MODULE-2.

Operational Amplifiers and Oscillators.

Syllabus:

Operational Amplifiers: operational amplifier parameters, operational amplifier characteristics, operational amplifier configurations, operational amplifier circuits.

Oscillators: Barkhausen criterion, sinusoidal and non-sinusoidal oscillators, Ladder network oscillator, wein bridge Oscillator, Multivibrators, single-stage astable oscillator, Crystal controlled Oscillators.

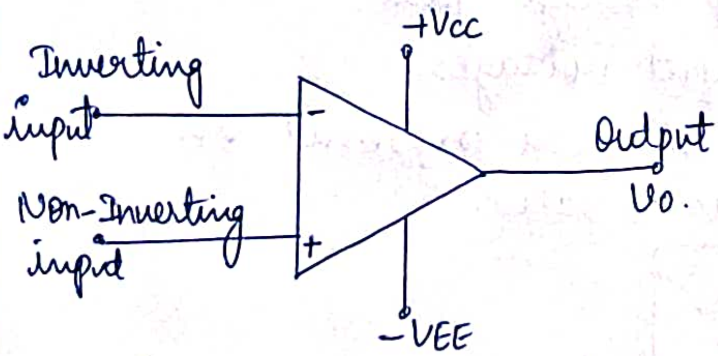
Operational Amplifiers:

→ An operational amplifier is a high-gain amplifier circuit with two high-impedance input terminals and one low-impedance output.

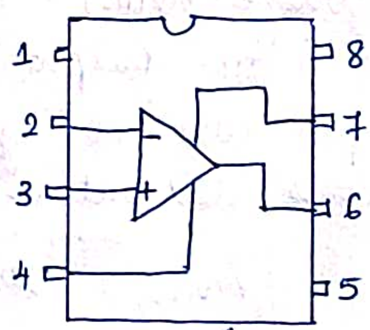
→ The inputs are identified as inverting input and non-inverting input.

→ The voltage gains of integrated circuit (IC) operational amplifiers are extreamly high, typically 200000.

Circuit symbol and packages:



fig(a): Op-amp circuit Symbol.



Top view

fig(b): Terminal connections for DIP Packages.

→ Fig (a) shows the triangular circuit symbol for an operational amplifier. There are two input terminals, one output terminal, and two power supply terminals.

→ The inputs are identified as the inverting input (−Sign) and non-inverting input (+ Sign).

→ Plus/minus supplies are normally used with Op-amps, and so the supply terminals are identified as $+V_{CC}$ and $-V_{EE}$.

→ The '+' sign indicates zero phase-shift while '−' sign indicates 180° phase shift.

→ Since 180° phase shift produces an inverted waveform, the '−ve' input is often referred to as the inverting input. Similarly the '+' input is known as the non-inverting input.

Operational Amplifier Parameter:

(1) Open-loop voltage gain:

The open-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with no feedback applied.

$$\boxed{A_{V(OL)} = \frac{V_{OUT}}{V_{IN}}}$$

where $A_{V(OL)}$ = open-loop voltage gain.

V_{OUT} & V_{IN} = output and input voltages.

- The open-loop voltage gain is often expressed in decibels (dB) rather than as a ratio.

$$\boxed{A_{V(OL)} = 20 \log_{10} \frac{V_{OUT}}{V_{IN}}}$$

- Most operational amplifiers have open-loop voltage gain of 90 dB.

② **Closed-loop Voltage gain:**

The closed-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with a small proportion of the output fed back to the input.

* closed loop voltage gain is once again the ratio of Output voltage to input voltage but with negative feedback applied.

Hence, $\boxed{A_{V(CL)} = \frac{V_{OUT}}{V_{IN}}}$

where, $A_{V(CL)}$ - open-loop voltage gain

V_{OUT} & V_{IN} - output and input voltages.

Problem:

* An operational amplifier operating with negative feedback produces an output voltage of 2V when supplied with an input of 400μV. Determine the value of closed-loop voltage gain.

Soln

$$A_{V(CL)} = \frac{V_{OUT}}{V_{IN}} = \frac{2}{400 \times 10^{-6}} = \frac{2 \times 10^{6}}{400}$$

$$\boxed{A_{V(CL)} = 5000}$$

$$A_{V(CL)} = 20 \log_{10} (5000) = 20 \times 3.7$$

$$\boxed{A_{V(CL)} = 74 dB}$$

③ **Input Resistance:**

The input resistance of an operational amplifier is defined as the ratio of input voltage to input current expressed in ohms.

$$\boxed{R_{IN} = \frac{V_{IN}}{I_{IN}}}$$

where R_{IN} - input resistance in ohms.
V_{IN} - input voltage, I_{IN} - input current.

Problem:

* An operational amplifier has an input resistance of $2M\Omega$. Determine the input current when an input voltage of 5mV is present.

Sol:

$$R_{IN} = \frac{V_{IN}}{I_{IN}}$$

Given: $R_{in} = 2M\Omega$
$V_{IN} = 5mV$

$$I_{IN} = \frac{V_{IN}}{R_{in}} = \frac{5\times10^{-3}}{2\times10^{6}} = 2.5\times10^{-9}A$$

$$\boxed{I_{in} = 2.5nA}$$

(4) Output Resistance:

The Output resistance of an operational amplifier is defined as the ratio of open-circuit output voltage to short-circuit output current expressed in ohms.

