ch 9 Operational Amplifier & Oscillator

Operational amplifier (op-amp) is a circuit that performs such mathematical operations as addition, subtraction, integration & differentiation. It is made with different internal configurations in linear IC's. It is so named because it originally was designed to perform mathematical operation. Op-amp is also used in oscillators for freq oscillation. Op-amp is a complete amplifier, however external components (resistor, capacitor) etc can be connected to its terminals to change external characteristics.

An op-amp is a very high gain differential amplifier with high input impedance & low o/p impedance. Op-amp are typically used to provide voltage amplitude change, oscillators, filter, & many types of instrumentation circuits.

The block diagram of op-amp is,

Non-inverting I/p

Input Stage — Intermediate Stage — Level shifting stage — O/p stage — O/p

Inverting I/p

Fig: Block diagram of op-amp.

I/p stage

It is a dual-i/p, balanced o/p differential amplifier. The basic requirements of i/p stage are

→ High voltage gain
→ High i/p impedance
→ Low o/p offset voltage
→ High CMRR
→ Low i/p bias current

The function of this stage is to amplify the difference betn two i/p signals.

Intermediate stage:

This is dual-i/p, unbalanced o/p (i.e. single-ended output) differential amplifier. Its main function is to provide the additional voltage gain required. Practically it is the chain of cascaded amplifier called multistage amplifier.

Level shifting stage:

All the stages are directly-coupled to each other. As the op-amp amplifies the dc signals also, the coupling capacitor are not used to cascade the stages. So, the dc level also increased, stage by stage. Such a high dc voltage level may drive the transistors into saturation & may cause the distortion in o/p. Thus, it is necessary to bring such a high dc voltage level to zero before o/p stage.

A level shifter brings the dc level to ground potential when no i/p signal is applied. An emitter follower (i.e.) is used in level shifting stage.

Output stage:

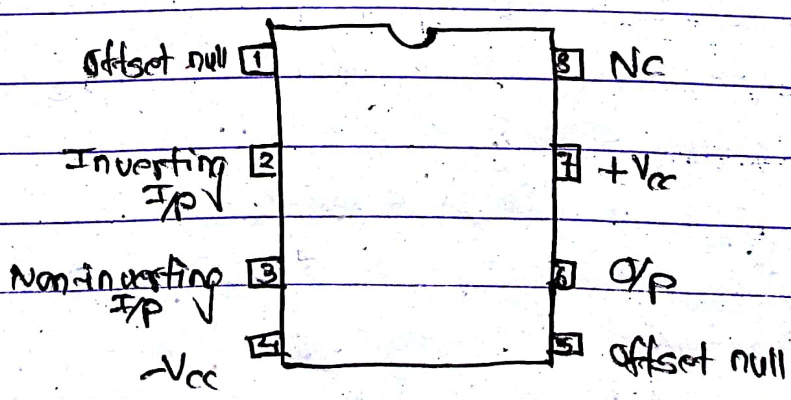
The complementary-symmetry, push-pull amplifier is used in the final stage. The basic requirements of an o/p stages are:

-> Low o/p impedance.

-> Large ac o/p voltage swing

-> Large current supplying capability.

The 8-pin DIP package of 741 op-amp is as given:



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An op-amp is a (5 terminal) active element. Its circuit symbol & its associated terminals and ports are as shown below:

Its five terminals are

*2 → Inverting i/p

*3 → Non-inverting i/p

*6 → O/p terminal

*4 → positive bias supply

*7 → Negative bias supply.

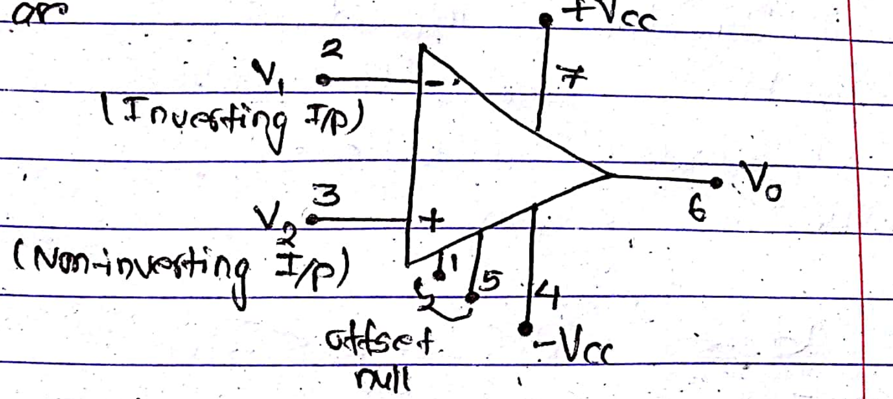


Fig: Symbol of 741 op-amp

Here, $V_0 = A(V_2 - V_1)$

Ideal Op-amp

An ideal op-amp is an op-amp that has perfect condition to allow it to function as an op-amp with 100% efficiency. An ideal op-amp is usually considered to have the following properties.

i) Infinite open loop voltage gain, $A_v = \infty$.

ii) Infinite i/p impedance, R_{in} or $Z_{in} = \infty$.

iii) Zero o/p impedance, $R_0 = 0$.

iv) Infinite bandwidth, $BW = \infty$

v) Zero o/p offset voltage, $V_{os} = 0 = V_{off(o/p)}$

vi) Infinite common mode rejectio ratio, $CMRR = \infty$

vii) Infinite slew rate, $SR = \infty$.

Practical or Non-ideal Op-Amp

The practical op-amp have little bit different characteristics than that of ideal op-amp. Practical op-amp have the

following properties.
i) Open loop voltage gain is high.
ii) Large i/p impedance.
iii) Very low o/p impedance.
iv) Finite bandwidth.
v) Small offset voltage.
vi) Finite CMRR.

Basic Op-Amp Circuit

The basic op-amp ckt is shown in figure below. An i/p signal V_1 is applied through resistor R_1 to inverting i/p terminal.

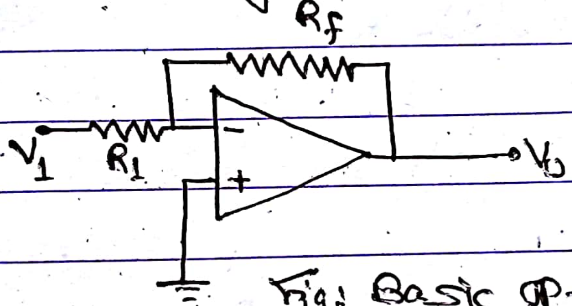


Fig: Basic op-amp ckt.

