RAJASTHAN INSTITUTE OF ENGINEERING & TECHNOLOGY JAIPUR, RAJASTHAN

B. Tech. I Midterm EXAMINATION 2017-18

Semester and Branch: II Year, IV Semester, EEE

Subject: LIC

SET A

Solution

***Duration*: 2 Hours** ***Maximum Marks*: 20**

1. Draw Circuit Diagram of a dual-input, balanced output differential amplifier and perform its DC Analysis.

To obtain the operating point (I_{CC} and V_{CEQ}) for differential amplifier dc equivalent circuit is drawn by reducing the input voltages v_1 and v_2 to zero as shown in **fig**

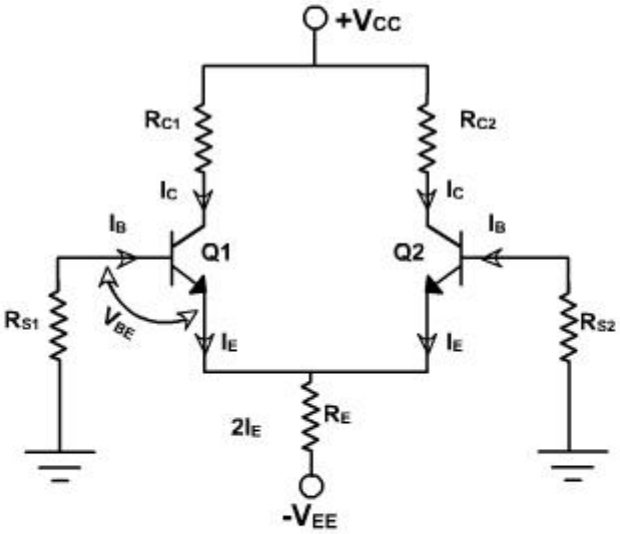


Fig.

The internal resistances of the input signals are denoted by R_S because $R_{S1}= R_{S2}$. Since both emitter biased sections of the different amplifier are symmetrical in all respects, therefore, the operating point for only one section need to be determined. The same values of I_{CQ} and V_{CEQ} can be used for second transistor Q_2.

Applying KVL to the base emitter loop of the transistor Q_1.

$$R_S\ I_B + V_{BE} + 2\ I_E\ R_E = V_{EE}$$

But $I_B = \dfrac{I_E}{\beta_{dc}}$ and $I_C \approx I_E$

$$\therefore I_E = I_C = \frac{V_{EE} - V_{BE}}{2R_E + R_S\ /\ \beta_{dc}} \qquad \text{(E-1)}$$

$V_{BE} = 0.6V$ for S_i and $0.2V$ for G_e.

Generally $\dfrac{R_S}{\beta_{dc}} << 2R_E$ because R_S is the internal resistance of input signal.

$$\therefore I_E = I_C = \frac{V_{EE} - V_{BE}}{2R_E}$$

The value of R_E sets up the emitter current in transistors Q_1 and Q_2 for a given value of V_{EE}. The emitter current in Q_1 and Q_2 are independent of collector resistance R_C.

The voltage at the emitter of Q_1 is approximately equal to $-V_{BE}$ if the voltage drop across R is negligible. Knowing the value of I_C the voltage at the collector $V_C$is given by

$V_C = V_{CC} - I_C R_C$

and

$V_{CE} = V_C - V_E = V_{CC} - I_C R_C + V_{BE}$

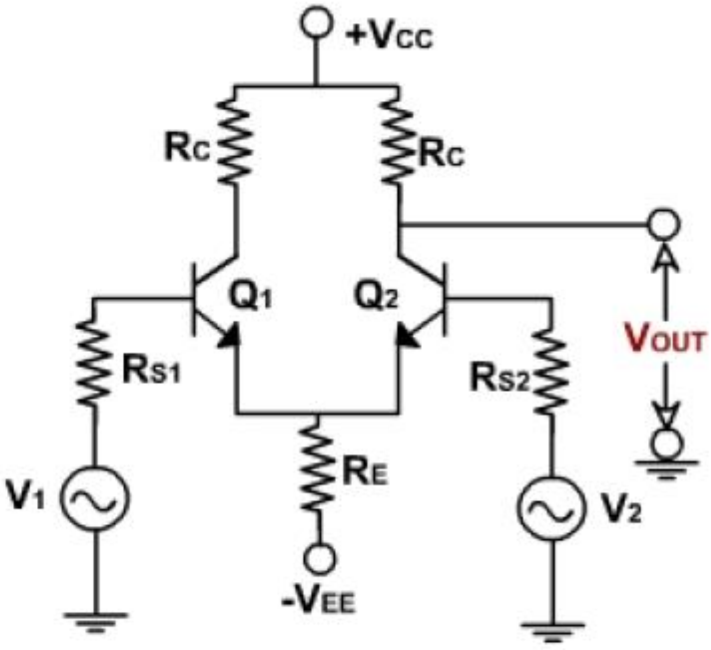
$V_{CE} = V_{CC} + V_{BE} - I_C R_C$ (E-2)

From the two equations V_{CEQ} and I_{CQ} can be determined. This dc analysis applicable for all types of differential amplifier.