* Typical values of output resistance range from less than 10Ω to around 100Ω, depending on configuration and amount of feedback employed.

$$\boxed{R_{OUT} = \frac{V_{OUT(OC)}}{I_{OUT(SC)}}}$$

where, R_{OUT} - output resistance in ohms
$V_{OUT(OC)}$ - open circuit output voltage.
$I_{OUT(SC)}$ - Short circuit output current.

(5) Input-offset voltage:

The voltage that must be applied differentially to the operational amplifier input in order to make the output voltage exactly zero is known as input-offset voltage.

* Input offset voltage may be minimized by applying relatively large amounts of negative feedback.

6. **Full-power Bandwidth:**

The full-power bandwidth for an operational amplifier is equivalent to the frequency at which the maximum undistorted peak output voltage swing falls to 0.707 of its low-frequency value.

* Typical full-power bandwidths range from 10KHz - 1MHz for some high-speed devices.

7. **Slew Rate:**

Slew rate is the rate of change of output voltage with time, when a rectangular step input voltage is applied.

$$\boxed{\text{Slew rate} = \frac{\Delta V_{out}}{\Delta t}}$$

where ΔV_{OUT} - change in output voltage
Δt - corresponding interval of time.

* slew rate is measured in V/s and typical values range from 0.2 V/μs to over 20V/μs.

OPERATIONAL AMPLIFIER CHARACTERISTICS:

The characteristics for an Ideal-operational Amplifiers are

1. The open-loop voltage gain should be very high (ideally infinite)
2. The input resistance should be very high (ideally infinite)
3. The output resistance should be very low (ideally zero)
4. Full-power Bandwidth should be as wide as possible.
5. Slew-rate should be as large as possible.
6. Input offset should be as small as possible.

Problem (Slew-rate)

1. A perfect rectangular pulse is applied to the input of an operational amplifier. If it takes 4μs for the output voltage to change from −5V to +5V. determine the slew rate of the device.

Soln

$$\text{Slew rate} = \frac{\Delta V_{OUT}}{\Delta t} = \frac{10\,V}{4\,\mu s}$$

$$\text{Slew rate} = 2.5\,V/\mu s$$

2. A wideband operational amplifier has a slew-rate of 15V/μs. If the amplifier is used in a circuit with a voltage gain of 20 and a perfect step input of 100mV is applied to its input, determine the time taken for the output to change level.

Soln The output voltage change will be 20×100 = 2000mV

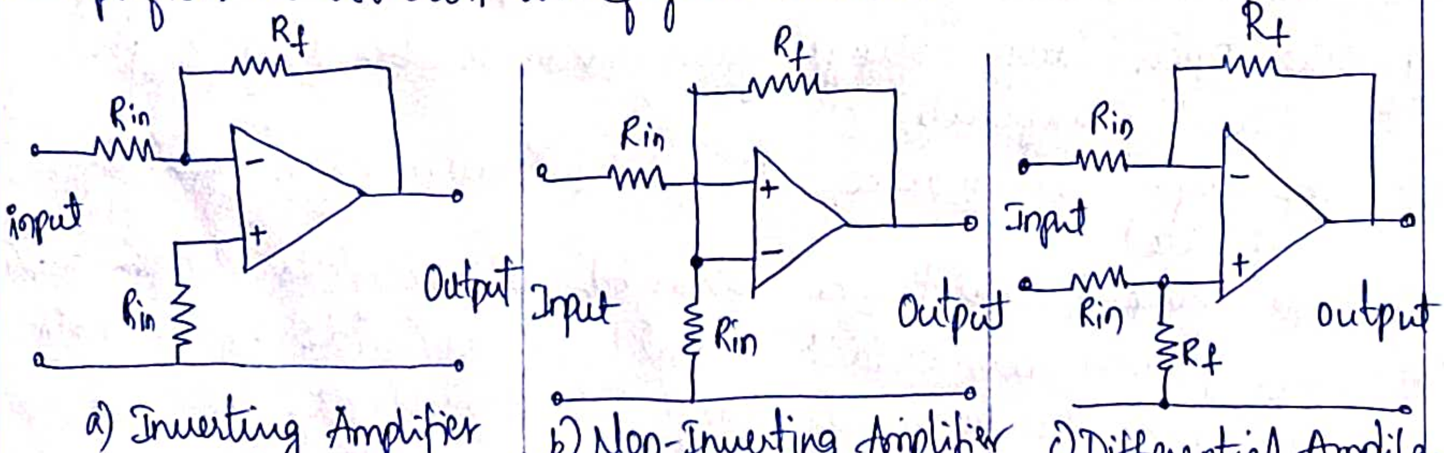
Re-arranging formula for slew-rate,

$$\Delta t = \frac{\Delta V_{OUT}}{\text{Slew rate}} = \frac{2\,V}{15\,V/\mu s}$$

$$\Delta t = 0.133\,\mu s.$$

OPERATIONAL AMPLIFIER CONFIGURATION:

The three basic configurations for operational voltage amplifiers is shown in figure below.



a) Inverting Amplifier   b) Non-Inverting Amplifier   c) Differential Amplifier

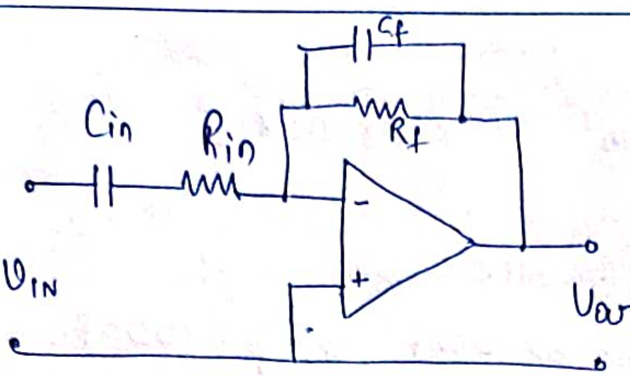


fig: Adding Capacitors to modify the frequency response of an inverting operational Amplifier.

