Lecture 31

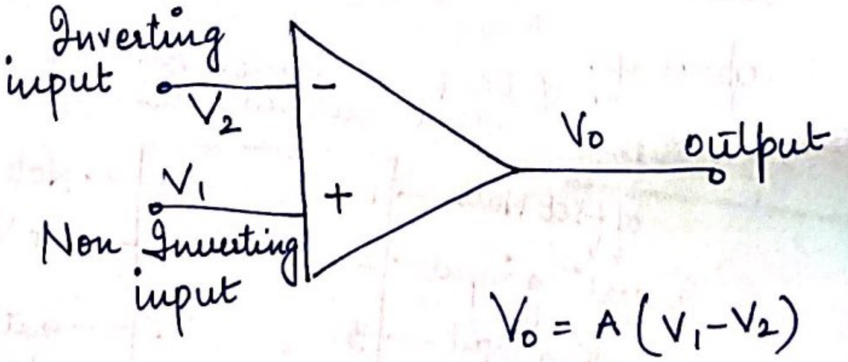
Unit 3 : Operational Amplifiers

Contents

- Introduction of op amp
- Block diagram of opamp.
- 741 IC of opamp.

Introduction of opamp

- opamp is a very high gain differential amplifier with high input impedance and low output impedance.
- It performs mathematical operations like addition, subtraction, integration, differentiation.
- Applications of op-amp - amplification, oscillators, filter circuits etc.
- consist of a number of differential amplifier stages to achieve a very voltage gain.



$V_0 = A(V_1 - V_2)$

A = open loop gain.

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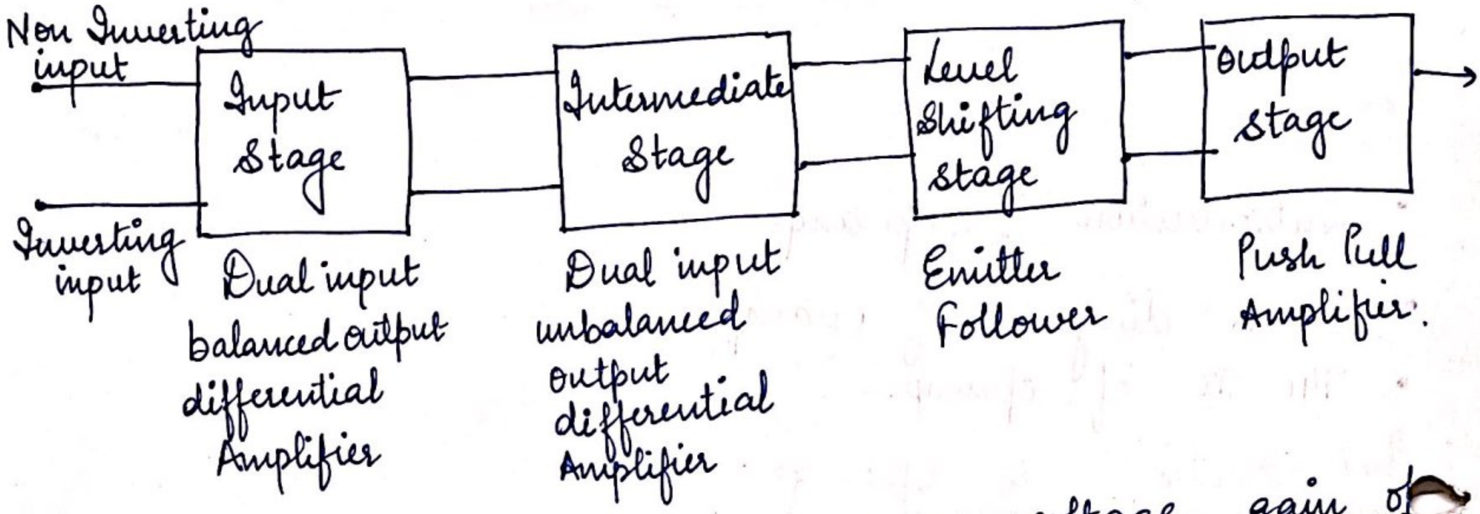
Block Diagram of opamp



Input stage : It provides most of the voltage gain of amplifier.

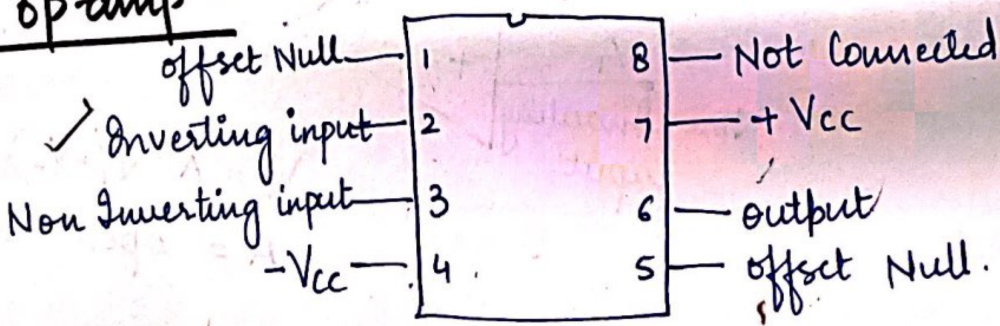
Intermediate Stage : It increases the overall gain of the amplifier.

Level shifting stage : It shift the dc level at the output of intermediate stage down to zero volts with respect to ground.

Output stage : It increases the overall output voltage and current supplying capability of op-amp.

