Chapter

Operational Amplifier [Op-Amp]

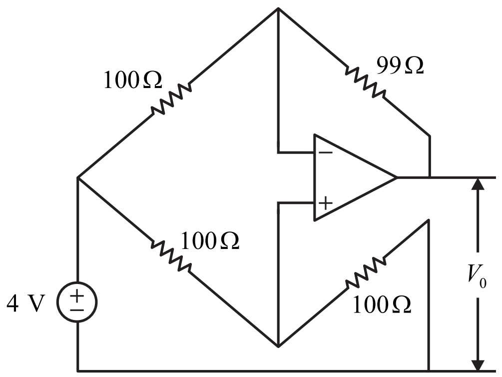
Answer Keys, Solutions and Corrections

1. BASIC IDEAL & PRACTICAL OP-AMP :

1.1	D	1.2	– 4	1.3	C, D	1.4	D	1.5	B
1.6	0.02	1.7	D	1.8	C	1.9	C	1.10	D
1.11	A	1.12	D	1.13	D	1.14	A	1.15	B
1.16	D	1.17	D	1.18	C, D	1.19	D	1.20	D
1.21	D	1.22	A	1.23	B	1.24	C	1.25	A
1.26	B	1.27	B	1.28	B	1.29	D	1.30	B
1.31	D	1.32	A	1.33	C	1.34	D	1.35	B
1.36	C	1.37	C	1.38	B	1.39	A	1.40	B
1.41	A	1.42	A	1.43	B	1.44	B	1.45	B
1.46	C	1.47	A	1.48	B	1.49	B	1.50	C
1.51	B	1.52	A	1.53	B	1.54	C	1.55	B
1.56	A	1.57	D	1.58	B	1.59	A	1.60	A
1.61	B	1.62	A	1.63	C	1.64	C	1.65	B
1.66	C	1.67	D	1.68	B	1.69	0.6	1.70	12
1.71	250	1.72	1	1.73	1.39	1.74	B	1.75	B
1.76	–1	1.77	100	1.78	100	1.79	D	1.80	D
1.81	C	1.82	B	1.83	C	1.84	B	1.85	B

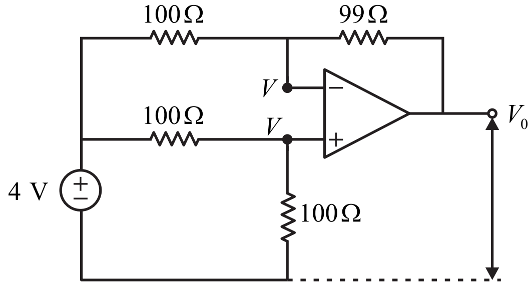
1.6 For the ideal Op-Amp circuit of figure. Determine the output voltage V_0

[GATE EC 1993, IIT-Bombay]



Ans. **0.02 V**

Sol. Circuit will reduce as follows



Due to virtual ground condition

$$V_+ = V_- = V$$

Apply KCL at non-inverting terminals

$$\frac{V-4}{100} + \frac{V}{100} = 0$$

$$\frac{2V}{100} = \frac{4}{100} \quad \Rightarrow \quad V = 2 \text{ Volts}$$

Apply KCL at inverting terminal

$$\frac{V-4}{100} + \frac{V-V_0}{99} = 0$$

Put $V = 2$ Volts.

$$\frac{2-4}{100} + \frac{2-V_0}{99} = 0$$

$$\frac{2-V_0}{99} = \frac{2}{100}$$

$$200 - 100V_0 = 198$$

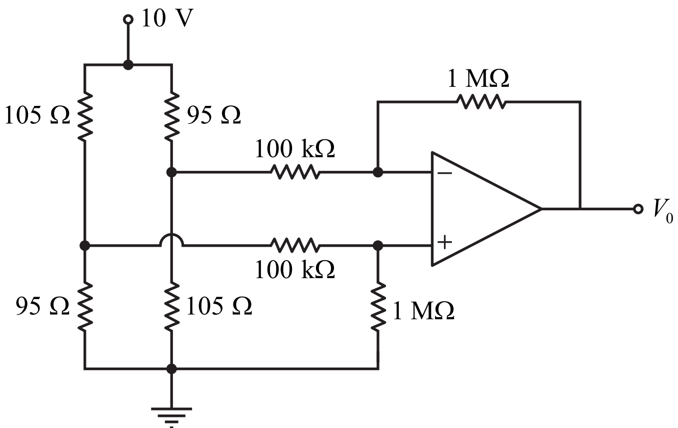
$$100V_0 = 2$$

$$V_0 = 0.02 \text{ Volt}$$

1.8 **Correction Option (C)** $1 + \frac{R_f}{R}$

1.55 For the Op-Amp circuit shown below, V_0 is approximately equal to

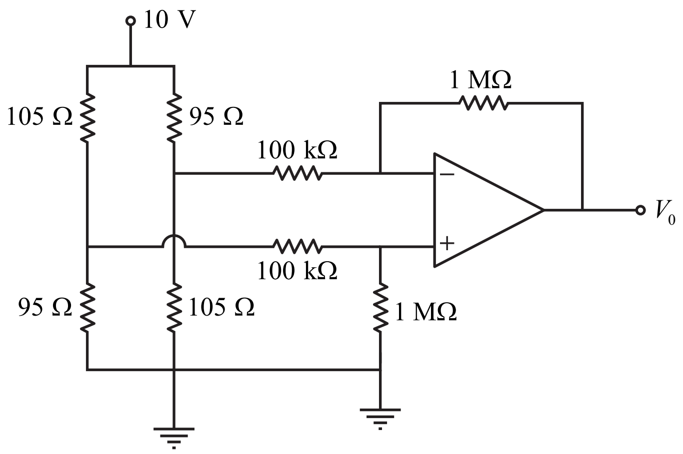
[GATE IN 2008, IIT-Bangalore]

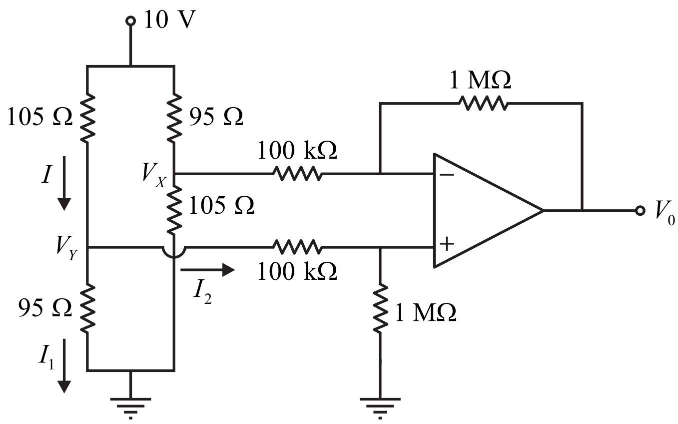


(A) –10 V (B) – 5 V (C) + 5 V (D) + 10 V

Ans. **(B)**

Sol.





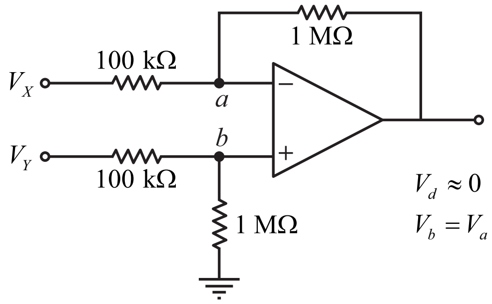
$$V_X = 10\left(\frac{105}{200}\right) = 5.25 \text{ V}$$

$$I = I_1 + I_2$$

$$I_1 >> I_2 \qquad \text{[Due to small resistance } 95\ \Omega\text{]}$$

$\Rightarrow$ 95 Ω and 105 Ω will be in series

$$V_Y = 10\left(\frac{95}{200}\right) = 4.75 \text{ V} \qquad \text{[By VDR]}$$



Apply KCL at '*b*'

$$\frac{V_Y - V_b}{100} = \frac{V_b}{1000} \qquad \Rightarrow \qquad 10V_Y = 11V_b$$

$$V_b = \left(\frac{10}{11}\right)V_Y = 4.31817 \text{ Volts}$$

Apply KCL at '*a*'

$$\frac{V_X - V_a}{100} = \frac{V_a - V_0}{1000}$$

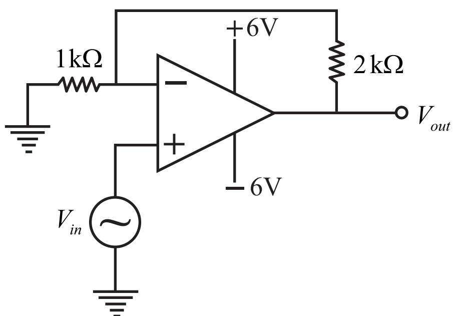
$$10V_X = 11V_a - V_0$$

$$V_0 = 11V_a - 10V_X$$

$$V_0 = 10(4.31187) - 10(5.25) = 47.5 - 52.5$$

$$V_0 = -5 \text{ V}$$

1.58 The nature of feedback in the Op-Amp circuit shown is **[GATE EE 2009, IIT-Roorkee]**



(A) Current - Current feedback
(B) Voltage - Voltage feedback
(C) Current - Voltage feedback
(D) Voltage - Current feedback