Virtual Ground Concept

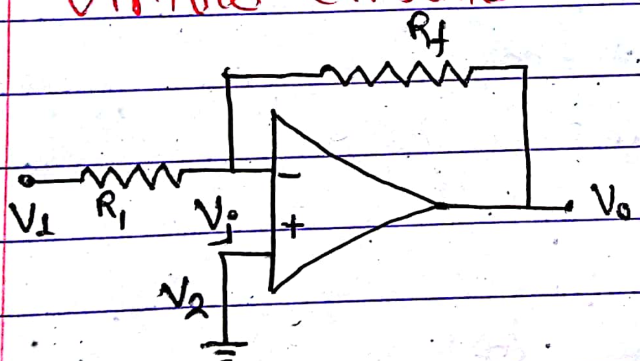


Fig: Inverting op-amp

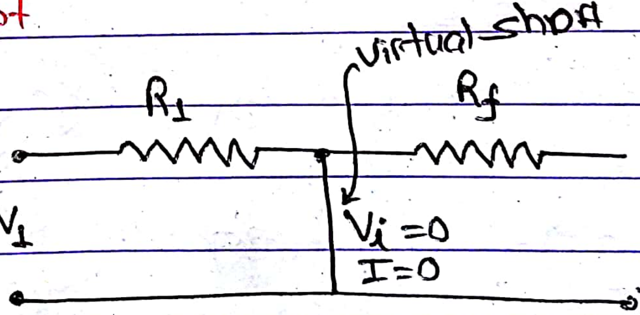


Fig: Virtual ground.

For a op-amp, as given in above fig,

$$V_0 = A V_i$$

$$\text{or, } V_i = \frac{V_0}{A}$$

For an ideal op-amp, it has infinite voltage gain.

i.e. $A = \infty$,

so, $V_i = \frac{V_o}{A} = \frac{V_o}{\infty} = 0$

Also, $V_i = V_1 - V_2$

or, $V_1 - V_2 = 0$

$\Rightarrow V_1 = V_2$

Thus, we can say that there is a virtually short circuit betn the two i/p terminals in the sense that their voltages are same. However, no current flows from the terminals to the ground. The current flows through a resistor R_1 to R_f.

The very large voltage gain forces the voltage at inverting & non-inverting inputs to be approximately equal.

Op-Amp Parameters

1) Differential mode gain (A_d)

$V_o = A_d (V_1 - V_2)$

$\Rightarrow A_d = \frac{V_o}{V_1 - V_2} = \frac{V_o}{V_i}$

2) Common mode gain (A_{cm})

If $V_1 = V_2$, then, $V_1 - V_2 = 0$ i.e. $V_i = 0$

$V_{cm} = \frac{V_1 + V_2}{2}$

$V_o = A_{cm} * V_{cm}$

Now, total o/p, $V_o = A_d V_i + A_{cm} * V_{cm}$

[For ideal, $A_d \simeq \infty$ & $A_{cm} = 0$]

3) Common Mode Rejection Ratio (CMRR)

When the same i/p signal are applied to the both i/ps, common mode operation results. A significant feature of a differential connection is that the signals that are opposite at i/ps are highly amplified whereas those signals that are common to the two i/ps are only slightly amplified. An op-amp amplify the difference signal while rejecting the common signal at the two i/p. This operating feature is referred to as common mode rejection.

The common mode rejection ratio is defined as the ratio of differential gain to common gain.

i.e.

$$\rho = \frac{|A_d|}{|A_{cm}|}$$

Ideally, $\rho = \infty$. This means that the common signals like noises are perfectly rejected by the amplifier.

Here,

common mode gain, $A_{cm} = \frac{V_0}{V_{cm}} = \frac{V_0}{\left(\frac{V_1+V_2}{2}\right)}$

Differential mode gain, $A_d = \frac{V_0}{V_1 - V_2}$

Now, Total o/p of any differential amplifier can be expressed as,

$$V_0 = A_d V_i + A_{cm} V_{cm}$$

where, $V_i = V_1 - V_2$

$V_{cm} = \frac{V_1 + V_2}{2}$

For ideal case, $A_d = \infty$, $A_{cm} = 0$, V_i = very small.

4) Slew rate(SR):

The slew rate of an op-amp is measured of how fast the o/p voltage can change & is measured in volt per µs (V/µs). If the slew rate of an op-amp is 0.5V/µs, it means that the o/p from the amplifier can change by 0.5V every µs.

The slew rate (SR) is defined as the maximum rate at which the o/p voltage can change, no matter how large an i/p signal is applied.

$$\text{i.e.}\quad SR = \left.\frac{dV_{out}}{dt}\right|_{max}$$

Since frequency is a function of time, slew rate can be used to determine the maximum operating freq of an op-amp.

$$f_{max} = \frac{\text{slew rate}}{2\pi * V_p}$$

where, V_p = peak o/p voltage.

5) Input offset voltage

Input offset voltage is defined as that voltage which is to be applied both the i/p terminals to make $V_0 = 0$ i.e to remove offset voltage.

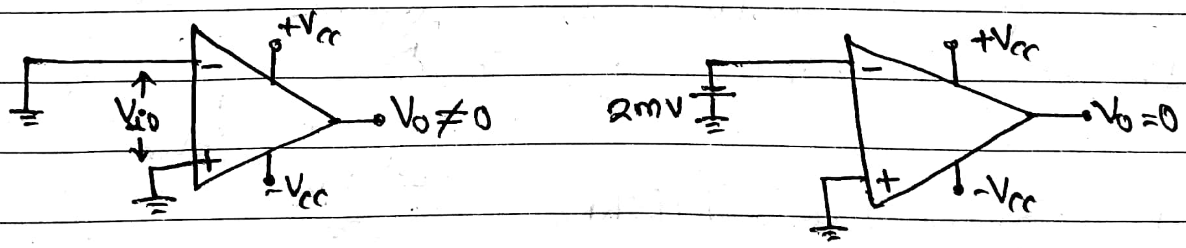
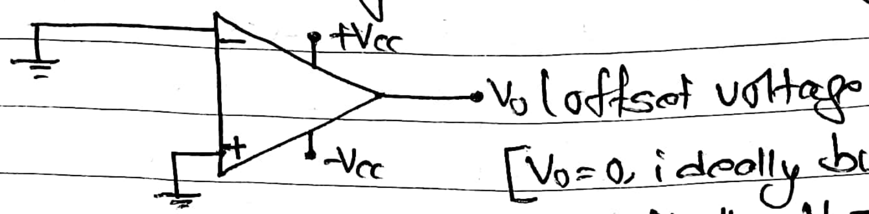


Fig: Input offset voltage.

5) Output offset voltage

The o/p offset voltage is the dc voltage (+ve or -ve) present at the o/p terminal when the two i/p terminals are grounded.

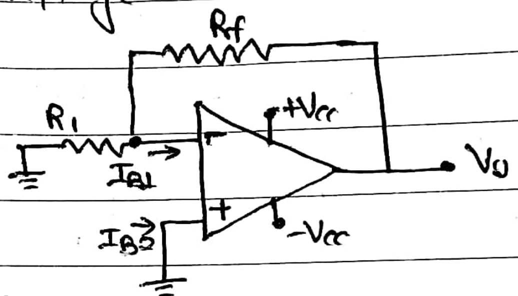
Ideally, the offset voltage = 0. Practically, there exists a small o/p voltage even though both the i/ps are grounded.



