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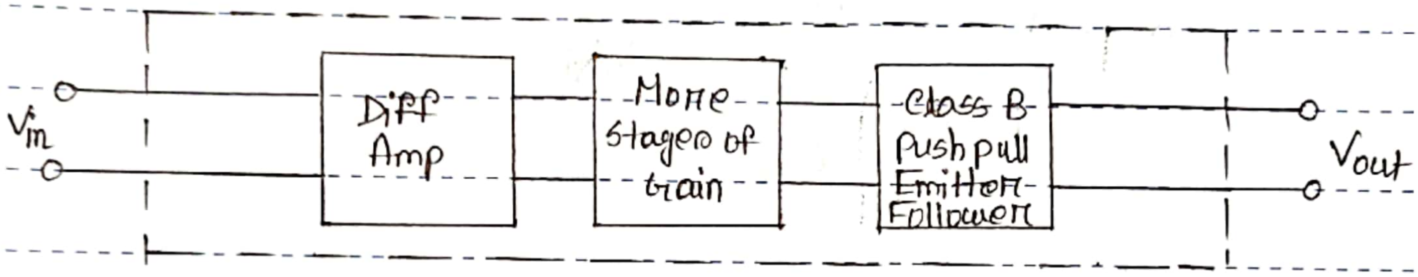
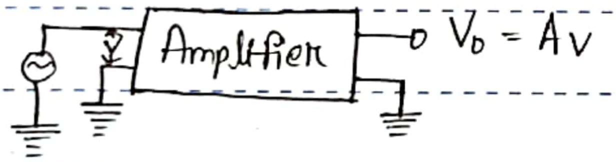
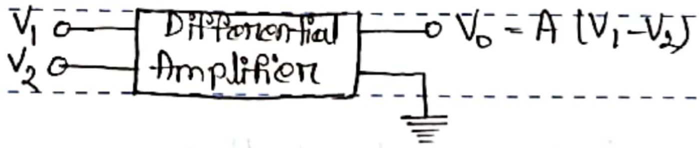
operation amplifier: An operation amplifier is a circuit that can perform such mathmatical operations as addition, subtraction, integration and differentiation.



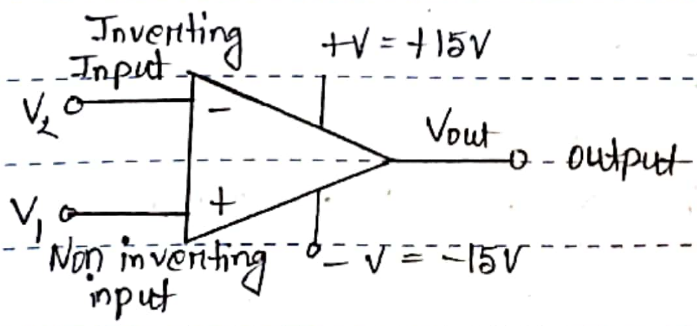
Block diagram of op-amp

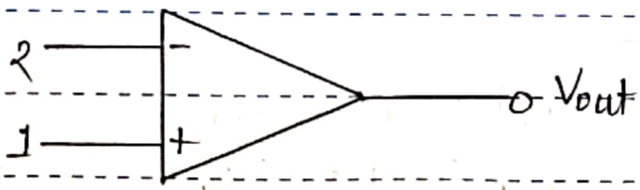
Differential amplifier: A differential amplifier is a circuit that can ~~input~~ accept two input signals and amplify the difference between these two input signals.





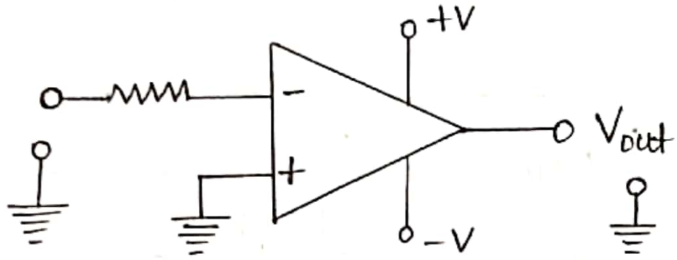
Schematic symbol of operational Amplifier:



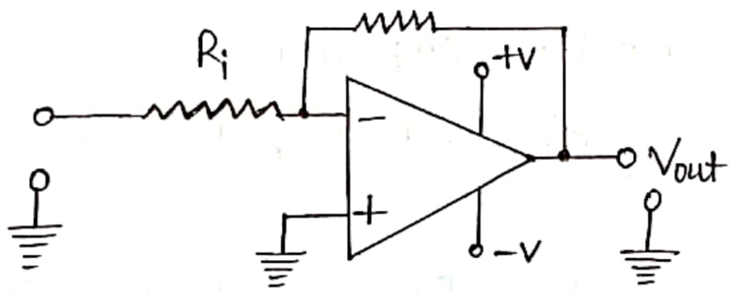


Voltage gain of op-amp: The maximum possible voltage gain from a given op-amp is called open-loop voltage gain. and denoted by the symbol A_{OL}.

open-loop voltage gain:



closed loop voltage gain:



A.C analysis of op-Amp:

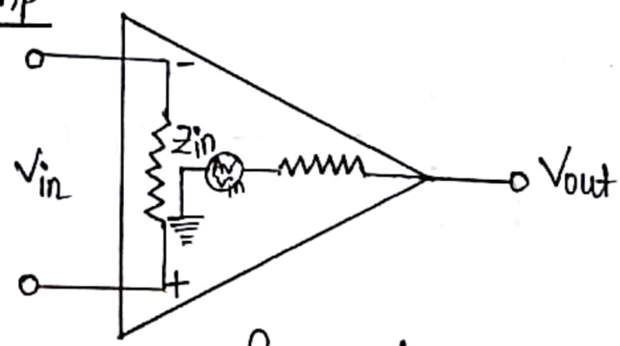
Equivalent circuit of practical op-Amp:

characteristics of practical op-amp are:

(i) Very high voltage gain

(ii) very high input impedance

(iii) Very low output impedance



Practical op-Amp

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Properties of practical op-amp are–

(a) Since the voltage gain (A_v) of a practical op-amp is very high, an extremely small input voltage (V_{in}) will produce a large output voltage (V_{out})

(b) Since the input impedance (Z_{in}) is very high, a practical op-amp has very small input current.

(c) Since the output impedance (Z_{out}) of a practical op-amp is very low, it means the output voltage is practically independent of the value of load ~~reis~~ is connected to op-amp.