OR

Draw Circuit Diagram of a dual-input, unbalanced output differential amplifier and perform its DC Analysis.

Dual Input, Unbalanced Output Differential Amplifier: In this case, two input signals are given however the output is measured at only one of the two-collector w.r.t. ground as shown in fig.. The output is referred to as an unbalanced output because the collector at which the output voltage is measured is at some finite dc potential with respect to ground.

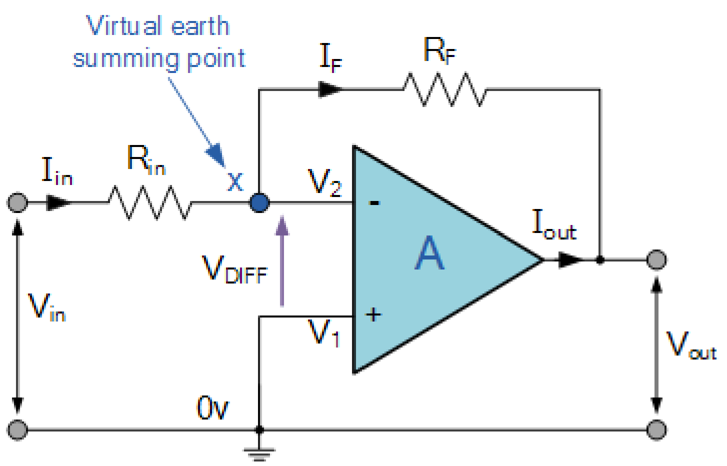


In other words, there is some dc voltage at the output terminal without any input signal applied. DC analysis is exactly same as that of above case.

$$I_E = I_{CQ} = \frac{V_{EE} - V_{BE}}{2R_E + R_2 / \beta_{dc}}$$

$$V_{CEQ} = V_{CC} + V_{BE} - I_{CQ} R_C$$

2. Explain the Inverting Configuration of Differential Amplifier.



In this **Inverting Amplifier** circuit the operational amplifier is connected with feedback to produce a closed loop operation. When dealing with operational amplifiers there are two very important rules to remember about inverting amplifiers, these are: "No current flows into the input terminal" and that "V1 always equals V2". However, in real world op-amp circuits both of these rules are slightly broken.

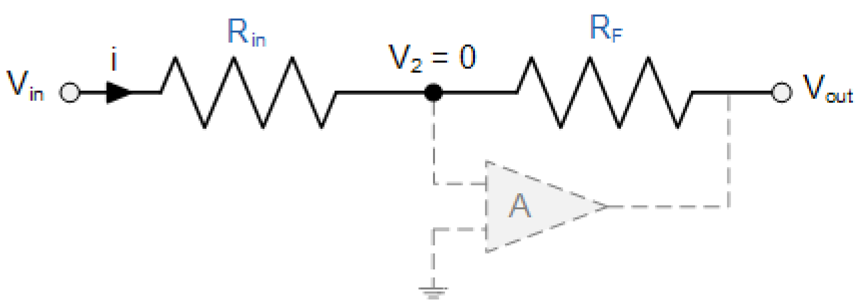
This is because the junction of the input and feedback signal (X) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a **"Virtual Earth"**. Because of this virtual earth node the input resistance of the amplifier is equal to the value of the input resistor, Rin and the closed loop gain of the inverting amplifier can be set by the ratio of the two external resistors.

We said above that there are two very important rules to remember about **Inverting Amplifiers** or any operational amplifier for that matter and these are.

- No Current Flows into the Input Terminals
- The Differential Input Voltage is Zero as V1 = V2 = 0 (Virtual Earth)

Then by using these two rules we can derive the equation for calculating the closed-loop gain of an inverting amplifier, using first principles.