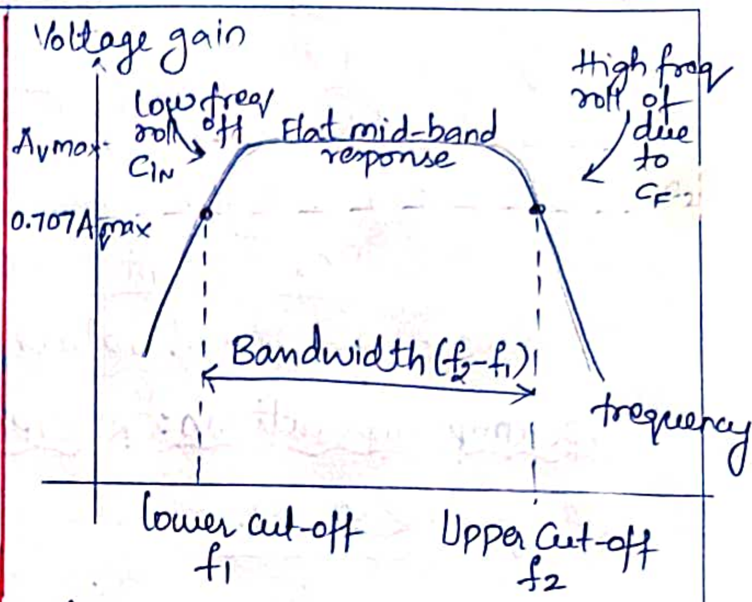


fig: Effect of adding capacitors C_{IN} and C_f to modify the frequency response of an operational amplifier.

$R_2 = A_V \times R_1$

$$f_1 = \frac{1}{2\pi C_{in} R_{in}} = \frac{0.159}{C_{in} R_{in}}$$

$$f_2 = \frac{1}{2\pi C_f R_f} = \frac{0.159}{C_f R_f}$$

Problem:

(1) An inverting opamp is to operate according to the following specification.
voltage gain - 100
Input resistance (at mid-band - 10 KHz)
Lower-cut-off frequency = 250 Hz
Upper-cut-off frequency = 15 KHz
Devise a circuit to satisfy the above specification using an operational amplifier.

Sol: $R_{in} = 10\,k\Omega$ The nominal input resistance is the same as the value of R_{in}

$$A_V = \frac{R_2}{R_1}$$

$$f_1 = \frac{0.159}{C_{in} R_{in}}$$

$R_2 = 100 \times 10\,k\Omega$, $C_{in} = \dfrac{0.159}{f_1 R_{in}} = \dfrac{0.159}{250 \times 10 \times 10^3}$

$R_2 = 1000\,k\Omega$

$C_{in} = 63 \times 10^{-9} \Rightarrow \boxed{C_{in} = 63\,nF}$

$$f_2 = \frac{0.159}{C_f R_f} \Rightarrow C_f = \frac{0.159}{f_2 R_{in}} = \frac{0.159}{15\times10^3 \times 100\times10^3}$$

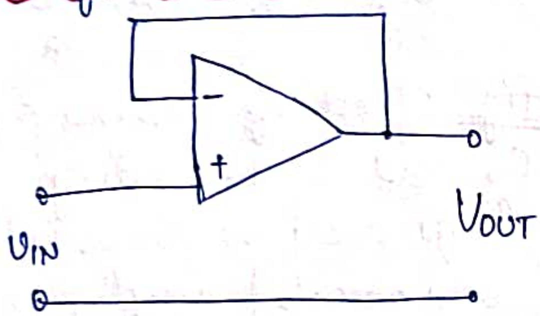
$$C_f = 0.106\times10^{-9}$$

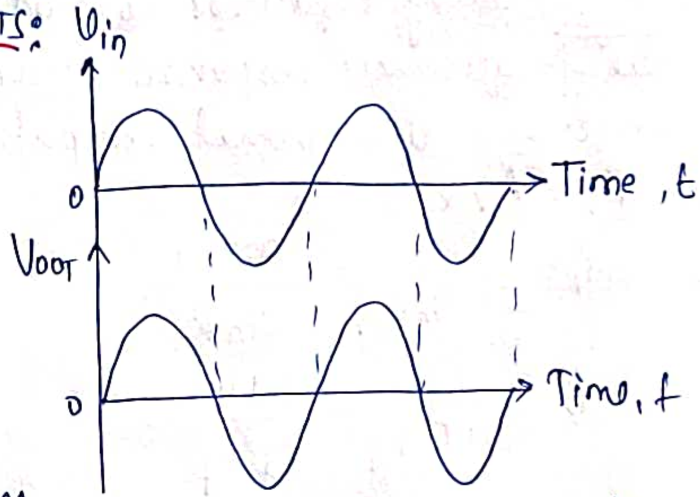
$$\boxed{C_f = 106\,pF}$$

choose preffered values C_{IN} as 680F & $C_f = 100pF$.