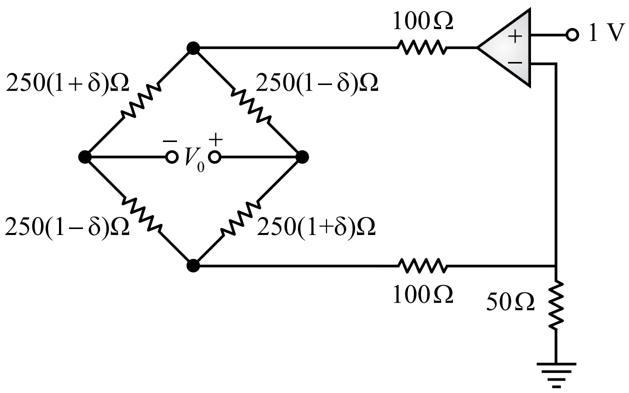
Ans. (B)

Sol. (i) Voltage (sampling) + Series (mixing) feedback

(ii) Series (mixing) + Shunt (sampling) feedback

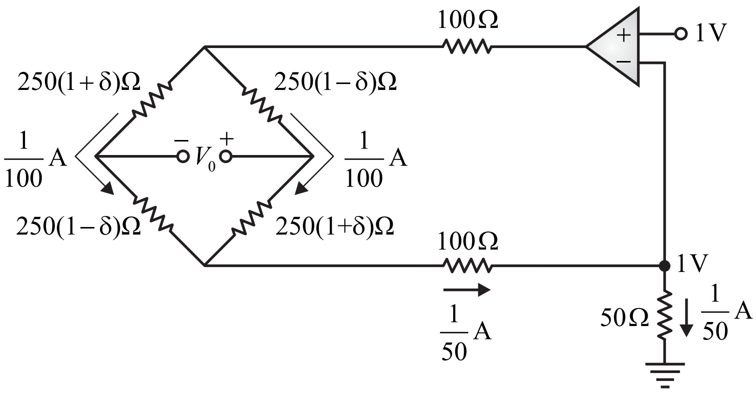
(iii) Voltage (sampling) + Voltage (mixing) feedback

1.71 In the circuit shown, assume that the Op-Amp is ideal. The bridge output voltage V_0 (in mV) for $\delta = 0.05$ is________________. **[GATE EC 2015 (Set-01), IIT-Kanpur]**



Ans. **(250)**

Sol.



Due to virtual ground concept

$$V_+ = V_- = 1\text{V}$$

Current in 100 Ω and 50 Ω resistor will be same

$$I_{50\Omega} = I_{100\Omega} = \frac{1}{50}\text{A}$$

So, output voltage is given by,

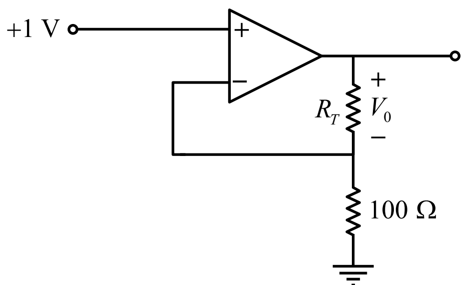
$$V_0 = \frac{1}{100}[250(1+\delta) - 250(1-\delta)] = \frac{1}{100} \times 500\delta$$

$$V_0 = 5\delta = \delta \times 0.05 = 0.25 \text{ V}$$

$$V_0 = 250 \text{ mV}$$

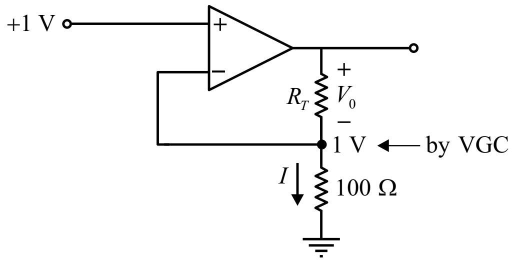
1.73 In the figure shown, R_T represents a resistance temperature device (RTD), whose characteristic is given by $R_T = R_0(1+\alpha T)$, where $R_0 = 100\,\Omega, \alpha = 0.0039\,^0\text{C}^{-1}$ and T denotes the temperature in ^0C. Assuming the op-amp to be ideal, the value of V_0 in volts when $T = 100^0\text{C}$, is ____________V.

[GATE IN 2015, IIT-Kanpur]



Ans. **(1.39 V)**

Sol.



Given : $\alpha = 0.0039^0\text{C}^{-1}$, $R_0 = 100$, $T = 100^0\text{C}$

$$R_T = R_0(1+\alpha T) = 100(1+0.0039\times 100)$$

$$R_T = 139\ \Omega$$

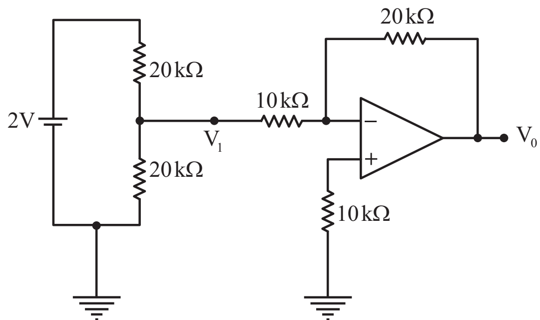
$$I = \frac{1}{100}\text{A}$$

$$V_0 = I\times R_T = 139\times\frac{1}{100}$$

$$V_0 = 1.39\ \text{V}$$

1.76 In the circuit given below, the OP-AMP is ideal. The output voltage V_0 in volt is ________.

[GATE IN 2016, IISc Bangalore]



Sol.

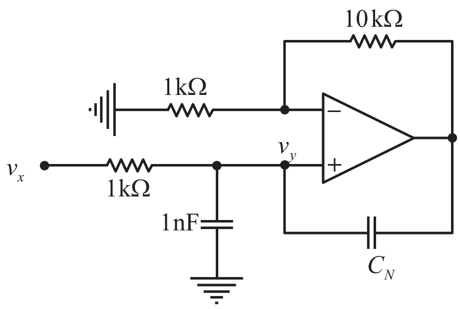
$$\frac{V_1-2}{20}+\frac{V_1}{20}+\frac{V_1}{10}=0$$

$$V_1 = 0.5\ V$$

$$V_0 = \frac{-20}{10}\times 0.5 = -1\,\text{V}$$

1.77 In the circuit given below, the OP-AMP is ideal. The input v_x is a sinusoid. To ensure $v_y = v_x$, the value of C_N in picofarad is __________

[GATE IN 2016, IISc Bangalore]



Sol. Appling KCL at inverting terminal,

$$\frac{V_y-0}{1\text{k}\Omega}+\frac{V_y-V_0}{10\ \text{k}\Omega}=0$$

$$\frac{V_y}{1}+\frac{V_y}{10}=\frac{V_0}{10}$$

$$V_0 = 11\,V_y \qquad \dots \text{(i)}$$

Applying KCL at non-inverting terminal,

$$\frac{V_y - V_x}{1\text{ k}\Omega} + \frac{V_y}{\frac{1}{sC}} + \frac{V_y - V_0}{\frac{1}{sC_N}} = 0$$

$$V_y.sC + (V_y - 11\,V_y).sC_N = 0$$

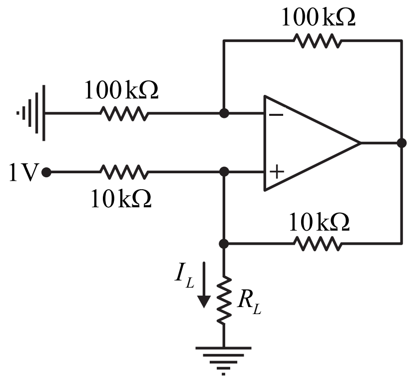
$$V_y.sC - 10V_y\,.sC_N = 0$$

$$V_y.sC = 10V_y\,.sC_N$$

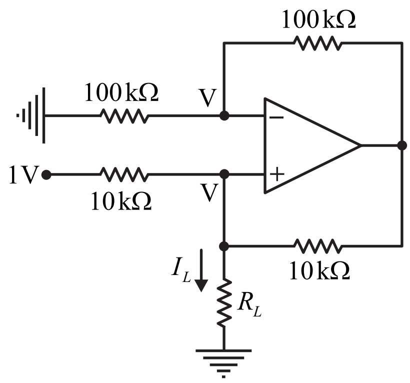
$$C_N = \frac{C}{10} = 0.1\text{ nF} = 100\text{ pF}$$