[$V_0 = 0$, ideally but practically $V_0 \neq 0$]

Fig: o/p offset voltage.

7) Input Bias Current



The i/p bias current is

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

The i/p bias current is very very small ($\sim$nA). Although the input bias current is very small, it may cause significant o/p offset voltage.

Fig: I/p bias current

8) Input offset current

The i/p offset current is defined as the algebric difference both the two i/p bias currents I_{B1} & I_{B2}.

i.e.

$$I_{in(offset)} = |I_{B2} - I_{B1}|$$

The max^m i/p offset current is 20nA(DC) for op-amp 741.

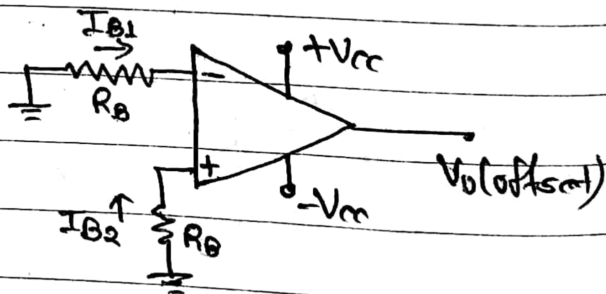


Fig: I/p offset current.

9) Power supply rejection ratio (PSRR):

$$PSRR = \frac{\text{change in i/p offset voltage}}{\text{change is supply voltage}}$$

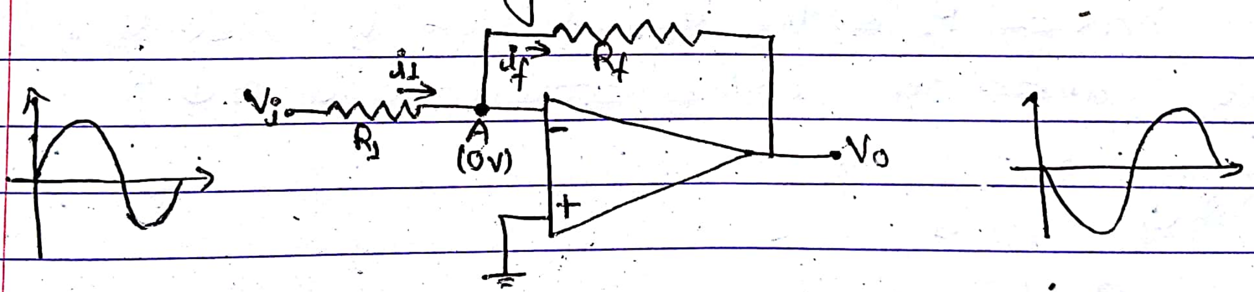
$$= \frac{\Delta V_{IOS}}{\Delta V_{CC}} \text{ for a fixed } V_{EE}$$

or, $$PSRR = \frac{\Delta V_{IOS}}{\Delta V_{EE}} \text{ for a fixed } V_{CC}.$$

Inverting Amplifier

An op-amp can be operated as an inverting amplifier as shown in fig below. An i/p signal V_i is applied through i/p resistor R_1 to the inverting (-ve) i/p. The o/p is fed back to the same inverting i/p through a feedback resistor R_f. The non-inverting (+ve) i/p is grounded. Since the i/p signal is applied to the inverting i/p, the o/p will be inverted (i.e. 180° out of phase) as compared to the i/p. Hence, the name inverting amplifier.

* An op-amp has an infinite i/p impedance. This means that there is zero current at the inverting i/p. If there is zero current through the i/p impedance, then there must be no voltage drop betn the inverting & non-inverting i/ps. This means the voltage at the inverting point or i/p is zero, because other (non-inverting) i/p is grounded. The 0V (zero volt) at the inverting i/p terminal (point A) is referred to as virtual ground.



From the figure, $i_1 = \frac{V_i - V_A}{R_1} = \frac{V_i}{R_1} = \frac{\text{Voltage drop at } R_1}{R_1}$

& $i_f = \frac{V_A - V_o}{R_f} = \frac{-V_o}{R_f}$

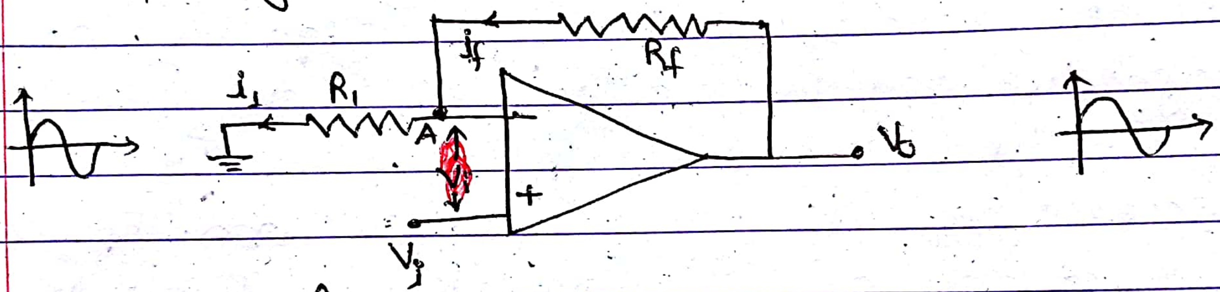
Applying KCL at node A,

$$i_1 = i_f$$

or, $\frac{V_i}{R_1} = \frac{-V_o}{R_f} \Rightarrow \frac{V_o}{V_i} = -\frac{R_f}{R_1}$, which is voltage gain of inverting amplifier.

Non Inverting Amplifier

When an i/p signal is applied to non-inverting terminal of an op-amp, then such op-amp can be used as an non-inverting op-amp. Its o/p signal will be the same polarity as i/p signal as shown in fig below. The o/p is also fed back to i/p through the feedback ckt formed by feedback resistor R_f & R_1. The resistor R_f & R_1 form a voltage divider at the inverting point. Here R_1 is grounded & i/p signal is applied to non-inverting input, the o/p will be non-inverted i.e. o/p signal will be in phase with i/p signal. Hence the name non-inverting amplifier.



Because of virtual short betn the two op-amp terminal, voltage across R_1 is the input voltage V_i. Also V_o is applied across the series combination of R_1 & R_f.