Current (i) flows through the resistor network as shown.



$$i = \frac{Vin - Vout}{Rin + Rf}$$

$$\text{therefore, } i = \frac{Vin - V2}{Rin} = \frac{V2 - Vout}{Rf}$$

$$i = \frac{Vin}{Rin} - \frac{V2}{Rin} = \frac{V2}{Rf} - \frac{Vout}{Rf}$$

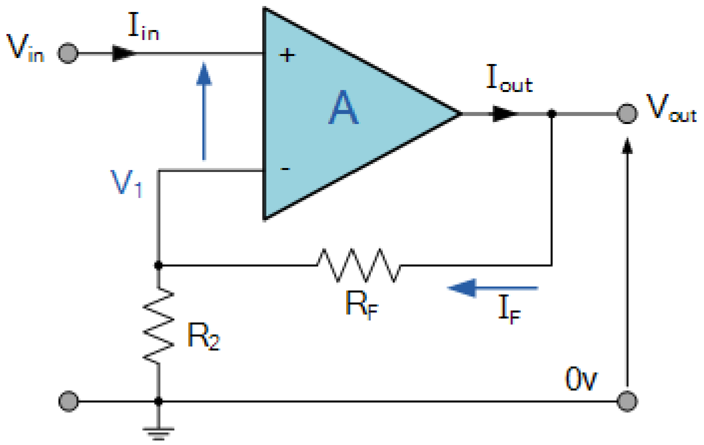
$$\text{so, } \frac{Vin}{Rin} = V2\left[\frac{1}{Rin} + \frac{1}{Rf}\right] - \frac{Vout}{Rf}$$

$$\text{and as, } i = \frac{Vin - 0}{Rin} = \frac{0 - Vout}{Rf} \qquad \frac{Rf}{Rin} = \frac{0 - Vout}{Vin - 0}$$

$$\text{the Closed Loop Gain (Av) is given as, } \frac{Vout}{Vin} = -\frac{Rf}{Rin}$$

OR

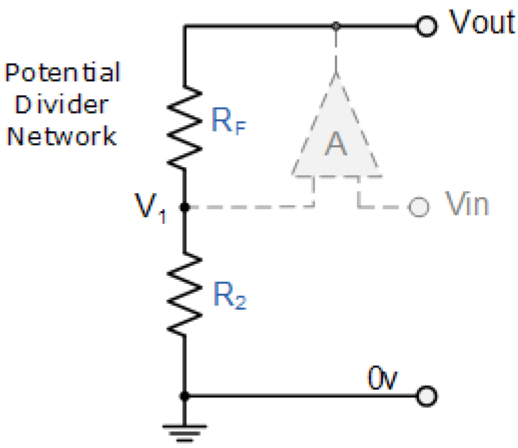
Explain the Non Inverting Configuration of Differential Amplifier.



In the previous Inverting Amplifier tutorial, we said that for an ideal op-amp "No current flows into the input terminal" of the amplifier and that "V1 always equals V2". This was because the junction of the input and feedback signal (V1) are at the same potential.

In other words the junction is a "virtual earth" summing point. Because of this virtual earth node the resistors, Rf and R2 form a simple potential divider network across the non-inverting amplifier with the voltage gain of the circuit being determined by the ratios of R2and Rf as shown below.

Equivalent Potential Divider Network



Then using the formula to calculate the output voltage of a potential divider network, we can calculate the closed-loop voltage gain (A_V) of the **Non-inverting Amplifier** as follows:

$$V_1 = \frac{R_2}{R_2 + R_F} \times V_{OUT}$$

$$\text{Ideal Summing Point: } V_1 = V_{IN}$$

$$\text{Voltage Gain, } A_{(V)} \text{ is equal to: } \frac{V_{OUT}}{V_{IN}}$$

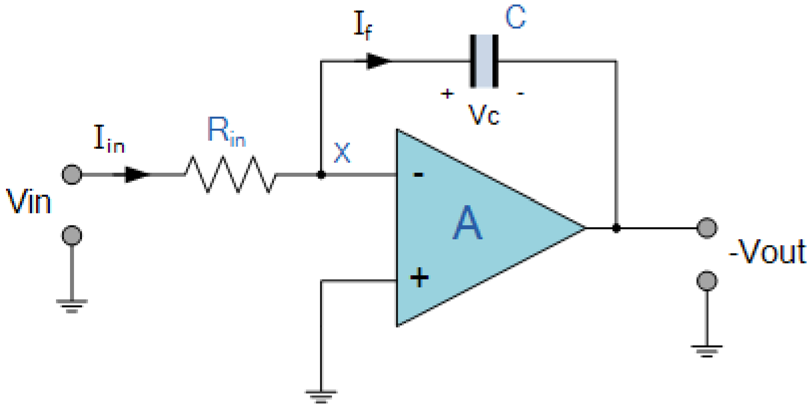
$$\text{Then, } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = \frac{R_2 + R_F}{R_2}$$

$$\text{Transpose to give: } A_{(V)} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_2}$$

Then the closed loop voltage gain of a **Non-inverting Operational Amplifier** will be given as:

$$A_{(v)} = 1 + \frac{R_F}{R_2}$$

3. **Explain the Integrator circuit of OP-AMP 741 IC**



As its name implies, the **Op-amp Integrator** is an operational amplifier circuit that performs the mathematical operation of **Integration**, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an *output voltage which is proportional to the integral of the input voltage*.