Q. Define op-amp with the help of block diagram. Also draw its equivalent circuit. List the ideal characteristics. (2017-18)(even)

741 IC of op-amp



Lecture 32

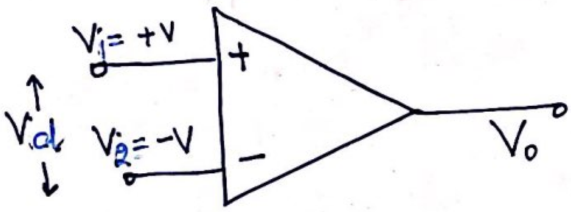
Unit 3: Operational Amplifiers

Contents

- Differential and common Mode Operation.
- CMRR (common Mode rejection Ratio)

Differential and Common Mode operation

Differential Mode operation



$V_d = V_1 - V_2$

differential input

$V_c = \frac{1}{2}(V_1 + V_2)$

Common input

$$\boxed{V_o = A_d V_d + A_c V_c}$$

A_d = differential gain

V_d = differential input

A_c = common mode gain

V_c = common input.

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If opposite polarity inputs applied to opamp are such that $V_1 = +V$

$V_2 = -V$

$\therefore \; V_d = V_1 - V_2$ $\qquad V_c = \dfrac{V_1 + V_2}{2}$

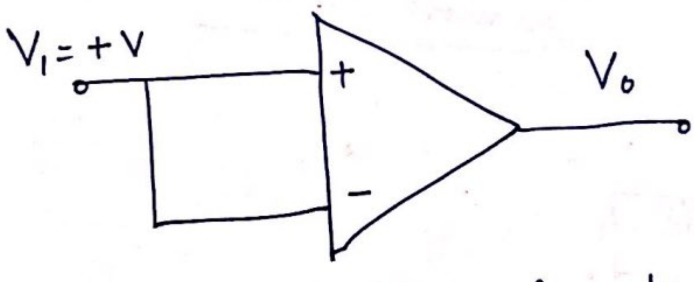
$= 2V$ $\qquad = 0$

$V_o = A_d(2V) + A_c(0)$

$$\boxed{V_o = 2A_d V}$$

It shows the ability of an opamp to greatly amplify the signals that are opposite in polarity.

Common Mode operation



If same polarity inputs are applied to an op-amp such that $V_1 = +V$

$V_2 = +V$

$\therefore \; V_d = V_1 - V_2$ $\qquad V_c = \dfrac{V+V}{2}$

$= 0$

$V_c = V$

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$$V_o = A_d V_d + A_c V_c$$

$$= A_d(0) + A_c V$$

$$\boxed{V_o = A_c V}$$

This shows that opamp has the tendency to slightly amplify the common signals.

Thus we can say that op-amp amplifies opposite input signals and rejects common Mode signals.

CMRR (common Mode Rejection Ratio)

CMRR indicates the ability of an op-amp to reject the common mode signals.

$$CMRR = \frac{A_d}{A_c}$$

$$\boxed{\text{CMRR in dB (decibels)} = 20 \log_{10} \left(\frac{A_d}{A_c}\right)}$$

Important formulas

Differential input $V_d = V_1 - V_2$

common mode input $V_c = \frac{V_1 + V_2}{2}$

Differential output $V_{od} = A_d V_d$

Common Mode output $V_{oc} = A_c V_c$

Total output voltage $\boxed{V_o = A_d V_d + A_c V_c}$

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Q1. Determine the output voltage of an op-amp for input voltages of $V_{i1} = 200V$ $V_{i2} = 140V$. The amplifier has a differential gain $A_d = 6000$ and value of CMRR is. (2015-16) (5 Marks)

(i) 200

(ii) 10^5

$\Rightarrow$

$$CMRR = \frac{A_d}{A_c}$$

$$200 = \frac{6000}{A_c}$$

$$\boxed{A_c = 30}$$

$$V_d = V_{i1} - V_{i2}$$
$$= 200 - 140$$
$$\boxed{V_d = 60V}$$

$$V_c = \frac{V_{i1} + V_{i2}}{2}$$

$$= \frac{200+140}{2}$$

$$\boxed{V_c = 170V}$$

$$\boxed{V_o = A_d V_d + A_c V_c}$$

$$V_o = 6000 \times 60 + 170 \times 30$$

$$\boxed{V_o = 365100 V}$$

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iii) CMRR $= 10^5$

$$10^5 = \frac{6000}{A_c}$$

$$\boxed{A_c = 0.06}$$

$$V_o = A_d V_d + A_c V_c$$

$$= 6000 \times 60 + 0.06 \times 170$$

$$\boxed{V_o = 360010.2 V}$$

Q2. The two input terminals of an opamp are connected to voltage signals of strength 745 µV and 740 µV respectively. The gain of opamp in differential mode is 5×10^5 and its CMRR is 80 dB. Calculate the output voltage.

→ $V_1 = 745 \mu V$

$V_2 = 740 \mu V$.

$A_d = 5 \times 10^5$

CMRR $= 80$ dB.

$$\text{CMRR in dB} = 20 \log_{10} \frac{A_d}{A_c}$$

$$80 = 20 \log_{10} \left(\frac{5 \times 10^5}{A_c} \right)$$

$$10^4 = \frac{5 \times 10^5}{A_c} \qquad \boxed{A_c = 50}$$

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$$\boxed{V_o = A_d V_d + A_c V_c}$$

$$V_d = V_1 - V_2$$

$$= (745 - 740)\,\mu V$$

$$\boxed{V_d = 5\,\mu V}$$

$$V_c = \frac{V_1 + V_2}{2}$$

$$\boxed{V_c = 742.5\,\mu V}$$

$$V_o = 5 \times 10^5 \times 5 \times 10^{-6} + 50 \times 742.5 \times 10^{-6}$$

$$\boxed{V_o = 2.53\ V}$$

Q3. Define CMRR and slew rate of op-amp (2015-16) (2 Marks)

Q4. An operational amplifier has differential gain of $10^{\wedge}2$ and CMRR of 80 dB, input voltages are 100 microvolts and 60 microvolt. Determine the output voltage (2016-17).

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Lecture 33

Unit 3: operational Amplifiers

Contents

- Slew Rate, Maximum signal frequency.
- Ideal opamp Characteristics
- Practical opamp characteristics.

