

Q1. A linear time invariant system yields output $y(t)$ for an input $x(t)$ as shown in Fig. Q1a). What will be the system's output for an input $x_1(t)$ shown in Fig. Q1b)?

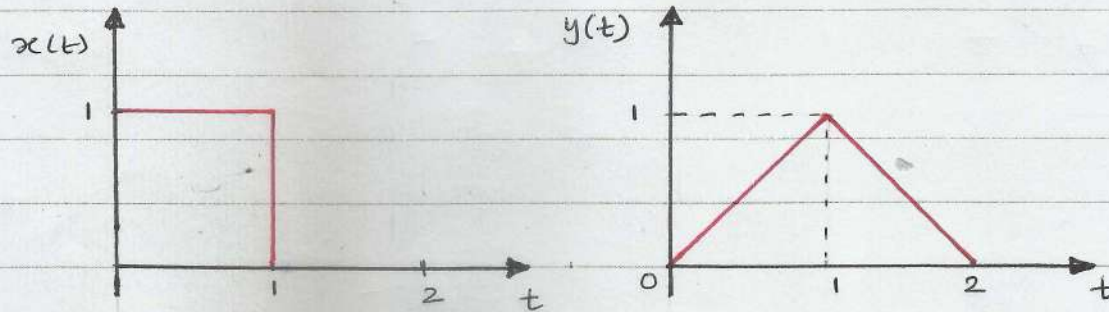


Fig. Q1a

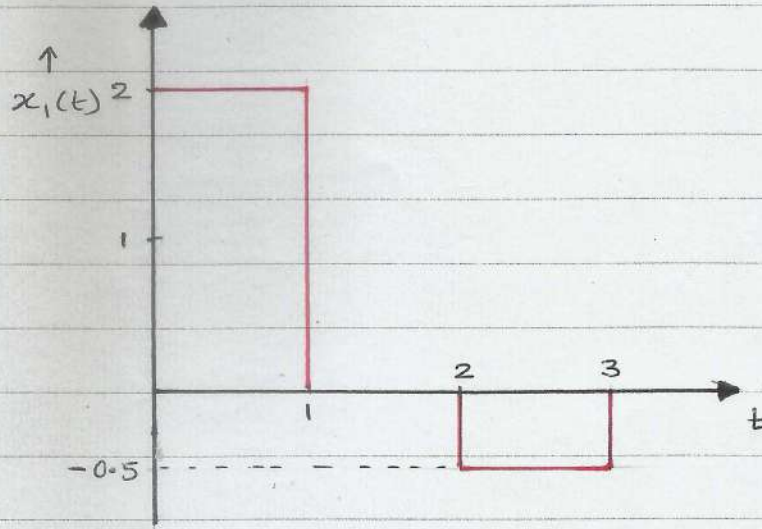
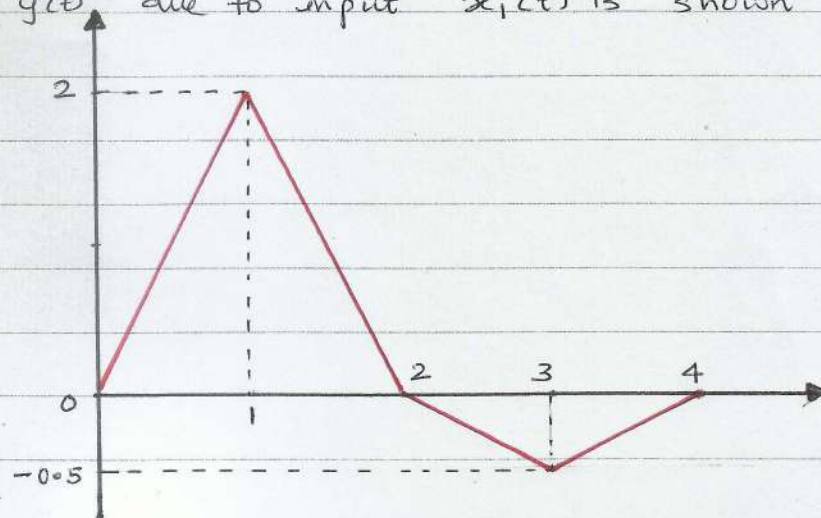


Fig. Q1b

Sol. The output $y(t)$ due to input $x_1(t)$ is shown below.