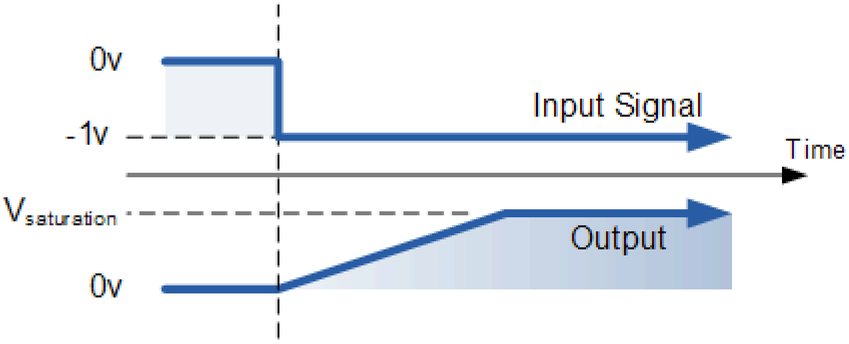
In other words the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

When a step voltage, Vin is firstly applied to the input of an integrating amplifier, the uncharged capacitor C has very little resistance and acts a bit like a short circuit allowing maximum current to flow via the input resistor, Rin as potential difference exists between the two plates. No current flows into the amplifiers input and point X is a virtual earth resulting in zero output. As the impedance of the capacitor at this point is very low, the gain ratio of X_C/R_{IN} is also very small giving an overall voltage gain of less than one, (voltage follower circuit).

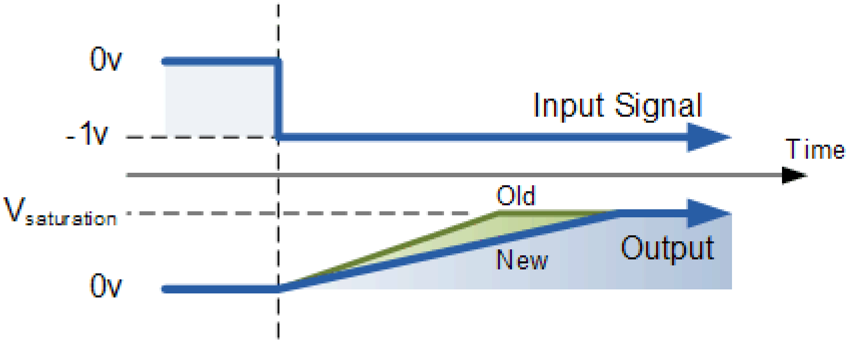
As the feedback capacitor, C begins to charge up due to the influence of the input voltage, its impedance Xc slowly increase in proportion to its rate of charge. The capacitor charges up at a rate determined by the RC time constant, (τ) of the series RC network. Negative feedback forces the op-amp to produce an output voltage that maintains a virtual earth at the op-amp's inverting input.

Since the capacitor is connected between the op-amp's inverting input (which is at earth potential) and the op-amp's output (which is negative), the potential voltage, Vc developed across the capacitor slowly increases causing the charging current to decrease as the impedance of the capacitor increases. This results in the ratio of Xc/Rin increasing producing a linearly increasing ramp output voltage that continues to increase until the capacitor is fully charged.

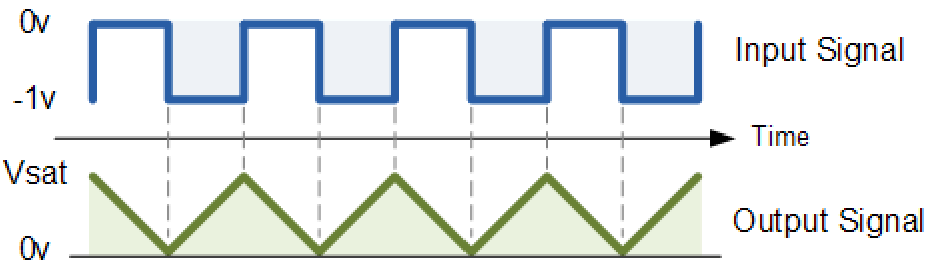
At this point the capacitor acts as an open circuit, blocking any more flow of DC current. The ratio of feedback capacitor to input resistor (X_C/R_{IN}) is now infinite resulting in infinite gain. The result of this high gain (similar to the op-amps open-loop gain), is that the output of the amplifier goes into saturation as shown below. (Saturation occurs when the output voltage of the amplifier swings heavily to one voltage supply rail or the other with little or no control in between).