Applying KVL at point A,

$$i_1 + i_f = 0$$

$$\text{or, } i_1 = i_f$$

$$\text{or, } \frac{V_A}{R_1} = \frac{V_o - V_A}{R_f} \quad \text{or, } \frac{V_i}{R_1} = \frac{V_o - V_i}{R_f}$$

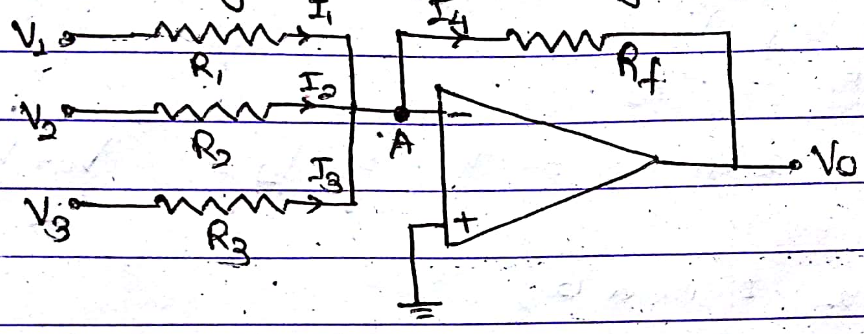
$$\text{or, } \frac{V_o}{R_f} = V_i\left(\frac{1}{R_1} + \frac{1}{R_f}\right)$$

$$\text{or, } V_o/V_i = \left(R_f/R_1 + 1\right)$$

$$\therefore A_V = \frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_1}\right)$$, which is voltage gain of non-inverting op-amp.

Adder or Summing Amplifier

A summing amplifier is an inverted op-amp that can accept two or more i/ps. The adder or summer ckts provides an o/p voltage proportional to or equal to the algebric sum of two or more i/p voltages each multiplied by a constant gain factor.



Applying KCL at node A,

$$I_1 + I_2 + I_3 = I_4$$

or, $$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} + \frac{V_3 - V_A}{R_3} = \frac{V_A - V_0}{R_f}$$

Since $V_A = 0$ volt, due to virtual ground,

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_0}{R_f}$$

or, $$V_0 = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]$$

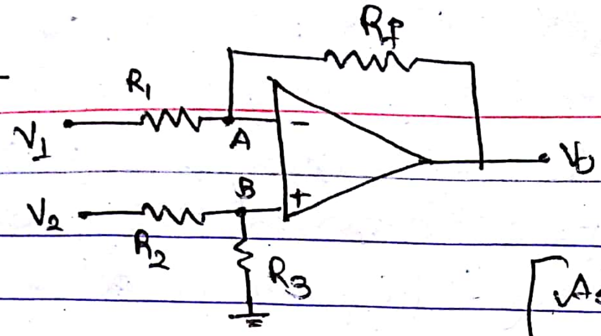
If $R_1 = R_2 = R_3 = R$

Then, $$V_0 = -\frac{R_f}{R}\left(V_1 + V_2 + V_3\right)$$

Thus, the o/p voltage is proportional to the algebric sum of the i/p voltages.

Subtractor or Difference Amplifier

The subtractor or difference amplifier provides an o/p proportional to or equal to the difference of two i/p signals.



(Assume $R_1 = R_2 = R_f = R = R_3$)

Applying KVL at node A,

$$\frac{V_A - V_1}{R_1} + \frac{V_A - V_0}{R_f} = 0$$

or, $2V_A - V_1 = V_0 \Rightarrow V_A = \frac{V_0 + V_1}{2}$

Applying KVL at node B,

$$\frac{V_B - V_2}{R} + \frac{V_B}{R} = 0$$

$$\Rightarrow 2V_B = V_2$$

or, $V_B = V_2/2$

By virtual ground concept,

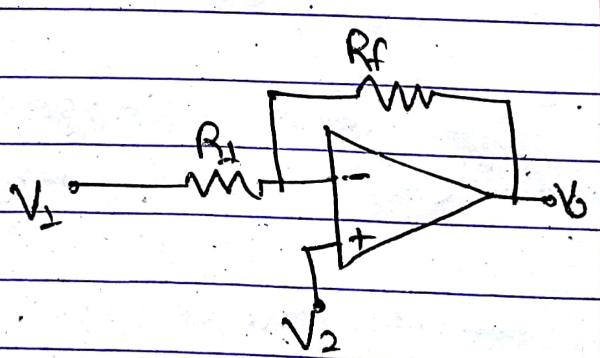
$$V_A = V_B$$

or, $\frac{V_0 + V_1}{2} = \frac{V_2}{2}$

$$\Rightarrow V_0 = V_2 - V_1$$

Thus, the ckt is called substractor circuit.

OR



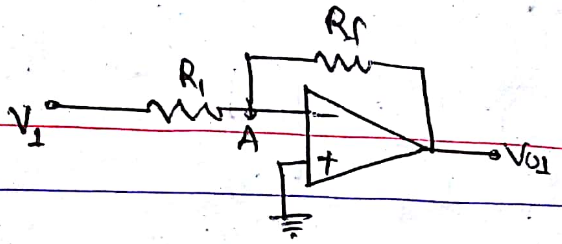
According to superposition theorem,

$V_0 = V_{01} + V_{02}$

where, V_{01} = o/p produced by V_1 alone

V_{02} = " " by V_2 alone

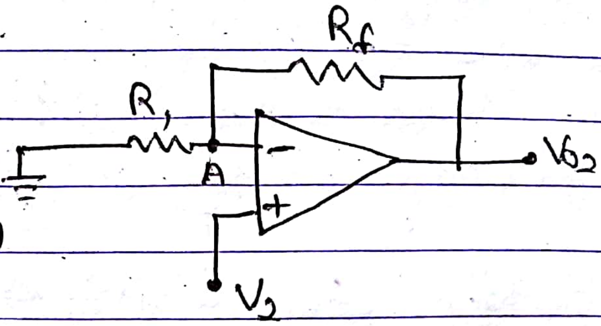
Considering V_1 alone,



Here,

$$V_{o1} = -\frac{R_f}{R_1} V_1 \quad \text{—(i)}$$

Considering V_2 alone,



Here,

$$V_{o2} = \left(1 + \frac{R_f}{R_1}\right) V_2 \quad \text{—(ii)}$$

Applying KCL at node A,

$$\frac{V_A - 0}{R_1} + \frac{V_A - V_{o2}}{R_f} = 0$$

$$\text{or, } \frac{V_2}{R_1} + \frac{V_2}{R_f} - \frac{V_{o2}}{R_f} = 0 \qquad (\because V_A = V_2, \text{ virtual ground})$$

$$\text{or, } \frac{V_{o2}}{R_f} = V_2\left(\frac{1}{R_1} + \frac{1}{R_f}\right)$$

$$\Rightarrow V_{o2} = \left(1 + \frac{R_f}{R_1}\right) V_2$$

From eqn (i) & (ii), by superposition theorem,

$$V_o = V_{o1} + V_{o2}$$

$$= -\frac{R_f}{R_1} V_1 + \left(1 + \frac{R_f}{R_1}\right) V_2$$

$$= -\frac{R_f}{R_1} V_1 + \frac{R_f}{R_1} V_2 \qquad \left[\because \frac{R_f}{R_1} >> 1, \ 1 + \frac{R_f}{R_1} \approx \frac{R_f}{R_1}\right]$$

$$= \frac{R_f}{R_1}(V_2 - V_1)$$

$$\therefore V_o = \frac{R_f}{R_1}(V_2 - V_1)$$

The o/p voltage is proportional to difference of i/p voltages.