Q2 Derive the expression for V_o in terms of V_1 and V_2 for the circuit shown in Fig. Q2. Assume that the op-amps are ideal and operate in linear region.

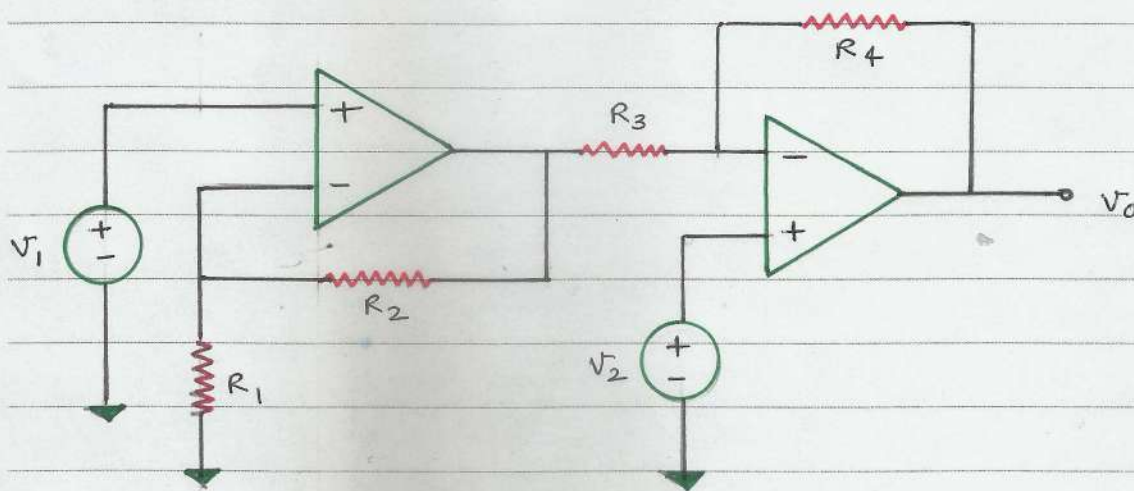


Fig. Q2

How can this amplifier be used as a subtractor?

Sol.

Output voltage of 1st op-amp is

$$V_1' = \left(1 + \frac{R_2}{R_1}\right) V_1$$

$$V_o = \left(-\frac{R_4}{R_3}\right) V_1' + \left(1 + \frac{R_4}{R_3}\right) V_2$$

$$= -\left(\frac{R_4}{R_3}\right) \left(1 + \frac{R_2}{R_1}\right) V_1 + \left(1 + \frac{R_4}{R_3}\right) V_2$$

$$\Rightarrow V_o = \left(1 + \frac{R_4}{R_3}\right) V_2 - \left(\frac{R_4}{R_3} + \frac{R_4 R_2}{R_3 R_1}\right) V_1$$

If $R_1 = R_4$ and $R_2 = R_3$ then

$$V_o = \left(1 + \frac{R_4}{R_3}\right) V_2 - \left(1 + \frac{R_4}{R_3}\right) V_1$$

$$\Rightarrow V_o = \left(1 + \frac{R_4}{R_3}\right) (V_2 - V_1)$$

- Q3 Specify the values of R_1 and R_2 in Fig. Q3 that are required to cause V_3 to be related to V_1 and V_2 by the equation $V_3 = 6V_1 - 0.8V_2$. Assume that all the op-amps are ideal and operate in linear region.