The rate at which the output voltage increases (the rate of change) is determined by the value of the resistor and the capacitor, “RC time constant“. By changing this RC time constant value, either by changing the value of the Capacitor, C or the Resistor, R, the time in which it takes the output voltage to reach saturation can also be changed for example.



Op-amp Integrator Ramp Generator



We know from first principals that the voltage on the plates of a capacitor is equal to the charge on the capacitor divided by its capacitance giving Q/C. Then the voltage across the capacitor is output Vout therefore: -Vout = Q/C. If the capacitor is charging and discharging, the rate of charge of voltage across the capacitor is given as:

$$V_c = \frac{Q}{C}, \qquad V_c = V_x - V_{out} = 0 - V_{out}$$

$$\therefore -\frac{dV_{out}}{dt} = \frac{dQ}{Cdt} = \frac{1}{C}\frac{dQ}{dt}$$

But dQ/dt is electric current and since the node voltage of the integrating op-amp at its inverting input terminal is zero, X = 0, the input current I(in) flowing through the input resistor, Rin is given as:

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current flowing through the feedback capacitor C is given as:

$$I_f = C\frac{dV_{out}}{dt} = C\frac{dQ}{Cdt} = \frac{dQ}{dt} = \frac{dV_{out}.C}{dt}$$

Assuming that the input impedance of the op-amp is infinite (ideal op-amp), no current flows into the op-amp terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$I_{in} = I_f = \frac{V_{in}}{R_{in}} = \frac{dV_{out}.C}{dt}$$

$$\therefore \frac{V_{in}}{V_{out}} \times \frac{dt}{R_{in}C} = 1$$

From which we derive an ideal voltage output for the **Op-amp Integrator** as:

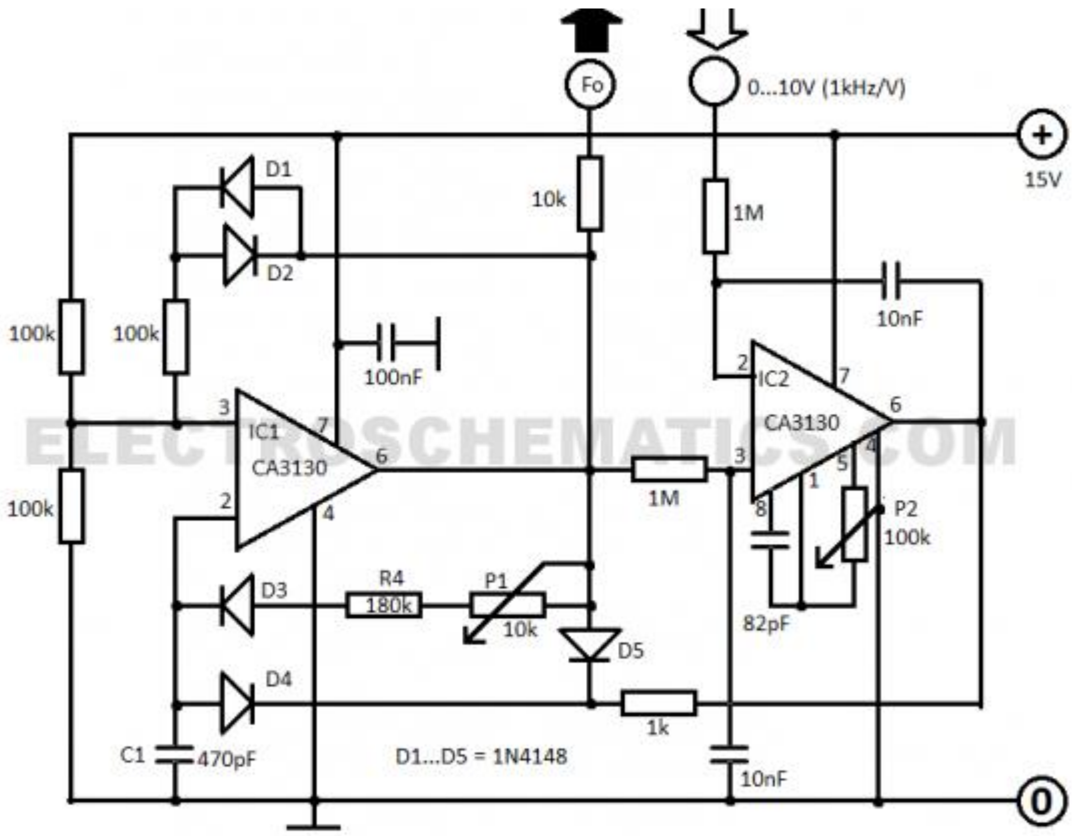
$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt = -\int_0^t V_{in}\frac{dt}{R_{in}.C}$$