1.78 In the circuit given below, the OP-AMP is ideal. The value of current I_L in microampere is ______

[GATE IN 2016, IISc Bangalore]



Sol. Applying KCL at inverting terminal,



$$\frac{V - 0}{100\,K} + \frac{V - V_0}{100\,K} = 0$$

$$\frac{2V}{100\,K} = \frac{V_0}{100\,K}$$

$$V_0 = 2V$$

Applying KCL at non inverting,

$$\frac{V - 1}{10\,K} + I_L + \frac{V - V_0}{10\,K} = 0$$

$$\frac{V}{10\,K} - \frac{1}{10\,K} + I_L - \frac{V}{10\,K} = 0$$

$$I_L = 0.1\text{mA} = 100\ \mu\text{A}$$

1.81 In an Op-Amp, if the feedback voltage is reduced by connecting a voltage divider at the output, which of the following will happen? **[IES EC 2016]**

1. Input impedance increases
2. Output impedance reduces
3. Overall gain increases

Which of the above statements is/are correct?

(A) 1 only (B) 2 only (C) 3 only (D) 1, 2 and 3

Ans. (C)

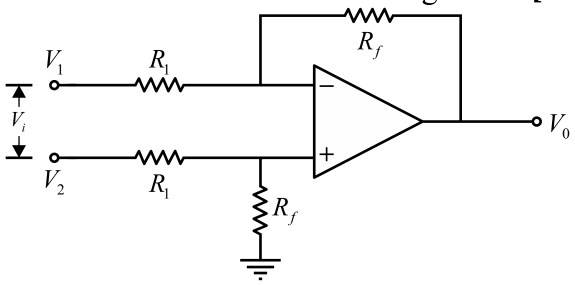
Sol.

$V_f \downarrow$	$\beta \downarrow$	$A_f \approx \frac{1}{\beta} \uparrow$

2. OP-AMP APPLICATION (ADDER / SUBTRACTOR) :

2.1	C	2.2	1	2.3	D	2.4	A	2.5	C
2.6	B	2.7	B	2.8	A	2.9	D	2.10	C
2.11	C	2.12	A	2.13	B	2.14	B	2.15	C
2.16	A	2.17	B	2.18	C	2.19	D	2.20	C
2.21	B	2.22	B	2.23	C	2.24	B	2.25	C
2.26	C	2.27	B	2.28	1.5	2.29	15		

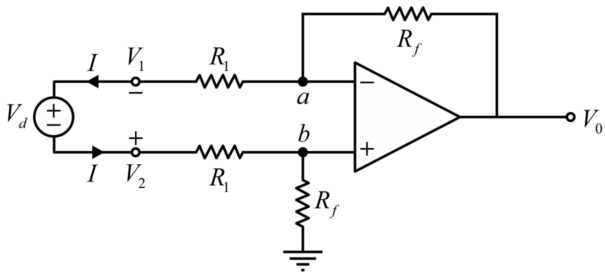
2.5 The differential input resistance of the circuit shown in figure is **[GATE IN 1996, IISc-Bangalore]**



(A) R_1　　(B) $R_1/2$　　(C) $2R_1$　　(D) R_f

Ans. (C)

Sol.



Voltage at node 'b', $V_b = \dfrac{R_f}{R_1 + R_f} \cdot V_2$

For ideal Op-Amp, $V_- = V_+$

$$\therefore \qquad V_a = V_b = \frac{R_f}{R_1 + R_f} \cdot V_2$$

Current supplied by source, $I = \dfrac{V_a - V_1}{R_1}$

Differential input resistance, $R_d = \dfrac{V_d}{I}$

$$I = \frac{\dfrac{R_f}{R_1 + R_f} \cdot V_2 - V_1}{R_1}$$

For differential input, $V_1 = \dfrac{-V_d}{2}$, $V_2 = \dfrac{V_d}{2}$

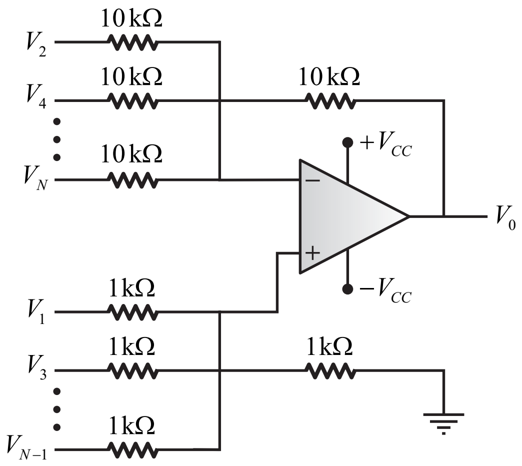
$$I = \frac{\left[\dfrac{1}{2} + \dfrac{R_f}{R_1 + R_f} \cdot \dfrac{1}{2}\right] V_1}{R_1}$$

$$\frac{V_d}{I} = \frac{2R_1(R_1 + R_f)}{R_1 + 2R_f} \cong 2R_1$$

2.25 **Correction option (C)** $-4\cos\omega t$ V

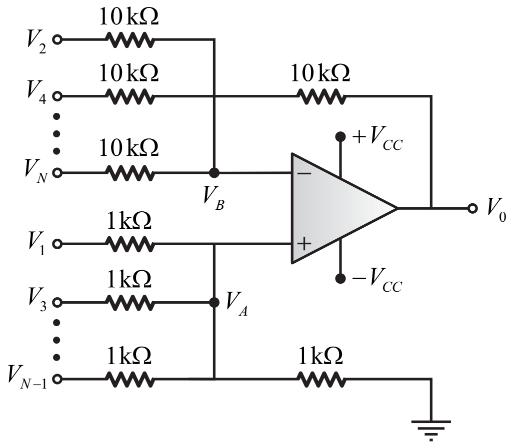
2.29 An ideal op-amp has voltage sources $V_1, V_3, V_5, \ldots\ldots, V_{N-1}$ connected to the non-inverting input and $V_2, V_4, V_6, \ldots\ldots, V_N$ connected to the inverting input as shown in the figure below ($+V_{CC}$ = 15 volt, $-V_{CC} = -15$ volt). The voltages $V_1, V_2, V_3, V_4, V_5, V_6, \ldots\ldots$ are 1, − 1/2, 1/3, −1/4, 1/5, −1/6, …. volt, respectively. As N approaches infinity, the output voltage (in volt) is ____________.

[GATE EC 2016 (Set - 01), IISc Bangalore]



Ans. **15**

Sol.



Apply nodal analysis at node A,

$$\frac{V_A - V_1}{1\text{ k}\Omega} + \frac{V_A - V_3}{1\text{ k}\Omega} + ... + \frac{V_A - V_{N-1}}{1\text{ k}\Omega} + \frac{V_A}{1\text{ k}\Omega} = 0$$

$$V_A\left[\frac{N}{2}+1\right] = V_1 + V_3 + ...V_{N-1}$$

$\because$ $V_B = V_A$ [$\because$ Virtual ground concept]

Apply nodal analysis at node B,

$$\frac{V_A - V_2}{10\text{ k}\Omega} + \frac{V_A - V_4}{10\text{ k}\Omega} + ... \frac{V_A - V_N}{10\text{ k}\Omega} + \frac{V_A - V_0}{10\text{ k}\Omega} = 0 \quad [\text{We used } V_B = V_A]$$

$$V_0 = V_A\left[\frac{N}{2}+1\right] - (V_2 + V_4 + V_6 + ...V_N)$$

$$V_0 = \left[\frac{N}{2}+1\right]\frac{(V_1 + V_3 + ...V_{N-1})}{\left(\frac{N}{2}+1\right)} - (V_2 + V_4 + V_6 + ...V_N)$$

$$V_0 = V_1 - V_2 + V_3 - V_4 + ... = 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + ...$$

$$V_0 = \sum \frac{1}{N} = \infty$$

Output of op-amp goes to saturation

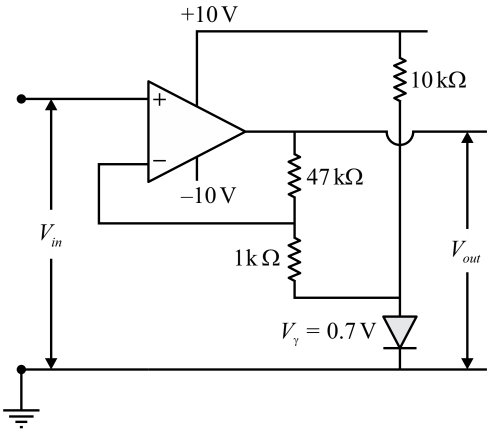
$$V_0 = V_{sat} = V_{CC} = 15\text{ Volt}$$

Hence, the correct answer is 15.