Differentiator

The function of the differentiator is to provide an o/p which is proportional to the rate of change of i/p voltage.

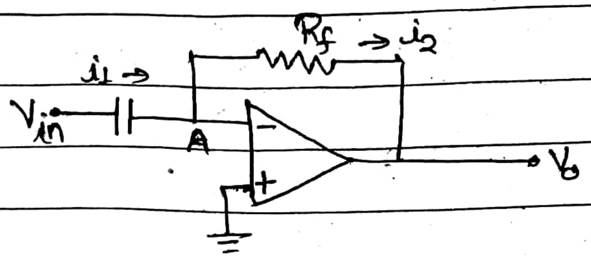


Fig: Opamp as differentiator

As we know, current $(i) = \frac{dQ}{dt}$ —— (i)

Also, $Q = CV$

so, $i_1 = \frac{d(CV_{in})}{dt} = C\frac{dV_{in}}{dt}$ —— (ii)

And from figure,

$i_2 = \frac{V_A - V_0}{R_f} = \frac{-V_0}{R_f}$ [$V_A = 0$, virtual ground]

Apply KCL at node A,

$i_1 = i_2$

or, $C\frac{dV_{in}}{dt} = \frac{-V_0}{R_f}$

or, $V_0 = -R_fC\frac{dV_{in}}{dt}$

Thus, o/p voltage is proportional to the derivative of the i/p voltage with having scale factor as $-R_fC$.

Integrator

An integrator provides an o/p voltage which is proportional to the integral of input voltage.

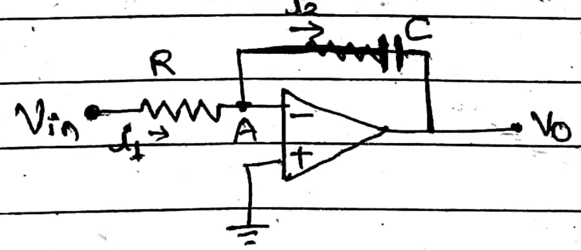


Fig: Op-amp as integrator

From ckt diagram,

$i_1 = \frac{V_{in} - V_A}{R} = \frac{V_{in}}{R}$

and, $i_2 = \frac{C\,dV_C}{dt} = -\frac{C\,dV_0}{dt}$ $\quad [\because V_A - V_0 = V_C \Rightarrow V_C = -V_0]$

Applying KCL at node A,

$$i_1 = i_2$$

or, $\frac{V_{in}}{R} = -\frac{C\,dV_0}{dt}$

or, $\frac{dV_0}{dt} = \frac{-V_{in}}{RC}$

On integrating both sides,

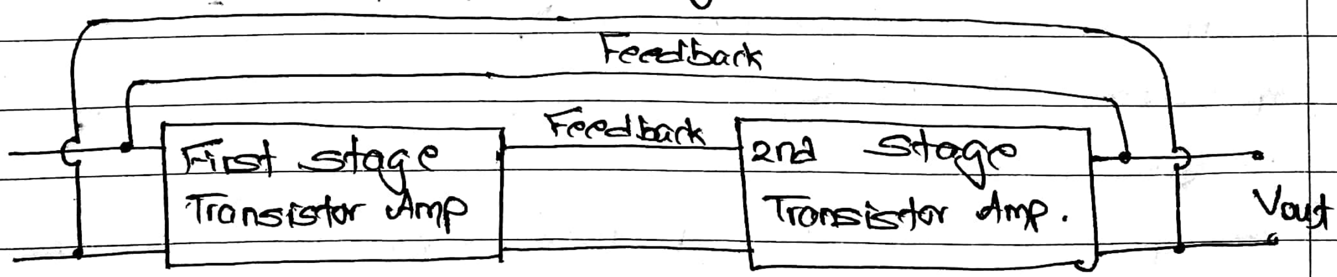
$$V_0 = -\frac{1}{RC}\int_0^t V_{in}\,dt$$

This eqn shows that o/p is integral of i/p with inversion & scale multiplier of $1/RC$.

Multivibrators

An electronic circuit that generates square wave or other non-sinusoidal such as rectangular, triangular waves is known as multivibrators.

It is basically two stage amplifier with o/p of one feedback to i/p of other as shown in fig. below.



Depending upon the manner in which the two stages interchanges their states, multivibrators are classified as,

1) Astable or free-running multivibrator
2) Mono-stable or one-shot "
3) Bi-stable or flip-flop "

Astable Multivibrator (Square Wave Generator)

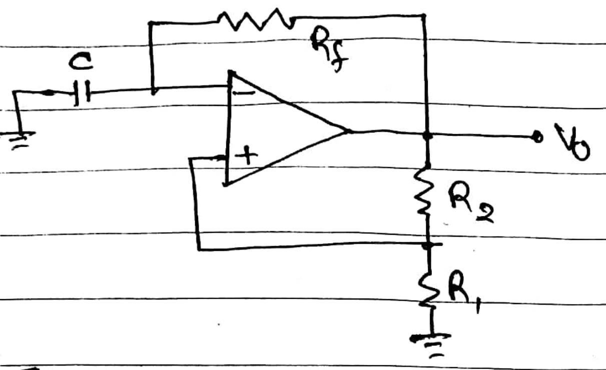


Fig: Square wave generator.

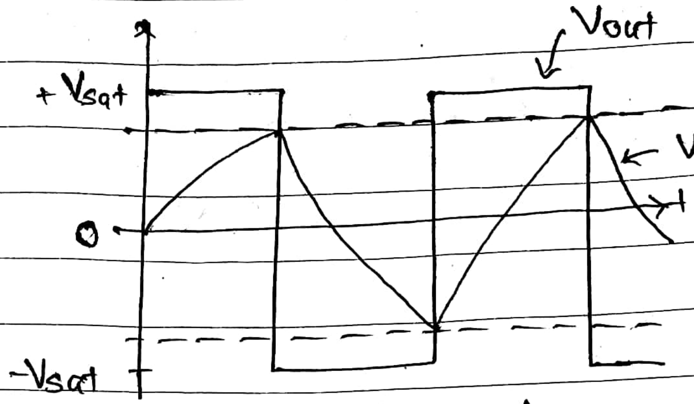
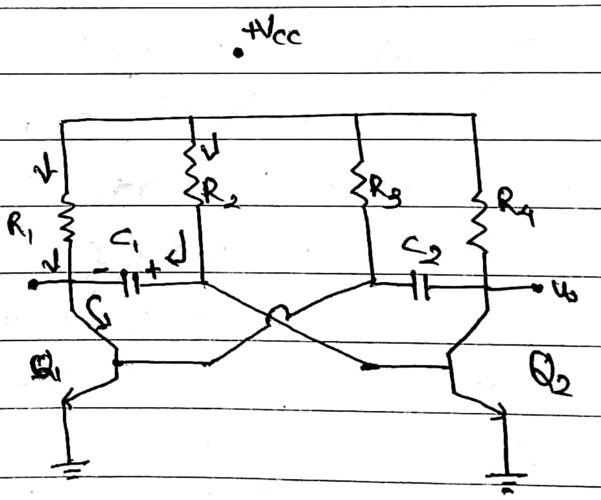


Fig: O/P waveform.

