summation, subtraction, integration and differentiation which operation are operation are important in analog computer.

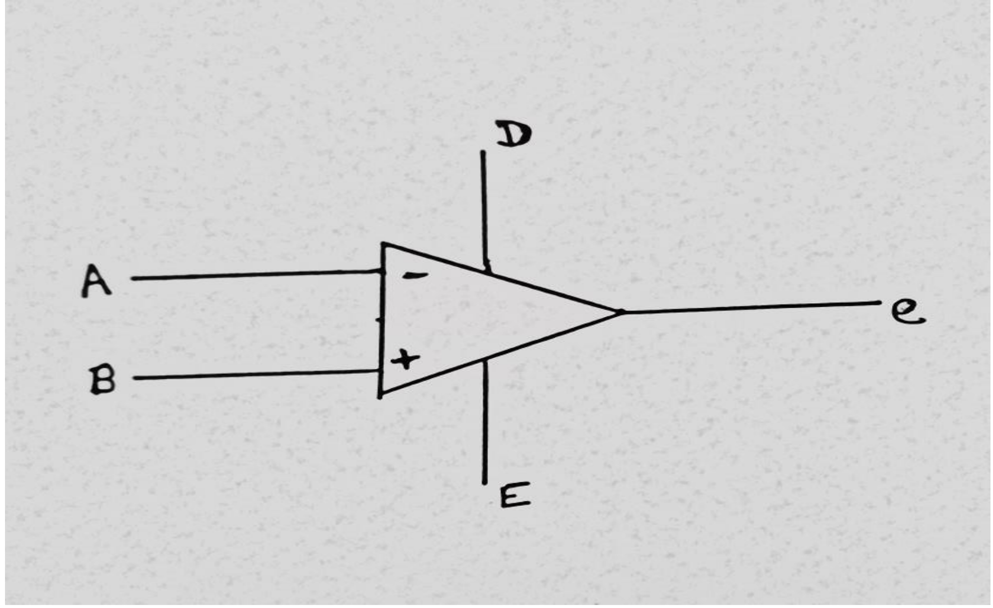

Fig 3

It is used in signal amplification, wave forming AD or DA converter, impedance transformation, oscillator, voltage regulator e.t.c. The advantage of OPAMP is that negative feedback is controlled by feedback element independent of characteristic of transistor and other elements that constitute the OPAMP. As the feedback element is passive the circuit operation is stable and predictable. It has two input terminal and one output terminal. As shown in fig below, A terminal is known as inverting input and signified by $(-)$. The significant of the $(-)$ sign is that a signal applied at terminal A appears at C with polarity reversed. The terminal B is known as non-inverting input and is signified by $(+)$.

The signal put at B appears as same polarity at output C. The output C is proportional to the difference of two signal voltage applied to two input terminal simultaneously. The constant of proportionality gives open loop voltage gain (A) of operational amplifier. A is a real constant and for an ideal amplifier A approaches infinity for all frequency.