OPERATIONAL AMPLIFIER CIRCUITS:

① Voltage Follower:





* This circuit is essentially an inverting amplifier in which 100% of the output is fedback to the input.
* The amplifier has an unity voltage gain, a very high input and output resistance. $\boxed{V_0 = V_{in}}$ $\boxed{A_V = 1}$.

② Differentiators:

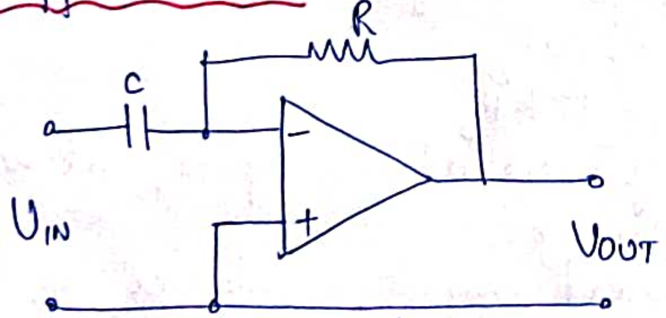
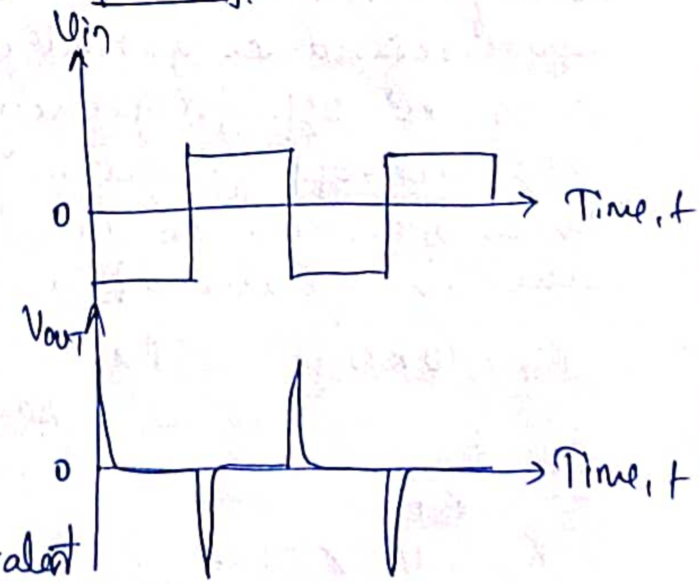


fig: Differentiator



* A differentiator produces an output voltage that is equivalent to the rate of change of its input.
* The Square wave input is converted to a train of short duration pulses at the output.

(3) INTEGRATORS:

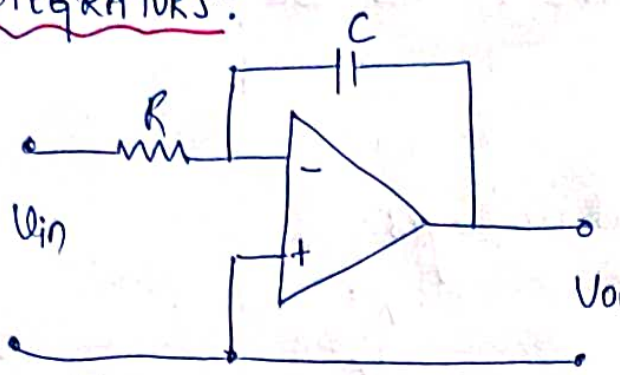
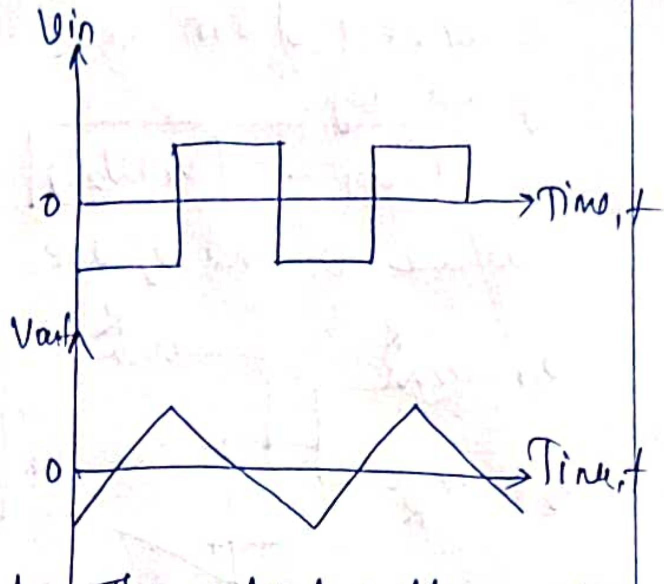


fig: An Integrator



* This circuit provides the opposite function to that of a differentiator. The output voltage ramp up or down according to the polarity of the input.