At first, let O/P is +Vsat,
At the instant of turning ON, capacitor starts to charge through R. It slowly developes the voltage V_c across the capacitor which is also the voltage connected to an inverting terminal.

⇒ An astable multivibrator is also known as free-running multivibrator. It is called free running because it has no stable state i.e. it alternate betn two different O/P voltage levels during the time it is ON.

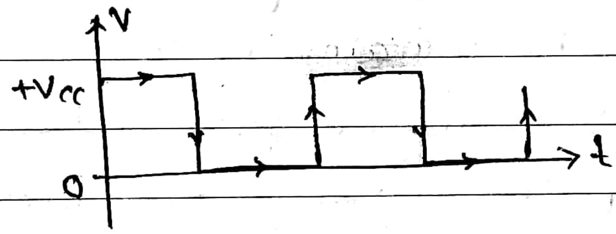


The O/P remains at each voltage level for a definite period of time (if you look at this O/P on oscilloscope). You would see continuous square or rectangular waveform. The astable multivibrator is said to oscillate.
To understand why the astable multivibrator is said to oscillate. Assume that Q1 saturates and Q2 is cutoff

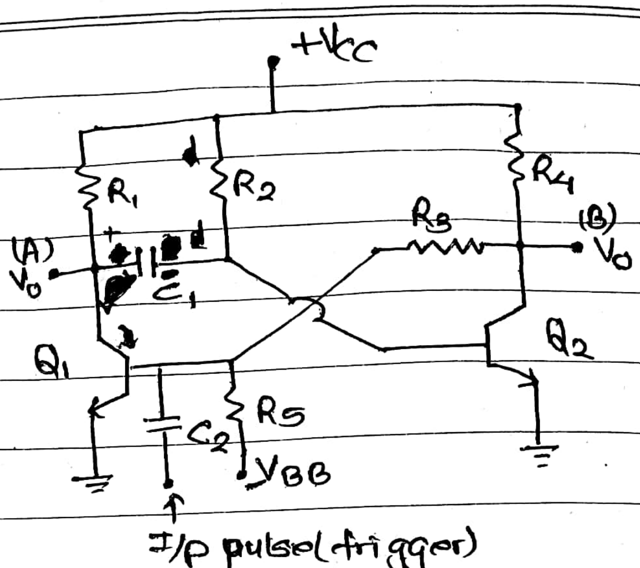
when circuit is energized. The capacitor C_1 gets charged as polarity shown in figure. As capacitor gets sufficiently charged then Base of next transistor Q_2 will be +ve and Q_2 turns ON as well as collector of Q_2 will drop to zero (0) volt and Q_1 turns off & collector Q_1 becomes Vcc.

Now C_2 starts to charge and when sufficient voltage is build up in C_2, then C_2 turns the Q_1 and Q_1 turns ON and Q_2 turns OFF. In this way when Q_1 turns ON C_1 will force Q_2 to turn OFF and vice-versa.

So o/p from collector of any transistor is changed from Vcc to 0.



Monostable Multivibrator



Here, Q_1 & Q_2 are connected as shown in figure. It is called monostable because o/p remains stable during one cycle. Two transistors Q_1 & Q_2 are similar & matched to each other.

The value of R_5 & $-V_{BB}$ are choosen such as to reverse bias Q_1 & keep it at cutoff. The collector supply V_{cc} & R_2 forward biased Q_2 & keep it at saturation, so o/p at AB, $V_0 = 0$. This state is stable & ckt remains in this state.

To change the state, trigger pulse should be applied through the capacitor C_2. When +ve trigger pulse is of sufficient amplitude, it will make Q_1 conduction and into a saturation. So o/p at A, $V_0 = 0$. Now the capacitor C_1 charges in a direction as shown in figure. But capacitor C_1 provides -ve to the transistor Q_2 & transistor remains in cutoff.

But this state doesnot remain for long, as capacitor C_2 starts to discharge and within small time base of Q_1 becomes Negative (-ve) and Q_1 becomes cutoff and initial state is retained.

Generally,
Stable state : Q_2 = ON & Q_1 = OFF

As trigger is applied : Q_1 = ON & Q_2 = OFF. But this state doesn't remain long & return to stable state.

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Barkhausen Criteria for Oscillation

The closed loop gain of +ve feedback amplifier is,

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

where, A = gain of an Amplifier
& β = feedback ratio (factor)

When $A\beta = 1$,

$$A_f = \frac{A}{1-1} = \frac{A}{0} = \infty$$

This means o/p may appear with very small i/p, ideally no i/p can also produce an output.

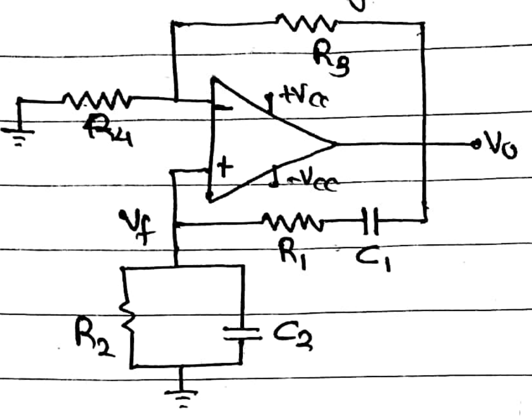
So, Barkhausen criteria for oscillations are as given below:

1) Loop gain must be unity. i.e. $A\beta = 1$
2) There must be +ve feedback i.e. i/p and feedback should be in same phase (Total phase shift must be 0° or 360°).

Oscillator

An electronic device that generates oscillations of desired frequency is known as oscillator. A transistor amplifier with proper positive feedback can acts as an oscillator i.e. it can generate oscillations without any external signal source.

