QUESTION BANK

Subject: Basic Electronics

Course Code: EC1001-1 (3 credits)

UNIT II

1. With the help of a neat circuit diagram, derive the expression for the output voltage of non-inverting amplifier/inverting amplifier/integrator/differentiator circuit using Op-amp.
2. Design an inverting summer circuit using Op-Amp for the output voltage $V_o = -2\ [0.1\ V_1 + 0.5V_2 + 2\ V_3]$. Given the feedback resistor as 10 kΩ. Draw the circuit diagram for the same.
3. Design an inverting adder circuit using Op-amp to obtain output voltage given by $V_O = 2V_1+3V_2+4V_3$ where V_1, V_2 and V_3 are input voltages. Given R_f= 20 KΩ. Draw the circuit indicating all resistor values.
4. Explain the operation of non-inverting /inverting comparator with negative reference voltage with neat circuit diagram and relevant waveforms.
5. For an inverting amplifier with R_1 = 10 kΩ and R_f = 1MΩ, calculate the closed loop voltage gain and the required input voltage to obtain an output voltage of 3V.
6. Find the gain and output voltage for a non-inverting amplifier using Op-amp when the input voltage is 0.7 Vpeak. The supply voltage employed is $\pm 15V$. Given R_f = 7 kΩ and R_1 = 1 kΩ. Sketch the waveforms.
7. An Op-Amp has a differential voltage gain of 2500 and CMRR of 30000. Calculate the common mode gain.
8. Explain the operation of non-inverting/inverting comparator with positive reference voltage with neat circuit diagram and relevant waveforms.
9. List out the ideal characteristics of an Op-Amp.
10. Briefly describe the Op-amp parameters

i) CMRR ii) Slew Rate iii) Input offset voltage iv) Input offset current

11. Draw and explain the internal architecture of IC 555 timer.
12. With a neat circuit diagram explain as how IC 555 timer operates as a free running oscillator.
13. A 555 timer is configured to operate in free running mode with $R_1 = 4\ k\Omega$, $R_2 = 4\ k\Omega$ and $C = 0.01\mu F$. Determine the frequency and duty cycle of the output waveform.
14. For an IC 555 timer, given $D = 60\%$, $f = 2$ KHz, $R_2 = 5\ k\Omega$, and $C = 0.1\mu F$. Calculate R_1.
15. For an IC 555 timer, $D = 75\%$, $f = 1$ kHz, $R_2 = 3.6\ k\Omega$ and $C = 0.1\mu F$. Calculate T_{ON} and R_1.
16. With an example explain the saturable property and virtual ground concept of an Op-Amp
17. Describe the operation of IC78XX series voltage regulator with feedback.
18. In a Colpitt's oscillator, $L = 2$ mH. Calculate the value of each capacitor required to generate oscillations of 1 MHz frequency. Assume $C_1 = C_2$. Write the circuit diagram.
19. With the concept of positive feedback, explain as how sustained oscillations are generated.
20. State Barkhausen's criterion for generating sustained oscillations.
21. Discuss the concept of voltage series feedback with a neat block diagram. Derive an expression for closed loop voltage gain. Comment on the closed loop gain with feedback.
22. List out the advantages of negative feedback
23. In a Colpitts oscillator, $L = 5$ mH. Find C_1 and C_2 if the frequency of oscillation is $f = 50$ kHz. Assume a feedback factor of 10%. Draw the circuit diagram for the same.
24. In a Hartley oscillator, the frequency of operation is 25 kHz. If $C = 0.02\mu F$, calculate L_1 and L_2 for 20% feedback.
25. Compute the value of R in RC phase shift oscillator for a frequency of 2 kHz and $C = 0.1\mu F$.
26. With a neat circuit diagram, explain the operation of a RC phase shift/ Hartley/ Colpitts' oscillator.

1. Inverting amplifier

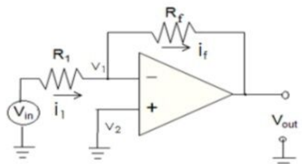


Figure 7. Inverting amplifier

Input signal v_{in} is applied to inverting input terminal and non-inverting input terminal is grounded. Feedback from the output to inverting input terminal is provided through the feedback resistor R_f.

Since non inverting input terminal is grounded, $v_2 = 0$. Due to virtual ground at the input of op-amp, $v_1 = v_2 = 0$ (1)

Due to high input impedance, current flowing into its inverting input terminal is zero.

Same current flows through R_1 and R_f.

i.e., $i_1 = i_f$ (2)

But, $i_1 = \frac{v_{in} - v_1}{R_1}$

Since, $v_1 = 0$,

$i_1 = \frac{v_{in}}{R_1}$ (3)

$i_f = \frac{v_1 - v_{out}}{R_f} = \frac{-v_{out}}{R_f}$ (4)

Sub (3) & (4) in (2) we get,

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

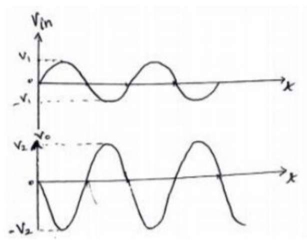
Or, output voltage of an inverting op-amp is $v_{out} = -\left(\frac{R_f}{R_1}\right) v_{in}$

The closed loop gain is

$$A_f = \frac{v_{out}}{v_{in}} = \frac{-R_f}{R_1}$$

where A_f is closed loop gain with negative feedback.

Input/output waveforms:



Op amp Non-Inverting Amplifier

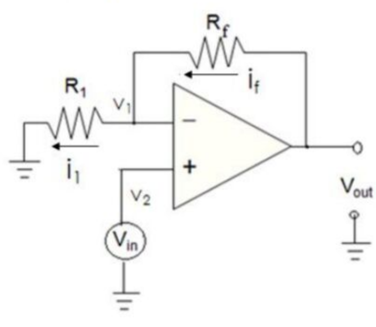


Figure 8. Non-Inverting amplifier

Here, input voltage is applied to non-inverting terminal of op-amp and inverting terminal grounded. Feedback resistor R_f is connected to inverting terminal. Due to virtual ground at the input terminals of op-amp, $v_1 = v_2 = 0$

Since, $v_2 = v_{in}, \ v_1 = v_{in}$

$$\therefore v_1 = v_2 = v_{in} \qquad (1)$$

Due to high input impedance, current does not flow into the input terminals of the op-amp. Hence, $i_1 = i_f$ (2)

But, $i_1 = \frac{v_1}{R_1} = \frac{v_{in}}{R_1}$ (3)

$$i_f = \frac{v_{out} - v_1}{R_f} = \frac{v_{out} - v_{in}}{R_f} \qquad (4)$$

$$Sub\ (3)\&(4) in\ (2),$$

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

$$\frac{v_{out}}{R_f} = \frac{v_{in}}{R_f} + \frac{v_{in}}{R_1}$$

$$\frac{v_{out}}{R_f} = v_{in}\left(\frac{1}{R_f} + \frac{1}{R_1}\right)$$

$$\frac{v_{out}}{v_{in}} = R_f\left(\frac{1}{R_f} + \frac{1}{R_1}\right)$$

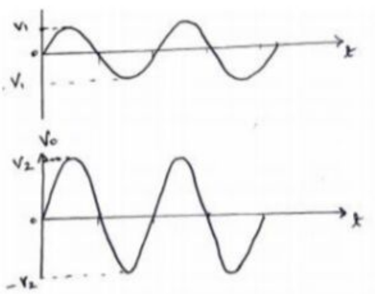
The output voltage of a non-inverting op-amp is

$$V_{out} = V_{in}\left(1 + \frac{R_f}{R_1}\right)$$

The closed loop gain is, $A_f = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

where $\boldsymbol{A_f}$ is closed loop gain with negative feedback.

Input/output waveforms



Op-amp Integrator

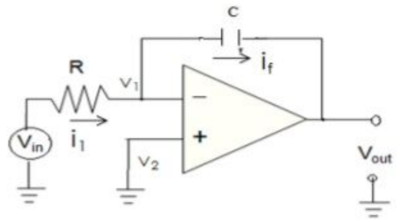


Figure 11. Integrator

In an integrator circuit, the output voltage is integration of the applied input voltage. When a step input voltage is applied, initially capacitor C is not charged and maximum current flows through resistor R. No current flows through amplifier input as $v_2 = 0$ *and* $v_1 = v_2$ due to virtual short. When the capacitor C begins to charge up to the input voltage, its impedance Xc increases slowly proportional to its rate of charge. The capacitor charges up to a rate determined by RC network. Ratio Xc/R increases and produces a ramp output till the capacitor is fully charged. During negative input voltage, capacitor discharges. Output voltage is inverted since v_{in} is applied to the inverting input terminal of the op-amp.

Voltage across the capacitor is, $v_c = \frac{Q}{C}$ (1)

Due to virtual ground, $v_1 = 0$

Current through resistor R is

$$i_1 = \frac{v_{in} - v_1}{R}$$

$$i_1 = \frac{V_{in}}{R_{in}} \qquad (2)$$

No current flows through inverting terminal of op-amp.