(4) COMPARATORS:

*

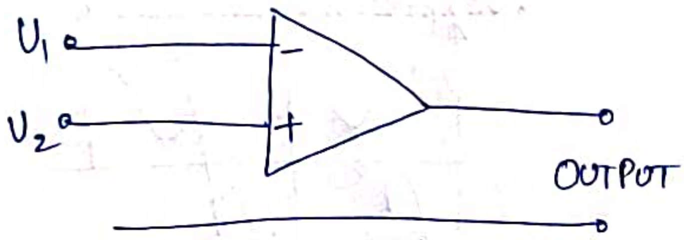
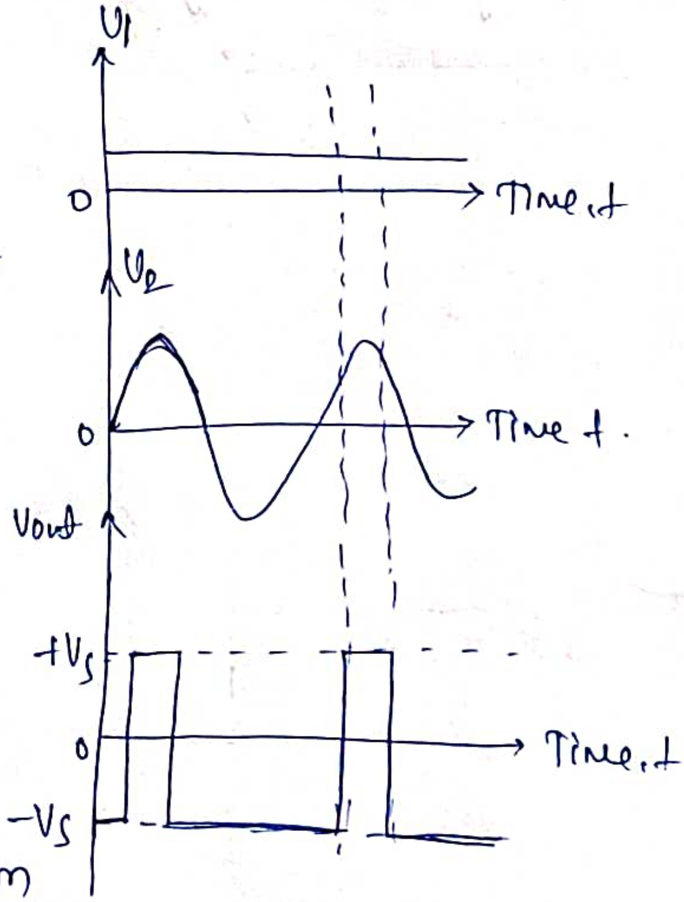


fig: Comparator



* Since no-negative feedback has been applied, this circuit uses the maximum gain of the operational amplifier.
* The output voltage produced by the operational amplifier will thus rise to the maximum possible value.

(5) SUMMING AMPLIFIERS:

* This circuit produces an output that is the sum of its two input voltages. However, since the operational amplifier

is connected in inverting mode, the output voltage is given by,

$$\boxed{V_{OUT} = -(V_1 + V_2)}$$

where V_1 and V_2 are input voltages.

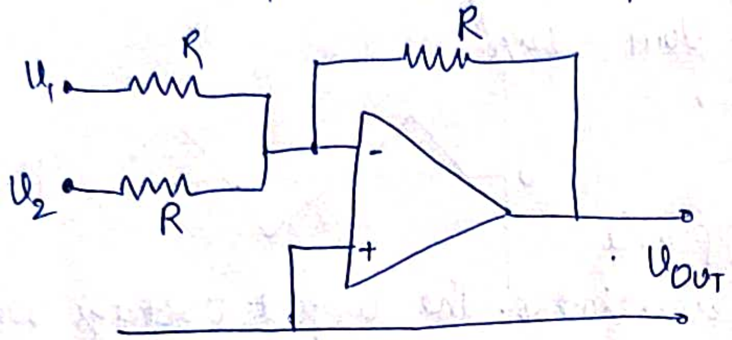
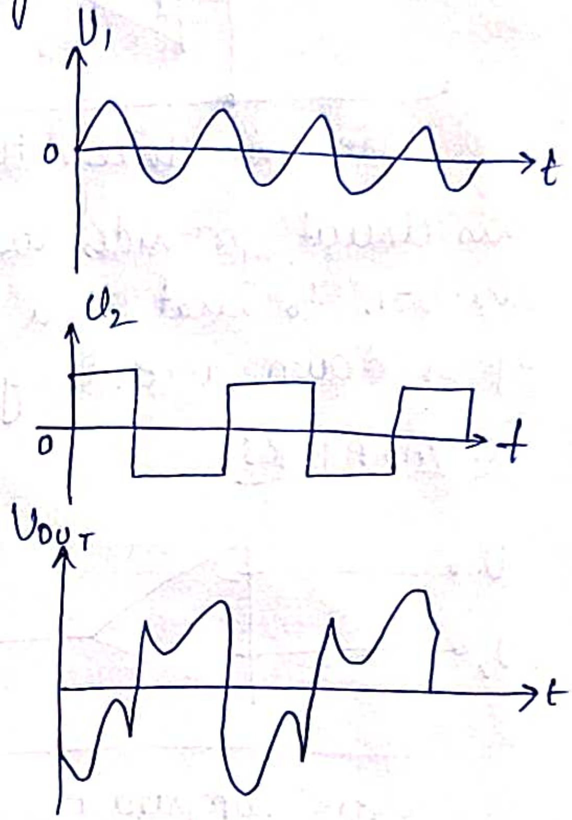


fig: A Summing Amplifier



Sinusoidal and Non-Sinusoidal Oscillator:

Sinusoidal Oscillator:

- A sinusoidal oscillator is an oscillator that generates a periodic signal in the shape of a sinusoidal wave.
- Types:

* Tuned circuits Oscillators – Hartley, Colpits Oscillator.
* RC Oscillators – weign bridge oscillators.
* Crystal oscillators – Crystal Oscillator made up of Quartz crystal.