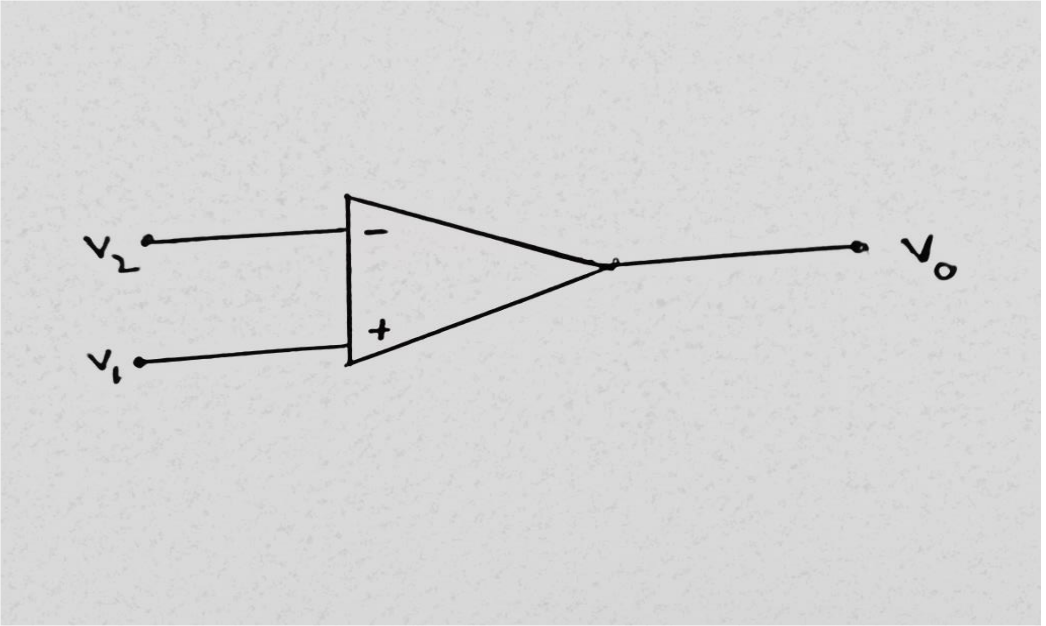

Fig 4

The power supply voltage which are usually balanced with respect to ground to the terminal D and E. Some characteristic are –

(i) Infinite voltage gain

(ii) Infinite input impedance

(iii) Zero output impedance

(iv) Infinite Band Width (BW)

(v) No drifting with temperature

(vi) Perfect Balance

Difference Signal

$$V_d = V_1 - V_2 \rightarrow (i)$$

Average or Common Mode Signal

$$V_c = \left(\frac{V_1 + V_2}{2}\right) \rightarrow (ii)$$

In practice $V_c\ and\ V_d$ are amplified to produce the output voltage. We have

$$V_0 = A_1V_1 + A_2V_2 \rightarrow (iii)$$

Where $A_1$is voltage gain when terminal A is grounded and A_2 is the voltage gain when B is grounded.

Now

$$V_1 = V_c + \frac{1}{2}V_d \rightarrow (iv)$$

And

$$V_2 = V_c - \frac{1}{2}V_d \rightarrow (v)$$

Therefore

$$V_0 = \frac{1}{2}(A_1 - A_2)V_d + (A_1 + A_2)V_c$$

$$V_O = A_dV_d + A_cV_c \rightarrow (vi)$$

Where

$$A_d = \frac{1}{2}(A_1 - A_2)$$

And

$$A_c = (A_1 + A_2)$$

Here A_d is known as voltage gain differential signal and A_c is common mode signal. For ideal case A_d is infinitely large and A_c is zero. The figure of merit or $CMRR$ for OPAMP is

$$CMRR = \left|\frac{A_d}{A_c}\right| \text{ in dB (decibel)}$$

Or

$$CMRR = 20log_{10}\left|\frac{A_d}{A_c}\right|\ dB \rightarrow (vii)$$

Since A_d needs to large and A_c is very small, amplifier must be designed that $CMRR$ is much larger than unity. Ideally $CMRR$ is infinitely large.

Offset Error Voltage and Current:

An ideal OPAMP is ideally balanced i.e. $V_0 = 0$, when $V_1 = V_2$

In practice an OPAMP shows an unbalance due to mismatch of the built in transistors following thr inverting and non-inverting terminals. The mismatch gives unequal bais currents flowing through the input terminals.

Thus an input offset voltage has to be applied between the two input terminals to balance the output. The input bais current is half of the sum of the individual currents entering the two input terminals of a balanced amplifier. The input bais current