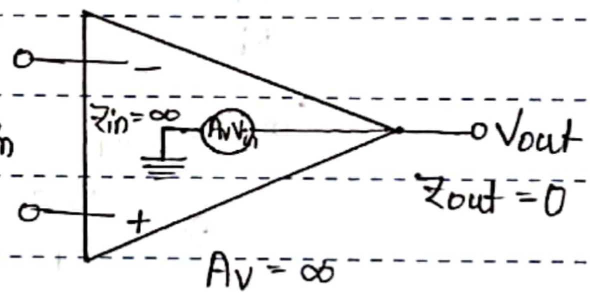
Equivalent circuit of Ideal op-Amp:

The characteristics of an ideal op-amp are–

(i) Infinite voltage gain

(ii) Infinite Input Impedance

(iii) Zero output impedance



Ideal op-amp

Properties of ideal op-amp are–

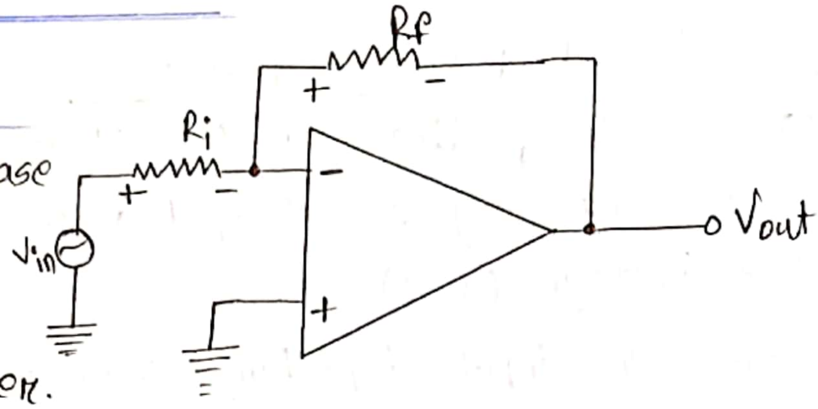
(a) Since the voltage gain (A_v) of an ideal op-amp is infinite, it means that $V_{in} = 0V$

(b) Since the input impedance (Z_{in}) is infinite, an ideal op-amp has zero input current.

(c) Since the output impedance (Z_{out}) of an ideal op-amp is zero, it means the output voltage does not depend on the value of load connected to op-amp.

Op-amp with negative feedback:

Inverting Amplifier: An Amplifier which has phase shift of 180° between input and output is called inverting amplifier.



Here, $I_{in} = \dfrac{\text{Voltage across } R_i}{R_i}$; $I_f = \dfrac{\text{Voltage Across } R_f}{R_f}$

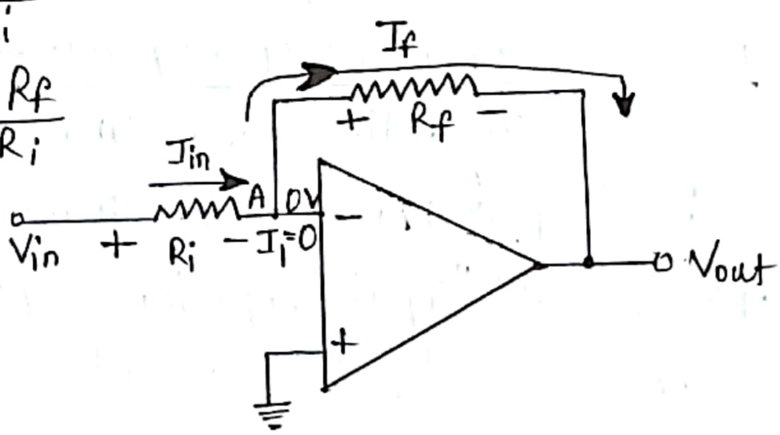
$$I_{in} = \frac{V_{in} - V_A}{R_i} = \frac{V_{in} - 0}{R_i} = \frac{V_{in}}{R_i}$$

$$I_f = \frac{V_A - V_{out}}{R_f} = \frac{0 - V_{out}}{R_f} = \frac{-V_{out}}{R_f}$$

Since, $I_f = I_{in}$

$$\Rightarrow -\frac{V_{out}}{R_f} = \frac{V_{in}}{R_i}$$

$\therefore$ Voltage Gain, $A_{CL} = \dfrac{V_{out}}{} = -\dfrac{R_f}{R_i}$



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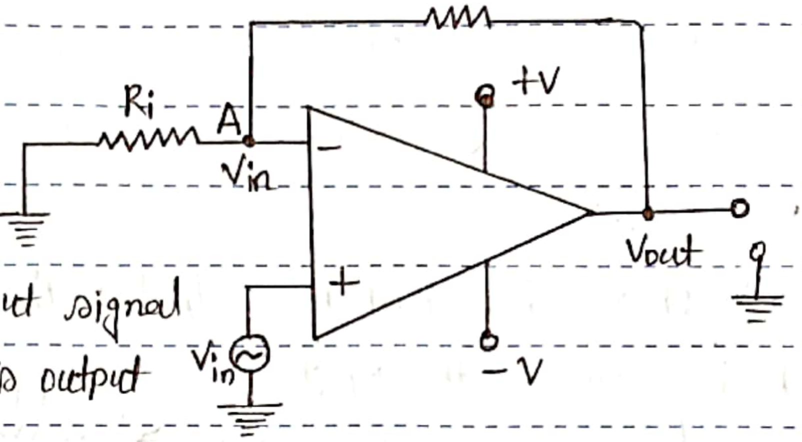
Non inverting amplifier:

A non inverting amplifier produces an output signal that is in phase with the input signal whereas an inverting amplifier's output is out of phase.