Current through C is i_f. Also voltage across the capacitor is

$$v_c = v_1 - v_{out}$$

$$\therefore v_c = -v_{out}, \qquad (3)$$

we know that, $v_c = \frac{Q}{C} = -v_{out}$ (4)

differentiating the equation (4), we get

$$\frac{1}{C}\frac{dQ}{dt} = -\frac{dv_{out}}{dt} \quad \text{or}$$

$$\frac{dQ}{dt} = -C\frac{dv_{out}}{dt}$$

The rate of change of charge is current i_f through the capacitor C and is given by

$$i_f = -C.\frac{dv_{out}}{dt} \qquad (5)$$

Equating (2) and (5) we get,

$i_1 = i_f$, i.e., we have

$$\frac{V_{in}}{R} = -C\frac{dv_{out}}{dt}$$

Integrating on both sides, we get

$$\int_0^t \frac{v_{in}}{R} dt = -C \int \frac{dv_{out}}{dt} dt \quad \text{i.e.,}$$

$$\int_0^t \frac{v_{in}}{R} dt = -Cv_{out}$$

$$\therefore v_{out} = -\frac{1}{RC}\int_0^t v_{in} dt \qquad (6)$$

In Eq. 6, RC is known as time constant. Negative sign indicates that there is a phase shift of 180° between input and output signals.

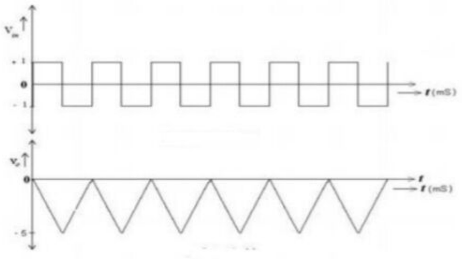


Figure: Input/output waveforms of Op-amp integrator

Op-amp Differentiator

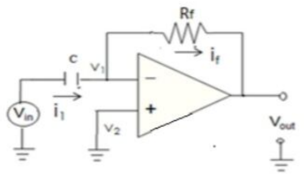


Figure 12.a Differentiator

The circuit which produces differentiation of the applied input voltage at its output is called as differentiator. The input signal is applied to a capacitor. The capacitor blocks DC & allows only AC voltage to pass. The capacitor will charge to the applied input voltage. Non inverting terminal is at ground potential and hence $v_1 = 0$. According to virtual short concept, $v_2 = 0$. Hence, no current flows into the input terminals of the op-amp.

As capacitor charges, voltage across it is $v_c = \frac{Q}{C}$ (1)

$$v_c = \frac{Q}{C} = v_{in} - v_1, \qquad (2)$$

Differentiating (2) on both side, we get

$$\frac{dQ}{dt}\frac{1}{C} = \frac{d(v_{in} - v_1)}{dt}$$

Due to virtual ground, $v_1 = 0$

$$\therefore \frac{dQ}{dt} = C\frac{dv_{in}}{dt}$$

Rate of change of charge is current i_1 through the capacitor.

$$i_1 = C\frac{dv_{in}}{dt} \qquad (3)$$

Current through the resistor R_f is

$$i_f = \frac{v_1 - v_{out}}{R_f}$$

$$i_f = \frac{-v_{out}}{R_f} \qquad (4)$$

Equating (3) and (4), we have

$$i_i = i_f$$

$$C\frac{dv_{in}}{dt} = \frac{-v_{out}}{R_f}$$

$$v_{out} = -CR_f\frac{dv_{in}}{dt} \qquad (5)$$

Negative sign indicates that there is a phase shift of 180° between input & output signal. CR_f is the time constant of the differentiator.

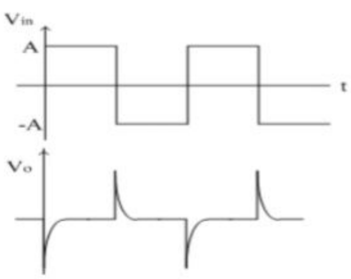


Figure 12.b: Input/ output waveforms of Op-amp differentiator

Unit - II Q.B

2. Given - $V_0 = -2[0.1V_1 + 0.5V_2 + 2V_3]$

$R_F = 10k\Omega$

Multiplying Rearranging, $V_0 = -[0.2V_1 + 1V_2 + 4V_3]$ —— ①

For Inverting Summer we hv o/p voltage,

$$V_0 = -\left(\frac{R_F}{R_A}V_1 + \frac{R_F}{R_B}V_2 + \frac{R_F}{R_C}V_C\right)$$

From eqⁿ ①,

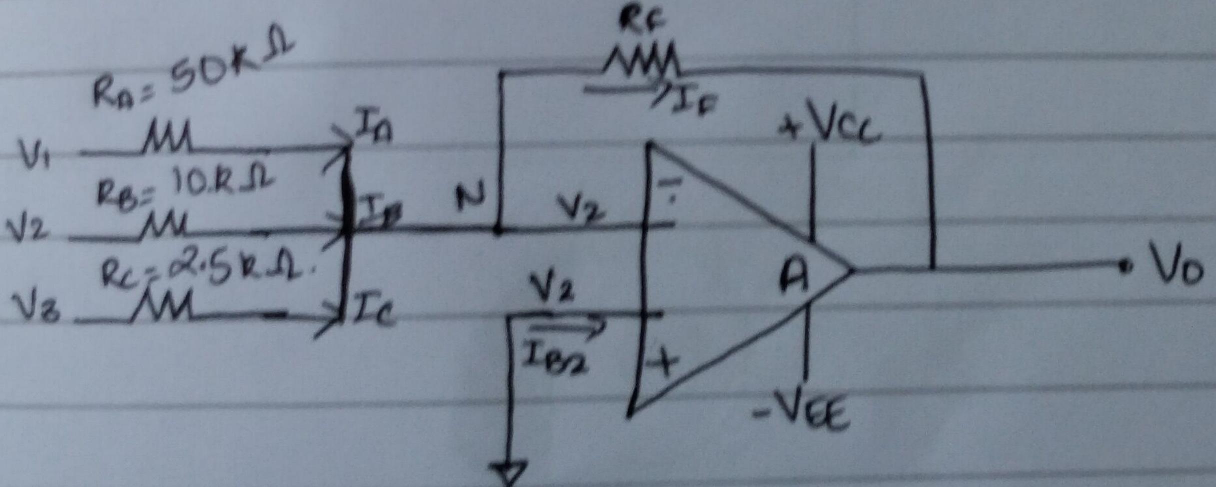
$\Rightarrow 0.2\cancel{V_1} = \frac{R_F}{R_A}\cancel{V_1}$ $\qquad\Rightarrow 1\cancel{V_2} = \frac{R_F}{R_B}\cancel{V_2}$

$R_A = \frac{10}{0.2} = \underline{50k\Omega}$ $\qquad R_B = \frac{10}{1} \Rightarrow \underline{10k\Omega}$

$\Rightarrow 4\cancel{V_3} = \frac{R_F}{R_C}\cancel{V_3}$

$R_C = \frac{10}{4} = \underline{2.5k\Omega}$

$\therefore R_A = \underline{50k\Omega}$ $\qquad R_B = \underline{10k\Omega}$ $\qquad R_C = \underline{2.5k\Omega}$



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3) Given : $V_o = [2V_1 + 3V_2 + 4V_3]$ $R_f = 20k\Omega$

Rearranging, $V_o = -[-2V_1 - 3V_2 - 4V_3]$ — ①

For Inverting Adder we hv o/p voltage,

$$V_o = -\left(\frac{R_F}{R_A}V_1 + \frac{R_F}{R_B}V_2 + \frac{R_F}{R_C}V_3\right)$$

From eqⁿ ①,

$\therefore$ $2\cancel{V_1} = \frac{R_F}{R_A}\cancel{V_1}$

$2 = \frac{20}{R_A}$ $\because$ $\boxed{R_F = 20k\Omega}$

$R_A = 10k\Omega$

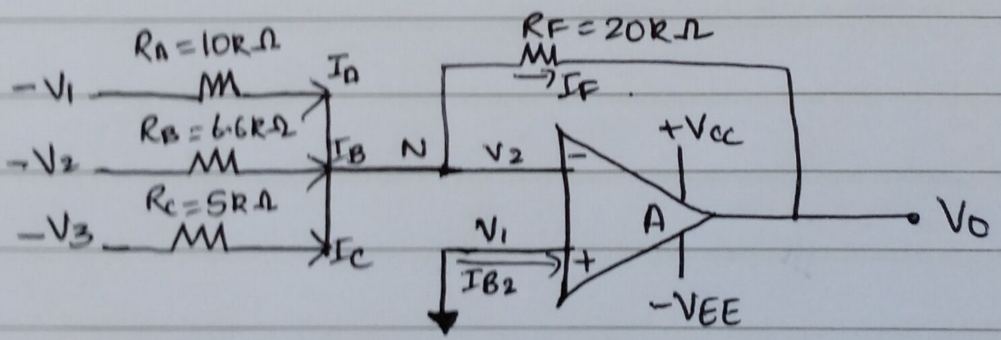
$3\cancel{V_2} = \frac{R_F}{R_B}\cancel{V_2}$

$R_B = \frac{20}{3}$

$R_B = 6.6\ k\Omega$

$4\cancel{V_3} = \frac{R_F}{R_C}\cancel{V_3}$

$R_C = \frac{20}{4} = 5k\Omega$



4. Non Inverting comparator

Case 2: with negative V_{ref}: When V_{in} is greater than V_{ref}, the non-inverting input becomes positive w.r.t inverting input and hence the output V_{out} goes to $+V_{sat}$ ($\cong +V_{CC}$). When V_{in} is less than V_{ref}, voltage at inverting terminal is greater than voltage level at the non inverting terminal. Hence the output votage V_{out} is at $-V_{sat}$ ($\cong -V_{EE}$).