3. OP-AMP APPLICATION (COMPARATOR / SCHMITT TRIGGER) :

3.1	D	3.2	D	3.3	D	3.4	A	3.5	A
3.6	D	3.7	A	3.8	B	3.9	B	3.10	A
3.11	B	3.12	A	3.13	B	3.14	A	3.15	D
3.16	B	3.17	C	3.18	D	3.19	A	3.20	C
3.21	C	3.22	B	3.23	C	3.24	D	3.25	D
3.26	D	3.27	D	3.28	C	3.29	D	3.30	8.10
3.31	1	3.32	A	3.33	B	3.34	0.67	3.35	D

3.9 **Correction Diagram :**

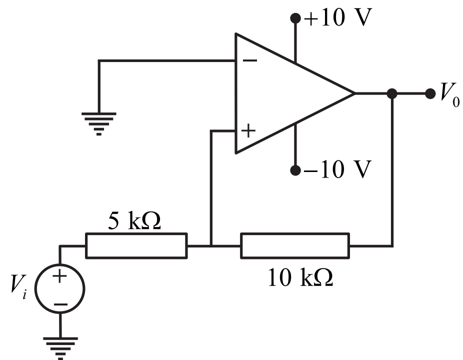


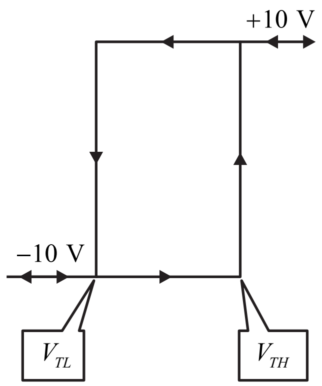
Ans. **(B)**

Sol. For increasing input voltage if $V_{out} = +10\text{ V}$ then triggering voltage using superposition

$$= \frac{1}{48} \times 10 + \frac{47}{48} \times 0.7 = 0.893\text{ V}$$

3.15 Shows a Schmitt trigger circuit and the corresponding hysteresis characteristics. The values of V_{TL} and V_{TH} are **[GATE IN 2004, IIT-Delhi]**





(A) $V_{TL} = -3.75\text{ V}, V_{TH} = +3.75\text{ V}$

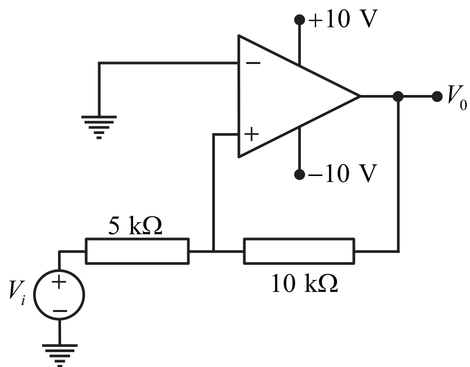
(B) $V_{TL} = -1\text{ V}, V_{TH} = +5\text{ V}$

(C) $V_{TL} = -5\text{ V}, V_{TH} = +1\text{ V}$

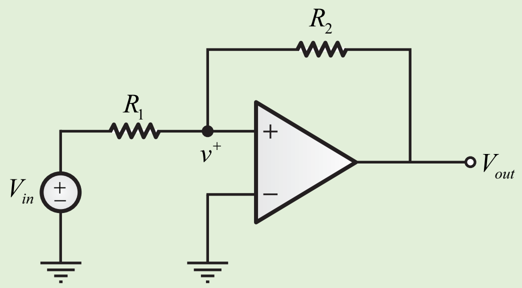
(D) $V_{TL} = -5\text{ V}, V_{TH} = +5\text{ V}$

Ans. **(D)**

Sol. Given circuit is shown below.



NON-INVERTING SCHMITT TRIGGER CIRCUIT



Op-amp with positive feedback act as a comparator and input is given to non-inverting terminal. So this is a non-inverting Schmitt trigger circuit.

Voltage v^+ is given by,

$$v^+ = \frac{V_{in} \cdot R_2}{R_1 + R_2} + \frac{V_{out} \cdot R_1}{R_1 + R_2}$$

When $V_{out} = +V_{CC}$,

Then $$v^+ = V_1 = \frac{V_{in} R_2}{R_1 + R_2} + \frac{V_{CC} R_1}{R_1 + R_2}$$

Again $V_{out} = +V_{CC}$ if $v^+ > 0$

i.e. $$\frac{V_{in} R_2}{R_1 + R_2} + \frac{V_{CC} R_1}{R_1 + R_2} > 0$$

$$V_{in} > -V_{CC}\frac{R_1}{R_2} \qquad \text{...... (i)}$$

When $V_{out} = -V_{CC}$

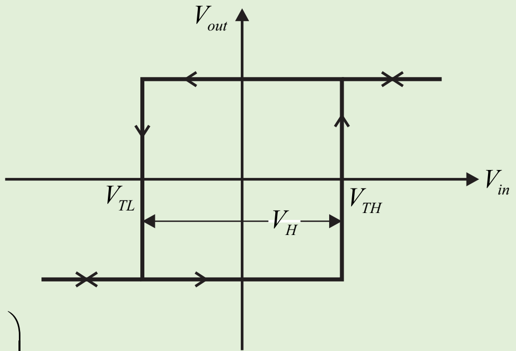
Then $$v^- = V_2 = \frac{V_{in} R_2}{R_1 + R_2} - \frac{V_{CC} R_1}{R_1 + R_2}$$

Again $V_{out} = -V_{CC}$ if $v^+ < 0$

$$\frac{V_{in} R_2}{R_1 + R_2} - \frac{V_{CC} R_1}{R_1 + R_2} < 0$$

$$V_{in} < \frac{V_{CC} R_1}{R_2} \qquad \text{...... (ii)}$$

Transfer characteristics is shown below.



Where $V_{TH} = \frac{V_{CC} R_1}{R_2}$ and $V_{TL} = \frac{-V_{CC} R_1}{R_2}$

Hysteresis is given by,

$$V_H = V_{TH} - V_{TL} = \frac{V_{CC} R_1}{R_2} - \left(\frac{-V_{CC} R_1}{R_2}\right)$$

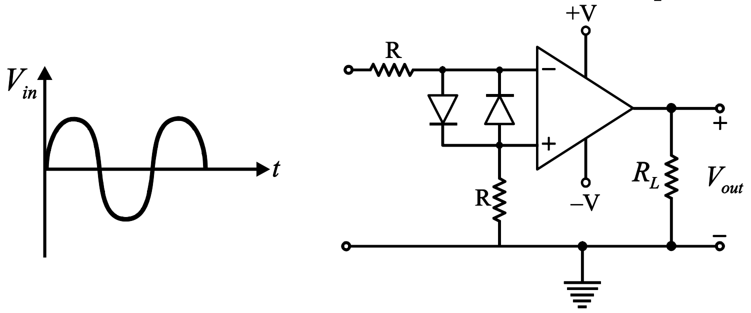
$$V_H = 2V_{CC}\frac{R_1}{R_2}$$

$$V_{TH} = \frac{V_{CC} R_1}{R_2} = \frac{10 \times 5}{10} = 5 \text{ V}$$

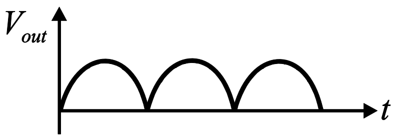
$$V_{TL} = \frac{-V_{CC} R_1}{R_2} = \frac{-10 \times 5}{10} = -5 \text{ V}$$

3.17 In the given figure, if the input is a sinusoidal signal, the output will appear as shown in

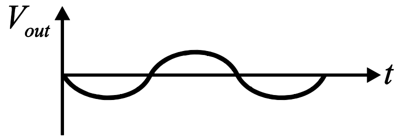
[GATE EE 2005, IIT-Bombay]



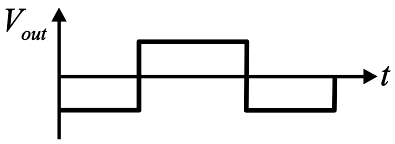
(A)



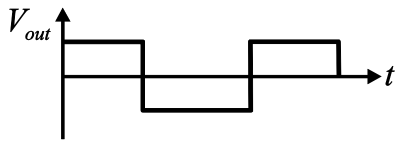
(B)



(C)

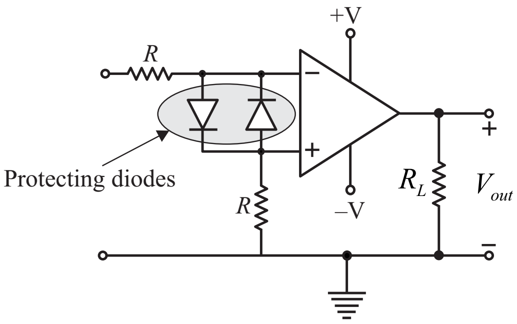


(D)



Ans. (C)

Sol.