Slew Rate (SR)

Slew Rate is the maximum rate at which amplifier output can change in volts per microsecond. (V/us)

$$SR = \frac{\Delta V_o}{\Delta t} \quad V/\mu s.$$

Maximum signal frequency.

The maximum frequency at which an op-amp may operate depends on BW and SR of opamp.

For a Sinusodial signal

$$V_o = K \sin(2\pi f t)$$

the maximum rate of change of voltage can be

$$= K 2\pi f \quad V/s$$

To prevent distortion the above should not exceed SR.

$$\omega K \leq SR \Rightarrow \omega \leq \frac{SR}{K} \quad rad/s$$

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Ideal opamp Characteristics

- The input impedance of an ideal opamp is ∞

$$Z_i = \infty$$

- The output impedance of an ideal opamp is 0

$$Z_o = 0$$

- The open loop gain of an ideal opamp is ∞

$$A = \infty$$

- The CMRR of an ideal opamp is ∞

$$CMRR = \infty$$

- The slew rate of an ideal opamp is ∞

$$SR = \infty$$

- The bandwidth of an ideal opamp is ∞

$$BW = \infty$$

- The offset voltage for an ideal opamp is 0

offset voltage = 0

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Practical opamp Characteristics

- The input resistance of practical opamp is in M-Ω;
- The output resistance of practical opamp is in few ohms.
- The open loop gain of practical opamp is in range of thousands. (741 IC: 2×10^5)
- The bandwidth of practical opamp is in few hundred KHz.
- The offset voltage of opamp is in few mV.
- The CMRR of practical opamp is very high. For IC 741, CMRR is 90 dB.
- Slew rate of practical opamp is high.

University Question

Q. List the ideal characteristics of opamp (2 Marks) (2015-16). (2017-18)(even)

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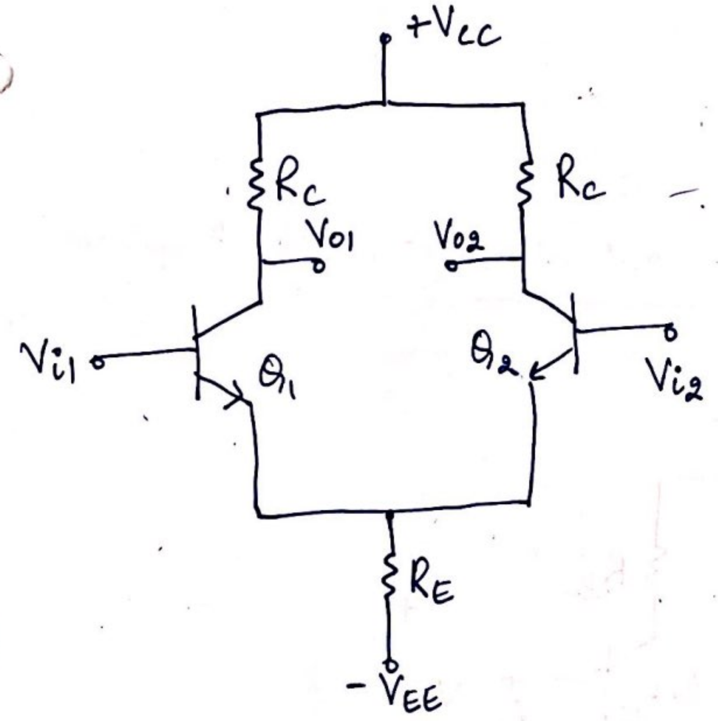
Lecture 34

Unit 3: operational Amplifiers

Contents

- Basic differential amplifier circuit.
- Differential amplifier circuits.
- Negative feedback.

Basic Differential Amplifier circuit



Differential amplifier circuits

- Dual input balanced output differential amplifier
- Dual input unbalanced output differential amplifier
- Single input balanced output differential amplifier
- Single input unbalanced output differential amplifier

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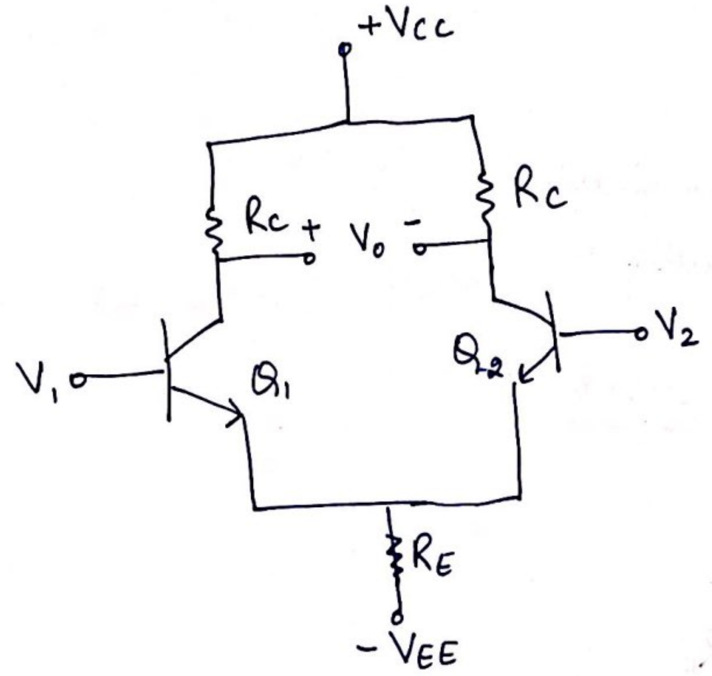
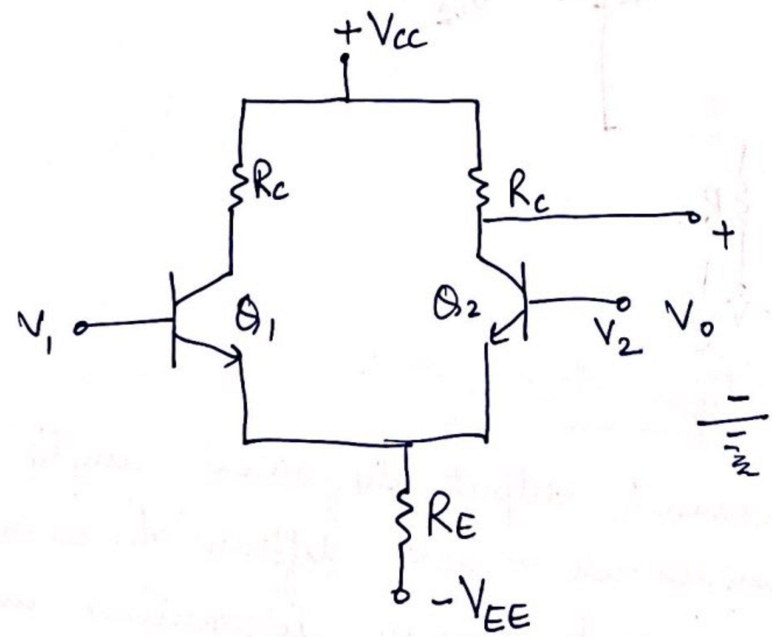
Dual input balanced output differential Amplifier