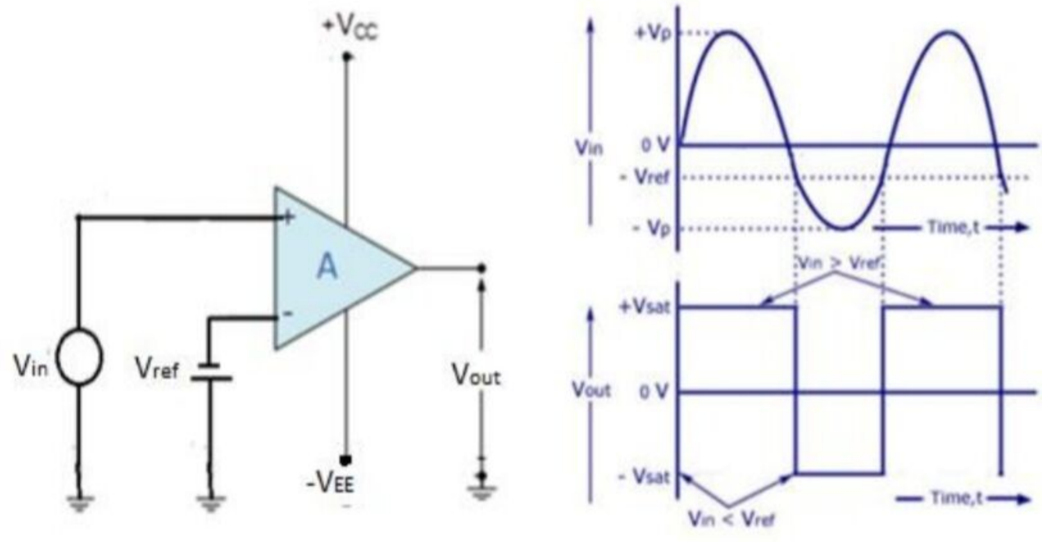


Figure 14. Non inverting comparator with $-V_{ref}$ voltage

Inverting comparator

Case 2: with negative V_{ref}: When V_{in} is greater than V_{ref}, the non-inverting input becomes negative w.r.t inverting input and hence the output voltage V_{out} goes to $-V_{sat}$ ($\cong -V_{EE}$). When V_{in} is less than V_{ref}, the output voltage V_{out} is at $+V_{sat}$ ($\cong +V_{CC}$) because the voltage at the inverting input is less than that of non-inverting input.

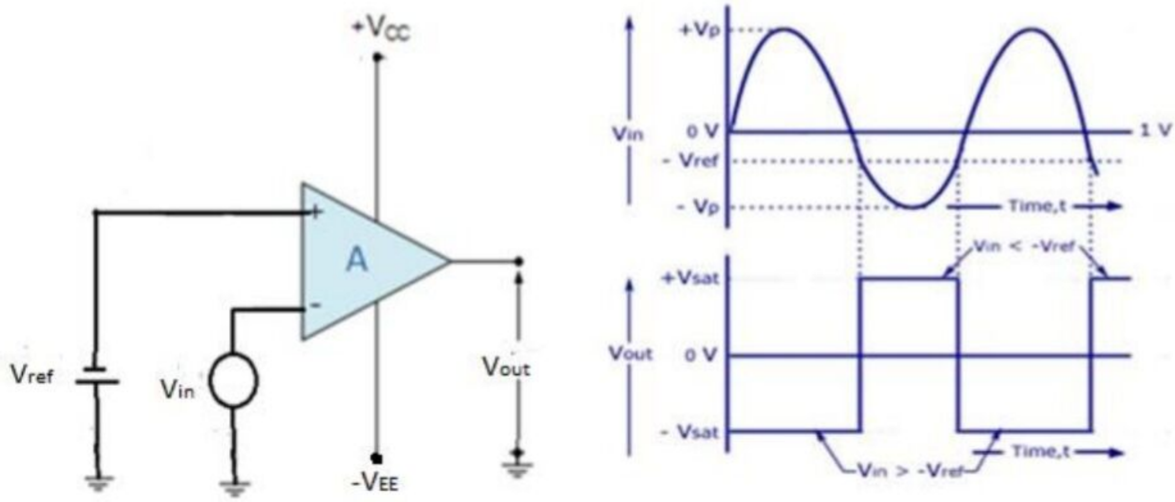


Figure 16. Inverting comparator with $-V_{ref}$ voltage

5) Given: $R_{in} = 10k\Omega = 10 \times 10^3 \Rightarrow \underline{1 \times 10^4 \Omega}$

$R_f = 1M\Omega = \underline{1 \times 10^6 \Omega}$ $V_o = 3V$

To find $A_v = ?$ $V_{in} = ?$

$$\boxed{A_v = -\frac{R_f}{R_{in}}} = -\frac{1 \times 10^6}{1 \times 10^4} \Rightarrow \underline{-100}$$

$\therefore$ The closed loop gain voltage $\underline{A_v = -100}$

For Inverting amplifier,

$$V_o = A_v \times V_{in}$$

$$\boxed{V_{in} = \frac{V_o}{A_v}} = \frac{3}{-100} \Rightarrow \underline{-0.03V}$$

or

$-\underline{30mV}$

⑥ Given : $V_{in} = 0.7\,V$

$R_f = 7\,k\Omega$

$R1 = 1\,k\Omega$

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_{in}$$

$$= \left[1 + \left(\frac{7\times10^3}{10^3}\right)\right] 0.7$$

$$= (8) \times 0.7$$

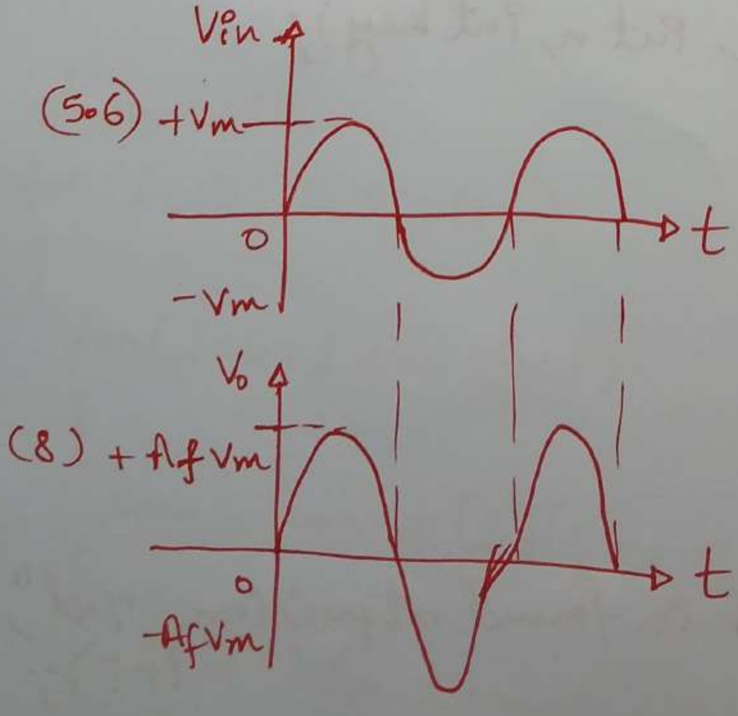
$$= \underline{\underline{5.6\,\Omega}}$$

$$A_F = 1 + \frac{R_F}{R_1}$$

$$= 1 + \left(\frac{7\times\cancel{10^3}}{1\times\cancel{10^3}}\right)$$

$$= \underline{\underline{8}}\ \cancel{abs}\ V$$

Waveforms:



(7) $CMRR = 30{,}000 V$

$A_d = 2500 V$

$$CMRR = \frac{A_d}{A_{cm}}$$

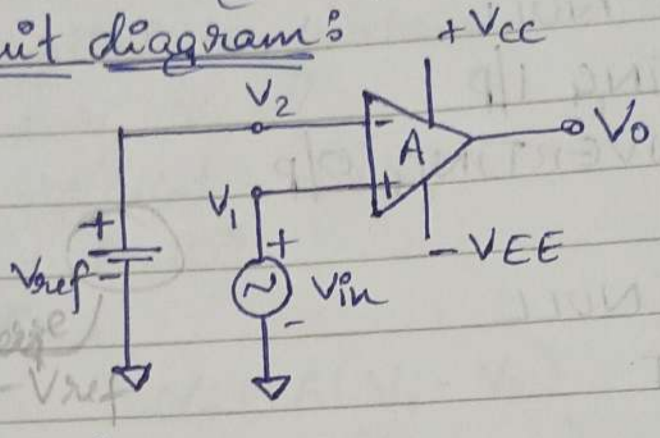
$$30{,}000 = \frac{2500}{A_{cm}}$$

$$A_{cm} = \frac{25\cancel{00}}{30{,}\cancel{00}0}$$

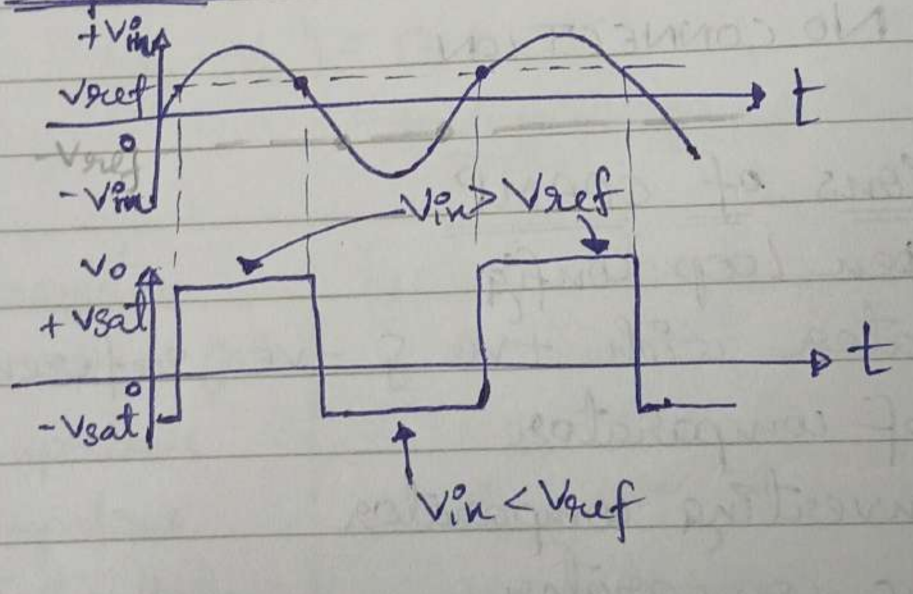
$$\underline{A_{cm} = 0.083 V}$$

① a·i) Non-inverting comparator with $+V_{ref}$

<u>Circuit diagram</u>:



<u>Waveforms</u>:



Working:-

For OPAMP,

$V_0 = A(V_1 - V_2)$ —— ①

From the circuit,

$$\left.\begin{aligned} V_1 &= V_{in} \\ V_2 &= V_{ref} \end{aligned}\right\} \text{—— ②}$$

In eq ①, if $V_1 > V_2$, V_0 is +ve and is equal to $+V_{sat}$ ~~the~~ as OPAMP is in open loop config and A is large.

If $V_1 < V_2$, V_0 is -ve & and it is $-V_{sat}$ as A is large.

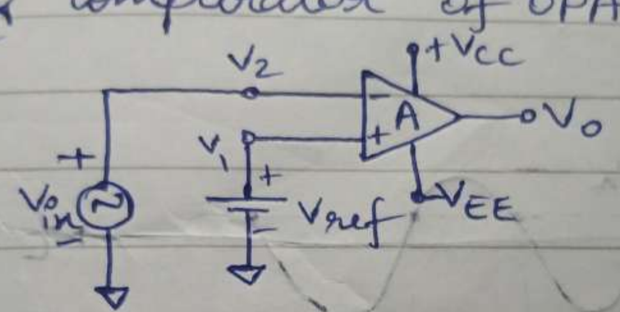
Using eq ②, when $V_{in} > V_{ref}$

$V_0 = +V_{sat}$

when $V_{in} < V_{ref}$

$V_0 = -V_{sat}$

ii) Inverting comparator of OPAMP with $+V_{ref}$



Working: For OPAMP,

$V_o = A(V_1 - V_2)$ —— (1) in open loop config.

When $V_1 > V_2$

$V_o = +V_{sat}$; $V_o = +ve$

When $V_1 < V_2$

$V_o = -ve$; $V_o = -V_{sat}$

From the circuit,

$V_1 = V_{ref}$

$V_2 = V_{in}$

Subs the above in eq^n 1, we get

$V_o = A(V_{ref} - V_{in})$

If $V_{in} > V_{ref}$; $V_o = -ve$

and $V_o = -V_{sat}$

If $V_{in} < V_{ref}$; $V_o = +ve$

and $V_o = +V_{sat}$

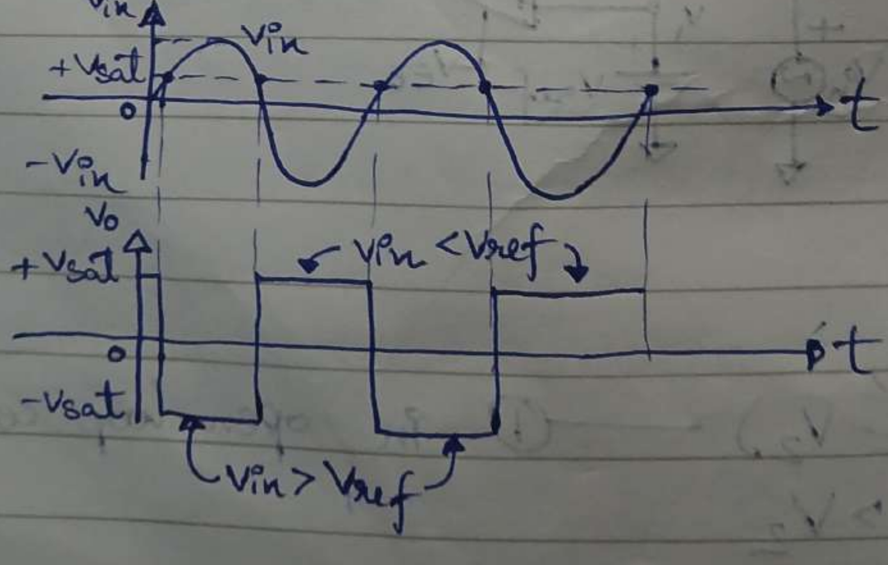
NOTE: In OPAMP:

$- \rightarrow V_2$ (inverting)

$+ \rightarrow V_1$ (non-inverting)

V_1 down ; V_2 up

Waveforms:



Characteristics of Ideal Op-amp

9. 1. An ideal op-amp has Infinite input resistance ($Ri = \infty$).

2. An ideal op-amp has zero output resistance ($Ro = 0$).
3. Infinite voltage gain (i.e., $A = \infty$)
4. An ideal op-amp amplifies signals of any frequency with a constant gain, which means it has infinite bandwidth ($B.W. = \infty$)

5. When equal voltages are applied to both inputs the output voltage is zero. Thus it has perfect balance.
6. Common mode rejection ratio is infinite ($i.e., CMRR = \infty$)
7. An ideal op-amp has infinite slew rate ($i.e., S = \infty$)
8. The characteristics an ideal op amp does not change with temperature.

10. • **Common mode rejection ratio (CMRR):** CMRR is defined as the ratio of differential gain A_d to the common mode gain. CMRR= $\rho = \frac{|A_d|}{|A_c|}$

CMRR is often expressed in decibels as CMRR = $20\log_{10}\frac{|A_d|}{|A_c|}$ dB. Typical value of CMRR for µA741 IC is 90dB. For an ideal op amp A_d infinite and A_c is zero so that CMRR is infinite. For a practical op amp A_d is very large A_c is non zero but small. So that CMRR is very large. CMRR is a measure of the op-amp to reject signals common to both inputs.

Slew rate (SR) of an op-amp

Slew rate is defined as maximum time rate of change of its output voltage, expressed in volts per microsecond.

10.ii

SR or Max. SR= $\left.\frac{dv_o}{dt}\right|_{max}$ V/µs.

Slew rate is a measure of how fast the op-amp output can change in response to changes in the input signal.

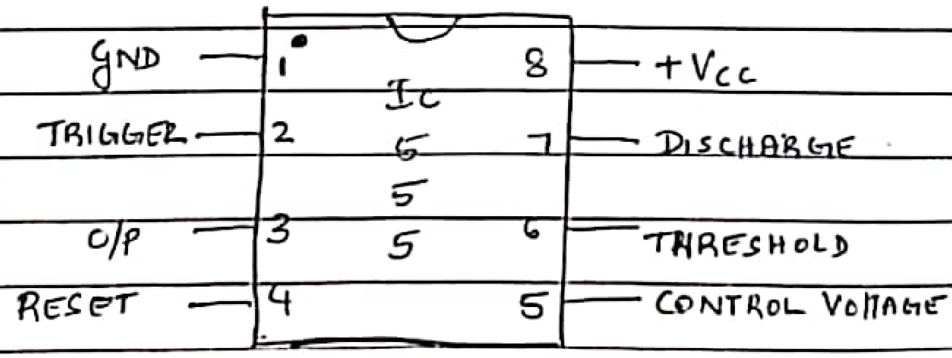
10.

- **Input offset voltage (V_{io});** Input offset voltage is the voltage that must be applied between the two input terminals such that the output voltage becomes zero. Typical values of V_{io} =1 mV.
- **Input offset current (I_{io});** It is the algebraic difference between the currents flowing into non-inverting and inverting terminals.

  i.e., Input offset current $I_{io}=|I_{B1} - I_{B2}|$

  where I_{B1} = current into inverting terminal. I_{B2} = current into non-inverting terminal

11. IC diagram.



Internal diagram and pin description.