Non-Sinusoidal Oscillator:

- The Oscillators that produce an output having a Square, rectangular or saw-tooth waveform are called non-sinusoidal oscillators.

Multivibrators:

→ Single-stage Astable Oscillator

→ Crystal Controlled Oscillator.

OSCILLATORS: It is an electronic source of alternating current or voltage having sine, square or sawtooth or pulse shapes.

POSITIVE FEEDBACK:

An alternative form of feedback, where the output is fed back in such a way as to reinforce the input is known as positive feedback.

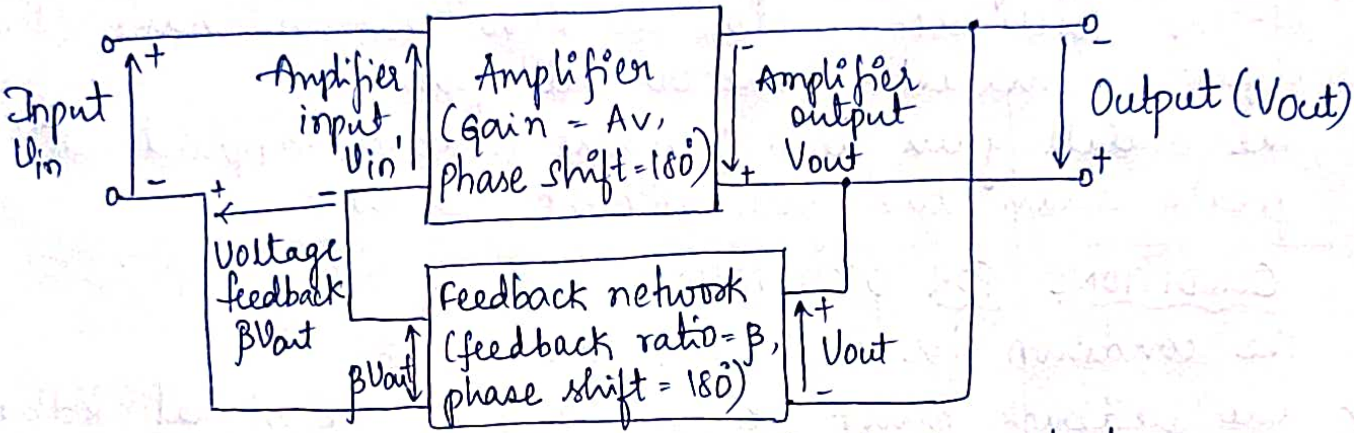


fig: Amplifier with positive feedback applied.

* The figure above shows the block diagram of an amplifier stage with positive feedback applied.
* Note that the amplifier provides a phase shift of 180° and the feedback network provides a further 180°. Thus the overall phase shift is 0°. The overall voltage gain G is given by.

$$\boxed{\text{Overall gain, } G = \frac{V_{out}}{V_{in}}}$$

By applying Kirchoff's voltage law

$$\boxed{V_{in}' = V_{in} + \beta V_{out}}$$

Thus, $\boxed{V_{in} = V_{in}' - \beta V_{out}}$

and $\boxed{V_{out} = A_v \cdot V_{in}}$

where A_v – internal gain of the amplifier.

Overall gain, $G = \dfrac{A_v \cdot V_{in}'}{V_{in}' - \beta V_{out}} = \dfrac{A_v \cdot V_{in}'}{V_{in}' - \beta(A_v \times V_{in}')}$

Thus, $\boxed{G = \dfrac{A_v}{(1-\beta A_v)}}$

* when loop gain βA_v approaches Unity, the denominator $(1-\beta A_v)$ will become close to zero. This will have the effect of increasing the overall gain.
* The overall gain with positive feedback applied will be greater than the gain without feedback.

CONDITIONS FOR OSCILLATION:

The condition for oscillation are:

1) the feedback must be positive (i.e, the signal fedback must arrive back in-phase with the signal at the input).
2) the overall loop voltage gain must be greater than 1. (i.e, the amplifier's gain must be sufficient to overcome the losses associated with any frequency selective feedback network).

* A number of circuits can be used to provide 180° phase shift, one of the simplest being a three stage C-R ladder network that we shall meet next.

LADDER NETWORK OSCILLATOR:

* A simple phase-shift oscillator based on a three stage C-R ladder network is shown below.
* TR1 operates as a conventional common-emitter amplifier stage with R_1 and R_2 providing base bias potential and R_3 and C_1 providing emitter stabilization.

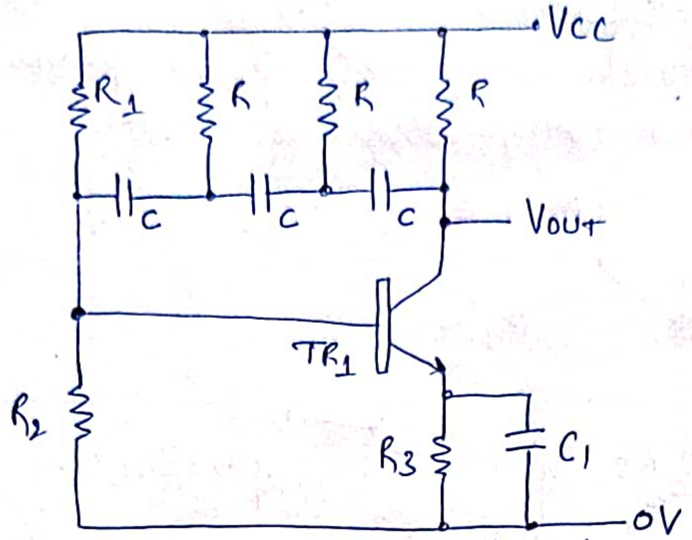


fig: Sine wave Oscillator based on three stage C-R Ladder network.