Protecting diodes are used to protect the Op-Amp form the damage due to application of high voltage.

This is an open loop system so Op-Amp behaves as a comparator.

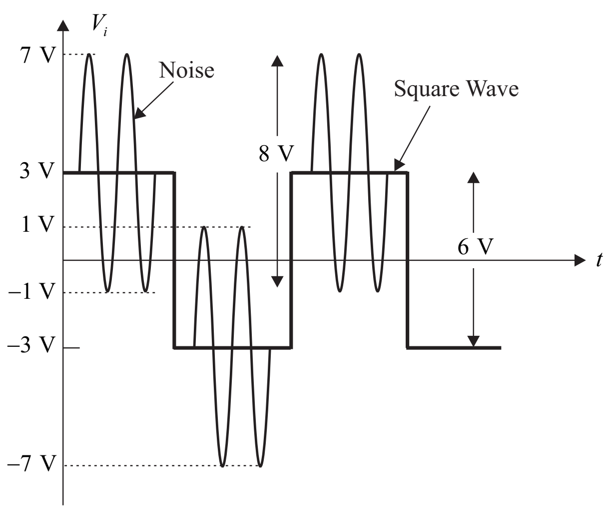
For positive half cycle, $I > NI$

$\Rightarrow \qquad V_0 = -V_{sat}$

For negative half cycle, $NI > I$

$\Rightarrow \qquad V_0 = +V_{sat}$

3.22 The input signal shown in the figure below is fed to a Schmitt trigger. The signal has a square wave amplifier of amplitude of 6 V p-p. It is corrupted by an additive high frequency noise of amplitude 8 V p-p. **[GATE IN 2007, IIT-Kanpur]**

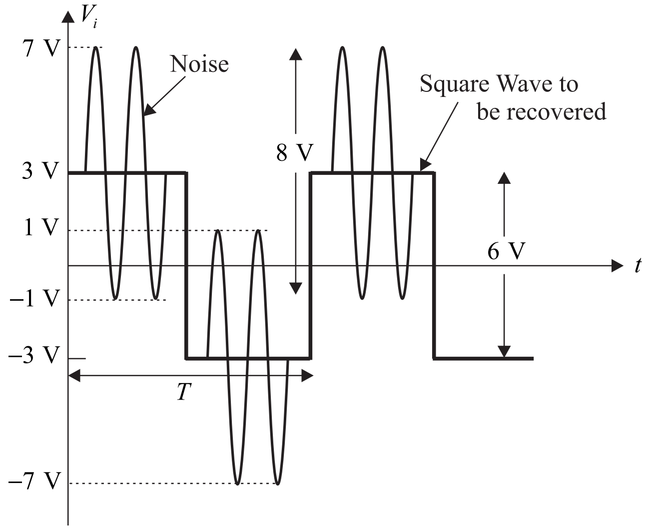


Which one of the following is an appropriate choice for the upper and lower trip points of the Schmitt trigger to recover a square wave of the same frequency from the corrupted input signal V_i ?

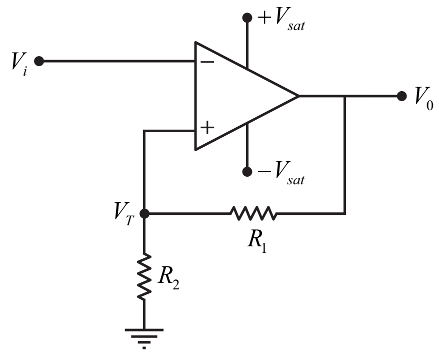
(A) ± 8.0 V (B) ± 2.0 V (C) ± 0.5 V (D) 0 V

Ans. (B)

Sol.



The above corrupted signal is given as an input to Schmitt trigger circuit.



Operation of Schmitt trigger :

For $V_i > V_{UTP}$ $\Rightarrow$ V_0 switches from $+V_{sat}$ to $-V_{sat}$

For $V_i < V_{LTP}$ $\Rightarrow$ V_0 switches from $-V_{sat}$ to $+V_{sat}$

Calculation of Trip point voltage :

$$V_T = \frac{V_0 \times R_2}{R_1 + R_2} \text{ [By VDR]}$$

When $V_0 = +V_{sat}$

$V_T = V_{UTP}$ = upper trip point

$$\therefore \quad V_{UTP} = \frac{V_{sat} \times R_2}{R_1 + R_2} \quad \ldots\ldots \text{(i)}$$

When $V_0 = -V_{sat}$

$V_T = V_{LTP}$ = lower trip point

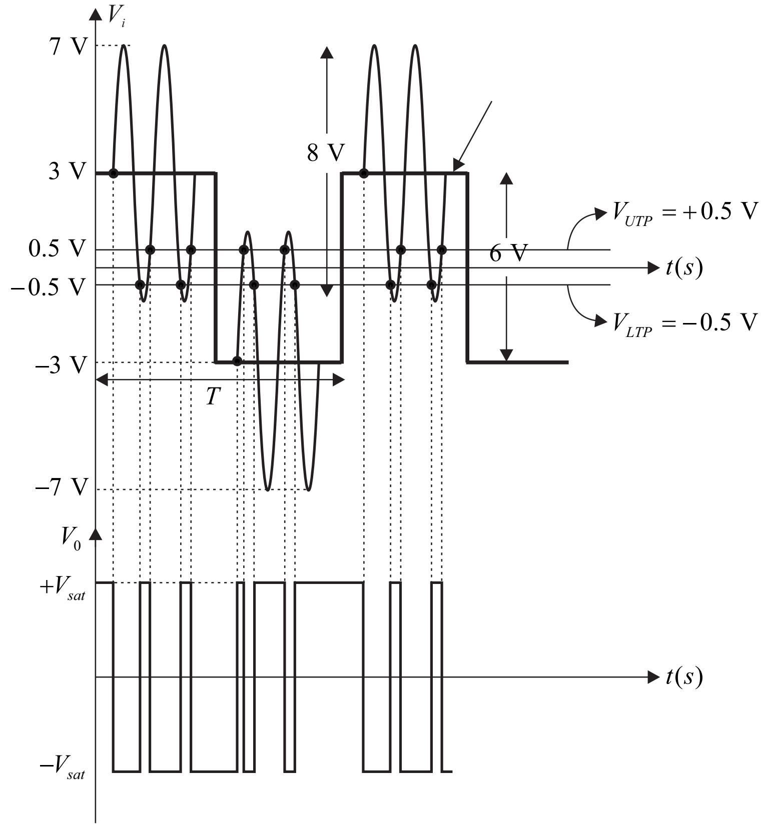
$$\therefore \quad V_{LTP} = \frac{-V_{sat} \times R_2}{R_1 + R_2} \quad \ldots\ldots \text{(ii)}$$

From equation (i) and (ii), we can conclude that both V_{UTP} and V_{LTP} are lesser in magnitude than $|V_{sat}|$ for proper operation.

Since the signal to be recovered is square wave of peak amplitude of +3 V. we should adjust the $\pm V_{sat}$ in such a way that it is equal to ± 3 V . (As output of Schmitt trigger is $\pm V_{sat}$) therefore the V_{UTP} and V_{LTP} will have magnitude less than 3 V.

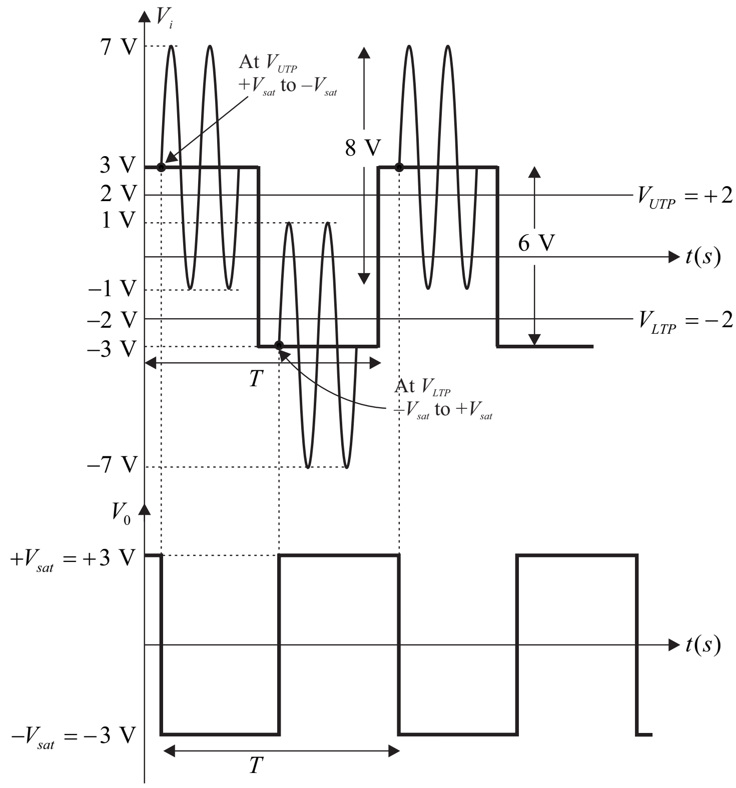
So, option (A) ± 8 V is straight forwardly rejected. So now we are left with option (B), (C) and (D).