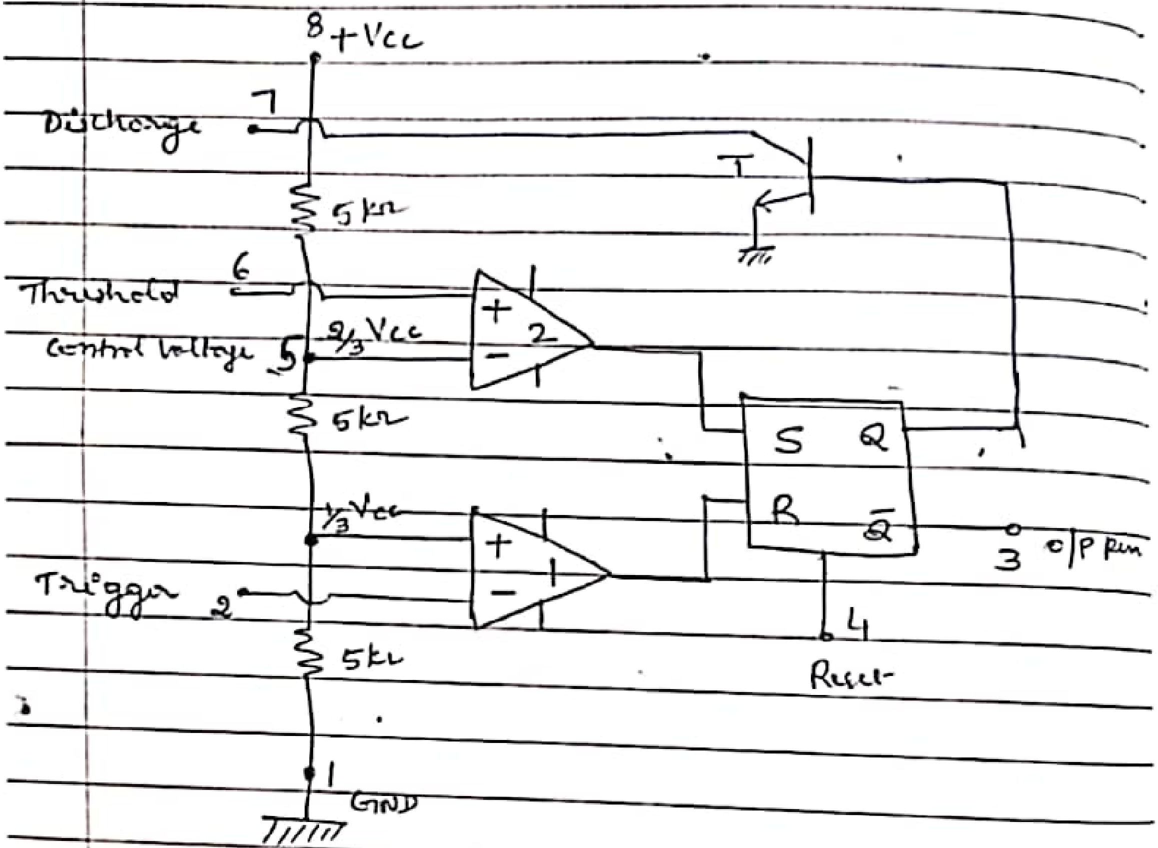


Fig: Internal Architecture of IC555.

Pin 1: Ground. All voltages are measured with respect to ground.

Pin 2 & Pin 6: Trigger and Threshold pins.
Pin 2 is called trigger pin. It is connected to the inverting terminal of 1st OP-Amp comparator. If the voltage at trigger pin goes below $\frac{1}{3}Vcc$, then the output of comparator 1 goes high that resets the RS flip flop.

Date PN 3

Pin 6 is called the threshold pin. It is connected to the non inverting terminal of comparator 2. When the voltage level at threshold pin is greater than 2/3 Vcc, the o/p of comparator 2 goes high that sets the RS flip flop.

Hence pin 2 & pin 6 are used to control the o/p s of the comparators.

Pin 3 : It is an o/p pin.

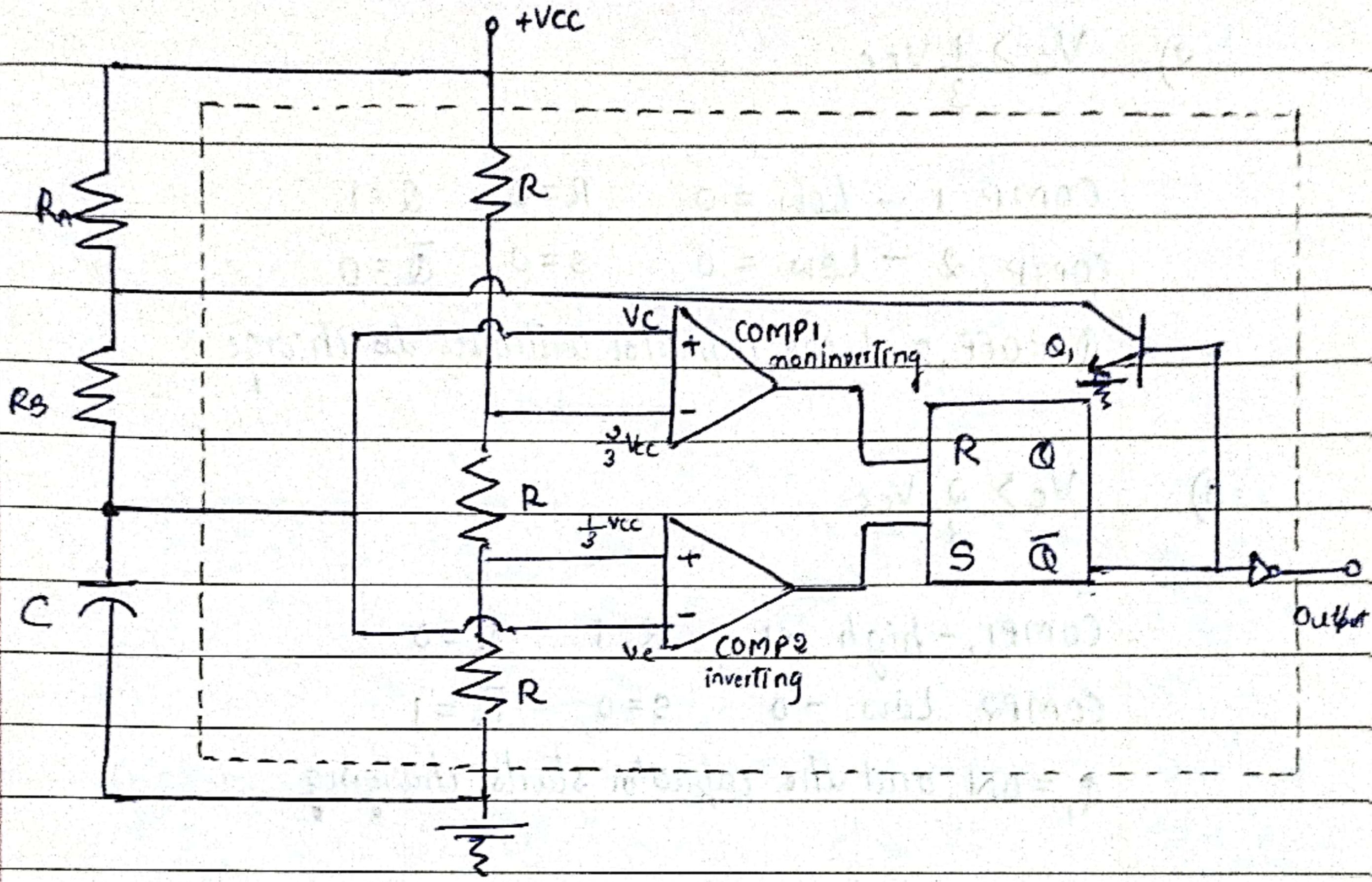
Pin 4 : It is used to reset the flip flop. It can be used to interrupt the operation and make the capacitor discharge.

Pin 5 : Pin 5 is called as control voltage pin. It is directly connected to the inverting terminal of the first comparator. The reference voltage of 2/3 Vcc is set at pin 5.

Pin 7 : It is called as discharge pin. It is connected to the collector terminal of the transistor.

Pin 8 : Pin 8 is +Vcc. It is used to give power supply to IC 555. The voltage from 4.5V to 15V can be given to the IC.

12.



Ic 555 Timer as free running oscillator.

Working

1 Initially $V_c = 0$

COMP1 (noninverting) → Vin > Vref → Output will be high.

COMP2 (inverting) → Vin < Vref → Output will be low.

COMP1 – Low → 0   R = 0   Q = 1

COMP2 – High → 1   S = 1 $\bar{Q} = 0$

Q_1 = OFF, Hence capacitor starts charging.

As capacitor starts charging, V_c increases at one point $V_c > \frac{1}{3} V_{cc}$.

2) $V_c > \frac{1}{3} V_{cc}$

COMP 1 – Low = 0 $\quad R=0 \quad Q=1$

COMP 2 – Low = 0 $\quad S=0 \quad \bar{Q}=0$

Q_1 = OFF and the capacitor continues to charge.

3). $V_c > \frac{2}{3} V_{cc}$

COMP1, – high – 1 $\quad R=1 \quad Q=0$

COMP2, Low – 0 $\quad S=0 \quad \bar{Q}=1$

Q_1 = ON, and the capacitor starts charging

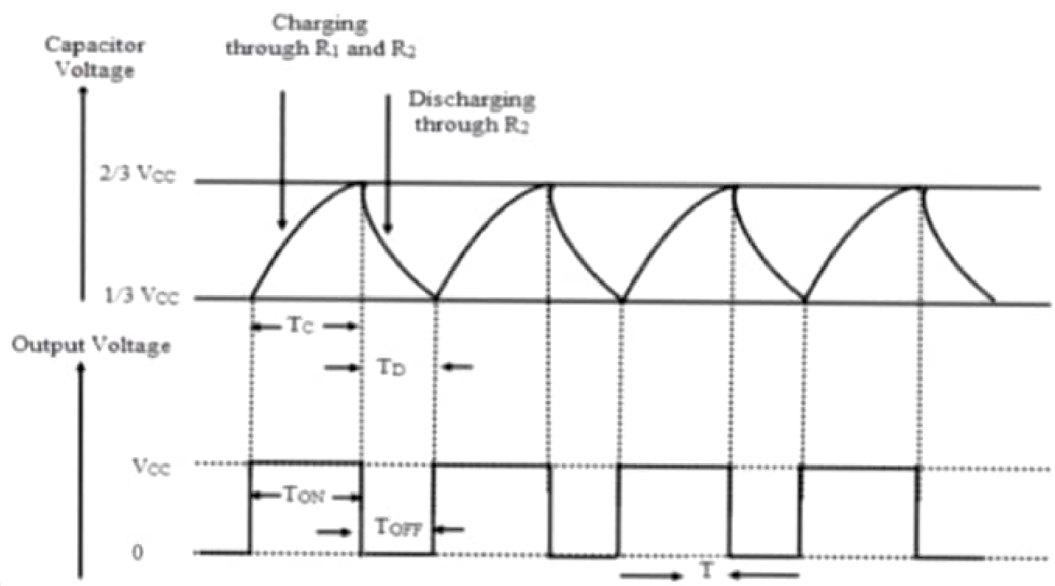


Figure 22: Voltage across capacitor at pin 2 & Output voltage at pin 3

13 A 555 timer is configured to operate in free running mode with $R_1 = 4K\Omega$, $R_2 = 4K\Omega$ and $C = 0.01\mu F$. Determine the frequency and duty cycle of the output waveform.