$$i_B = \frac{i_{b1} + i_{b2}}{2}, \qquad when\ V_0 = 0$$

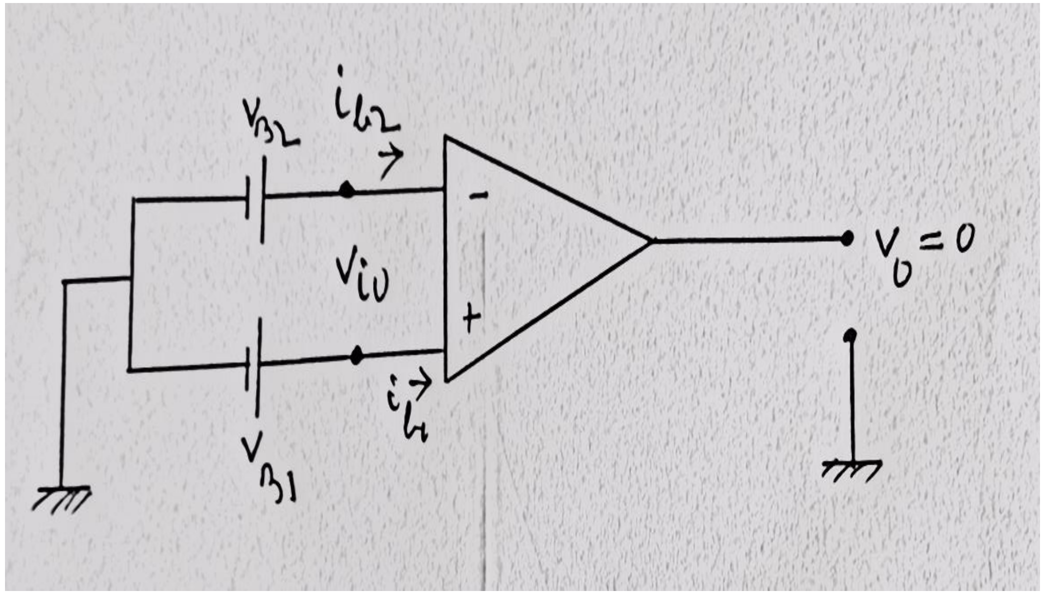

Fig 5 Input Offset Voltage

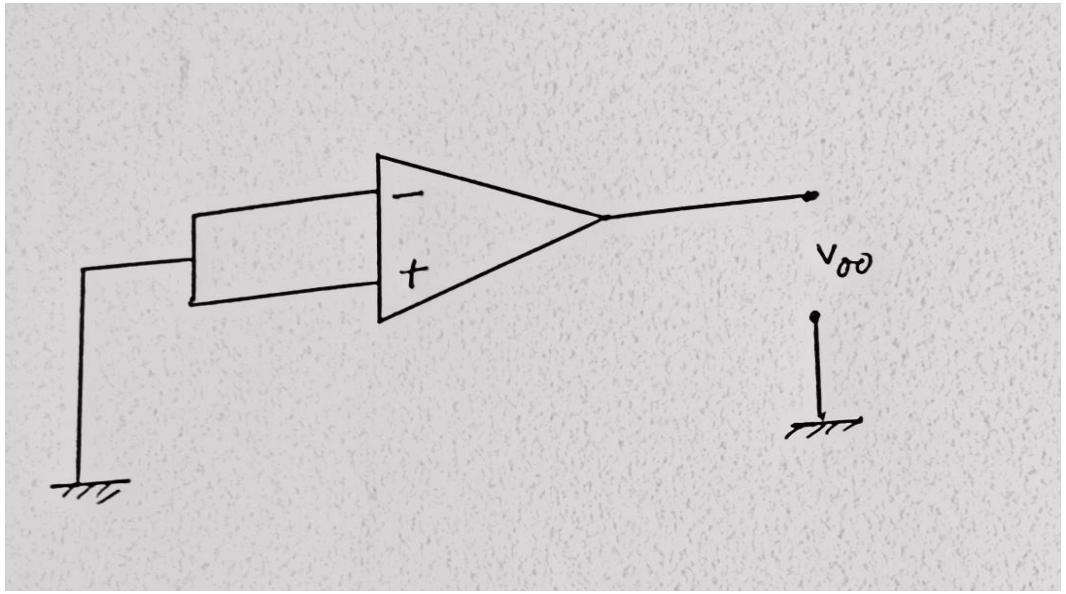

Fig 6 Output Offset Voltage

The input offset current i_{io} is the difference between the individual currents entering the input terminals of a balance amplifier. Thus

$$i_{io} = i_{b1} - i_{b2}, \qquad when\, V_0 = 0$$

The input offset voltage V_{io} is the voltage to be applied between the input terminals to balance the amplifier.