To simplify the math's a little, this can also be re-written as:

$$V_{out} = -\frac{1}{j\omega RC}V_{in}$$

OR

Draw and explain Voltage to Frequency converter with suitable diagram.



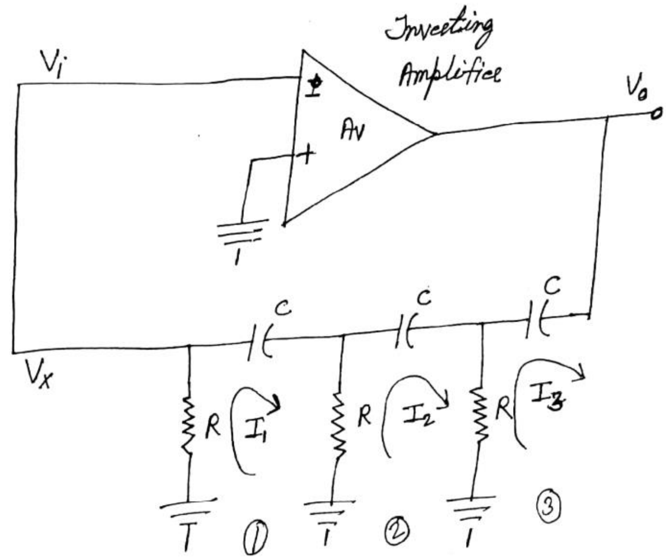
This voltage to frequency converter circuit has an oscillator that is voltage controlled and has a small, 0.5% deviation. IC1 function as a multivibrator and produces rectangular impulses with equal width. The width of the impulses depend on R4, P1 and C1. With P1 we can do fine adjustments of the output frequency.

The output frequency can be easily adjusted with the help of U1 voltage. D3 diode is required because we want to eliminate R4 and P1 influence. D1 and D2 diodes produce a small flow of temperature. With P2 we adjust the offset voltage. Because of its high quality, this voltage-frequency converter (VCO) can be used in a large field of applications.

4. **Explain the R-C Phase shift Oscillator with the help of OP-AMP 741 IC.**

RC phase shift Oscillator ⇒

At low frequencies (around 100 KHz or less) , resistors are usually employed to determine the frequency oscillation . Various Circuits are used in the feedback circuit Including ladder network.



A block diagram of a ladder type RC phase shift oscillator is shown in fig . It Consists of three resistor R and C Capacitors. If the phase shift through the amplifier is 180°, then oscillation may occur at the frequency where the RC network produces an additional 180 phase shift.

To find the freq. of Oscillation, let us neglect the loading of the phase shift network.

Writing the KVL equations.

$$V_X = -I_1 R$$

$$X_C = \frac{1}{\omega C}$$

apply the KVL in path ①, ② and ③

$$I_1 R + \frac{I_1}{j\omega C} + (I_1 - I_2) R = 0 \quad \text{—— } ①$$

$$(I_2 - I_1) R + \frac{I_2}{j\omega C} + (I_2 - I_3) R = 0 \quad \text{—— } ②$$

$$(I_3 - I_2) R + \frac{I_3}{j\omega C} + V_0 = 0 \quad \text{—— } ③$$

$$I_1 = \frac{-V_X}{R} \quad \text{—— } ④$$

from eq ①

$$I_1 R + \frac{I_1}{j\omega C} + I_1 R - I_2 R = 0$$

$$I_2 R = 2 I_1 R + \frac{I_1}{j\omega C}$$

$$I_2 = \frac{2 I_1 \cancel{R}}{\cancel{I_2} \cancel{R}} + \frac{I_1}{j\omega R C} = I_1 \left(2 + \frac{\cancel{I_1}\, 1}{j\omega R C} \right)$$