→ $R_1 = 4K\Omega$

$R_2 = 4K\Omega$

$C = 0.01\mu F$

frequency, $f = ?$

Duty cycle $= ?$

$$f = \frac{1}{T}$$

$$T = T_{ON} + T_{OFF}$$

$$T_{ON} = 0.693\,(R_1 + R_2) \times C$$
$$= 0.693\,(4\times10^3 + 4\times10^3) \times 0.01\times10^{-6}$$
$$= 0.693\,(8\times10^3) \times 0.01\times10^{-6}$$
$$= 55.44\times10^{-6}$$
$$T_{ON} = \underline{55.44\,\mu sec}$$

$$T_{OFF} = 0.693\,R_2\,C$$
$$= 0.693\times4\times10^3\times0.01\times10^{-6}$$
$$= 27.72\times10^{-6}$$
$$T_{OFF} = \underline{27.72\,\mu sec}$$

$$T = 55.44 + 27.72 = \underline{83.16\,\mu sec}$$

$$\therefore f = \frac{1}{T} = \frac{1}{83.16} = \underline{12KHz}$$

$$\text{Duty cycle} = \frac{T_{ON}}{T} = \frac{55.44\,\mu sec}{83.16\,\mu sec}$$
$$= 0.666$$

$$\%D \text{ is } = \underline{66.6\%}$$

14. For an IC 555 timer, given $D = 60\%$, $f = 2$ KHz, $R_2 = 5\ k\Omega$, and $C = 0.1\mu F$.

Calculate R_1.

–Similar to 15

15. For an IC 555 timer, given $D = 75\%$, $f = 1$ KHz, $R_2 = 3.6\ k\Omega$, $C = 0.1\mu F$. Calculate R_1.

Solution:

Given: $D = 75\% \Rightarrow 0.75$

$f = 1\ kHz,\ R_2 = 3.6\ k\Omega,\ C = 0.1\mu F$

$$D = \frac{T_{ON}}{T}$$

$$T = \frac{1}{f} \Rightarrow 1 \text{ m sec}$$

$$T_{ON} = D \times T$$

$$T_{ON} = 0.75 \times 10^{-3} sec = 750\ \mu sec$$

$$T_{OFF} = 0.693\ R_2\, C$$

$$T_{OFF} = 249\ \mu sec$$

Since $D > 50\%$, $T_{ON} > T_{OFF}$

$$T_{ON} = 0.693(R_1 + 3600)0.1 \times 10^{-6}$$

Therefore $R_1 = 7.215\ k\Omega$

16)

Saturable property of an op amp

The property by which Op-amp output saturates at two saturation levels (±Vsat) decided by the supply voltages is called as saturable property of Op-amp.

As the open loop gain of op-amp is very large, of the order of 10^5 or more, even a very small difference input voltage $(v_2 - v_1)$ produces extremely high output voltage.

However maximum output voltage is limited by supply voltage.

As a rule, maximum output voltage may be taken 1.5V less than supply voltage.

For example for a supply voltage of ±15V, the output voltage is limited to maximum of ±13.5V. Once the output reaches this limit, it does not increase further even if the magnitude of input voltage is increased. Under this condition op-amp is said to be clipped or saturated.

Example, $A=2x10^5$ and saturation voltage =±13.5V.

$v_o = A(v_2 - v_1)$

$(v_2 - v_1) = \frac{V_o}{A}$=$13.5/2x10^5$=67.5μV

Therefore magnitude of differential input voltage that causes op-amp to saturate is 67.5μV.

For higher values of $(v_2 - v_1)$ output will be limited either to+13.5V or -13.5V.

- **Concept of virtual short in an op-amp**

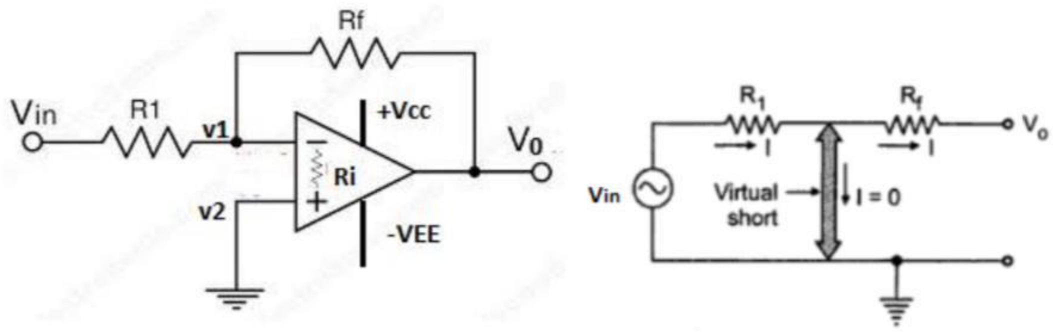


Figure 6. Virtual ground concept

Figure 6 shows circuit of op-amp inverting amplifier with negative feedback.

R_i represents input resistance. Output voltage v_o is given by

$$v_o = A\,(v_2 - v_1) \quad \text{or } (v_2 - v_1) = \frac{v_o}{A}$$

where A is open loop voltage gain of op-amp. The output voltage v_o cannot exceed the DC supply voltage given to the op-amp. For µA741 IC, supply voltage is 12V and open loop voltage gain is $2\text{x}10^5$. To get an output voltage of 10V by applying an input voltage of 1 V, the required differential input voltage is, $(v_2 - v_1) = \frac{v_o}{A} = 10V/2 \times 10^5 = 50\mu V$. This value is very small compared to input & output voltages and may be considered as 0V.

i.e., $(v_2 - v_1) \cong 0V$ or $v_2 = v_1$

Above equation indicates that inverting and non-inverting input terminals are at same potential. Therefore voltage across R_i is zero. No current flows from input terminals to ground. The virtual short is also called as virtual ground.

17) not needed

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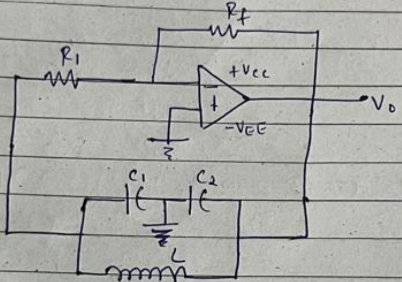
18. In a Colpitts oscillator, L = 2mH. Calculate the value of each capacitor required to generate oscillations of 1 MHz frequency. Assume $C_1 = C_2$. Write the circuit diagram.

Ans. Given: $C_1 = C_2$

$L = 2\,mH = 2 \times 10^{-3}\,H$

$C_1 = C_2 = ?$

$f = 1 \times 10^{6}\,Hz$



$$f = \frac{1}{2\pi\sqrt{L C_{eq}}}.$$

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{C_1^2}{2C_1} = \frac{C_1}{2} \quad \ldots (1).$$

$$\Rightarrow \cancel{f = \frac{1}{2 \times 3.14\sqrt{2 \times 10^{-3} \times \frac{C_1}{2}}}}$$

$$(f)^2 = \left(\frac{1}{2\pi\sqrt{LC_{eq}}}\right)^2.$$

$$f^2 = \frac{1}{4\pi^2 L C_{eq}}.$$

$$C_{eq} = \frac{1}{4\pi^2 L f^2}$$

$$\frac{C_1}{2} = \frac{1}{4 \times 9.85 \times 2 \times 10^{-3} \times (10^6)^2}$$

$$C_1 = \frac{2}{78.8 \times 10^9}$$

18)

$C_1 = 0.025 \times 10^{-9}$

$C_1 = 0.025\,nF$

$\therefore C_1 = C_2 = 0.025\,nF$

Concept of positive feedback:

When the input signal and part of the output signal is fed back in phase, the feedback is called as positive feedback. Positive feedback results in oscillations.

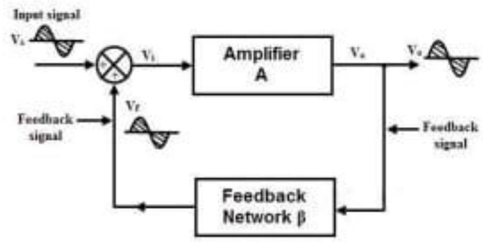


Fig.27: Positive Feedback Amplifier

Consider an inverting amplifier with voltage gain, A as in Fig.27. Assume that sinusoidal input signal, V_{in} is applied to the block. As the amplifier is of inverting type, the output voltage, V_o is out of phase by 180^0 w.r.t input signal, V_{in}. A part of V_o is fed back to the input with the help of the feedback network. The amount of V_o that has to be fed back is decided by the feedback factor, β. The feedback network introduces a phase shift of 180^0 to V_0. Phase of the feedback signal is same as that of the input signal applied. Hence the feedback is called as positive feedback.