Consider option (C) ± 0.5 V



Key Point : Multiple triggering occurs if we select $|V_{UTP}|$ or $|V_{LTP}| < 1$ V. So we can't recover square wave with same frequency because due to noise frequency will change.

Consider option (B) ± 2 V

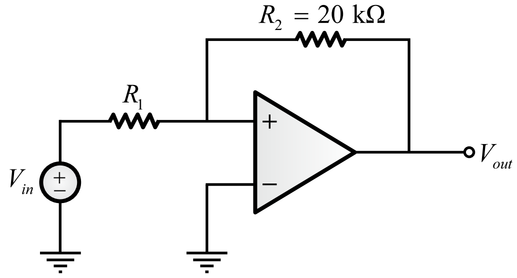


Key Point : For $|V_{UTP}|$ or $|V_{LTP}| > 1$ V we get square wave same as input square wave.

So, $V_{UTP} = +2$ V and $V_{LTP} = -2$ V satisfies all the required conditions for recovery of square wave with same frequency.

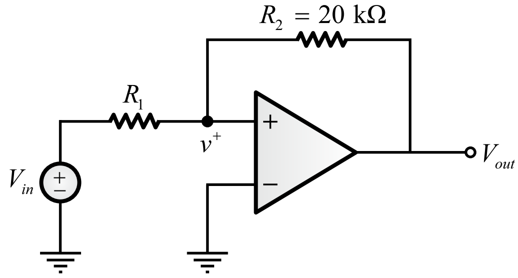
Hence, the correct option is (B).

3.31 In the bistable circuit shown, the ideal Op-Amp has saturation levels of $\pm 5\text{V}$. The value of R_1 (in $\text{k}\Omega$) that gives a hysteresis width of 500 mV is _____. **[GATE EC 2015 (Set-02), IIT-Kanpur]**



Ans. 1

Sol. Given circuit is shown below.



Op-amp with positive feedback at as a comparator.

Voltage v^+ is given by, $v^+ = \dfrac{V_{in} \cdot R_2}{R_1 + R_2} + \dfrac{V_{out} \cdot R_1}{R_1 + R_2}$

When $V_{out} = +V_{CC}$,

Then $$v^+ = V_1 = \frac{V_{in}R_2}{R_1 + R_2} + \frac{V_{CC}R_1}{R_1 + R_2}$$

Again $V_{out} = +V_{CC}$ if $v^+ > 0$

i.e. $$\frac{V_{in}R_2}{R_1 + R_2} + \frac{V_{CC}R_1}{R_1 + R_2} > 0$$

$$V_{in} > -V_{CC}\frac{R_1}{R_2} \qquad \ldots\ldots \text{(i)}$$

When $V_{out} = -V_{CC}$

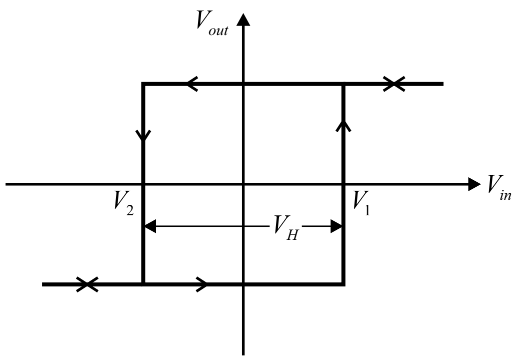
Then $$v^- = V_2 = \frac{V_{in}R_2}{R_1 + R_2} - \frac{V_{CC}R_1}{R_1 + R_2}$$

Again $V_{out} = -V_{CC}$ if $v^+ < 0$

$$\frac{V_{in}R_2}{R_1 + R_2} - \frac{V_{CC}R_1}{R_1 + R_2} < 0$$

$$V_{in} < \frac{V_{CC}R_1}{R_2} \qquad \ldots\ldots \text{(ii)}$$

Transfer characteristics is shown below.



Where $V_1 = \frac{V_{CC}R_1}{R_2}$ and $V_2 = \frac{-V_{CC}R_1}{R_2}$

Hysteresis is given by,

$$V_H = V_1 - V_2 = \frac{V_{CC}R_1}{R_2} - \left(\frac{-V_{CC}R_1}{R_2}\right)$$

$$V_H = 2V_{CC}\frac{R_1}{R_2}$$

Given : $V_H = 0.5\text{ V}$

$$2\times 5\times\frac{R_1}{20} = 0.5$$

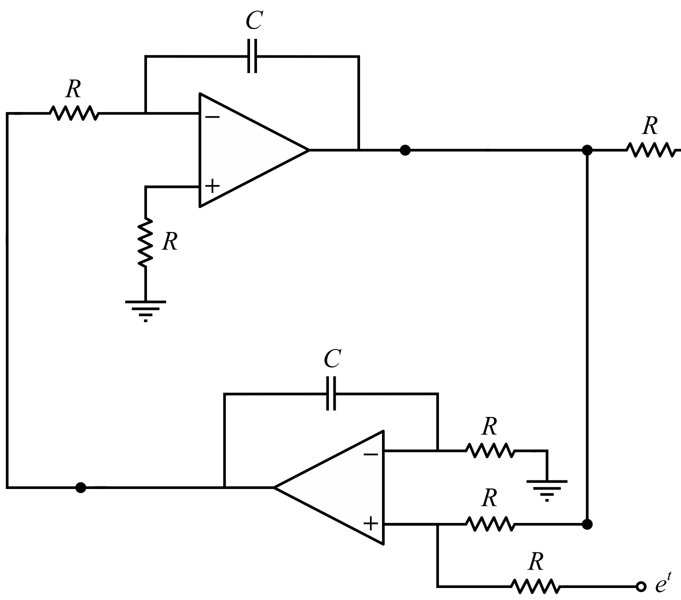
$$R_1 = 1\text{ k}\Omega$$

4. OP-AMP APPLICATION (INTEGRATOR / DIFFERENTIATOR / ACTIVE FILTER / FREQUENCY RESPONSE) :

4.1	A	4.2	D	4.3	C	4.4	C	4.5	A
4.6	A	4.7	D	4.8	B	4.9	*	4.10	C
4.11	D	4.12	C	4.13	D	4.14	A	4.15	C
4.16	C	4.17	A	4.18	A	4.19	D	4.20	B
4.21	A	4.22	D	4.23	A	4.24	A	4.25	A
4.26	A	4.27	D	4.28	A	4.29	C	4.30	C
4.31	B	4.32	C	4.33	D	4.34	D	4.35	A
4.36	D	4.37	D	4.38	D	4.39	C	4.40	B
4.41	A	4.42	A	4.43	D	4.44	B	4.45	A
4.46	3.1-3.26	4.47	A	4.48	15-16	4.49	159.15	4.50	D
4.51	A	4.52	1.245	4.53	B	4.54	C	4.55	D
4.56	–1	4.57	A	4.58	44.37	4.59	2.95		

4.9 (**A** - R, **B** - S, **C** - P)

4.2 In the following circuit, the output 'V', follows an equation of the form $\frac{d^2V}{dt^2} + a\cdot\frac{dV}{dt} + bV = f(t)$. The value of a, b and $f(t)$ are respectively **[GATE EE 1992, IIT-Delhi]**



(A) $a = \frac{1}{2RC}, b = \frac{1}{2R^2C^2}, \ f(t) = \frac{1}{2R^2C^2}\left(1 + \frac{1}{RC}\right)e^{-t}$