$$= \frac{-V_X}{R} \left(2 - \frac{j\, \cancel{I_1}\, 1}{\omega R C} \right)$$

$$= \frac{-V_X}{R^2} \left(2R - jX_C \right) \quad \text{—— } ⑤$$

$$I_2R - I_1R + \frac{I_2}{j\omega C} + I_2R - I_3R = 0$$

$$I_3R = I_2\left(2R + \frac{1}{j\omega C}\right) - I_1R$$

$$I_3 = \frac{I_2}{R}\left(2R - jX_C\right) - \frac{I_1R}{R}$$

put the Value of I_2 and I_1 from eq ④ and ⑤

$$I_3 = \frac{-1}{R} \times \frac{V_X}{R^2}(2R - jX_C) \times (2R - jX_C) - \left(-\frac{V_X}{R}\right)$$

$$= V_X\left(-\frac{1}{R^3}(2R - jX_C)^2 + \frac{1}{R}\right)$$

$$= V_X\left(\frac{-(2R - jX_C)^2 + R^2}{R^3}\right)$$

$$= V_X\left(\frac{-(4R^2 - X_C^2 - 4jRX_C) + R^2}{R^3}\right)$$

$$= -\left(\frac{4R^2 - X_C^2 - j4RX_C - R^2}{R^3}\right)V_X$$

$$= -\left(\frac{3R^2 - X_C^2 - j4RX_C}{R^3}\right)V_X \quad \text{— ⑥}$$

from eq. ③

$$V_0 = (I_2 - I_3)R - \frac{I_3}{j\omega C} = (I_2 - I_3)R + jX_C I_3$$

$$= \left(-\frac{V_X(2R - jX_C)}{R^2} + \frac{3R^2 - X_C^2 - j4RX_C}{R^3}V_X\right)R + jX_C I_3$$

$$V_o = \left(-V_X \frac{(2R - jX_C)}{R^2} + \frac{3R^2 - X_C^2 - 4jRX_C}{R^3} V_X\right)R + jX_C \left(-\frac{(3R^2 - X_C^2 - j4RX_C)}{R^3} V_X\right)$$

$$V_o = V_X \left(\frac{\overset{XR}{(-2R^2 + jX_CR + 3R^2 - X_C^2 - 4jRX_C)}\;\overset{Xj}{(-(3R^2 + X_C^2 + 4jRX_C)}}{R^3}\right)$$

$$V_o = V_X \left(\frac{-2R^3 + jX_CR^2 + 3R^3 - X_C^2R - 4jR^2X_C - 3jX_CR^2 + jX_C^3 + \underbrace{4j^2RX_C^2}_{-4RX_C^2}}{R^3}\right)$$

$$V_o = V_X \left(\frac{R^3 - 6jX_CR^2 - 5RX_C^2 + jX_C^3}{R^3}\right)$$

$$\frac{V_X}{V_o} = \frac{R^3}{R^3 - 5RX_C^2 + j(-6X_CR^2 + X_C^3)}$$

Putting $X_C = \frac{1}{\omega C}$ we get

$$\frac{V_X}{V_o} = \frac{R^3}{R^3 - \frac{5R}{\omega^2C^2} + j\left(-\frac{6R^2}{\omega C} + \frac{1}{\omega^3C^3}\right)}$$

For phase shift equal to $180°$ between V_X and V_o, Imaginary terms of V_X/V_o must be Zero.

$$\frac{j}{\omega^3 C^3} - \frac{6 j R^2}{\omega C} = 0$$

$$\omega^2 C^2 = \frac{1}{6R^2}$$

$$\omega = \frac{1}{RC\sqrt{6}}$$

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

This is the frequency of oscillation. Substituting this frequency in V_x/V_o expression.

$$\frac{V_x}{V_o} = \frac{R^3}{R^3 - 5R \cdot 6R^2} = -\frac{1}{29} = \beta$$

So the gain of it feedback circuit becomes $\frac{1}{29}$.

Note ⇒

In order to ensure the oscillation, Initially $|A\beta| > 1$ and Under study state $A\beta = 1$. This means the gain of amplifier should be Intially greater than 29 (so that $A\beta >$ and Under steady stat Conditions it reduces to 29.