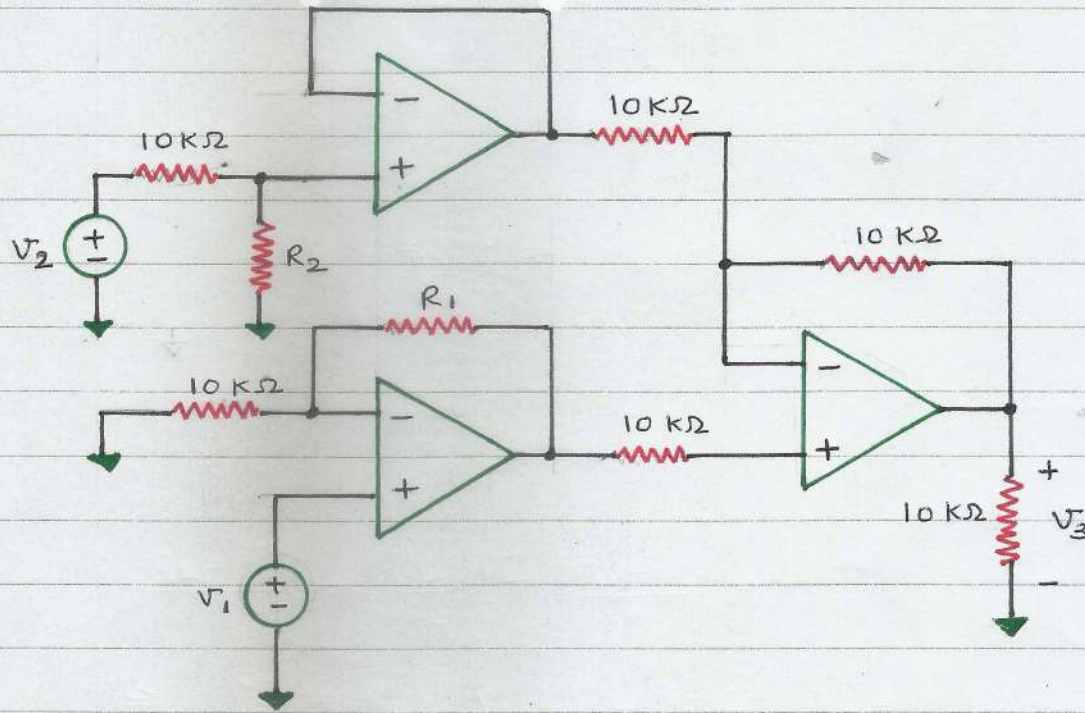
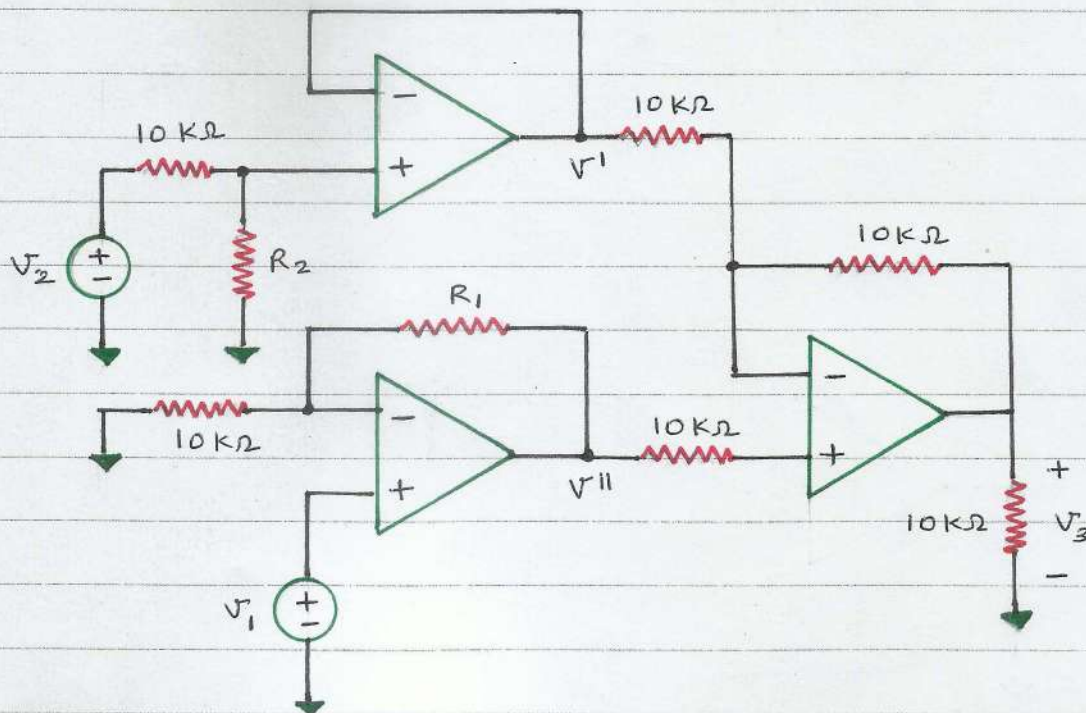