Dual input unbalanced output differential Amplifier



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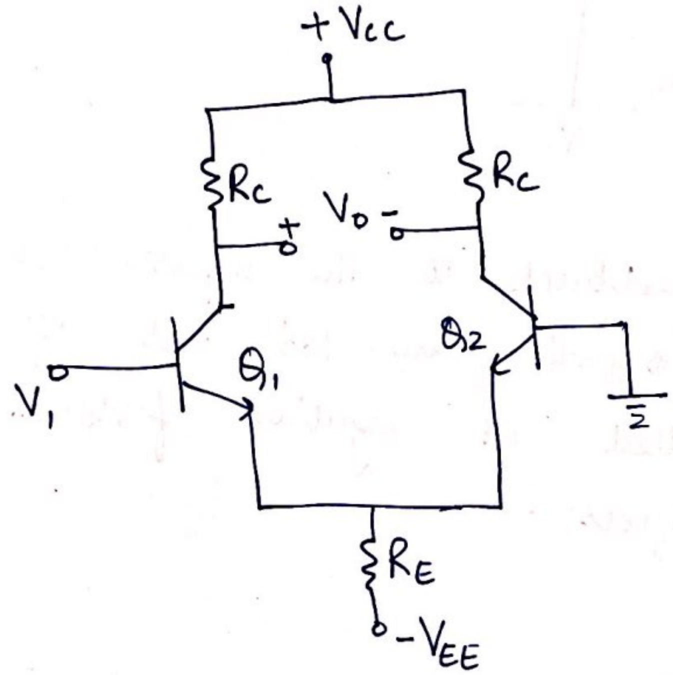
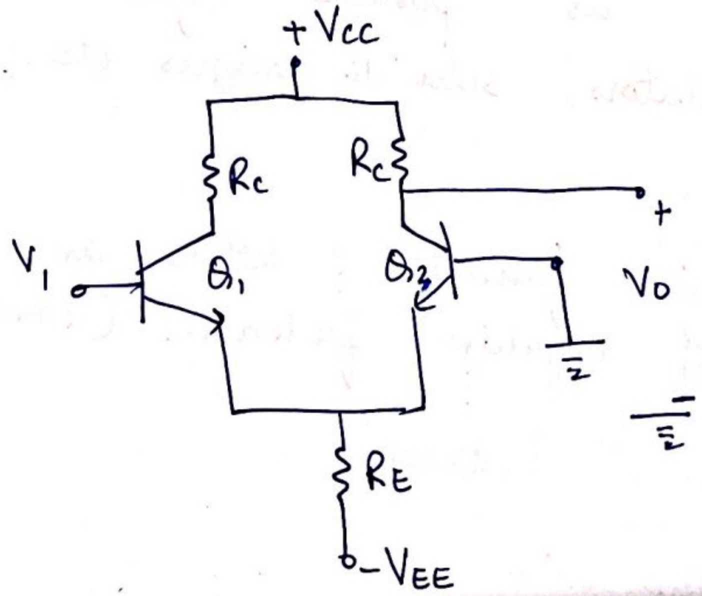
Single input balanced output differential amplifier



Single input unbalanced output differential Amplifier



Negative feedback

Feedback can be of two types:

- Negative feedback
- positive feedback.

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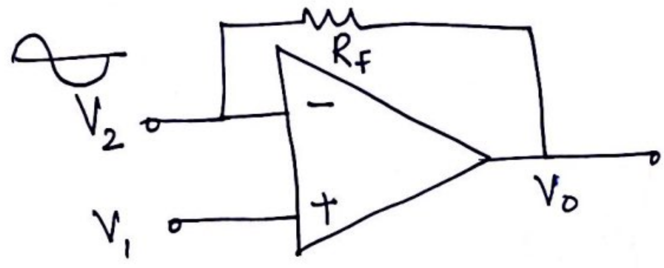
Negative feedback



If the signal feedback to the input and the original input signal are 180° out of phase, then it is called as negative feedback.

used for amplifiers.

Positive feedback

If the feedback signal and the original input signal are in phase with each other, then it is called as positive feedback

Used for oscillators, schmitt triggers etc.

University Question

Q What is negative feedback? What are the advantages of negative feedback. (2 Marks)

Advantages of negative feedback

- It stabilizes the gain
- Reduces distortion
- Increases the bandwidth.
- Reduces the effect of variations in temperature and supply voltage on the output of opamp.

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Lecture 35

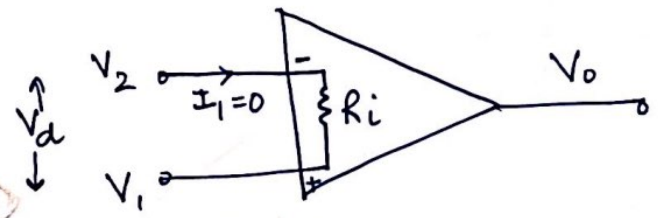
Unit 3: operational Amplifiers

Contents

- Virtual ground concept
- Practical opamp Configurations: Inverting, Non Inverting, Unity gain amplifier.