Expression for gain A_f with feedback:

For the overall block, the input supply is V_{in} & output is V_0. The ratio of output voltage, V_o to the input voltage, V_{in} with corresponding effect of feedback is called as closed loop gain of the network or gain with feedback denoted as A_f.

$$A_f = \frac{V_o}{V_{in}}$$

Since the feedback is positive & voltage V_f is added to V_{in} to generate the input signal V_i to the amplifier, from the block diagram, we can write,

$$V_i = V_{in} + V_f$$

V_f depends on β of the feedback network.

$$V_f = \beta V_o$$

Substituting V_f in V_i

$$V_i = V_{in} + \beta V_o$$

$$\therefore V_{in} = V_i - \beta V_o$$

$$A_f = \frac{V_o}{V_{in}} = \frac{V_o}{V_i - \beta V_o} = \frac{V_o / V_i}{1 - \beta V_o / V_i}$$

$$\therefore A_f = \frac{A}{1 - A\beta}$$

It can be observed as how gain with feedback varies with varying β as in table below:

A	β	A_f
20	0.005	22.22
20	0.04	100

It can be observed as how gain with feedback varies with varying β as in table below:

A	β	A_f
20	0.005	22.22
20	0.04	100
20	0.045	200
20	0.05	∞

We observe that gain with feedback increases as the amount of positive feedback increases & reaches infinity. This indicates that the circuit can produce output without external input ($V_{in} = 0$) signal just by feeding the part of the output as its own input. Hence, the output voltage cannot be infinity but gets driven to oscillations. β value must be less than 1. To start

with oscillations, Aβ > 1 must be set. But the circuit adjusts itself to get Aβ = 1 to produce sinusoidal oscillations while working as an oscillator. An oscillator is an amplifier that uses positive feedback & without any external input signal, generates an output waveform at a desired frequency.

Barkhausen's criterion for oscillations:

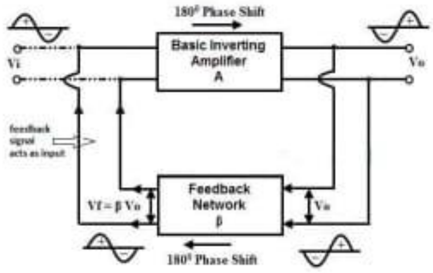


Fig.**28**: Block diagram of an Oscillator

The two conditions required for the circuit to work as an oscillator are called as Barkhausen's criteria for sustained oscillations

Barkhausen's criteria states that

1) Total phase shift around the loop as the signal proceeds from input through the amplifier, feedback network and back to input again completing a loop is 0^0 or 360°.

2) The magnitude of the product of the open loop gain A & the feedback factor is $|A\beta| = 1$

Satisfying these conditions, the circuit works as an oscillator producing sustained oscillations.

Inverting amplifier has a gain of A with phase shift of 180^0. Let the input, V_{in} applied to the amplifier be derived from its output using a feedback network. The network has feedback factor, β which is less than 1. The amplifier produces a phase shift of 180^0. The output voltage fed back using feedback network must be in phase with V_{in}. Thus the feedback

network must introduce a phase shift of 180^0 so that the total phase shift is 0^0 / 360^0 so that V_{in} is in phase with V_f.

Fig.**28** describes the block diagram of an oscillator. Let V_{in} be a fictitious voltage applied as input to the amplifier.

$$V_o = AV_{in} \qquad \text{..............(1)}$$

The feedback factor β divides the amount of feedback to be given to the input.

$$V_f = \beta V_o \qquad \text{...............(2)}$$

Substituting Eq. 1 in 2, we get

$$\therefore V_f = A\beta V_{in} \qquad \text{...............(3)}$$

For the oscillator, the feedback voltage V_f should drive the amplifier & hence V_f must act as V_{in}. From Eq. 3, we conclude that V_f is sufficient to act as V_{in} when

$$|A\beta| = 1$$

ie, $V_f = A\beta V_{in}$

or $V_f = V_{in}$

Phase of V_f should be same as V_{in}. Amplifier introduces the phase shift of 180° & feedback network with 180°. This ensures positive feedback. Hence total phase shift around loop is 360°.

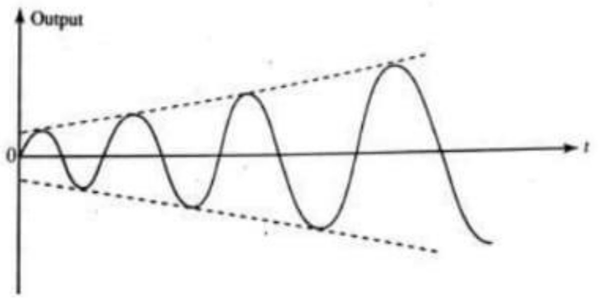
or $V_f = V_{in}$

Phase of V_f should be same as V_{in}. Amplifier introduces the phase shift of 180° & feedback network with 180°. This ensures positive feedback. Hence total phase shift around loop is 360°.

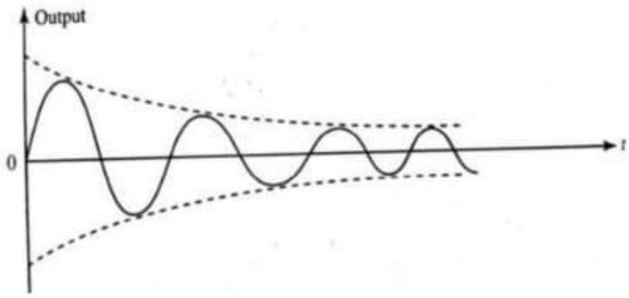
Under this condition, V_f drives the circuit without any external input, hence working as an oscillator.

Cases:

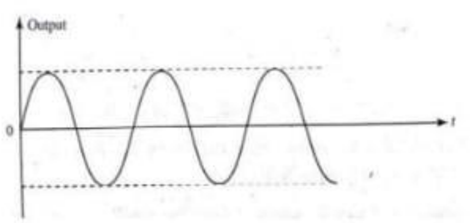
Case 1: $|A\beta| > 1$, oscillations are of growing type



Case 2: $|A\beta| < 1$, oscillations are of decaying type

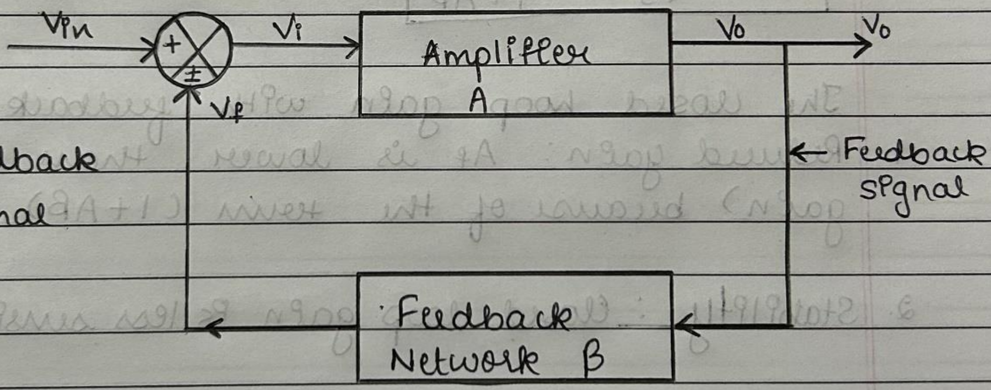


Case 3: $|A\beta| = 1$, oscillations with constant frequency and amplitude called as sustained oscillations



21 Discuss the concept of voltage series feedback with a neat block diagram. Derive an expression for closed loop voltage gain. Comment on the closed loop gain with feedback.

Ans In voltage-series feedback, a portion of the output voltage is fed back to the input in series. This is also known as "series-shunt feedback" because the output is sampled in shunt (parallel) and fed back in series with the input. The primary purpose of this feedback is to stabilize the gain, reduce distortion, increase bandwidth, and improve input and output impedence characteristics.



Derivation of closed-loop voltage gain

Let

A = open-loop gain of the amplifier

β = feedback factor

V_o = output voltage

V_S = input source voltage

V_f = feedback voltage

V_e = error voltage

Then, output voltage can be expressed as

$V_o = A V_e$

$V_f = \beta V_o$ $\quad \boxed{\because V_e = V_s - V_f}$

$V_e = V_s - \beta V_o$

$V_o = A(V_s - \beta V_o)$ ⟶ substituting V_e into eq for V_o.

Rearranging the equation.

$V_o = AV_s - A\beta V_o$

$V_o + A\beta V_o = AV_s$

$V_o(1 + A\beta) = AV_s$

Thus, closed loop A_f is given by

$$\boxed{A_f = \frac{V_o}{V_s} = \frac{A}{1 + A\beta}}$$

The closed loop gain with feedback :

1. Reduced gain : A_f is lower than A (open loop gain) because of the term $(1 + A\beta)$.

2. Stability : Closed loop gain is less sensitive to changes

3. Improved linearity : Reduces distortion.

4. Bandwidth : ~~With increase in nto~~ Negative feedback increases bandwidth. While gain decreases, the amplifier can operate over a larger frequency range.

5. Impedence : Voltage - series feedback increases the input impedence & decreases output impedance, which is beneficial in many practical applications.

Q22) List out the advantages of negative feedback .