The output offset voltage V_{oo} is the voltage at the output terminal when the two input terminals are grounded. Practical OPAMP have arrangement to balance the offset voltage. Ideally

$$i_{b1} = i_{b2}$$

And $i_{io}, V_{io}\ and\ V_{\infty}$ are zero.

If a change ∂V of the supply voltages effects a change ∂V_{io} of the input offset voltage, the Power Supply Rejection Ratio (PSRR) is defined by

$$PSRR = \frac{\partial V}{\partial V_{io}}\ dB$$

$$PSRR = 20\ log_{10} \frac{\partial V}{\partial V_{io}}$$

In ideal case PSRR goes to infinity

Inverting Amplifier:

The OPAMP is connected with an input resistance R_1 and feedback resistance R_f and it is connected the output terminal to the inverting input terminal , it provides a negative feedback. The non-inverting terminal is grounded. Let V be the voltage at inverting input terminal.

As open loop gain A of OPAMP is very high and V_0 is finite due to negative feedback, we have $\mathrm{V} = {}^{V_0}/_{A} \rightarrow 0$ as $|A| \rightarrow \infty$. Therefore inverting input terminal is practically at ground potential. Thus G is not actually connected to ground, it is virtually at ground potential whatever the magnitude of V_1 and V_0.

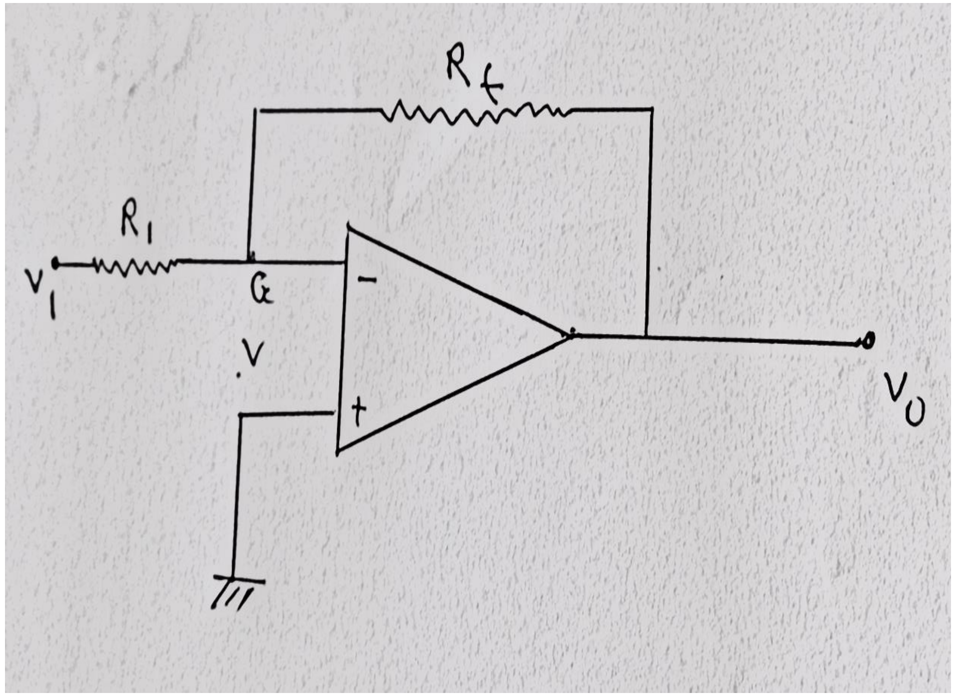

Fig 7

The current i through R_1 is

$$i = \frac{V_1 - V}{R_1}$$

At G –

$$\frac{V_1 - V}{R_1} = \frac{V - V_0}{R_f}$$

At G is virtually grounded as $V \approx 0$

$$\frac{V_1}{R_1} = -\frac{V_0}{R_f}$$

The close loop gain of the amplifier is

$$\frac{V_1}{V_0} = -\frac{R_f}{R_1}$$

In put resistance of the amplifier is

$$R_{in} = \frac{V_1}{i} = \frac{V_1}{\frac{V_1 - V}{R_1}} \approx R_1$$

Non-inverting Amplifier:

As shown in $Fig\ 8$, the input voltage V_1 is applied to the non-inverting terminal. Since the voltage gain of the OPAMP is infinite, the potential of the point G is also V_1 . The current flowing into the OPAMP is negligible, its input impedance being very large.

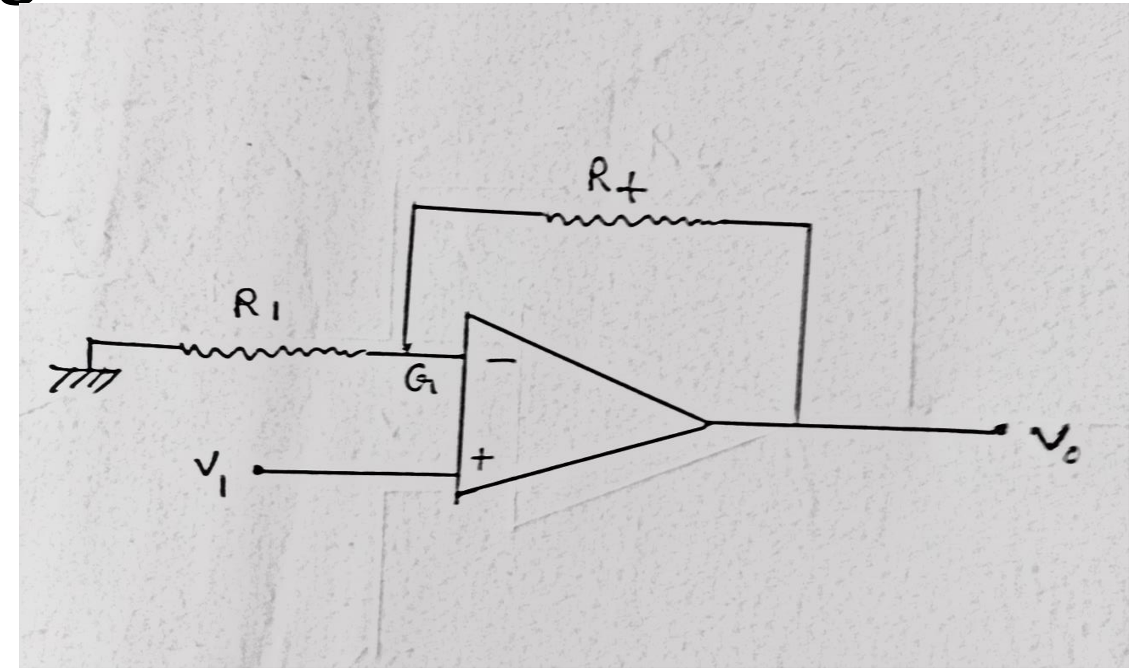

Fig 8

Hence Kirchhoff's current law at the point G we can find

$$\frac{V_0 - V_1}{R_f} = \frac{V_1}{R_1}$$

$$\frac{V_0}{V_1} = 1 + \frac{R_f}{R_1}$$

Which is the voltage gain of the amplifier system. The voltage gain is greater than unity by a factor ${R_f}/{R_1}$. As the gain is positive there is no phase difference between the input voltage V_1 and the output voltage V_0. The input impedance of the circuit is high and the output impedance is low.

If $R_f = 0$ and $R_1 = \infty$, the voltage gain becomes unity. Therefore the circuit is referred as unity gain buffer or a voltage follower. This circuit offers a high input impedance and a low output impedance and therefore can be employed as an impedance matching device between a high impedance source and a low impedance load.