Fig. Q3

Sol.



Let R_1 and R_2 be in $k\Omega$

$$V^I = \left(\frac{R_2}{R_2 + 10} \right) \times V_2$$

$$V^{II} = \left(1 + \frac{R_1}{10} \right) \times V_1$$

$$V_3 = \left(-\frac{10}{10} \right) \times V^I + \left(1 + \frac{10}{10} \right) \times V^{II}$$

$$= -V^I + 2V^{II}$$

$$= -\left(\frac{R_2}{R_2 + 10} \right) \times V_2 + 2 \left(1 + \frac{R_1}{10} \right) V_1$$

$$= 2 \left(1 + \frac{R_1}{10} \right) V_1 - \left(\frac{R_2}{R_2 + 10} \right) V_2$$

$$2 \times \left(1 + \frac{R_1}{10} \right) = 6 \quad \text{and} \quad \frac{-R_2}{R_2 + 10} = -0.8$$

$$\Rightarrow 1 + \frac{R_1}{10} = 3$$

$$\Rightarrow \frac{R_2 + 10}{R_2} = \frac{5}{4}$$

$$\Rightarrow \frac{R_1}{10} = 2$$

$$\Rightarrow 1 + \frac{10}{R_2} = \frac{5}{4}$$

$$\Rightarrow R_1 = 20 \, k\Omega$$

$$\Rightarrow \frac{10}{R_2} = \frac{1}{4}$$

$$\Rightarrow R_2 = 40 \, k\Omega$$

$$R_1 = 20 \, k\Omega \quad \text{or} \quad R_2 = 40 \, k\Omega \quad \text{for} \quad V_3 = 6V_1 - 0.8V_2$$

$$\therefore R_1 = 20 \, k\Omega \quad \text{and} \quad R_2 = 40 \, k\Omega \quad \text{for} \quad V_3 \quad \text{to be equal to} \quad 6V_1 - 0.8V_2$$

- Q4) For the amplifier circuit shown in Fig. Q4, find the expression for i_L in terms of V_S , if $R_2 = R_4$ and $R_1 = R_3$. What type of amplifier is it? Assume that the op-amp is ideal and operates in linear region.

