Unit - 2

Feedback
It is the process of feeding back some part of the output signal into the input of the circuit through a suitable network.

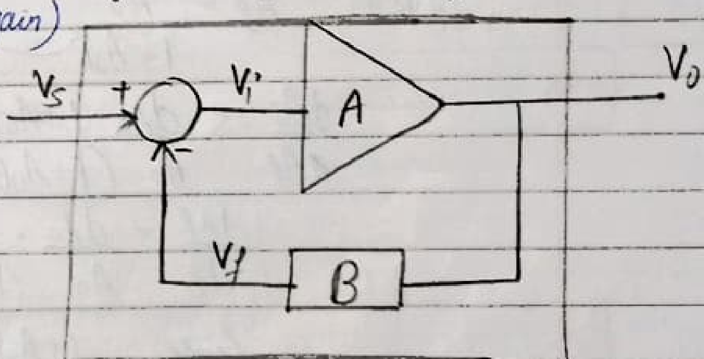
Types of Feedback
(i) Positive feedback →
The feedback signal has the same phase as of V_{in} signal.
Also called as regenerative / direct feedback.

(ii) Negative feedback →
The feedback signal has the opposite phase of V_{in} signal.
Also called as degenerative / inverse feedback.

Imp // Negative feedback derivation (Gain with/without feedback)

(open loop) (closed loop gain)

$A_o = \dfrac{V_o}{V_i}$, $A_f = \dfrac{V_o}{V_s}$



Feedback Amplifier

$V_i = V_s - V_f$

$V_s = V_i + V_f$

$A_f = \dfrac{V_o}{V_s} \Rightarrow \dfrac{V_o}{V_i + V_f} \Rightarrow \dfrac{V_o}{V_i + BV_o}$

divide numerator & denominator by V_i

$A_f = \dfrac{V_o}{V_i} \div \dfrac{V_i}{V_i} + \dfrac{B\,V_o}{V_i}$

$A_f = A_o \div 1 + BA_o$

$$\boxed{A_f = \dfrac{A_o}{1 + BA_o}}$$

Imp. Prove that the stability of the gain A_f of an amplifier with negative feedback increases by a factor $1+A_0B$ compared to that of an amplifier without feedback, where A_0 is open loop & B is feedback factor

$$A_f = \frac{A_0}{1+A_0B}$$

$$\frac{dA_f}{dA_0} = \frac{(1+A_0B)\frac{dA}{dA} - A_0\frac{d}{dA_0}(1+A_0B)}{(1+A_0B)^2}$$

$$\frac{dA_f}{dA_0} = \frac{(1+A_0B) - A_0B}{(1+A_0B)^2} \Rightarrow \frac{1}{(1+A_0B)^2}$$

$$dA_f = \frac{dA_0}{(1+A_0B)^2}$$ ~~divide both~~

divide both sides by A_f.

$$\frac{dA_f}{A_f} = \frac{dA_0}{A_f\,(1+A_0B)^2}$$

w.k.t, $A_f = \dfrac{A_0}{1+A_0B}$

$$\frac{dA_f}{A_f} = \frac{dA_0\,\cancel{(1+A_0B)}}{A_0\,(1+A_0B)^{\cancel{2}}}$$

$$\boxed{\frac{dA_f}{A_f} = \frac{dA_0}{A_0}\cdot\frac{1}{(1+A_0B)}}$$

Since, $1+A_0B >>> 1$, $\Rightarrow 1+A_0B = A_0B$

$$\boxed{\frac{dA_f}{A_f} = \frac{dA_0}{A_0}\cdot\frac{1}{A_0B}}$$

$\frac{dA_f}{A_f} \rightarrow$ fractional change in amplification with feedback

$\frac{dA_0}{A_0} \rightarrow$ fractional change in amplification without feedback

Imp

RC Phase shift oscillator

It consists of a common emitter single-stage amplifier ~~with~~ with a phase shift feedback network consisting of 3 identical RC sections.

It is suitable for low frequency applications.

Principle of working of RC phase shift oscillator

(i) The total phase shift around the loop must be 360°.

(ii) Along with the 180° phase shift with the ~~oscill~~ amplifier, the oscillator gives a 180° phase shift, & so, the total phase shift is 360° ≈ 0°.

Barkhausen condition for oscillations (Gain Equation)