Voltage Across, $R_i = V_{in} - 0$

Voltage Across, $R_f = V_{out} - V_{in}$

Now, current through R_i = Current through R_f

$$\Rightarrow \frac{V_{in} - 0}{R_i} = \frac{V_{out} - V_{in}}{R_f}$$

$$\Rightarrow V_{in} R_f = V_{out} R_i - V_{in} R_i$$

$$\Rightarrow V_{in} R_f + V_{in} R_i = V_{out} R_i$$

$$\Rightarrow V_{in}(R_f + R_i) = V_{out} R_i$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{R_f + R_i}{R_i}$$

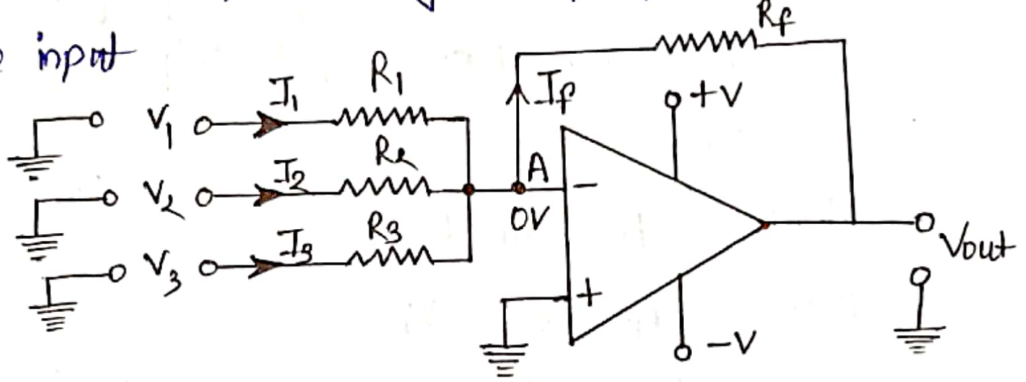
$$\Rightarrow \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i}$$

$\therefore$ closed loop Voltage Gain, $A_{CL} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i}$

$$\therefore A_{CL} = 1 + \frac{R_f}{R_i}$$

Summing Amplifier: A summing amplifier is an inverted op-amp that can accept two or more inputs. The output voltage of a summing amplifier is proportional to the negative of the algebraic sum of its input voltages.

{ (Question:) ⇒ Show that the output voltage is proportional to the algebraic sum of the input voltages. }



$$I_f = I_1 + I_2 + I_3$$

when all the three inputs are applied, output voltage is,

$$V_{out} = -I_f R_f$$

$$= -R_f (I_1 + I_2 + I_3)$$

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

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

If, $R_1 = R_2 = R_3 = R$ then we have,

$$V_{out} = -\frac{R_f}{R}(V_1 + V_2 + V_3)$$

If, $R_f = R_1 = R_2 = R_3 = R$ then output voltage is,

$$V_{out} = -(V_1 + V_2 + V_3)$$

Thus, when the gain of summing amplifier is unity the output voltage is the algebraic sum of the input voltages.

$$\therefore V_{out} = -\frac{R_f}{R}(V_1 + V_2 + V_3 + \dots)$$

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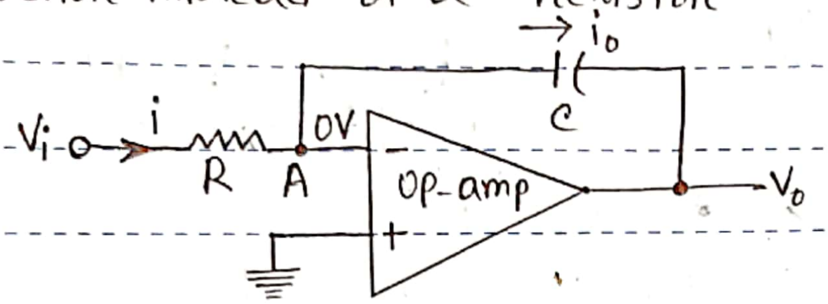
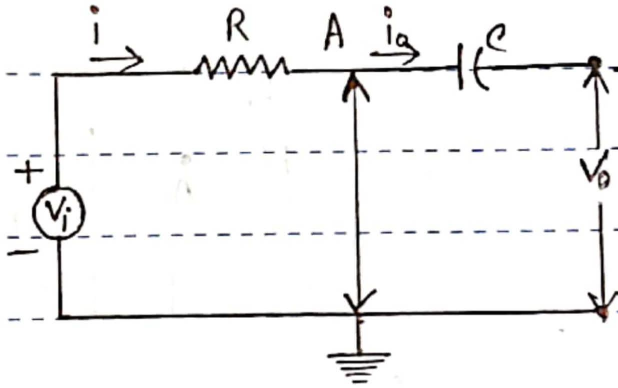
Op-Amp Integrator: An integrator is a circuit that performs integration of the input signal. Here, feedback component is a capacitor instead of a resistor





$$i = i_c$$

$$i = \frac{V_i - 0}{R} = \frac{V_i}{R} \quad \text{—— (1)}$$

Voltage across capacitor is $V_c = 0 - V_o = -V_o$

$$i_c = \frac{C dV_c}{dt} = -C\frac{dV_o}{dt} \quad \text{—— (2)}$$

From (1) and (2) $\frac{V_i}{R} = -C\frac{dV_o}{dt}$

$$\frac{dV_o}{dt} = -\frac{1}{RC}V_i \quad \text{—— (3)}$$

Integrating both sides, of eqn (3) we get,

$$V_o = -\frac{1}{RC}\int_0^t V_i\, dt$$

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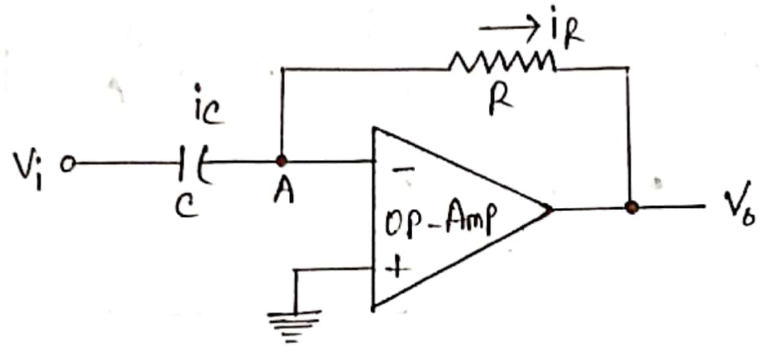
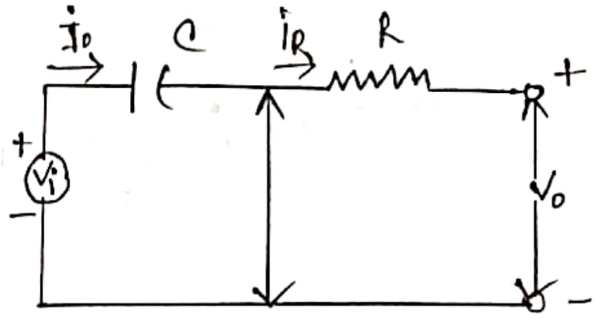
OP-Amp Differentiator: A differentiator is a circuit that performs differentiation of the input signal. A differentiator produces an output voltage that is proportional to the rate of change of the input voltage.





$$i_c = i_R$$

$$i_R = \frac{0 - V_o}{R} = \frac{-V_o}{R} \quad \text{and} \quad V_c = V_i - 0 = V_i$$

$$\Rightarrow i_c = C\frac{dV_c}{dt} = C\frac{dV_i}{dt}$$

$$\Rightarrow -\frac{V_o}{R} = C\frac{dV_i}{dt}$$

$$\therefore V_o = -RC\frac{dV_i}{dt}$$

Date: ..../.........../.......