Virtual ground concept

According to virtual Short concept, the potential difference between the two input terminals of an opamp is almost zero.



As $R_i = \infty$

$I_1 = 0$

The input impedance of an ideal opamp is ∞. Hence the current I_1 flowing from one input terminal to other is zero. and both the input terminals will be at the same potential. In short, they are said to be virtually Shorted to each other.

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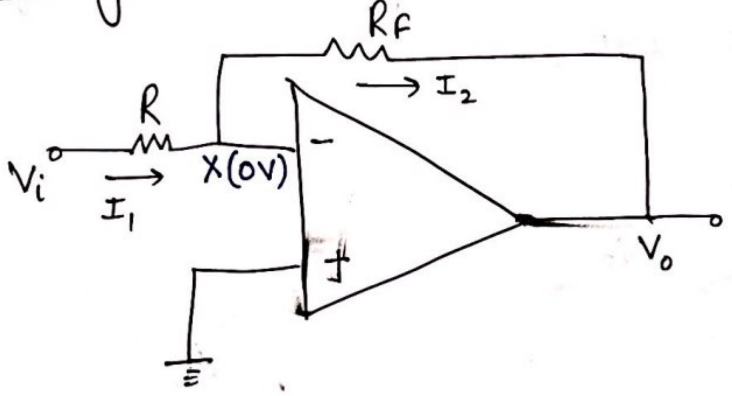
Now if non inverting terminal is at ground potential then due to 'virtual short', the inverting terminal will also be at ground and vice versa.

Practical opamp Configurations

- Inverting Amplifier.
- Non Inverting Amplifier
- Unity gain Amplifier / Voltage follower.

Inverting amplifier



According to virtual ground concept, the potential of non inverting terminal appears at point $X = 0V$

Apply KCL at 'X'

$$I_1 - I_2 = 0$$

$$I_1 = I_2$$

$$\frac{V_i - 0}{R} = \frac{0 - V_o}{R_f}.$$

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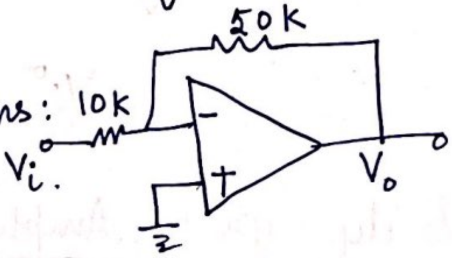
$$\boxed{V_o = -\frac{R_F}{R} V_i}$$

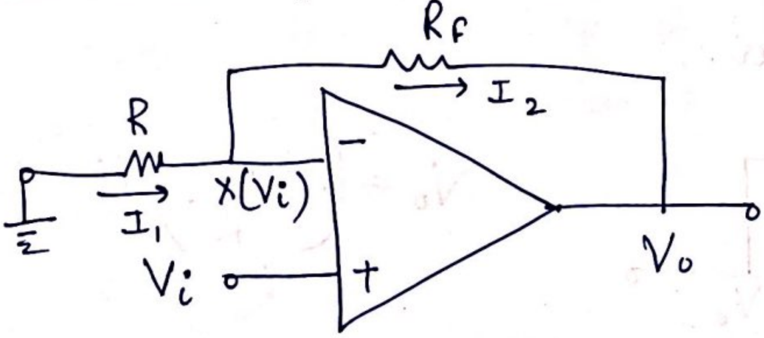
closed loop gain $\boxed{A_{cl} = \frac{-R_F}{R}}$

Q1. Design an inverting amplifier with a gain of -5 and input impedance of 10kΩ.

Ans:



Non Inverting Amplifier



According to virtual ground concept, the potential of Non Inverting terminal appears at Point 'x' = V_i Volts.

Apply KCL at 'x'

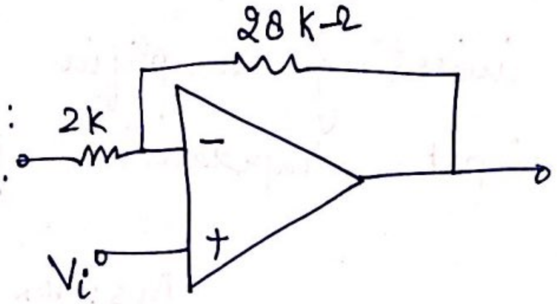
$$I_1 = I_2$$

$$\frac{0 - V_i}{R} = \frac{V_i - V_o}{R_F} \Rightarrow \boxed{V_o = \left(1 + \frac{R_F}{R}\right) V_i}$$

$$\boxed{A_{cl} = 1 + \frac{R_F}{R}}$$

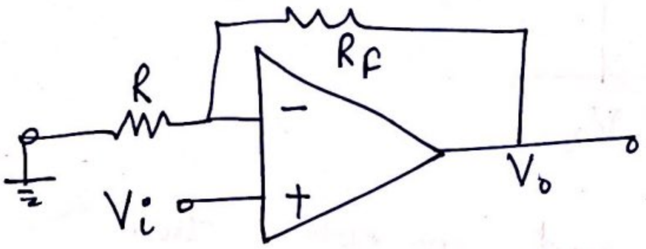
Q2. Design a non Inverting amplifier circuit that is capable of providing a voltage gain of 15. Assume that the ideal resistances should not exceed 30kΩ.

Ans:



Unity gain Amplifier

Unity gain amplifier is a special case of non inverting amplifier.