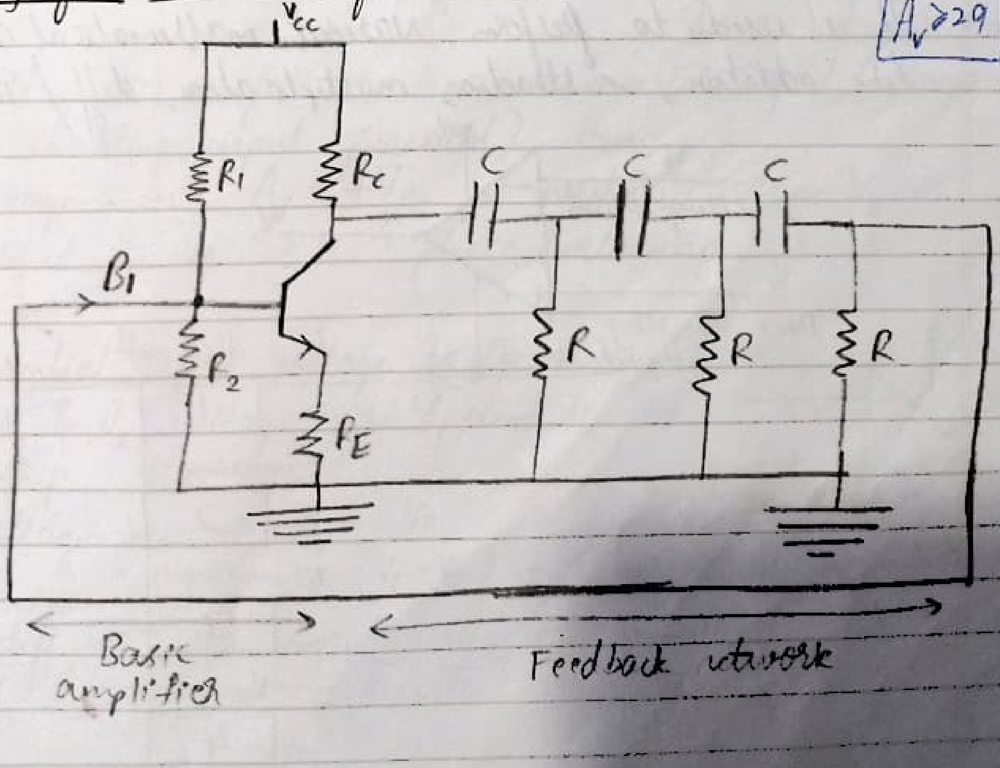
(i) Loop gain = one in absolute magnitude, i.e, $|BA| = 1$

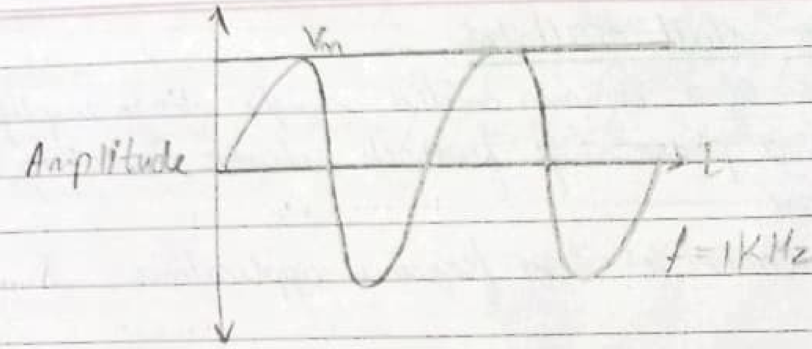
(ii) The phase shift is either zero / ~~multiple~~ integral multiple of $2\pi n$, $n = 0, 1, 2 \cdots$.

$\boxed{f = \frac{1}{2\pi RC\sqrt{6}}}$ $\boxed{\beta = \frac{1}{29}}$

$\boxed{A_v \geq 29}$

Working of RC Phase shift oscillation

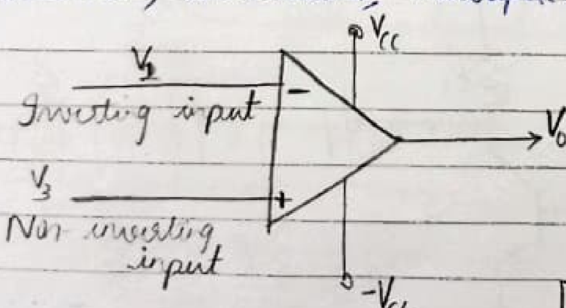


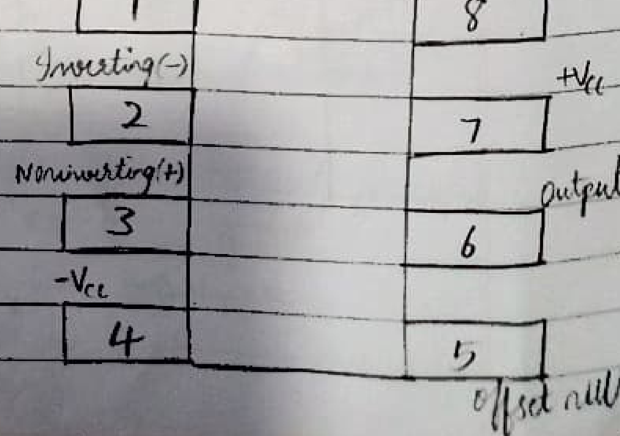


(i) RC oscillator consists of amplifier & feedback network.
(ii) The capacitors & Resistors are arranged in a ladder fashion
(iii) A single RC section can provide a max phase shift of 90°. so a minimum of 2 RC sections is required for 180° phase shift
(iv) In practical, each RC section provides a phase shift of 60°. so, for 180° phase shift, we will need 3 RC sections.