25.1 A differential amplifier has an open-circuit voltage gain of 100. The input signals are 3.25 V and 3.15 V. Determine the output voltage?

Solution: Here, $A = 100$, $V_1 = 3.25V$, $V_2 = 3.15\ V$

Output voltage, $V_0 = A\,(V_1 - V_2)$

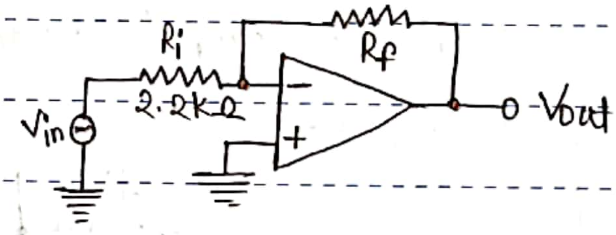
$= 100\,(3.25 - 3.15)$

$= 10V$

(Ans)

(Inveting Amplifier Math)

25.25 Given the op-amp configuration in Figure, determine the value of R_f required to produce a closed loop voltage gain of -100.



Solution:

$$A_{CL} = -\frac{R_f}{R_i}$$

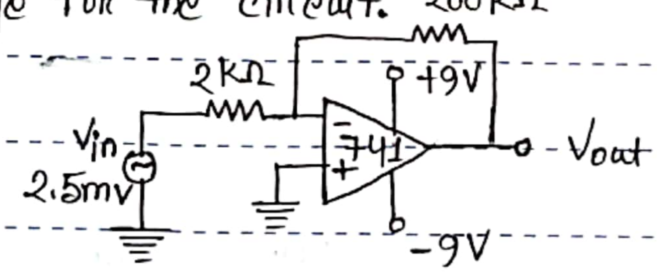
$$\Rightarrow -100 = -\frac{R_f}{2.2}$$

$$\Rightarrow R_f = 100 \times 2.2$$

$$\therefore R_f = 220\ k\Omega$$

(Ans)

25.26 Determine the output voltage for the circuit.



Solution:

$$A_{CL} = -\frac{R_f}{R_L}$$

$$= -\frac{200k\Omega}{2k\Omega} = -100$$

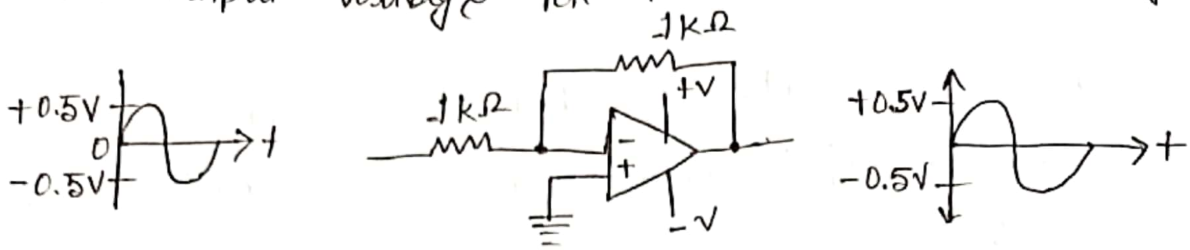
Output voltage, $V_{out} = A_{CL} \times V_{in}$

$= (-100) \times (2.5\ mV)$

$= -250\ mV$

$= -0.25V$ (Ans)

25.27 Find the output voltage for the circuit shown in figure.



Solution:

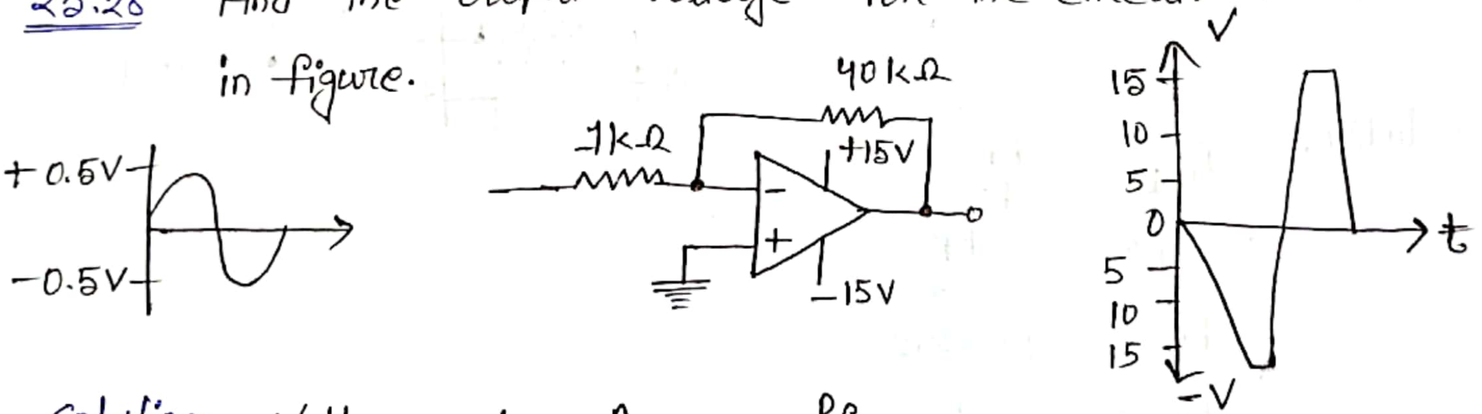
Voltage Gain, $A_{CL} = -\frac{R_f}{R_i}$

$= -\frac{1k\Omega}{1k\Omega}$

$= -1$

Since, the voltage gain of the circuit is −1, the output will have the same amplitude but with 180° phase inversion.