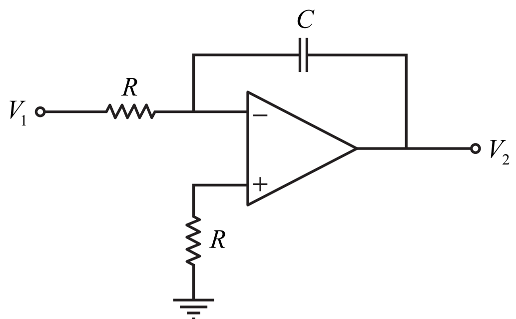
(B) $a = \frac{1}{2RC}, b = \frac{1}{2R^2C^2}, \ f(t) = \frac{1}{R^2C^2}\left(1 + \frac{1}{RC}\right)e^{-t}$

(C) $a = \frac{1}{RC}, b = \frac{1}{2R^2C^2}, \ f(t) = \frac{1}{2R^2C^2}\left(1 + \frac{1}{RC}\right)e^{t}$

(D) $a = \frac{1}{2RC}, b = \frac{1}{2R^2C^2}, \ f(t) = \frac{1}{2R^2C^2}\left(1 + \frac{1}{RC}\right)e^{t}$

Ans. (D)

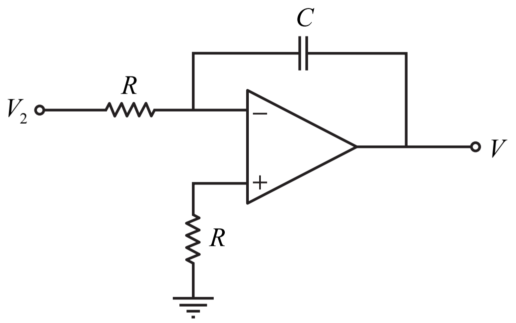
Sol. Solve the circuit in parts



Above circuit is an integrator.

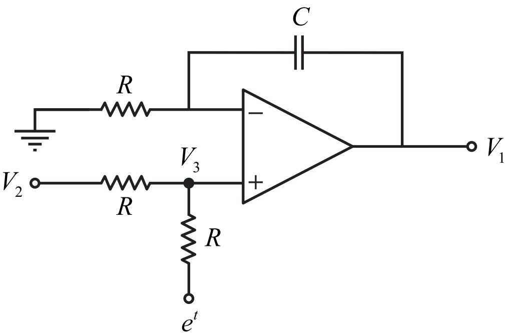
Output $V_2 = \frac{-1}{RC}\int V_1 dt$

Or $V_1 = -RC\frac{dV_2}{dt}$ …… (i)



Output $V = \frac{-1}{RC}\int V_2 dt$

Or $V_2 = -RC\frac{dV}{dt}$ …… (ii)



$V_3 = \frac{(V_2 + e^t)}{2}$

And $RC\frac{d}{dt}(V_1 - V_3) = V_3$

Or $$RC(V_1 - V_3) = \int V_3\, dt$$

$$RC(V_1 - V_3) = \frac{1}{2}\left[e^t + \int V_2\, dt\right]$$

Or $$RC\left[-RC\frac{d}{dt}\left(-RC\frac{dV}{dt}\right) - \left(\frac{V_2 + e^t}{2}\right)\right] = \frac{1}{2}\left[e^t + \int V_2\, dt\right]$$

$$RC\left[R^2C^2\frac{d^2V}{dt^2} - \frac{1}{2}e^t - \frac{1}{2}\left(-RC\frac{dV}{dt}\right)\right] = \frac{1}{2}\left[e^t - RCV\right]$$

$$\left[R^2C^2\frac{d^2V}{dt^2} + \frac{1}{2}RC\frac{dV}{dt}\right] - \frac{1}{2}e^t = \frac{1}{2RC}e^t - \frac{1}{2}V$$

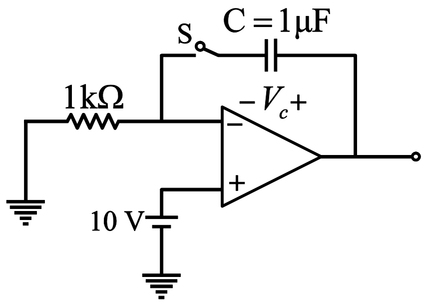
Or $$R^2C^2\frac{d^2V}{dt^2} + \frac{1}{2}RC\frac{dV}{dt} + \frac{1}{2}V = \frac{e^t}{2}\left(1 + \frac{1}{RC}\right)$$

Compare with

$$\frac{d^2V}{dt^2} + a\cdot\frac{dV}{dt} + bV = f(t)$$

$$a = \frac{1}{2RC},\ b = \frac{1}{2R^2C^2},\quad f(t) = \frac{1}{2R^2C^2}\left(1 + \frac{1}{RC}\right)e^t$$

4.27 For the circuit shown in the following figure, the capacitor C is initially uncharged. At $t = 0$ the switch S is closed. The voltage V_C across the capacitor at $t = 1\text{msec}$ is **[GATE EC 2006, IIT - Kharagpur]**

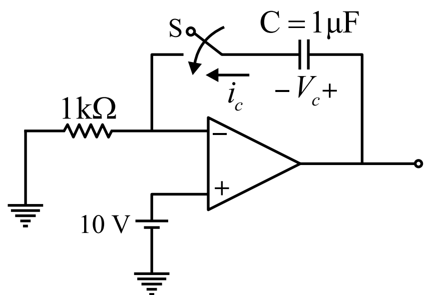


In the figures shown the OP-AMP is supplied with $\pm 15\,\text{V}$.

(A) 0 V (B) 6.3 V (C) 9.45 V (D) 10 V

Ans. (D)

Sol.



Above figure represents the linear charging of capacitor. Here transient equation is not valid.

After closing the switch apply KCL at non-inverting terminals.

Due to virtual ground

$$V_+ = V_- = 10\,\text{V}$$

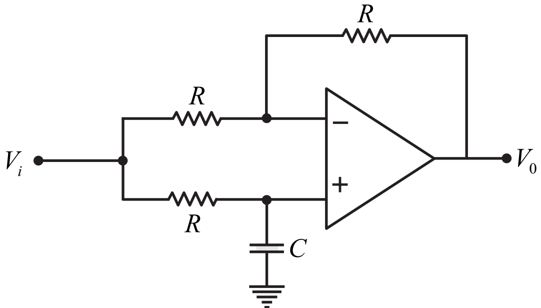
$$i_c = \frac{10}{1\text{k}}$$

$$c\frac{dV_c}{dt} = \frac{10}{1\text{k}}$$

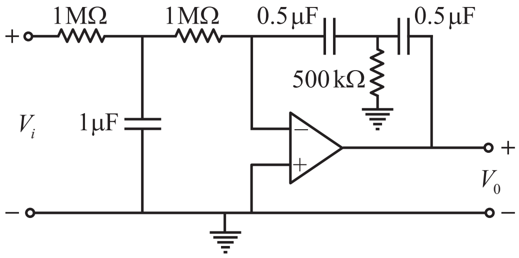
$$\frac{10^{-6} \times V_c}{1\times 10^{-3}} = \frac{10}{10^3}$$

$$V_c = 10 \text{ Volt}$$

4.28 and 4.29 Common data Correction diagram



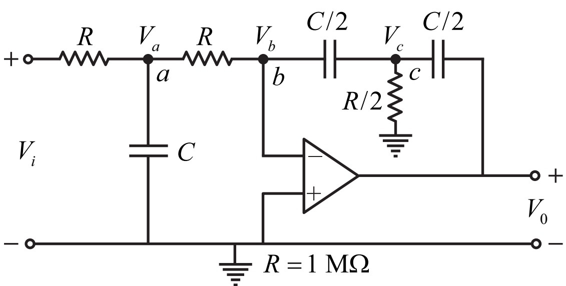
4.39 The ideal Op-Amp based circuit shown below acts as a **[GATE IN 2011, IIT-Madras]**



(A) low-pass filter (B) high-pass filter
(C) band-pass filter (D) band-reject filter

Ans. **(C)**

Sol. **Method 1**



The type of filter can be determined from the transfer function of circuit in s-domain. So transfer` function of circuit will be obtained first. From which conclusion will be draw about type of filter.