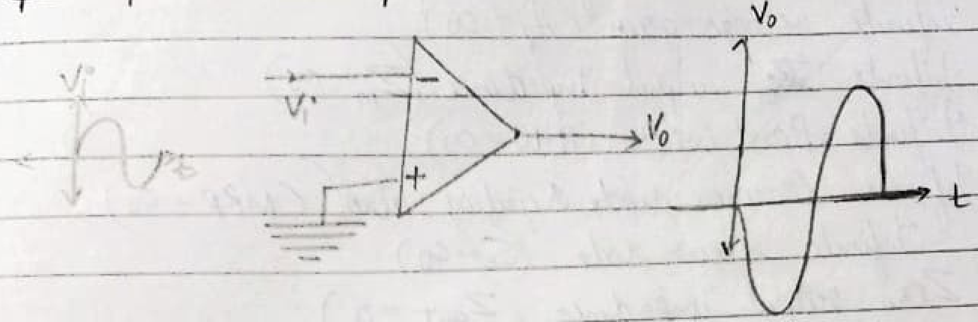
Operational Amplifier

→ It is a direct coupled, multistage, voltage amplifier with extremely high gain.
→ It is available in IC form.
→ It is used to perform various mathematical calculations like addition, subtraction, multiplication, diff / Integration





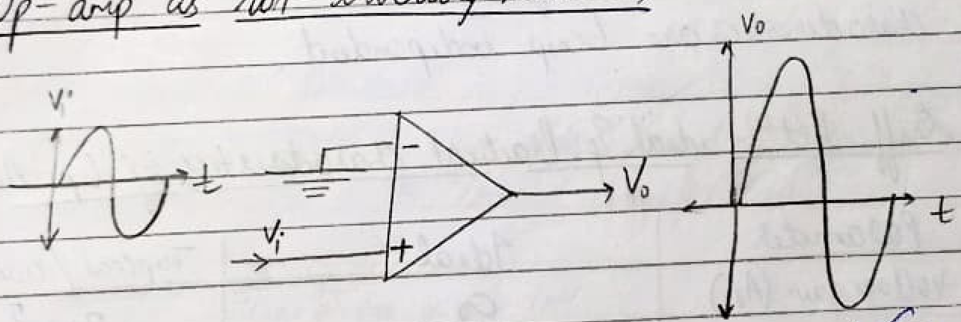
Op-amp in inverting mode (−)



→ If a voltage (V_i) is applied at the inverting input, Keep non-inverting input as grounded, then

→ Voltage gain $A_v = \frac{-V_o}{V_i}$ is negative, where (V_o) is inverted by 180° & ~~amplifide~~ amplified.

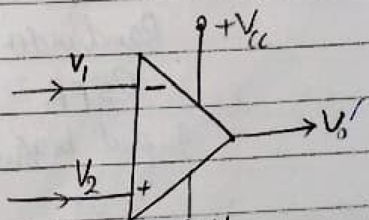
Op-amp as non-inverting mode (+)



→ If voltage (V_i) is fed at the non-inverting input, (Keeping the inverting input grounded), then,

→ Voltage gain, $A_v = \frac{+V_o}{V_i}$ is positive, where V_o is amplified & is in phase with input.

Differential input voltage to Op-amp



→ when V_1 & V_2 voltages are applied to the Op-Amp, then

→ voltage gain ⇒ $A_V = \frac{V_o}{(V_1 - V_2)}$

→ The diff betw the input voltages is amplified. So, Op-Amp is called "High gain differential amplifier.

Imp

Ideal characteristics of Op-Amp

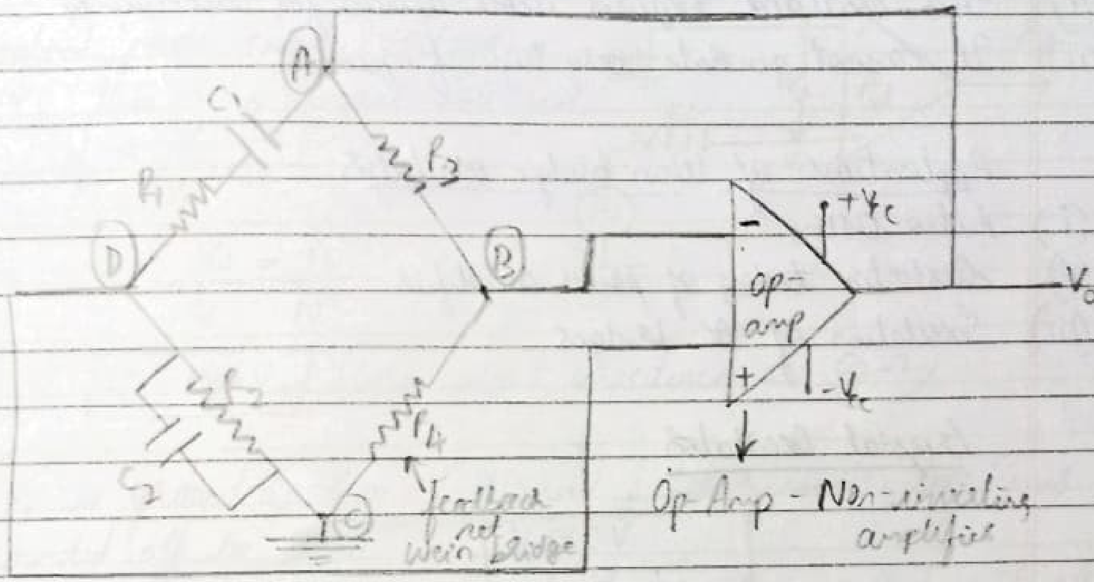
1) Infinite voltage gain ($A_v = \infty$)
2) Infinite input Impedance ($Z_{in} = \infty$)
3) Infinite Band width ($B \cdot W = \infty$)
4) Infinite Common mode rejection ratio ($CMRR = \infty$)
5) Infinite slew rate ($S = \infty$)
6) Zero output impedance ($Z_{out} = 0$)
7) Zero Power supply rejection ratio ($PSRR = 0$) [Output voltage is zero when power supply = 0]
8) Zero offset voltage [if input voltage = zero, output voltage = 0]
9) Perfect Balance [$V_0 = 0$, if the input voltages at the two terminals are equal]
10) characteristics are temp independent.