ANS:

Advantages of negative feedback:

1) Stabilized gain

2) Higher input impedance

3) Lower output impedance

4) Increased bandwidth

5) Reduction in noise.

5. In a Colpitts oscillator, $L = 5mH$. Find C_1 and C_2 if the frequency of oscillations is $f = 50\,kHz$. Assume a feedback factor of $\beta = 10\%$.

Soln: $L = 5mH$. $f = 50\,kHz$. $\beta = 10\% = 0.1$

$$f = \frac{1}{2\pi\sqrt{L C_{eq}}} \qquad C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

Squaring f,

$$f^2 = \frac{1}{4\pi^2 L C_{eq}}$$

$$C_{eq} = \frac{1}{4\pi^2 L f^2} = \frac{1}{4\pi^2 \times 5\times10^{-3} \times (50\times10^3)^2}$$

$$C_{eq} = 2.02nF$$

wkt $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$, $\beta = 0.1 = \frac{C_2}{C_1}$

$\therefore C_2 = 0.1 C_1$

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{C_1 \times 0.1 C_1}{1.1 C_1} = \frac{0.1 C_1}{1.1}$$

$$\Rightarrow C_{eq} = \frac{0.1 C_1}{1.1}$$

$$2.02nF = \frac{0.1 C_1}{1.1}$$

$$\therefore C_1 = 22.22nF$$

& $C_2 = 0.1 \times 22.22nF$

$= 2.222nF$

Ans: $f = 25000 Hz$ $C = 0.02 \times 10^{-6} F$

$$f = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

$$\beta = \frac{20}{100} = 0.2$$

$$\beta = \frac{L_1}{L_2} = 0.2$$

$$L_1 = 0.2L_2$$

$$25000 = \frac{1}{2\pi\sqrt{L_{eq} \cdot 0.02 \times 10^{-6}}}$$

$$\sqrt{L_{eq}} = \frac{1}{2\pi \times 0.141 \times 10^{-3} \times 25000}$$

$$\sqrt{L_{eq}} = \frac{1}{21.98}$$

$$\sqrt{L_{eq}} = 0.04554$$

$$L_{eq} = 2.021 \times 10^{-3}$$

$$L_{eq} = L_1 + L_2 = 2.021 \times 10^{-3}$$

$$L_1 = 0.2L_2$$

$$\therefore 0.2L_2 + L_2 = 2.02 \times 10^{-3}$$

$$1.2L_2 = 2.02 mH$$

$$L_2 = \frac{2.02}{1.2}$$

$$L_1 = 0.2 \times 1.68$$

$$\boxed{L_1 = 0.336 mH}$$

3) ~~Determine~~ calculate the value of R in a RC phase shift oscillator for frequency of oscillation 2KHZ and capacitance is 0.1MF.

Ans:- $\therefore f = \frac{1}{2\pi RC\sqrt{6}}$

given:- $f = 2KHZ$
$C = 0.1MF$
$R = ?$

$$R = \frac{1}{2 \times 3.14 \times fC\sqrt{6}}$$

$$R = \frac{1}{2 \times 3.14 \times 2 \times 10^{+3} \times 0.1 \times 10^{-6} \times \sqrt{6}}$$

$$R = \frac{1}{2\pi \times 2 \times 10^{-4}\sqrt{6}}$$

$$= \frac{1}{12.56 \times 10^{-4} \times 2.44}$$

$$= \frac{10^4}{30.765} = \underline{\underline{325\Omega}}$$

OP-Amp oscillators.

RC phase shift oscillator.

RC phase shift oscillator consists of an amplifier and a feedback network. In this circuit, OP-Amp with inverting configuration is used as an amplifier that generates a phase shift of 180°.
Feedback network consists of 3 RC sections connected in ladder form. Each RC section generates a phase shift of 60°. Hence a total of 180° phase shift is generated by the feedback network.

circuit diagram :

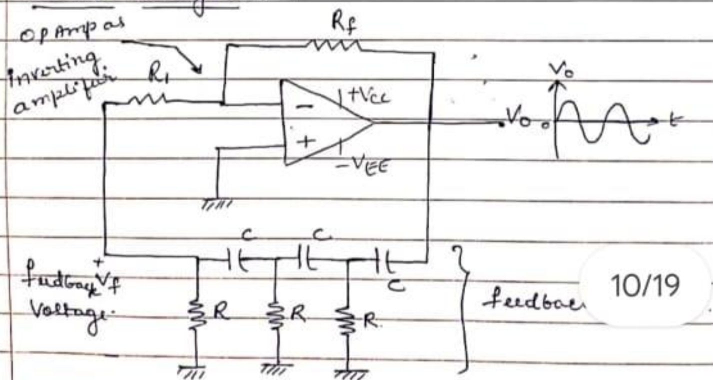


Fig: RC phase shift oscillator using OP-Amp.

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The output of the amplifier is given to the feedback network. The output of the feedback network drives the amplifier.
Hence, the total phase shift around the closed loop is 180° due to the inverting amplifier and 180° due to 3 RC sections. Thus 360°. This satisfies the required condition for positive feedback and circuit works as an oscillator.

The frequency of oscillations is given by

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

These oscillators are used over the audio frequency oscillator.

The frequency of oscillations is given by

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

These oscillators are used over the audio frequency range ie about 20Hz to 20kHz.
The circuit is simple to design, but the values of R & C of all the three sections must be changed simultaneously to satisfy the criteria.

LC oscillators.

1. Colpitts oscillator :
• The feedback network comprises of 2 capacitors and 1 inductor in Colpitts oscillator.

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Circuit diagram.

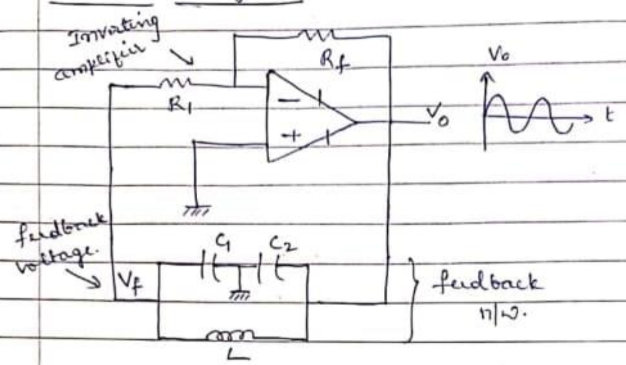

Fig: Op-Amp Colpitts Oscillator.

Colpitts oscillator consists of an inverting amplifier using Op-Amp that generates a phase shift of 180°.
The feedback network consists of a parallel LC resonant tank circuit. The feedback is achieved by the way of a capacitive divider to feed a fraction of the output signal back to the inverting terminal of the amplifier.
When the power supply is switched ON, capacitors C_1 and C_2 charges up and then discharges through inductor L. A phase shift of 180° is achieved through the tank circuit resulting in overall phase shift of 360°.

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The amount of feedback depends on the values of C_1 and C_2. Large amount of feedback voltage may generate distortion in the output sine wave. while small amount of Fb feedback may not allow the circuit to oscillate.

The frequency of oscillations is

$$f = \frac{1}{2\pi\sqrt{L C_{eq}}} \quad \text{where}$$

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

The feedback factor is $\beta = \frac{C_2}{C_1}$.

The condition for sustained oscillations is

$$|A\beta| > 1.$$

$$\text{or} \quad |A| > \frac{1}{\beta}.$$

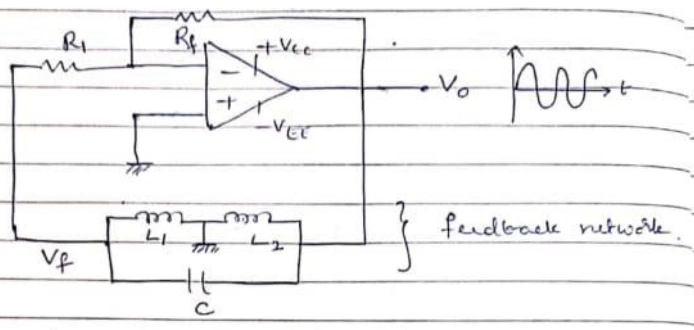
$$\text{or} \quad |A| > \frac{C_1}{C_2}$$

2. Hartley Oscillator:

The feedback network consists of 2 inductors and 1 capacitor in Hartley oscillator.

Date

circuit diagram:



Hartley oscillator consists of an OP-Amp circuit in inverting configuration that generates a phase shift of 180°
It consists of an LC tank circuit where two inductors L_1 and L_2 in series are connected in parallel with a single capacitor C.

when the DC power supply is switched on

C.

When the DC power supply is switched on, the capacitor C starts charging. When the capacitor is fully charged, it starts discharging through inductors L_1 and L_2. Hence an oscillatory current is generated to provide a phase shift of 180°. The voltage a/c C is the feedback voltage V_f connected to the inverting terminal of the OP-Amp. Hence a total phase shift of 360° is achieved.

Date PNB

Frequency of oscillations is given by

$$f = \frac{1}{2\pi\sqrt{L_{eq}C}} \quad \text{where } L_{eq} = L_1 + L_2$$

Feedback factor $\beta = \frac{L_1}{L_2}$.

Condition for sustained oscillations is

$$|A\beta| > 1$$

$$\text{or } |A| > \frac{1}{\beta} \quad \text{or } |A| > \frac{L_2}{L_1}.$$

If mutual inductance exists between L_1 & L_2, then with M,

$$L_{eq} = L_1 + L_2 + 2M.$$