* The total phase shift provided by the C-R ladder network (connected between collector and base) is 180° at the frequency of Oscillation.
* The transistor provides the other 180° phase shift in order to realize an overall phase shift of 360° or 0°.
* The frequency of oscillation of the circuit is

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

* The loss associated with the ladder network is 29, thus the amplifier must provide a gain of at least 29 in order for the circuit to oscillate.

Problem

* Determine the frequency of Oscillation of a three-stage ladder network Oscillator in which C=10nF and R=10KΩ

Soln: Given C = 10nF, R = 10KΩ

$$f = \frac{1}{2\pi\sqrt{6}CR} = \frac{1}{2\pi\sqrt{6}\times 10\times 10^{-9}\times 10\times 10^{3}} = \frac{10^{4}}{15.386}$$

$$\boxed{f = 647\,Hz}$$

WEIN BRIDGE OSCILLATOR:

* An alternative approach to providing the phase shift required is the use of a wein bridge oscillator network.

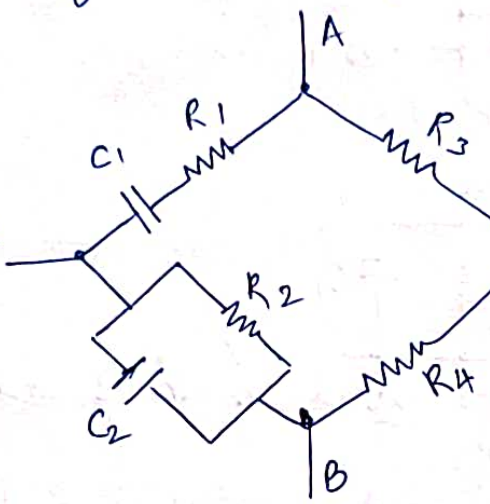


fig: A wein Bridge network.

* Like the C-R ladder, this network provides a phase-shift which varies with frequency.
* The input signal is applied to A and B while the output is taken from C and D.
* At one particular frequency, the phase shift produced by the network will be exactly zero. (input and output signals will be in-phase).
* If we connect the network to an amplifier producing 0° phase shift which has sufficient gain to overcome the losses of the wein bridge, oscillation will result.
* The minimum amplifier gain required to sustain oscillation is given by.

$$\boxed{A_V = 1 + \frac{C_1}{C_2} + \frac{R_2}{R_1}}$$

In most case, $C_1 = C_2$ and $R_1 = R_2$. Hence the amplifier gain will be $\boxed{A_V = 3}$

* The frequency at which the phase-shift will be zero

is given by

$$\boxed{f = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}}$$

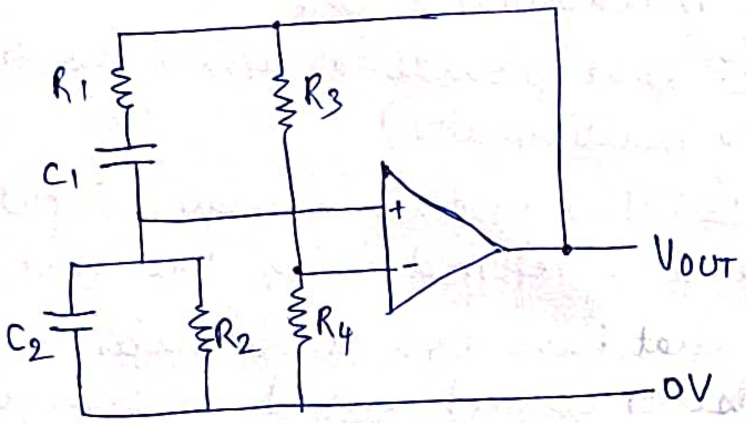
If $R_1 = R_2$ and $C_1 = C_2$

then, $f = \dfrac{1}{2\pi\sqrt{C^2R^2}}$, $\boxed{f = \dfrac{1}{2\pi RC}}$

where $R = R_1 = R_2$ and $C = C_1 = C_2$

Problem.

Figure below shows a wein bridge oscillator based on an operational amplifier. If $C_1 = C_2 = 100nF$. Determine the output frequencies produced by this arrangement (a) when $R_1 = R_2 = 1K\Omega$ and b) when $R_1 = R_2 = 6K\Omega$.