V. Imp

Diff betw ideal & Practical characteristics of Op-Amp

Parameter	Ideal	Typical / Practical value
voltage gain (A_v)	∞	2×10^5
Zout	0	75 Ω
Zin	∞	2M Ω
Input offset	0	2mV
CMRR	∞	90dB
slew rate	∞	0.5V μs^{-1}
Bandwidth	∞	1MHz
PSRR	0	30 μV/V
Input bias current	0	80 nA

~~Weg~~ Wein - Bridge Oscillator



→ ~~Weg~~ Wein Bridge Oscillator is an electronic device that generates sine waves.
→ Wein Bridge oscillator = Wein bridge circuit + differential amplifier
→ It is a two staged RC coupled amplifier circuit.

Working of Weign bridge oscillator

(i) It is made up of 4 resistors & 2 capacitors. The component values of both RC circuits are same.
(ii) At low frequencies, reactance of capacitors is very high. C_1 acts as open circuit & output voltage is 0.
(iii) At high frequencies, reactance of capacitors is very low. R_1 is short circuited & output voltage is 0.
(iv) At resonant frequency, phase shift betw input & output will be zero. Max output voltage is observed. $V_0 = V_i/3$

Adv of Wein bridge oscillator

(i) Overall gain of oscillator is high as it uses two-stage amplifier
(ii) Wein bridge oscillator has good frequency stability

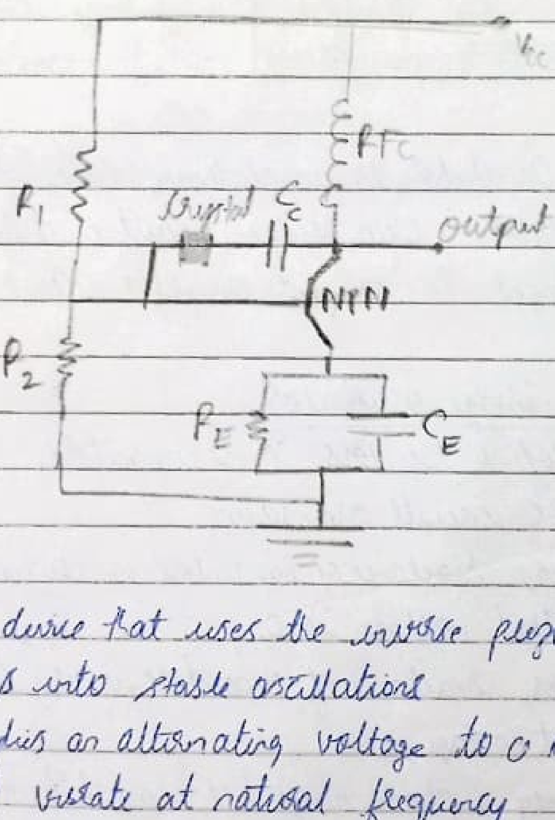
Disadv of Wein bridge oscillator

(i) This oscillator requires more devices for construction.
(ii) It cannot generate very high frequencies

Applications of Wein bridge oscillator

(i) Audio testing
(ii) Distortion testing of power amplifiers
(iii) Excitation of AC bridges.

Crystal Oscillator

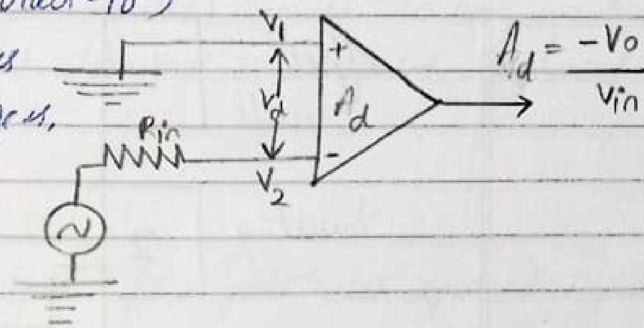


(i) It is a device that uses the inverse piezoelectric effect to convert vibrations into stable oscillations
(ii) It applies an alternating voltage to a crystal, which makes the crystal vibrate at natural frequency
(iii) The oscillators are designed to operate in low impedance mode/ high-impedance mode
(iv) The Oscillator offers excellent frequency stability
(v) These oscillators are used in devices like GPS, microprocessors.