25.28 Find the output voltage for the circuit shown in figure.



Solution: Voltage gain, $A_{CL} = -\frac{R_f}{R_i}$

$= -\frac{40k\Omega}{1k\Omega}$

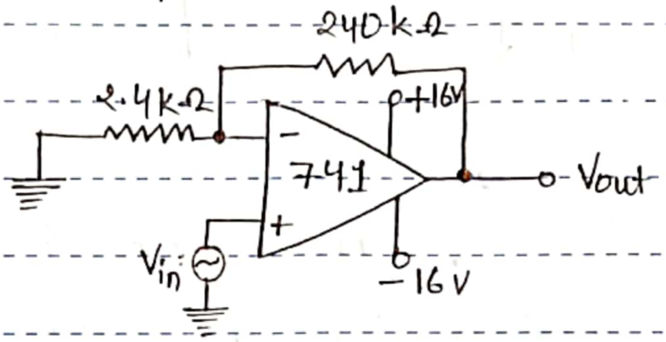
$= -40$

Here, voltage gain is −40. (Ans)

This means that the output will not have the same shape as input but will clip at the saturation voltage.

(Non-inverting amplifier Math) Date: ..../........../......

25.32 Calculate the output voltage from the noninverting amplifier circuit shown in figure for an input of 120 ~~m~~ μV.



Solution:

Voltage gain, $A_{CL} = 1 + \frac{R_f}{R_i}$

$= 1 + \frac{240k\Omega}{2.4k\Omega}$

$= 1 + 100$

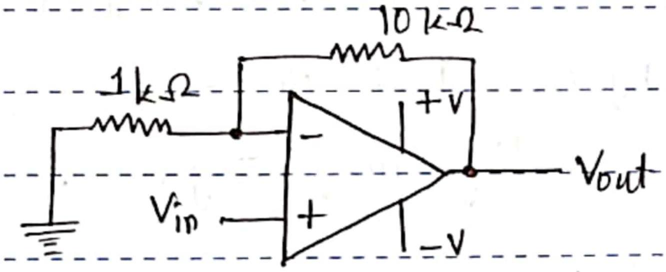
$= 101$

output voltage, $V_{out} = A_{CL} \times V_{in} = (101) \times (120) = 12120\,\mu = 12.12m$

(Ans)

25.33 For the noninverting amplifier circuit shown in figure. Find the output voltage for an input voltage of (i) 1V and (ii) −

Solution:



Voltage gain $A_{CL} = 1 + \frac{R_f}{R_i}$

$= 1 + \frac{10}{1}$

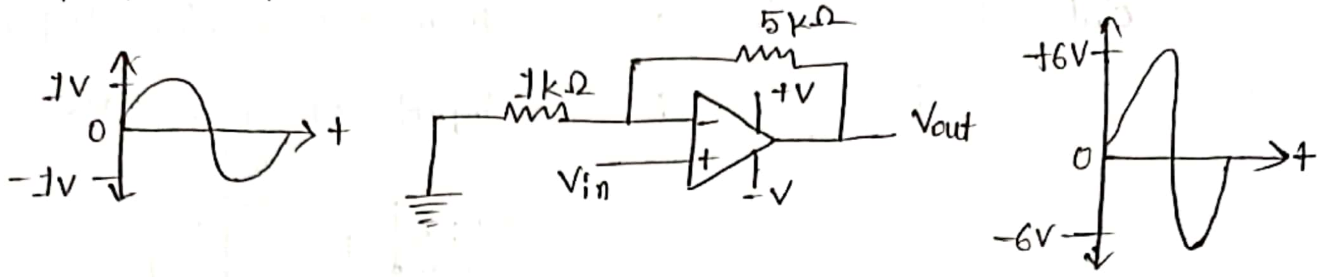
$= 11$

(i) For $V_{in} = 1V$; $V_{out} = A_{CL} \times V_{in} = (11 \times 1)V = 11V$

(ii) For $V_{in} = -1V$; $V_{out} = A_{CL} \times V_{in} = 11 \times (-1) = -11V$.

(Ans)

25.34 For the noninverting amplifier circuit shown in figure, find peak to peak output voltage.



Solution: The input signal is 2V peak to peak.

Voltage Gain, $A_{CL} = 1 + \frac{R_f}{R_i} = 1 + \frac{5k\Omega}{1k\Omega} = 1+5 = 6$

$\therefore$ Peak to peak output voltage $= A_{CL} \times V_{inpp}$

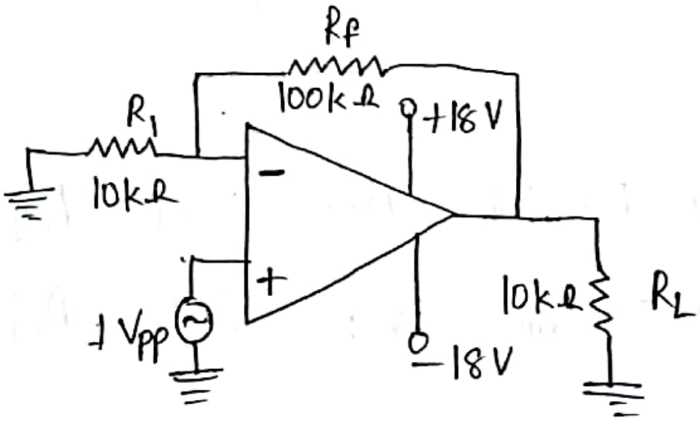
$= 6 \times 2$

$= 12V.$

(Ans)

25.35 For the non inverting amplifier circuit shown in figure, Find (i) closed loop voltage gain (ii) Maximum operating frequency. The slew rate is 0.5 V/µs.

Solution:



(i) Voltage gain, $A_{CL} = 1 + \frac{R_f}{R_i}$

$= 1 + \frac{100}{10}$

$= 1 + 10$

$= 11.$

Date: ..../............/.......