1) Wein Bridge Oscillator



OR

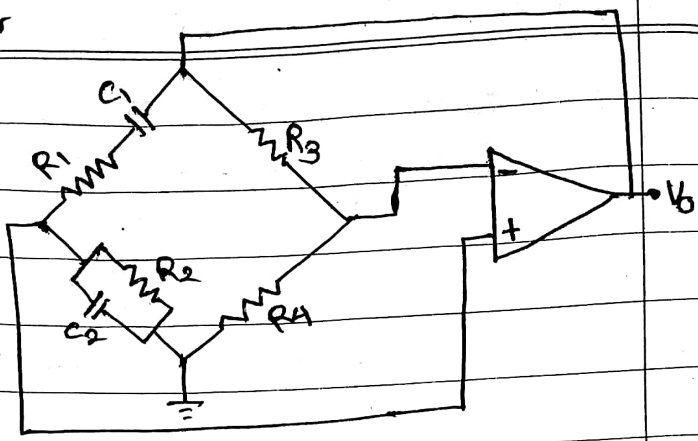


Fig: Wein Bridge oscillator

Here, the feedback signal V_f is connected to the non-inverting i/p terminal so the op-amp works as an non-inverting amplifier.

Here,

$Z_1 = R_1 - jX_c = R_1 - j/\omega C_1$

$Z_3 = R_3$

$Z_4 = R_4$

$Y_2 = 1/R_2 + j\omega C_2$

Neglecting the effect of op-amp i/p & o/p impedance,

At balanced condition,

$$Z_1 \cdot Z_4 = Z_2 \cdot Z_3$$

or, $$\frac{(R_1 - j/\omega C_1) \times R_4}{Z_2} = R_3$$

or, $$R_3 = \left(R_1 - \frac{j}{\omega C_1}\right) \times R_4 \times \left(\frac{1}{R_2} + j\omega C_2\right)$$

or, $$\frac{R_3}{R_4} = \frac{R_1}{R_2} + j\omega R_1 C_2 - \frac{j}{\omega R_2 C_1} + \frac{C_2}{C_1}$$

or, $\frac{R_3}{R_4} + \frac{j}{\omega R_2 C_1} = \frac{R_1}{R_2} + \frac{C_2}{C_1} + j\omega R_1 C_2$

On equating real & imaginary parts,

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \quad \text{——— (i)}$$

& $\frac{1}{\omega R_2 C_1} = \omega R_1 C_2$ — (ii)

or, $\omega^2 = \frac{1}{R_1 R_2 C_1 C_2}$

or, $f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$

If $R_1 = R_2 = R$ & $C_1 = C_2 = C$

Then,

frequency of oscillation, $f = \frac{1}{2\pi RC}$

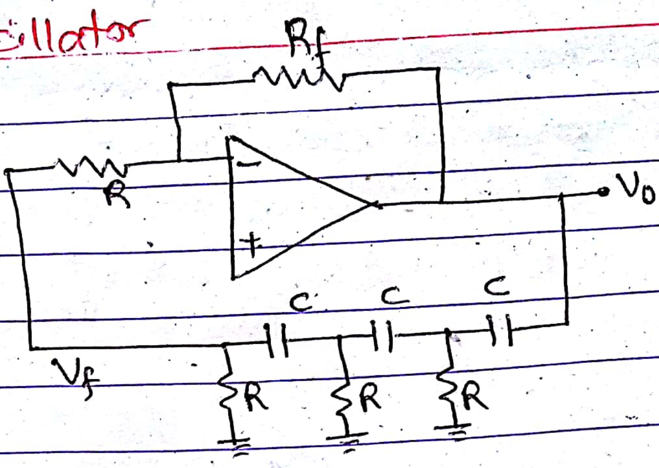
and from eq^n (i)

$$\frac{R_3}{R_4} = 1 + 1 = 2$$

$$\Rightarrow R_3 = 2R_4$$

Thus the ratio of R_3 to R_4 greater than 2 will provide sufficient loop gain for the circuit to oscillate at the frequency calculated above.

2) RC Phase Shift Oscillator



It consists of a negative gain operational amplifier & 3 section of RC n/w that produces 180° phase shift. The phase shift n/w is connected from op-amp o/p back to its inverting terminal.

As inverting op-amp provides 180° phase shift and 3RC n/w provides 180° phase shift, the total phase shift becomes 360°, which is one of criteria for oscillation.

If all resistor R & capacitors C in the phase shift oscillators are equal in value, then freq of oscillation is given by,

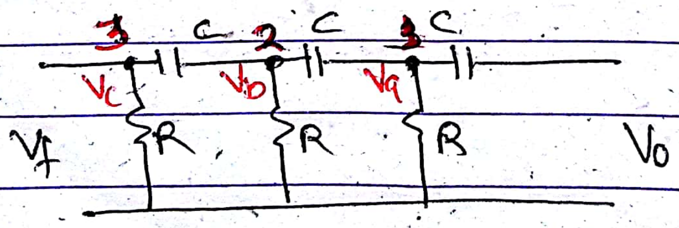
$$f_r = \frac{1}{2\pi RC\sqrt{2N}}$$

Where, R = resistance in Ω

C = capacitance in F

N = no. of RC stages

f_r = o/p freq in Hz



Applying KCL at nodes 1, 2 & 3,

$$\frac{V_f - V_b}{-jX_c} + \frac{V_f}{R} = 0 \quad \text{——— (1)}$$

$$\frac{V_b - V_f}{-jX_c} + \frac{V_b}{R} + \frac{V_b - V_f}{-jX_c} = 0 \quad \text{—— (ii)}$$

&

$$\frac{V_a - V_0}{-jX_c} + \frac{V_a}{R} + \frac{V_a - V_b}{-jX_c} = 0 \quad \text{—— (iii)}$$

On solving eqn (i), (ii) & (iii),

$$\frac{V_f}{V_0} = \beta = \frac{R^3}{(R^3 - 5RX_c^2) + j(X_c^3 - 6R^2X_c)}$$

β must be pure real for 180° phase shift.

i.e. $X_c^3 - 6R^2X_c = 0$

or, $X_c^2 = 6R^2$

or, $\left(\frac{1}{2\pi fc}\right)^2 = 6R^2$

or, $f = \frac{1}{2\pi CR\sqrt{6}} = \frac{1}{2\pi RC\sqrt{6}}$ —— (iv)

Thus for oscillation,

$$\beta = \frac{R^3}{(R^3 - 5RX_c^2)} = \frac{R^3}{R^3 - 5R\times(6R^2)}$$

$$= \frac{R^3}{-29R^3} = -\frac{1}{29}$$

Since for oscillation,

$A\beta = 1$ or, $A(-1/29) = 1$

$\Rightarrow A = -29$

Also we have, $A = -R_f/R$

or, $-29 = -R_f/R$

$$\Rightarrow R_f = 29R$$

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3) Tuned LC Oscillator

LC oscillator uses inductance capacitance ckt as their oscillator ckt. LC oscillators are very popular for generation of high freq o/p. There is large variety of LC oscillator such as Hartley, colpitts oscillator.