Concept of Virtual Ground

(i) Op-Amp has very high gain. (Order $= 10^5$)

(ii) If output power supply voltage is $\pm 15V$, then max input voltage is,



$$A_d = \frac{V_o}{V_i}$$

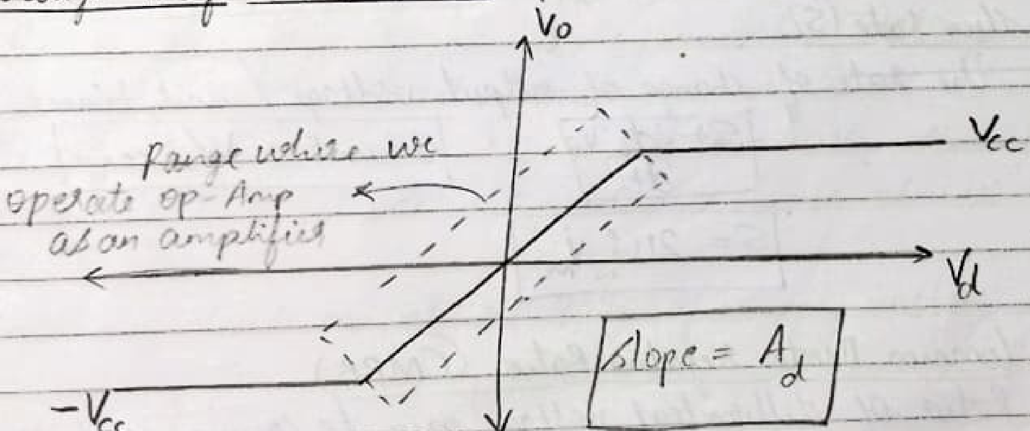
$$V_i = \frac{V_o}{A_d} = \frac{15}{10^5}$$

$\boxed{V_i = 150\mu V}$ (when input impedence is $\infty \Omega$)

(iii) If V_1 is grounded, then $V_2 \ngtr 150\mu V$. This is very less & is rounded off to zero. $\therefore V_2 \approx 0V$

(iv) But it is not really grounded & so it is called virtually grounded.

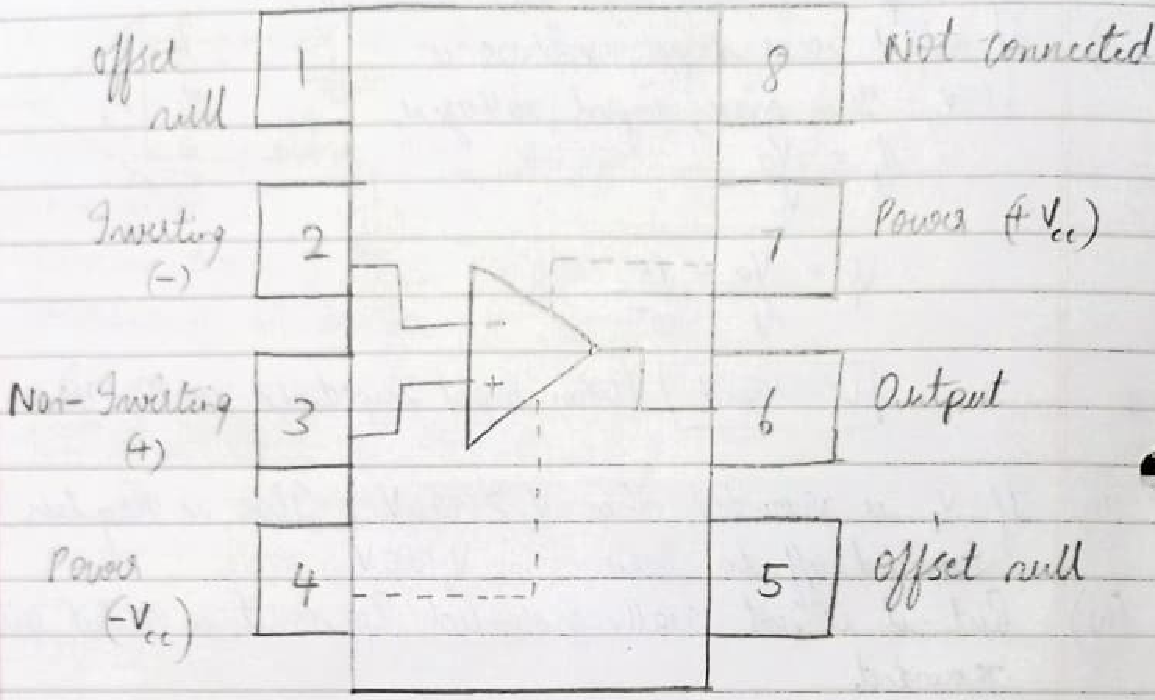
Voltage transfer characterstics



Applications of Op-Amp

(i) Amplifier
(ii) Adders & subtractors
(iii) Integrators & differentiators
(iv) Clock generators
(v) Oscillators
(vi) Inverting & Non-inverting Amplifier

Pin diagram of 741 Op-Amp



Terms

(i) Slew rate (S)

The rate of change of output voltage / unit time

$\boxed{S = \frac{d}{dt} V_o}$ $\boxed{\text{S.I. unit} = V/\mu sec}$

$\boxed{S = 2\pi f_m V_m}$

(ii) Common Mode Rejection Ratio (CMRR)