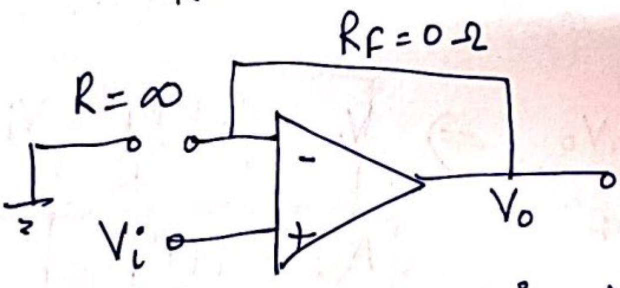


$$V_o = \left(1 + \frac{R_f}{R}\right) V_i$$

Non Inverting Amplifier

If $R_f = 0\,\Omega$
$R = \infty$

$\Rightarrow$



$$V_o = \left(1 + \frac{0}{\infty}\right) V_i$$

$$\boxed{V_o = V_i}$$

Unity gain Amplifier $\boxed{A_{cl} = 1}$

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ept, the

the gain is exactly equal to 1. Output voltage follows input voltage.

University Questions

(UPTU 2015-16) even sem.
(10 Marks).

Q. Explain the following.
(a) voltage follower
(b) Non Inverting amplifier.
(c). Differential amplifier in two modes of operation.

Q. Explain with the help of necessary diagram (2015-16) odd sem (10 Marks)
(a) Inverting amplifier.
(b). Integrator
(c) Differential amplifier in two modes of operation.

Q. Show that how input voltage gets reversed using operational amplifier. Also derive the expression for the voltage gain of inverting amplifier (10 Marks) (2014-15)

Q. Design and draw an inverting amplifier using opamp with gain of -5 and $R_i = 10k\Omega$. (2016-17) (5 Marks).

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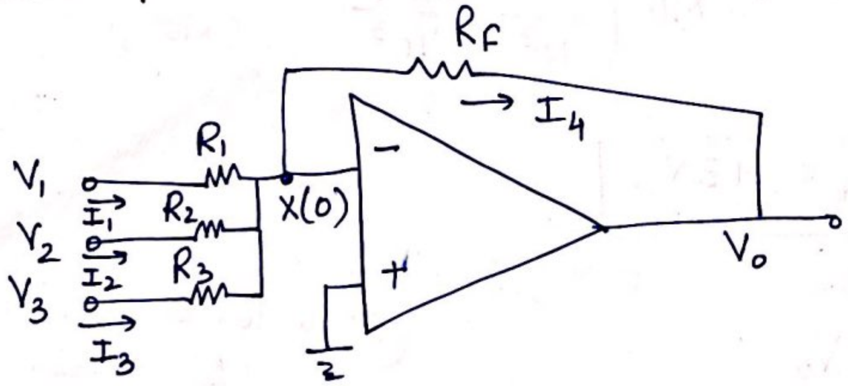
Lecture 36

Unit 3 : Operational Amplifiers

Contents

- opamp applications : Summer, Integrator, differentiator,

Summer/ Adder



Applying virtual ground concept, the potential of non inverting terminal appears at point 'x'

Apply KCL at 'x'

$$I_1 + I_2 + I_3 - I_4 = 0$$

$$I_1 + I_2 + I_3 = I_4$$

$$\frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_3 - 0}{R_3} = \frac{0 - V_o}{R_f}$$

$$\boxed{V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \dots\right)}$$

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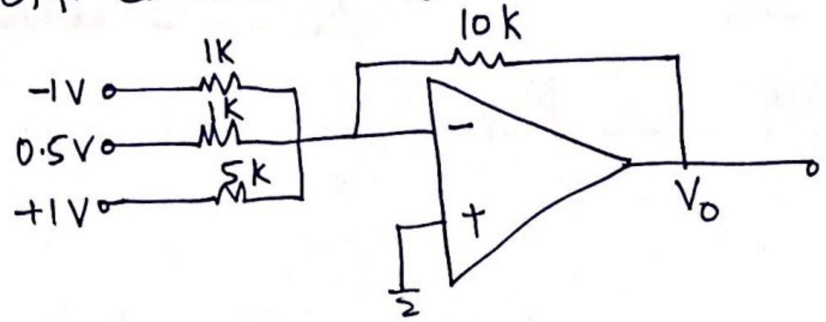
Q1. Calculate V_o

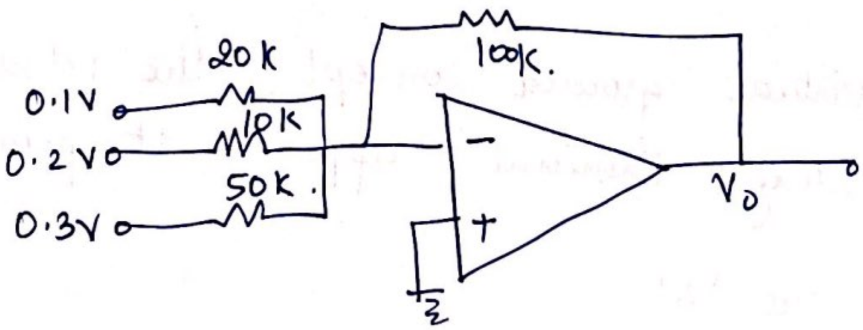


$$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

$$= -10\times10^3\left(\frac{-1}{10^3} + \frac{0.5}{10^3} + \frac{1}{5\times10^3}\right)$$

$$\boxed{V_o = +3V}$$

Q2. Calculate V_o (2015-16 even sem) (5 Marks)



$$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

$$= -100\times10^3\left(\frac{0.1}{20\times10^3} + \frac{0.2}{10\times10^3} + \frac{0.3}{50\times10^3}\right)$$