(iii) To determine the value of maximum operating frequency (f_{max}), we need to calculate the peak output voltage for the amplifier. The peak to peak output voltage is,

$$V_{out} = A_{CL} \times V_{in} = 11 \times (1 V_{pp}) = 11 V_{pp}$$

Peak output voltage, $V_{pk} = 11/2 = 5.5\,V$

$$f_{max} = \frac{\text{slew rate}}{2\pi V_{pk}} = \frac{0.5\,V/\mu s}{2\pi \times 5.5}$$

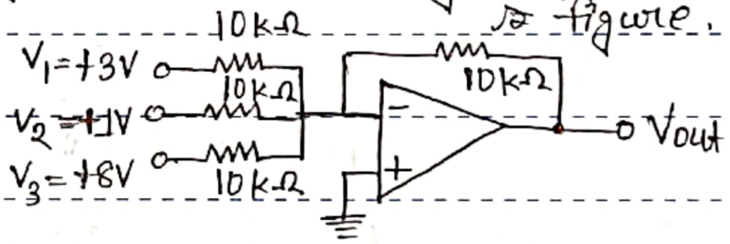
$$= \frac{500\,kHz}{2\pi \times 5.5} \quad [0.5\,V/\mu s = 500\,kHz]$$

$$= 14.47\,kHz$$

(Ans)

(Summing Amplifier Math)

25.44 Determine the output voltage for the summing amplifier in figure.

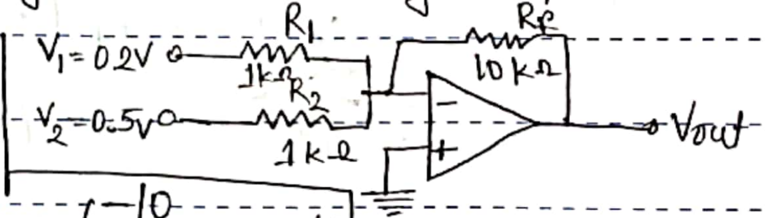


Solution:

$$V_{out} = -(V_1 + V_2 + V_3)$$
$$= -(3+1+8)$$
$$= -12V$$

(Ans)

25.45 Determine the output voltage for the summing Amplifier shown in figure.

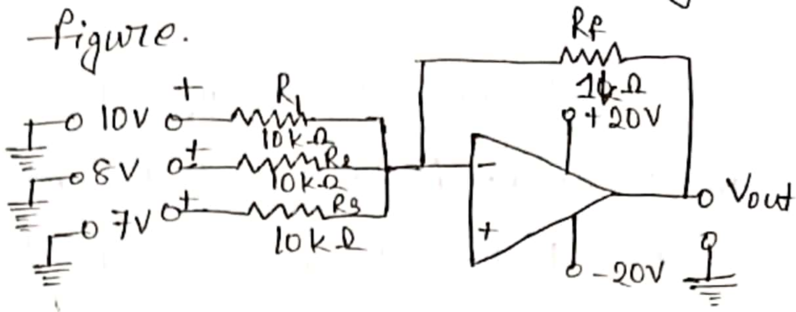


Solution: $R_f = 10k\Omega$, $R_1 = R_2 = R = 1k\Omega$

Gain of Amplifier $= -R_f/R = \left(\frac{-10}{1}\right) = -10$

$$V_{out} = -\frac{R_f}{R}(V_1 + V_2)$$
$$= -\frac{10k\Omega}{1k\Omega}(0.2 + 0.5)$$
$$= -7V \quad \text{(Ans)}$$

25.46 Determine the output voltage for the summing Amplifier shown in figure.



Solution: $R_f = 1k\Omega$

$R_1 = R_2 = R_3 = R = 10k\Omega$

gain of amplifier $= -\frac{R_f}{R} = -\frac{1}{10} = -1/10$

$$V_{out} = -\frac{R_f}{R}(V_1+V_2+V_3)$$

$$= -\frac{1}{10}(10+8+7)$$

$$= -2.5\ V$$

(Ans).

25.47 Two voltages of +0.6V and −1.4V are applied to the two input resistors of a summing amplifier. The respective input resistors are 400k Ω and 100k Ω and feedback ~~capacitor~~ resistor is 200 k Ω. Determine the output voltage.

Solution:

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

$$\therefore V_{out} = -200k\Omega\left(\frac{0.6}{400}+\frac{-1.4}{100}\right)$$

$$= 2.5\ V$$

(Ans)

Here,

$R_f = 200k\Omega$

$R_1 = 400k\Omega$

$R_2 = 100k\Omega$

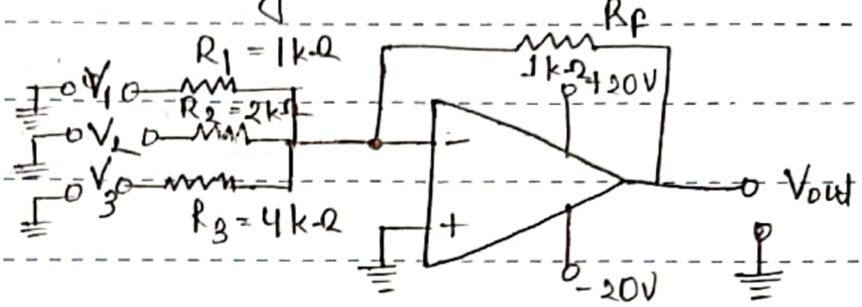
$V_1 = +0.6V$

$V_2 = -1.4V$

Date: ..../............/.......

2548 Determine the output voltage from the circuit shown in figure for each of the following input combinations.

$V_1(V)$	$V_2(V)$	$V_3(V)$
+10	0	+10
0	+10	+10
+10	+10	+10



Solution: $V_{out} = -\frac{R_f}{R_i}(V_1+V_2+V_3)$

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

$$= -\left(\frac{1}{1}V_1 + \frac{1}{2}V_2 + \frac{1}{4}V_3\right)$$

$$V_{out} = -(V_1 + 0.5V_2 + 0.25V_3)$$

The output voltage for the first set of input is

$$V_{out} = -(10 + 0.5\times 0 + 0.25\times 10) = -1.25\ V$$

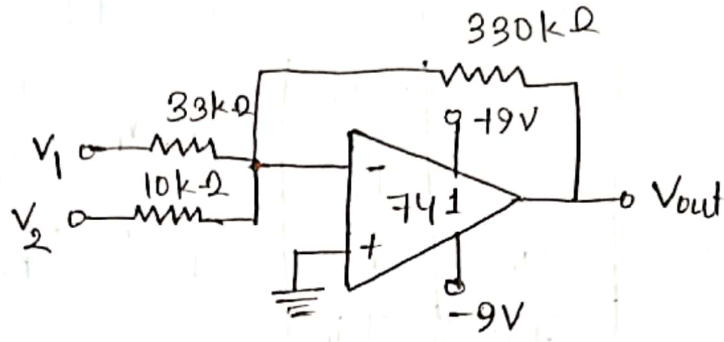
For the 2nd set of input is

$$V_{out} = -(0 + 0.5\times 10 + 0.25\times 10) = -7.5V$$

For the 3rd set of input is

$$V_{out} = -(10 + 0.5\times 10 + 0.25\times 10) = -17.5V.$$

25.49 Calculate the output voltage for the circuit of figures. The inputs are $V_1 = 50 \sin(1000t)$ mV and $V_2 = 10 \sin(3000t)$ mV.