Ratio of differential voltage gain to common mode voltage gain

$\boxed{CMRR = \frac{A_d}{A_c}}$ $\boxed{CMRR = 20 \log \left(\frac{A_d}{A_c}\right) dB}$

$CMRR = A_d - A_c$

(iii) Open loop voltage gain (A_o)

Ratio of output voltage to input voltage in the absence of feedback. $\boxed{A_v = \frac{V_o}{V_i}}$ $\boxed{A_v = 2 \times 10^5}$

(iv) Input Impedance (Z_{in})

The impedance seen by the input (source) Applied to one input terminal when the other input terminal is connected to ground.

$$\boxed{Z_i \approx 2M\Omega}$$

(v) Output Impedance (Z_{out})

The impedance given by the output for a particular applied input

$$\boxed{Z_0 = 75\Omega}$$

(vi) Power Supply Rejection Ratio (PSRR)

Defined as the change in the output voltage/unit changes in DC supply voltage

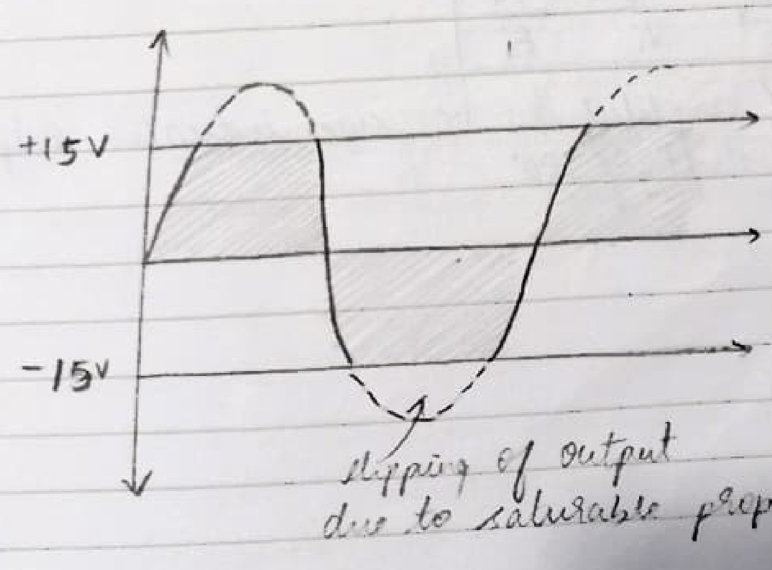
$$\boxed{PSRR = \frac{\Delta V_0}{\Delta V_{cc}}}$$

Saturable property of Op-Amp

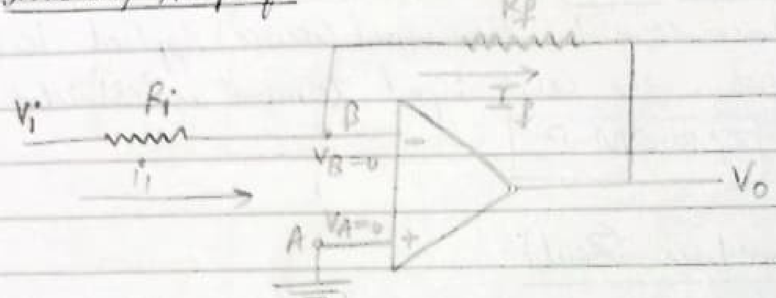
→ It is the prop of an Op-Amp in which voltage is swinging betw saturation voltages $+V_{cc}$ & $-V_{cc}$

- It V_0 rises more than $+V_{cc}$ / less than $-V_{cc}$ then it gets clipped off & gets saturated at the levels almost equal to $+V_{cc}$ & $-V_{cc}$

→ Saturation levels are almost 90% of supply voltage levels.



1) Inverting Amplifier



(i) Non inverting terminal is grounded & input signal is applied at Inverting terminal.

(ii) By virtual grounding, $\boxed{V_B = V_A = 0\,V}$

(iii) Due to high Z_{in} of op-amp, current flowing through inverting terminal is zero.

(iv) At point B,

$$I_1 = I_f$$

$$\frac{\Delta V}{R} = \frac{\Delta V}{R}$$

$$\frac{V_i - V_B}{R_i} = \frac{V_B - V_o}{R_f} \Rightarrow \frac{V_i}{R_i} = \frac{0 - V_o}{R_f}$$

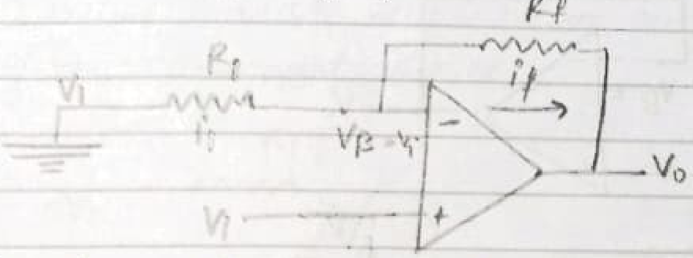
$$\frac{V_i}{R_i} = -\frac{V_o}{R_f}$$

Rearranging the terms, we get

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{R_f}{R_i}}$$

$\frac{R_f}{R_1}$ is gain of amplifier & (-ve) sign indicates output undergoes a phase shift of 180°