$$= -100\left(\frac{0.1}{20} + \frac{0.2}{10} + \frac{0.3}{50}\right)$$

$$= -100\left(.005 + .02 + .006\right)$$

$$\boxed{V_o = -3.1V}$$

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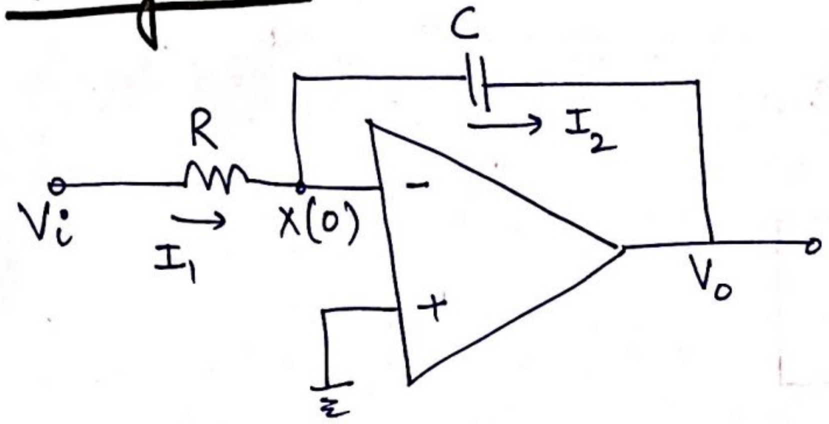
Integrator



According to virtual ground concept, the potential of non inverting terminal appears at point 'x'

Apply KCL at 'x'

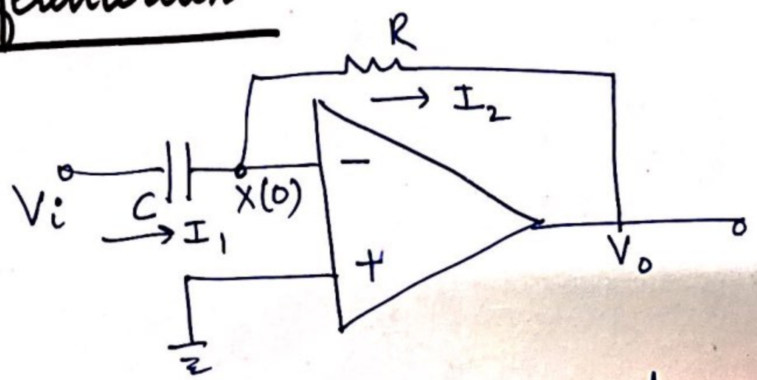
$$I_1 = I_2$$

$$i = \frac{c\,dv}{dt}.$$

$$\frac{V_i - 0}{R} = C\frac{d}{dt}(0 - V_o)$$

$$\boxed{V_o = -\frac{1}{RC}\int V_i(t)\,dt}$$

Differentiator



According to virtual ground concept, the potential of non inverting terminal appears at point 'x'.

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$$I_1 = I_2$$

$$i = \frac{c\,dV}{dt}$$

$$C\frac{d}{dt}(V_i - 0) = \frac{0 - V_o}{R}$$

$$\boxed{V_o = -RC\frac{d}{dt}V_i}$$

University Questions

Q. Describe in detail Integrator and Differentiator with suitable circuit. (10 Marks) (2014-15). (2017-18)

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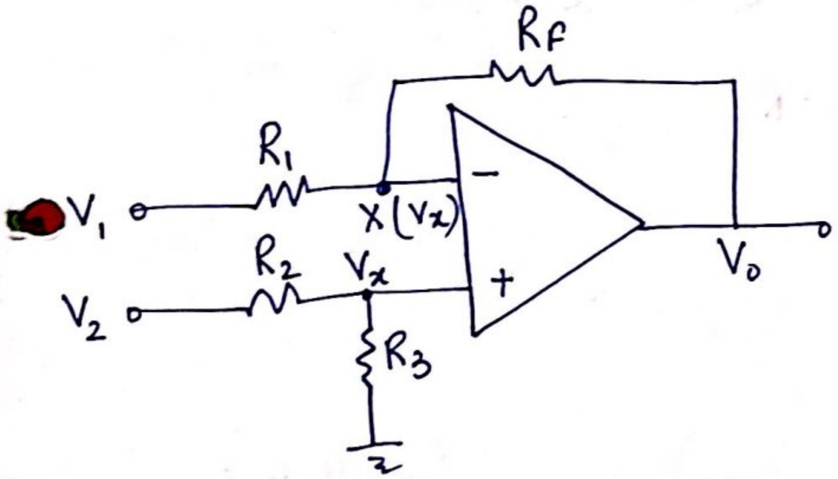
Lecture 37

Unit 3: operational Amplifiers

Contents

- Subtractor / Difference amplifier.



Apply superposition principle.

Case 1 V_1 = active $V_2 = 0$

$V_0 = V_{out\,1}$

$$V_{out1} = -\frac{R_F}{R_1} V_1$$

Case 2 V_2 = active $V_1 = 0$

$V_0 = V_{out\,2}$

$$V_{out2} = \left(1 + \frac{R_F}{R_1}\right) V_x$$

$$V_x = \frac{V_2 \times R_3}{R_2 + R_3}$$

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$$V_{out\,2} = \left(1+\frac{R_f}{R_1}\right)\left(\frac{V_2 R_3}{R_2+R_3}\right)$$

$$\text{Total } V_o = V_{out\,1} + V_{out\,2}$$

$$= -\frac{R_f}{R_1}(V_1) + \left(1+\frac{R_f}{R_1}\right)\left(\frac{V_2 R_3}{R_2+R_3}\right)$$