Solution: The output voltage for the circuit is,

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

$$= -\left(\frac{330 k\Omega}{33 k\Omega} V_1 + \frac{330 k\Omega}{10 k\Omega} V_2\right)$$

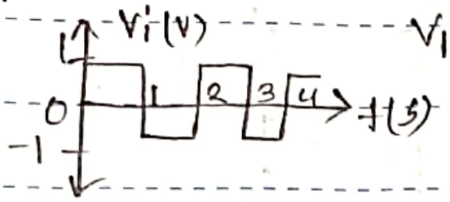
$$= -(110 V_1 + 33 V_2)$$

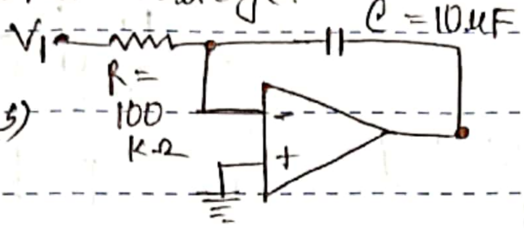
$$= -[10 \times 50 \sin(1000t) + 33 \times 10 \sin(3000t)] \text{ mV}$$

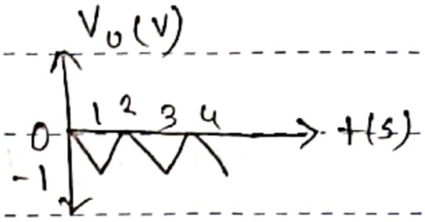
$$= -[0.5 \sin(1000t) + 0.33 \sin(3000t)] \text{ V}$$

(Op-amp Integrator math) Date: ..../.........../.......

25.50 Shows the op-amp integrator and the square wave input. Find the output voltage.







Solution: The output voltage of this circuit is given by,

$$V_o = -\frac{1}{RC}\int_0^t V_i dt$$

$$RC = (100)k\Omega \times (10)\mu F$$

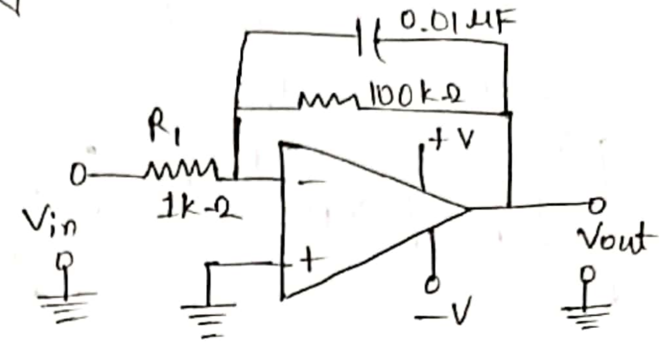
$$= (100 \times 10^3 \, k\Omega)(10 \times 10^{-6} F)$$

$$= 1S$$

$$V_o = -\int_0^t V_i dt$$

When we integrate a constant, we get a straight line, when input voltage to an integrator is constant, the output is a linear ramp. Then input to the integrator is applied to the inverting input, the output of the circuit will be 180° out of phase with the input. When input goes positive, the output will be a negative ramp. When the input is negative, the output will be a positive ramp.

25.51 Determine the lower frequency limit (critical frequency) for the integrator circuit shown in figure.



Solution:

The critical frequency for the integrator circuit shown in figure.

$$f_c = \frac{1}{2\pi R_f C}$$

$$= \frac{1}{2\pi \times (10^5) \times (0.01 \times 10^{-6})}$$

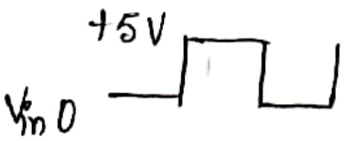
$$= 159\ Hz$$

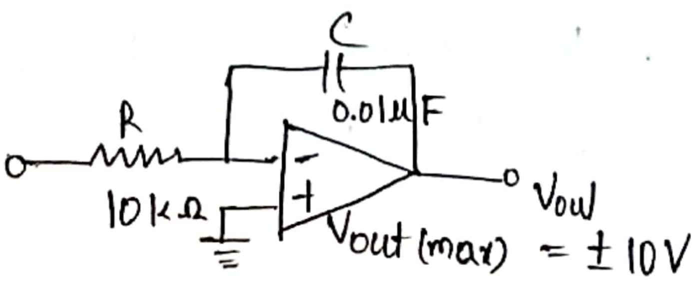
(Ans)

Here, $R_f = 100k\Omega$
$= 10^5\ \Omega$
$C = 0.01\ \mu F$
$= 0.01 \times 10^{-6} F$

25.52 (i) Determine the rate of change of the output voltage in response to a ~~signal~~ single pulse input to the integrator circuit is shown in figure.

(ii) show the output waveform.





<u>Solution:</u> <u>(i)</u> Output voltage, $V_{out} = -\frac{1}{RC}\int_0^t V_{in}\,dt$

The rate of change of output voltage is,

$$\frac{\Delta V_{out}}{dt} = -\frac{V_{in}}{RC} = -\frac{5V}{(10k\Omega)(0.01\mu F)}$$

$$= -50\ kV/s$$

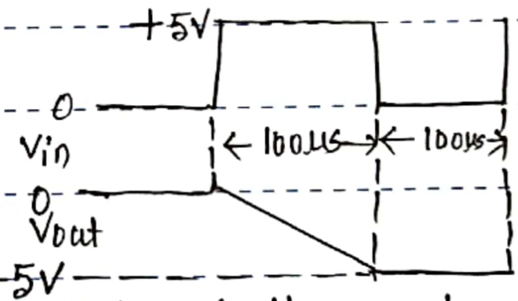
$$= -50\ mV/\mu s.$$

<u>(ii)</u> The rate of change of output voltage is $-50\ mV/\mu s$. When the input is at $+5V$, the output is a negative-going ramp. When the input is at $0V$. the output is a constant level. In $100\mu s$, the output voltage decreases.