2) Non-Inverting Amplifier



(i) Input signal is applied to non inverting terminal & inverting terminal is grounded through R_1

(ii) Due to virtual grounding,

$$\cancel{V_f = 0 \rightarrow V_B = 0} \;\&\; V_B = V_i \;\; \& \;\; V_1 = 0$$

(iii) Due to high input impedance of Op-Amp,

$$i_1 = i_f$$

$$\frac{\Delta V}{R} = \frac{\Delta V}{R} \Rightarrow \frac{V_1 - V_B}{R_1} = \frac{V_B - V_o}{R_f}$$

$$\Rightarrow \frac{0 - V_B}{R_1} = \frac{V_B - V_o}{R_f} \Rightarrow \frac{-V_i}{R_1} = \frac{V_i - V_o}{R_f}$$

$$\Rightarrow \frac{-V_i}{R_1} = \frac{V_i}{R_f} - \frac{V_o}{R_f}$$

$$\Rightarrow \frac{V_o}{R_f} = \frac{V_i}{R_f} + \frac{V_i}{R_1}$$

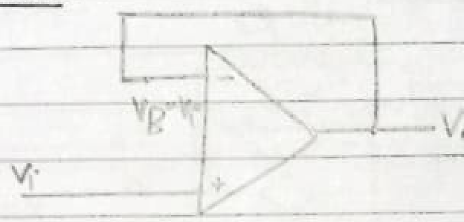
$$\frac{V_o}{R_f} = V_i\left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

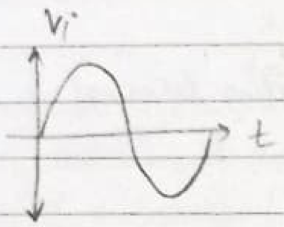
$$\frac{V_o}{V_i} = R_f\left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

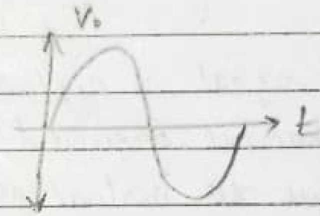
$$\boxed{A_V = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

$$\boxed{\beta = \frac{R_1}{R_1 + R_f}}$$

3) Voltage follower







- It is obtained by short circuiting R_f & open circuiting R_1
- All the output is feedback to the inverting terminal
- When $R_f = 0$ & $R_1 = \infty$,

  $V_f = V_i$ (Virtual ground)
- Inverting terminal is directly connected to output

  $V_f = V_o$

$\therefore$ $\boxed{V_i = V_o}$

Also, $\boxed{A_V = \frac{V_o}{V_i} = 1}$

Feedback of voltage follower,

$$A_f = \frac{A_o}{1+\beta A_o}, \quad \boxed{\beta = 1}$$

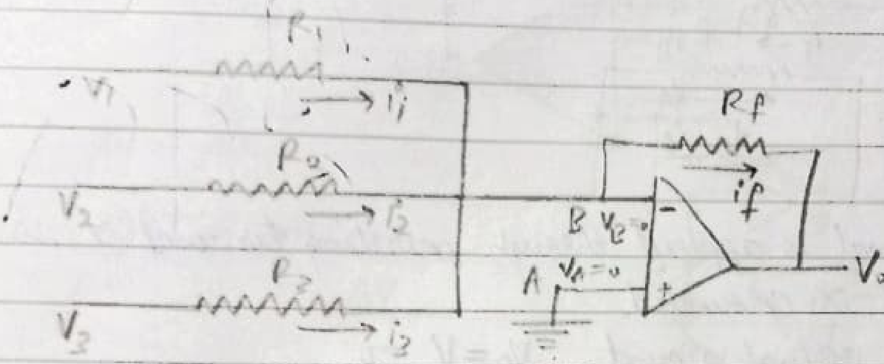
$\boxed{A_f = \frac{A_o}{1+A_o}}$ gain of voltage follower

$$\text{Error} = \left[1 - \frac{A_o}{1+A_o}\right] \times 100 = \%$$

- The voltage follower is non-inverting amplifier with voltage gain of unity

4) Summer Inverting Op-Amp

Inverting ladder is one whose output is the inverted sum of the constituent inputs.



$$i_1 = \frac{\Delta V}{R_1} = \frac{V_1 - V_B}{R_1} \Rightarrow \frac{V_1 - 0}{R_1} = \frac{V_1}{R_1}$$

$$i_2 = \frac{\Delta V}{R_2} \Rightarrow \frac{V_2 - V_B}{R_2} \Rightarrow \frac{V_2 - 0}{R_2} = \frac{V_2}{R_2}$$

$$i_3 = \frac{\Delta V}{R_3} \Rightarrow \frac{V_3 - V_B}{R_3} \Rightarrow \frac{V_3 - 0}{R_3} = \frac{V_3}{R_3}$$

$$i_f = \frac{\Delta V}{R_f} \Rightarrow \frac{V_B - V_0}{R_f} \Rightarrow \frac{0 - V_0}{R_f} = \frac{-V_0}{R_f}$$