KCL at node (*a*),

$$\frac{V_a - V_i}{R} + \frac{V_a - V_b}{R} + \frac{V_a - 0}{1/sC}$$

As node '*b*' is at virtual ground, so $V_b = 0$

$$V_a\left[\frac{2}{R} + sC\right] = \frac{V_i}{R}$$

$$V_a = \frac{V_i}{2 + sCR} \quad \ldots\ldots \text{(i)}$$

KCL at node (b),

$$\frac{0-V_a}{R}+\frac{0-V_c}{2/sC}=0$$

$$V_a=-\frac{sCR}{2}V_c \qquad \text{....... (ii)}$$

From equation (i) and (ii), we have

$$-\frac{sCR}{2}V_c=\frac{1}{2+sCR}V_i$$

$$V_c=-\frac{2}{sCR(2+sCR)}\times V_i \qquad \text{...... (iii)}$$

KCL at node (c),

$$\frac{V_c-0}{2/sC}+\frac{V_c}{R/2}+\frac{V_c-V_0}{2/sC}=0$$

$$V_c\left[sC+\frac{2}{R}\right]=\frac{sCV_0}{2}$$

$$V_c=\frac{sCR}{2(2+sCR)}V_0 \qquad \text{...... (iv)}$$

From equation (iii) and (iv), we have

$$\frac{sCR}{2(2+sCR)}V_0=-\frac{2}{sCR(2+sCR)}\times V_i$$

$$\frac{V_0}{V_i}=-\frac{4}{(sCR)^2}$$

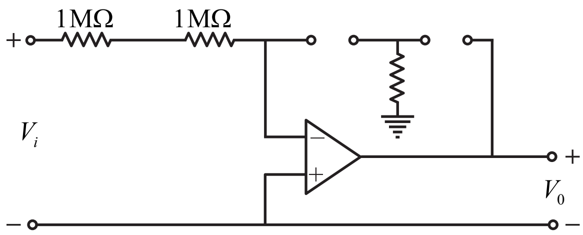
In frequency domain, $s=j\omega$

$$\therefore \quad \frac{V_0}{V_i}=\frac{4}{\omega^2CR}$$

Gain of circuit reduces as ω increases so given filter like low pass filter.

Method 2

At low frequency $f=0, X_C=\infty, C\to$ O.C.



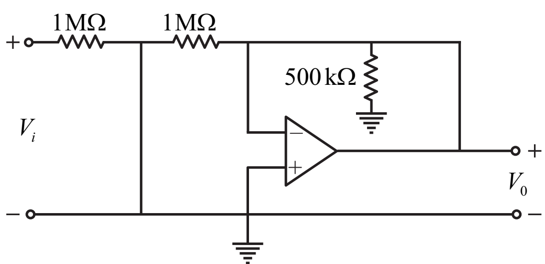
This is an open loop system. So, Op-Amp behaves as a comparator.

$\therefore$ if $V_i>0 \quad \Rightarrow \quad V_0=-V_{sat}$

If $V_i<0 \quad \Rightarrow \quad V_0=+V_{sat}$

In this case $V_0=|V_{sat}|=$ finite gain

At high frequency $f=\infty, X_C=0, C\to$ S.C.

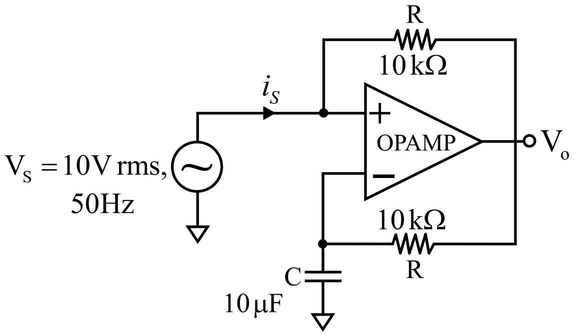


Here $V_0=0$ (Due to virtual ground)

So, this circuit act as a low pass filter.

4.42 The following circuit has $R = 10\,k\Omega$, $C = 10\,\mu F$ The input voltage is a sinusoidal at 50Hz with an rms value of 10 V. under ideal conditions, the current i_s from the source is

[GATE EE 2009, IIT-Roorkee]



(A) $10\pi\,mA$ leading by 90^0 (B) $20\pi\,mA$ leading by 90^0

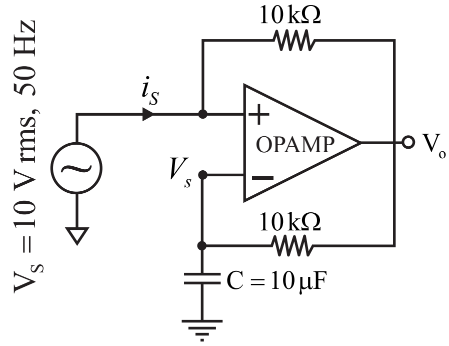
(C) $10\,mA$ leading by 90^0 (D) $10\pi\,mA$ lagging by 90^0

Ans. (A)

Sol.

$$V_s = \left(\frac{X_c}{R + X_c}\right) V_0$$

Where $$X_c = \frac{-j}{\omega C}$$



and $$i_s = \frac{V_s - V_0}{R} = \frac{V_s - \left(\frac{R + X_c}{X_c}\right) V_s}{R}$$

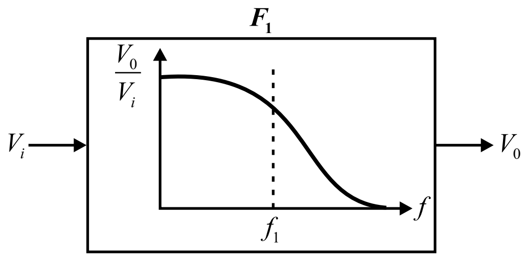
$$i_s = \frac{-RV_s}{RX_c} = -V_s\, j\omega C$$

$$i_s = -j(2\pi \times 50 \times 10 \times 10^{-6})$$

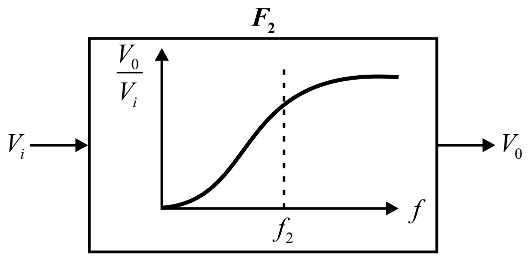
$$i_s = -j10\pi\ \text{mA}$$

So, 10π mA lagging by 90^0.

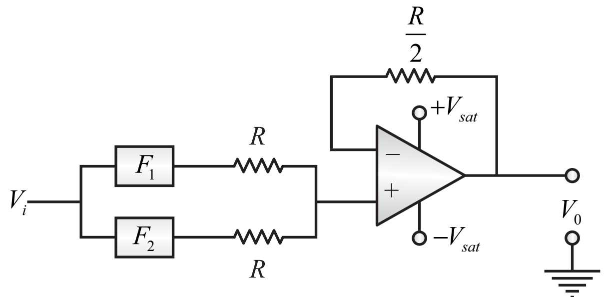
4.53 The filters F_1 and F_2 having characteristics as shown in figure (a) and (b) are connected as shown in figure (c). **[GATE EE 2015 (Set-02), IIT-Kanpur]**



(a)



(b)



(c)

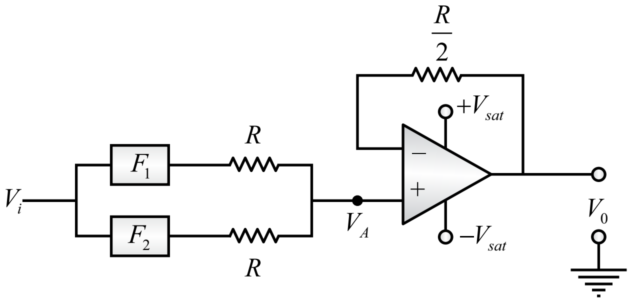
The cut-off frequencies of F_1 and F_2 are f_1 and f_2 respectively. If $f_1 < f_2$, the resultant circuit exhibits the characteristic of a

(A) Band-pass filter (B) Band-stop filter (C) All pass filter (D) High-Q filter

Ans. (B)

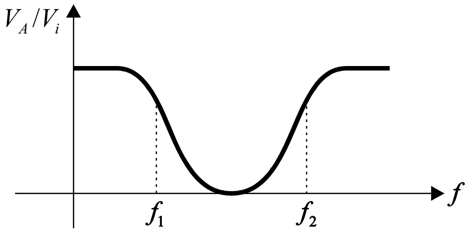
Sol. The given circuit represents F_1 as LPF & F_2 as HPF in parallel followed by a buffer.

LPF will pass all the frequencies less than f_1 and HPF pass all the frequencies above f_2.



Since $f_1 < f_2$; frequencies lying between f_1 and f_2 will be stopped.

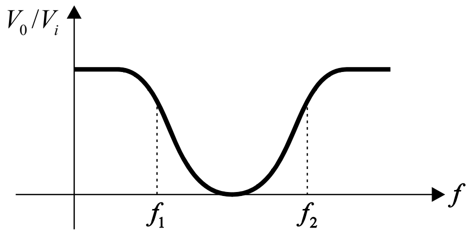
Since $f_1 < f_2$, so V_A / V_i will be



From figure $V_0 = V_a$ (voltage follower circuit)

So $$\frac{V_0}{V_i} = \frac{V_a}{V_i}$$

V_0 / V_i will be



Hence the circuit behaves like a band stop filter.