OR

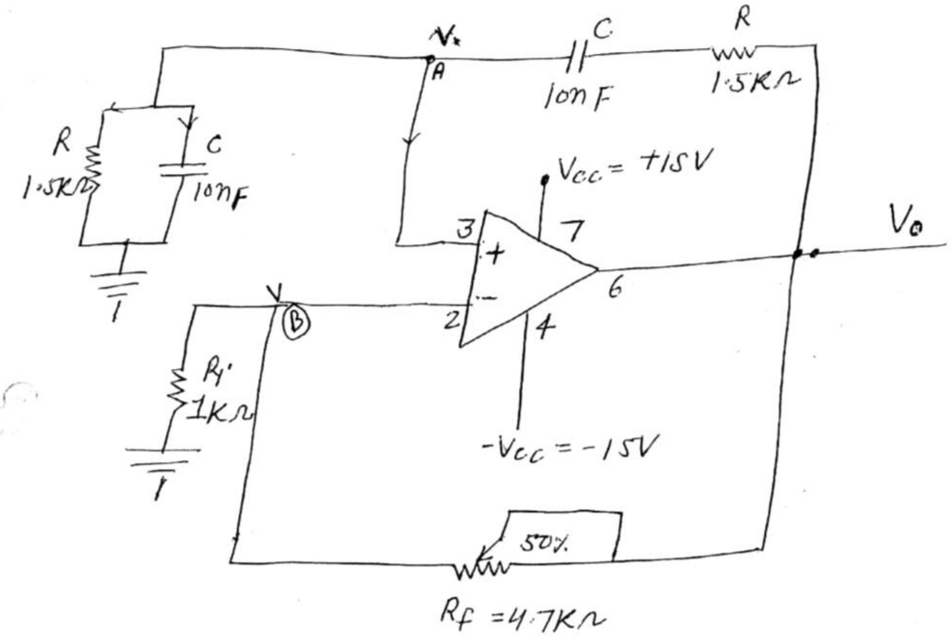
Explain the Wein Bridge Oscillator with the help of OP-AMP 741 IC.

Wein bridge Oscillator ⇒

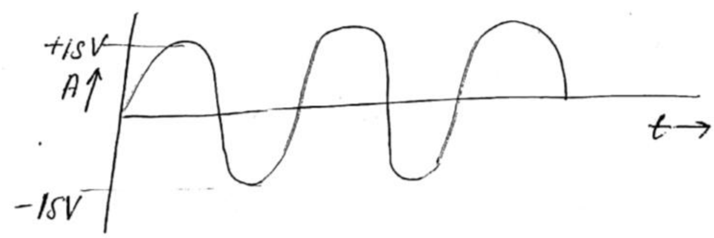
Wein bridge Oscillator is an audio frequency sine wave oscillator of high stability and simplicity. Before that let us see what is oscillator? An oscillator is a circuit that produces periodic electric signals such as sine wave or square wave. The application of oscillator Includes sine wave generator, local oscillator for synchronous receivers etc.

Here we are discussing Wein bridge oscillator using 741 OP amp IC. It is a low frequency Oscillator. The OP-amp used in this oscillator circuit is working as non-Inverting amplifier mode. Here the feedback network need not provide any phase shift. The circuit can be viewed as a Wein bridge with a series RC network in one arm and parallel RC network in the adjoining Arm. Resistors R_i and R_f are connected in the remaining two arms.

Wein bridge Oscillator Circuit Diagram ⇒



Output Waveform



Working of Wein bridge Oscillator

- The feedback signal in this oscillator circuit is connected to the non-inverting input terminal so that the op-amp works as a non-inverting amplifier.

- The Condition of Zero phase shift around the circuit is achieved by balancing the bridge, Zero phase shift is essential for sustained oscillations.

- The frequency of oscillation is the resonant frequency of the balanced bridge and is given by $\boxed{f_0 = \frac{1}{2\pi RC}}$

- At resonant frequency (f_0), the Inverting and non-Inverting Input Voltages will be equal and "in-phase" so that the negative feedback signal will be cancelled out by the positive feedback causing the circuit to oscillate.

<u>Calculation to find resonant frequency</u> ⇒

Apply the KCL at node A in the figure

$$\frac{0 - V}{R} + \frac{0 - V}{\frac{1}{j\omega C}} = \frac{V - V_0}{R + \frac{1}{j\omega C}}$$

$$\frac{-V}{R} - V(j\omega C) - \frac{V}{R + \frac{1}{j\omega C}} = \frac{-V_0}{R + \frac{1}{j\omega C}}$$

multiply by -1

$$V\left[\frac{1}{R} + j\omega C + \frac{1}{R + \frac{1}{j\omega C}}\right] = \frac{V_0}{R + \frac{1}{j\omega C}}$$

$$1 + j^2\omega^2R^2C^2 + \cancel{2}j\omega RC = \cancel{j\omega RC}\ \frac{\cancel{R}}{\cancel{R}}$$

$$1 - \omega^2R^2C^2 + j\omega RC = 0 \quad \text{—— (3)}$$

Compare the Real part of this equation

$$1 - \omega^2R^2C^2 = 0$$

$$1 = \omega^2R^2C^2$$

$$\omega^2 = \frac{1}{R^2C^2} \Rightarrow \omega = \frac{1}{RC}$$

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

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

this is the resonant freq. of the Oscillator.