Apply KCL at point B,

$$i_f = i_1 + i_2 + i_3$$

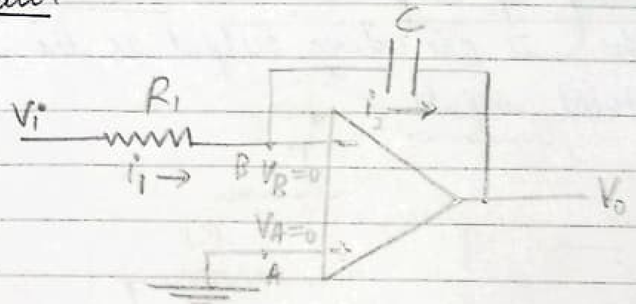
$$\frac{-V_0}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$\boxed{V_0 = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]}$$ Sealth Scaling Eqn

If $R_1 = R_2 = R_3 = R_f$

$$\boxed{V_0 = -\left[V_1 + V_2 + V_3\right]}$$ Average (V_0) Eqn

5) Integrator



→ Input signal is applied through inverting terminal & non-inverting terminal is grounded.

→ Through virtual ground $V_B = V_A = 0$

→ Apply KCL at point B,

$$i_1 = i_f$$

$$\frac{\Delta V}{R} = C\frac{dv}{dt}$$

$$\frac{V_i - V_B}{R_1} = C \cdot \frac{dv_0}{dt}$$

$$\frac{V_i}{R_1} = C\frac{d}{dt}(V_B - V_0)$$

$$\frac{V_i}{R_1} = -C\frac{d}{dt}V_0$$

$$\int \frac{dv_0}{dt} = \int \frac{-V_i}{R_1 C}$$

$$V_0 = \frac{-1}{R_1 C} \cdot \int_0^t V_i\,dt + V_0(0)$$

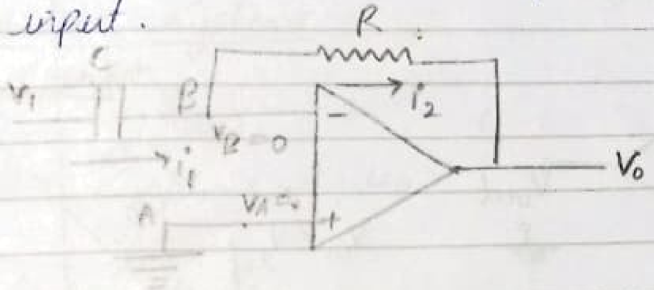
$$\boxed{V_0 = \frac{-1}{R_1 C}\int_0^t V_i\,dt}$$ output voltage for integrator

$V_0(0)$ is the initial voltage on capacitor at $t=0$, (its const)

→ There a phase shift of 180° betw input & output signals

6) **Differentiator**

A differentiator is one whose output is the differentiation of the input.



→ Input signal is applied through inverting terminal & non-inverting terminal is grounded

→ Through virtual grounding,

$$\boxed{V_A = V_B = 0}$$

→ Apply KCL at point B,

$$i_1 = i_2$$

$$\cancel{\frac{A\not{t}}{F}}\ C\frac{dV}{dt} = \frac{\Delta V}{R}$$

$$C \cdot \frac{d(V_1 - V_B)}{dt} = \frac{V_B - V_0}{R}$$

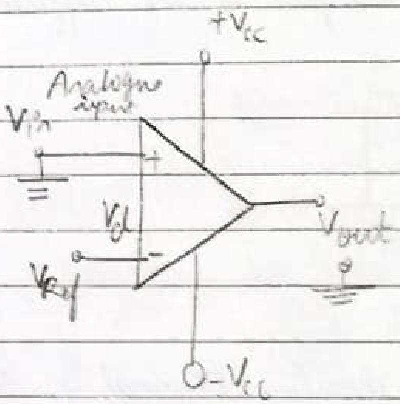
$$C \cdot \frac{dV_1}{dt} = \frac{-V_0}{R} \qquad (V_B = 0)$$

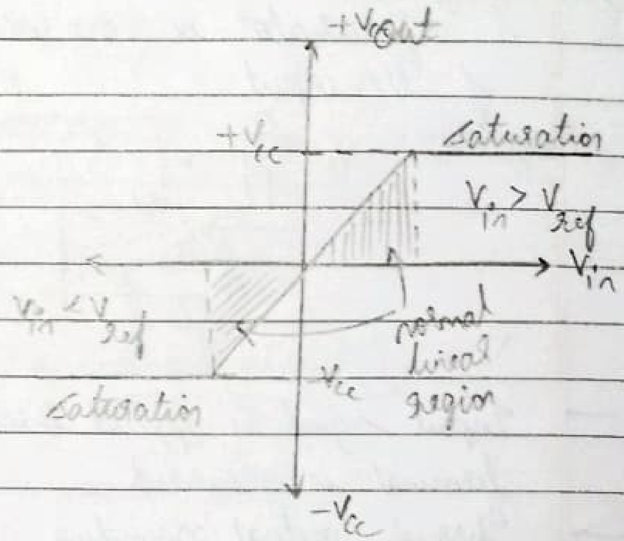
$$\boxed{V_0 = -RC \cdot \frac{dV_1}{dt}}$$

→ Output is $(-RC)$ times the differential of input. We observe a phase shift of 180° betw input & output signal.

→ Main adv of differentiator is the small time constant required for differentiation

Comparator





Graph of comparator