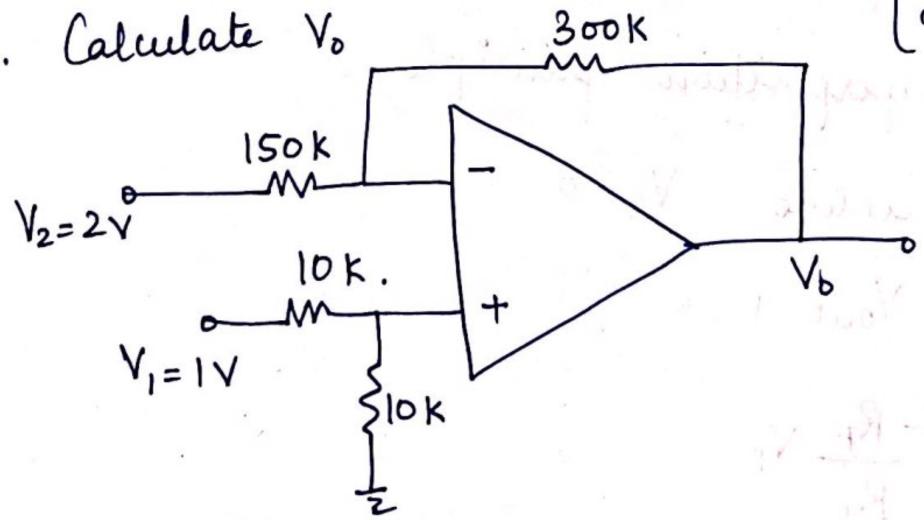
$$R_1 = R_2 = R_3 = R_f = R.$$

$$V_o = -V_1 + V_2$$

$$\boxed{V_o = V_2 - V_1}$$

Q1. Calculate V_o

(2014-15)
(5 Marks).



(2017-18)
(even) (7 Marks).

Apply superposition principle.

Case I V_2 = active $V_1 = 0$

$V_o = V_{out\,1}$

$$V_{out\,1} = \frac{-300K}{150K}(2V)$$

$$V_{out\,1} = -4V$$

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Case 2 $V_1 = \text{active} \quad V_2 = 0$

$V_o = V_{out\,2}$

$$V_{out\,2} = \left(1 + \frac{300k}{150k}\right) V_x$$

$$V_x = \frac{10k \times 1V}{20k}$$

$$= 0.5\ V.$$

$$V_{out\,2} = (1+2)\,0.5$$

$$V_{out\,2} = 1.5\ V$$

$$V_o = V_{out\,1} + V_{out\,2}$$

$$= -4 + 1.5$$

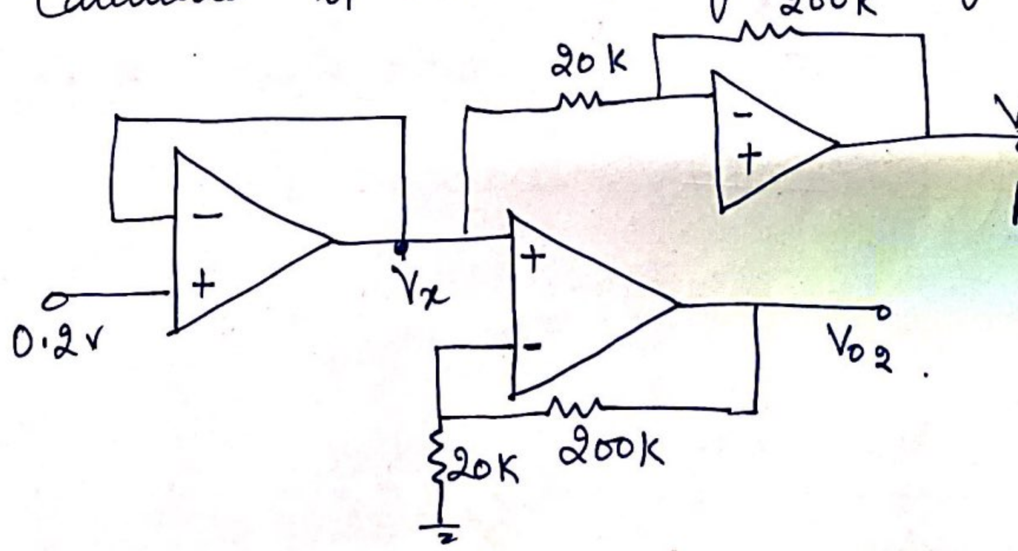
$$\boxed{V_o = -2.5\ V}$$

University Questions

Q Calculate V_{o1} and V_{o2} for the following circuit.

(2015-16 odd sem)

(10 Marks)



Ans: $V_{o1} = -2V$

$V_{o2} = 2.2V$

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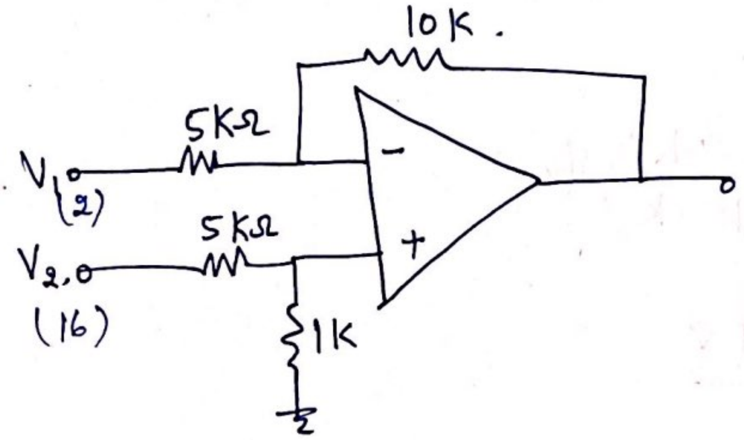
Q. find V_o of opamp. (2015-16 even sem) (5 Marks)



case1 V_1 = active $V_2 = 0$

$$V_o = V_{out1} = -\frac{10K}{5K} V_1$$

$$= -2V_1$$

case2 V_2 = active $V_1 = 0$

$$V_o = V_{out2} = \left(1 + \frac{10k}{5k}\right) V_x = (1+2) \times \frac{V_2}{6} = \frac{V_2}{2},$$

$$V_x = \frac{V_2 \times \cancel{10^3}}{6 \times \cancel{10^3}} = \frac{V_2}{6}$$

$$V_o = -2V_1 + \frac{V_2}{2}$$

$$= \left(\frac{-4V_1 + V_2}{2}\right)$$

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