$$\Delta V_{out} = \frac{\Delta V_{out}}{dt} \times dt$$

$$= \frac{-50\ mV}{\mu s} \times 100\ \mu s$$

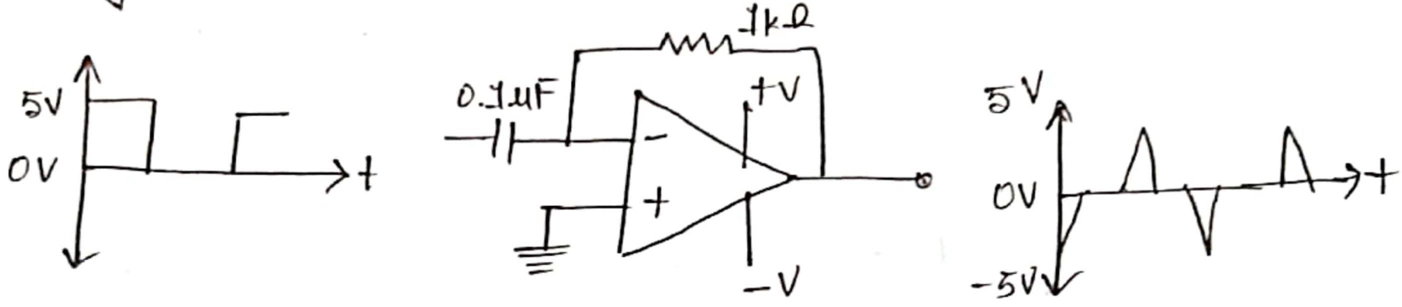
$$= -5V$$



The negative going ramp reaches $-5V$ at the end of the pulse. The output voltage the remains constant at $-5V$ for the time the input is zero.

Op-Amp differentiator (Math)

25.54 This figure shows the square wave input to a differentiator circuit. Find the output voltage if input goes from 0V to 5V in 0.1 ms.



Solution: output voltage, $V_o = -RC\dfrac{dv_i}{dt}$

$$RC = (1\,k\Omega) \times (0.1\,\mu F)$$
$$= (10^3\,\Omega)\,(0.1 \times 10^{-6}\,F)$$
$$= 0.1 \times 10^{-3}\,s$$

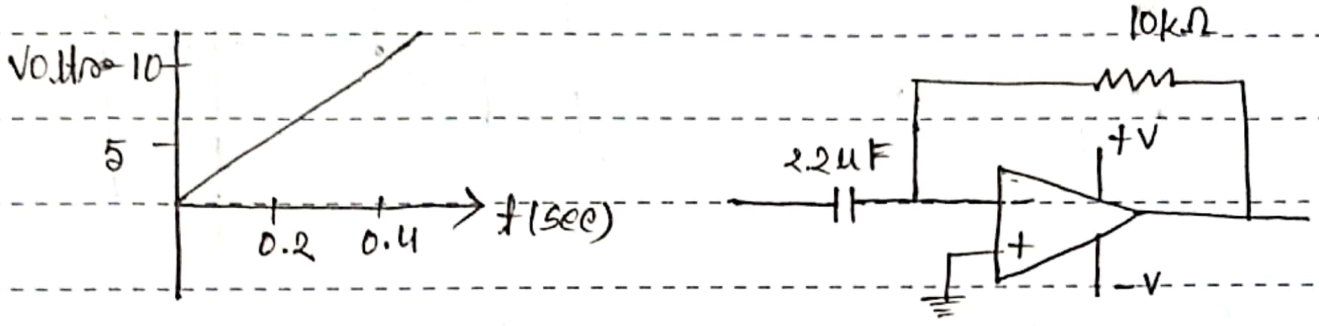
Also, $\dfrac{dv_i}{dt} = \dfrac{5V}{0.1ms} = \dfrac{5 \times 10^4 V}{s}$

$$= 5 \times 10^4\,V/s$$

$$V_o = -(0.1 \times 10^{-3})\,(5 \times 10^4)$$
$$= -5V$$

(Ans)

25.55 For the differentiator circuit shown in figure. determine the output voltage if the input goes from 0V to 10V in 0.4s. Assume the input voltage changes at constant rate.



Solution: Output voltage, $V_o = -RC\frac{dV_i}{dt}$

Now, $RC = (10k\Omega) \times (2.2\mu F) = (10^4\Omega)(2.2\times10^{-6}F)$

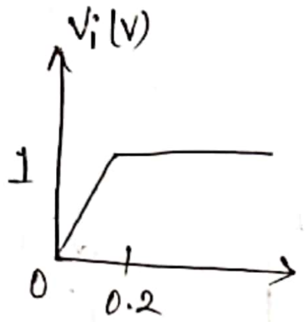
$= 2.2\times10^{-2}\ s$

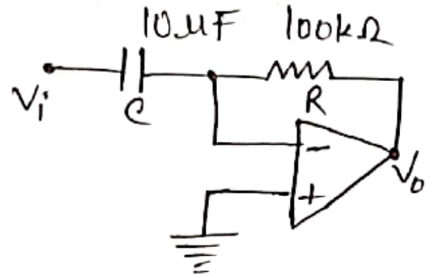
Also, $\frac{dv_i}{dt} = \frac{(10-0)V}{0.4s} = \frac{10V}{0.4s} = 25\ V/s$

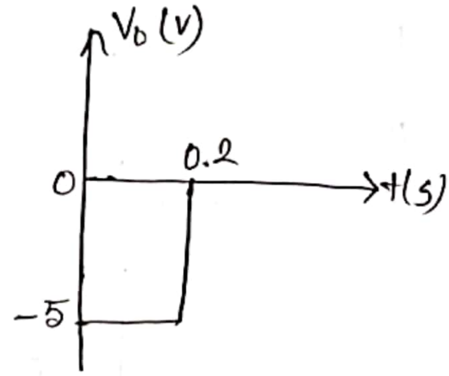
$V_o = -(2.2\times10^{-2})\times25 = -0.55\ V$

The output voltage stays constant at $-0.55V$.

25.56 For the differentiator circuit shown in figure
~~(i)~~ determine (i) the expression for the output voltage
(ii) the output voltage for the given input.







Solution: (i) For the differentiator

$$V_o = -RC\frac{dv_i}{dt}$$
$$= -(100\,k\Omega)\times(10\,\mu F)\frac{dv_i}{dt}$$
$$= -(100\times10^3\,\Omega)\times(10\times10^{-6}\,F)\frac{dv_i}{dt}$$
$$= -\frac{dv_i}{dt}$$

(ii) input voltage is a straight line between 0 and 0.2s. the output voltage is

$$V_o = -\frac{dv_i}{dt}$$
$$= -\frac{(1-0)}{0.2}$$
$$= -5V$$

Between 0 to 0.2s, the output voltage is constant at $-5V$. For $t > 0.2s$, the input is constant so that output voltage is zero.