i) Hartley Oscillator

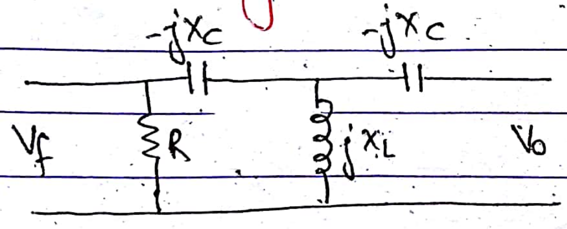


Fig: Feedback Network

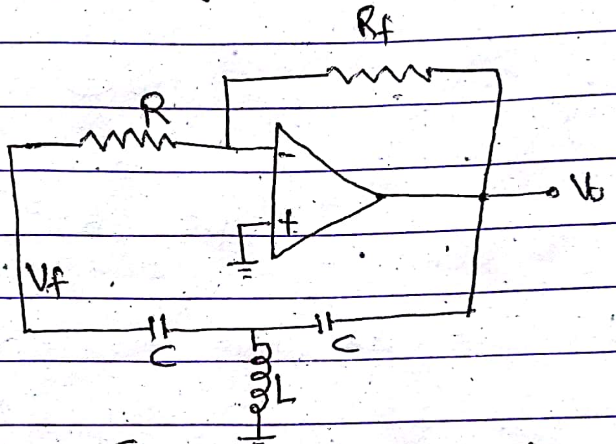


Fig: Hartley Oscillator

An op-amp Hartley oscillator is shown in figure. The inverting op-amp provides 180° phase shift. In order to get total phase shift of 360°, the LC ckt provides extra 180° phase shift. Here feedback is inductive.

Now, applying KCL at node 1 & node 2, we get

$$\frac{V_f}{V_o} = \beta = \frac{-R_1X_CX_L}{(R_1X_C^2 - R_1X_CX_L) + j(2X_LX_C^2 - X_C^3)} \quad \text{—— (i)}$$

Now the value of β must be pure real no. for 180 phase shift i.e.

$$2X_LX_C - X_C^3 = 0$$

$$\text{or, } 2X_L = X_C$$

$$\text{or, } 2\omega L = 1/\omega C$$

$$\Rightarrow \omega^2 = \frac{1}{2LC}$$

$$\text{or, } f = \frac{1}{2\pi\sqrt{LC}} \quad \text{—— (ii)}$$

$$\beta = \frac{-R_1 X_c X_L}{R_1 X_c^2 - R_1 X_c X_L} = \frac{-R_1 X_c \cdot X_c/2}{R_1 X_c^2 - R_1 X_c \cdot \frac{X_c}{2}}$$

$$= \frac{-R_1 X_c^2/2}{R_1 X_c^2/2} = -1$$

Since for oscillation βA must be unity.

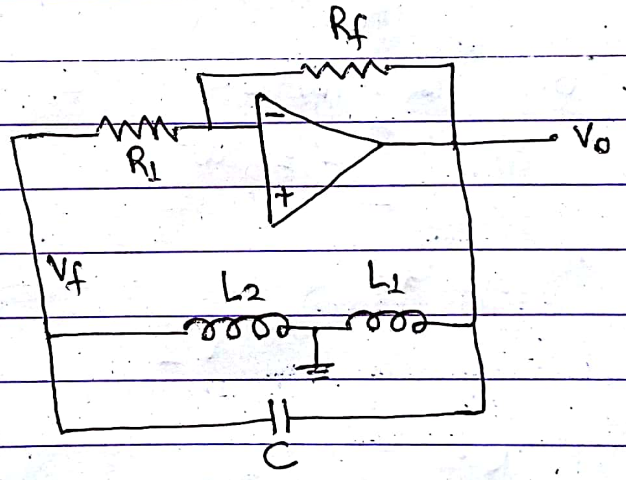
i.e. $A\beta = 1$

or, $A = -1$

or, $-\frac{R_f}{R} = -1$

$\Rightarrow R_f = R$

Also,



Here,

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

where,

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

$= L_1 + L_2$

[$\because$ M = mutual inductance, if M is not given = 0 else M = given]

ii) Colpitts Oscillator

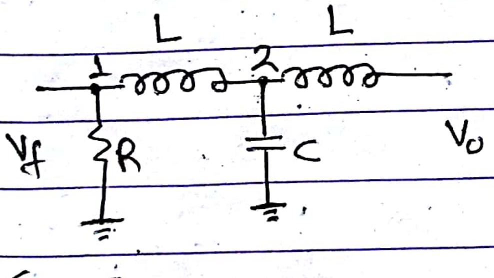


Fig: Feedback n/w

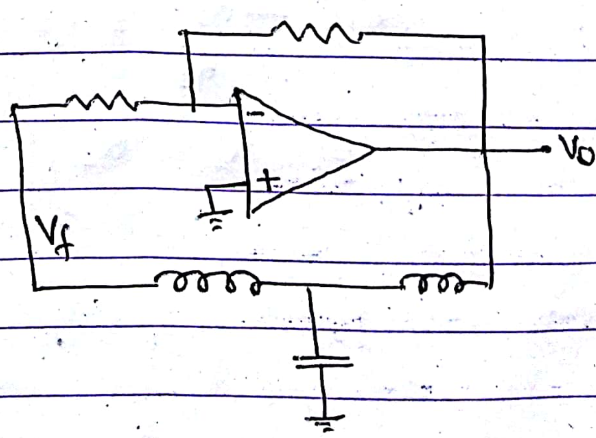


Fig: Colpitts Oscillator

An op-amp colpitts oscillators is shown in figure. The inverting op-amp provides 180° phase shift. In order to get total phase shift of 360°, the LC ckt provides 180° phase shift. Here the feedback ckt is capacitive.

Now applying KCL at node 1 & node 2 & solving

$$\frac{V_f}{V_0} = \beta = \frac{1}{(1-\omega^2 LC) + j\left(\frac{2\omega L - \omega^3 L^2 C}{R_1}\right)} \quad \text{--- (i)}$$

For 180° phase shift, β must be pure real no. i.e.

$$\frac{2\omega L - \omega^3 L^2 C}{R_1} = 0$$

$$\text{or,} \quad 2 = \omega^2 LC \quad \text{--- (ii)}$$

$$\text{or,} \quad \frac{2}{LC} = \omega^2$$

$$\Rightarrow f = \frac{1}{2\pi\sqrt{\frac{LC}{2}}} \quad \text{--- (iii)}$$

Now,

$$\beta = \frac{1}{1-\omega^2 LC} = \frac{1}{1-2} = -1$$

$$\therefore \beta = -1$$

Since Aβ must be unity for oscillation.

$$A\beta = 1$$

$$\Rightarrow A = -1$$

$$\text{or,} \quad -\frac{R_f}{R_1} = -1$$

$$\Rightarrow R_f = R_1$$

Also,

Here,

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

where,

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