Soln: a) when $R_1 = R_2 = 1K\Omega$

where $R = R_1 = R_2$ and $C = C_1 = C_2$

$$f = \frac{1}{2\pi RC} = \frac{1}{6.28 \times 100 \times 10^{-9} \times 1 \times 10^{3}}$$

$$\boxed{f = 1.59KHz}$$

b) when $R_1 = R_2 = 6K\Omega$

where $R = R_1 = R_2$ and $C = C_1 = C_2$

$$f = \frac{1}{2\pi RC} = \frac{1}{6.28 \times 100 \times 10^{-9} \times 6 \times 10^{3}}$$

$$\boxed{f = 265\ Hz}$$

MULTIVIBRATORS:

* There are many occasions when we require a square wave output from an oscillator rather than a sine wave output.
* Multivibrators are a family of oscillator circuits that produce output waveforms consisting of one or more rectangular pulses.
* The term 'Multivibrator' simply originates from the fact that this type of waveform is rich in harmonics (i.e 'multiple vibrations').
* Multivibrators use regenerative (i.e, positive) feedback.
* The principal types of multivibrators are

1) Astable multivibrators: that provide a continuous train of pulses. (free-running multivibrators)
2) Monostable multivibrators: that produce a single output pulse (have one stable state and referred to as 'one-shot')
3) Bistable multivibrators: that have two stable states and require a trigger pulse or control signal to change from one state to another.

SINGLE-STAGE ASTABLE OSCILLATOR:

* A simple form of astable oscillator that produces a square wave output can be built using just one operational amplifier as shown below.

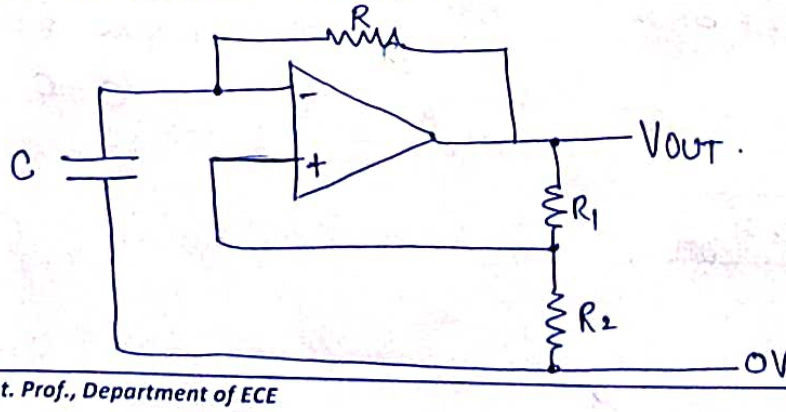


fig: Single-stage astable oscillator using op-Amps.

- The circuit employs positive feedback with the output fedback to the non-inverting input via the potential divider formed by R_1 and R_2.
- This circuit can make a very simple square wave source with a frequency that can be made adjustable by replacing R with a variable or preset resistor.
- Assume that C is initially uncharged and the voltage at the inverting input is slightly less than the voltage at the non-inverting input. The output voltage will rise rapidly to $+V_{CC}$ and voltage at the inverting input will begin to rise exponentially as capacitor C charges through R.
- Eventually, the voltage at inverting input will have reached a value that causes the voltage at the inverting input to exceed at non-inverting input. At this point, the output voltage will rapidly fall to $-V_{CC}$. Capacitor C will then start to charge in the other direction and the voltage at the inverting input will begin to fall exponentially and process continues.
- The Upper threshold voltage is given by

$$\boxed{V_{UT} = V_{CC} \times \frac{R_2}{R_1 + R_2}}$$

- The lower threshold voltage is given by

$$\boxed{V_{LT} = -V_{CC} \times \frac{R_2}{R_1 + R_2}}$$

- Finally, the time for one complete cycle of the output waveform produced by the astable oscillator is given by $\boxed{T = 2CR\ln\left[1 + 2\left(\frac{R_2}{R_1}\right)\right]}$

CRYSTAL CONTROLLED OSCILLATORS:

- A requirement of some oscillators is that they accurately maintain an exact frequency of oscillation.
- In such cases, a quartz crystal can be used as the frequency determining element. The Quartz Crystal vibrates whenever a potential difference is applied across its faces. The frequency of oscillation is determined by the crystal's 'cut' and physical size.
- Most Quartz Crystals can be expected to stabilize the frequency of oscillation of a circuit to within a few parts in a million.
- Crystals can be manufactured for operation in fundamental mode over a frequency range extending from 100KHz to around 20MHz and for overtone operation from 20MHz to well over 100MHz.
- Figure below shows a simple crystal Oscillator circuit in which the crystal provides feedback from the drain to the source of a junction gate FET

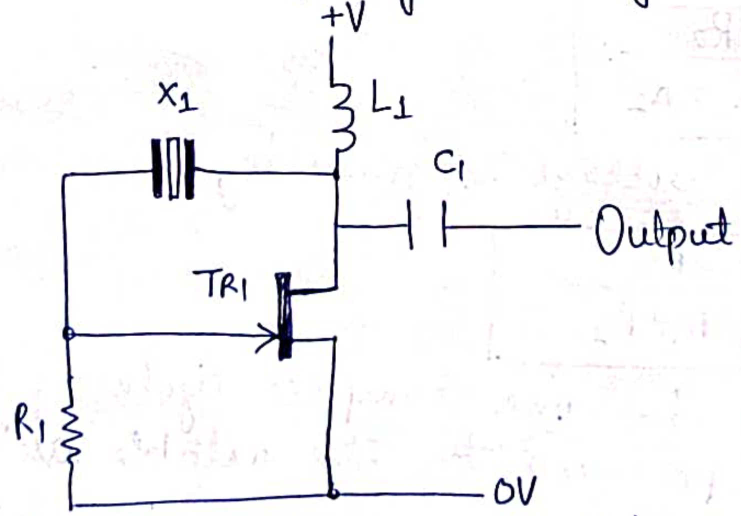


fig: A Simple JFET Oscillator.