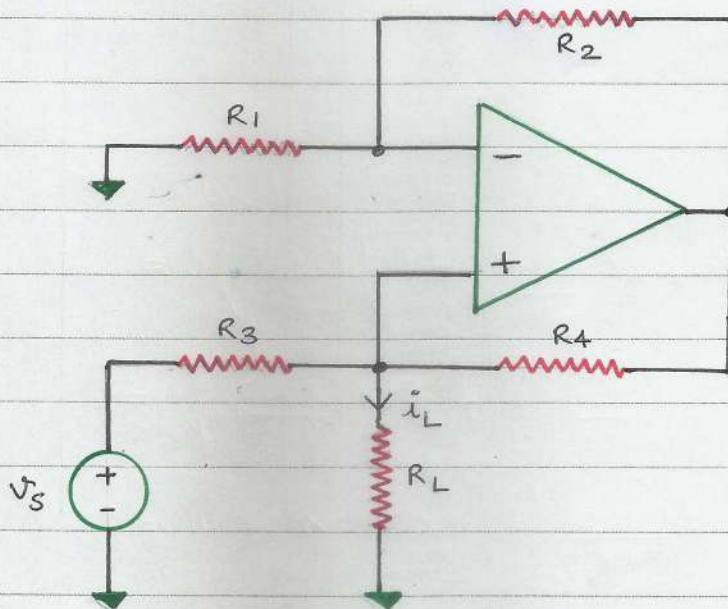
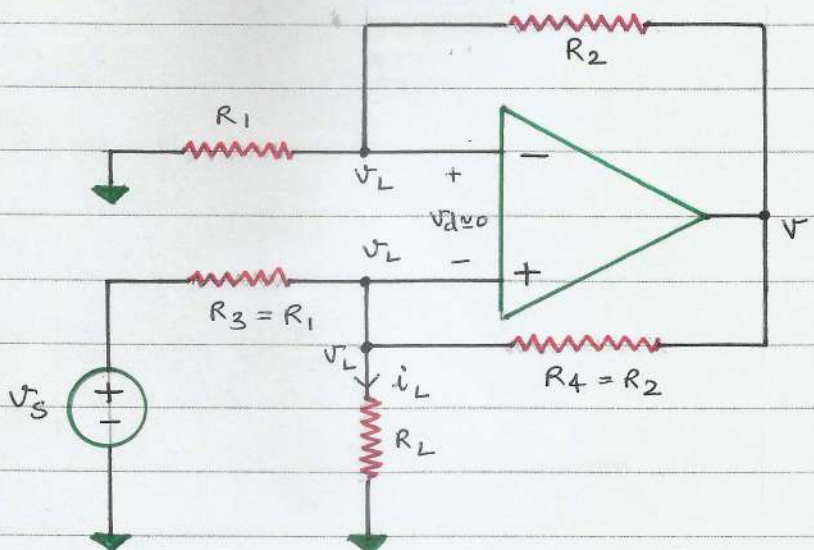


Fig. Q4

Sol.



Applying KCL at non-inverting input of op-amp

$$\frac{V_S - V_L}{R_1} + \frac{V_L}{R_L} + \frac{V_L - V'}{R_2} = 0 \quad \dots (A)$$

Applying KCL at inverting input of op-amp

$$\frac{V_L}{R_1} + \frac{V_L - V^1}{R_2} = 0$$

$$\Rightarrow V_L \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{V^1}{R_2}$$

$$\Rightarrow V^1 = R_2 \times V_L \frac{(R_1 + R_2)}{R_1 R_2}$$

$$\Rightarrow V^1 = \frac{(R_1 + R_2)}{R_1} V_L \quad \dots (B)$$

Substituting the expression for V^1 in (B) in eq. (A)

Eq (A)

$$\frac{V_L - V_S}{R_1} + \frac{V_L}{R_L} + \frac{V_L - V^1}{R_2} = 0$$

$$\Rightarrow V_L \left(\frac{1}{R_1} + \frac{1}{R_L} + \frac{1}{R_2} \right) - \frac{V^1}{R_2} = \frac{V_S}{R_1}$$

$$\Rightarrow V_L \left(\frac{1}{R_1} + \frac{1}{R_L} + \frac{1}{R_2} \right) - \frac{(R_1 + R_2)}{R_1 R_2} V_L = \frac{V_S}{R_1}$$

$$\Rightarrow V_L \left(\frac{1}{R_1} + \frac{1}{R_L} + \frac{1}{R_2} \right) - \left(\frac{1}{R_1} + \frac{1}{R_2} \right) V_L = \frac{V_S}{R_1}$$

$$\Rightarrow \frac{V_L}{R_L} = \frac{V_S}{R_1}$$

$$\Rightarrow \frac{I_L R_L}{R_L} = \frac{V_S}{R_1}$$

$$\Rightarrow \boxed{I_L = \frac{V_S}{R_1}}$$

▢ Load current depends on source (input) voltage irrespective of load resistance (R_L). It is a transconductance amplifier.

Q5 Find the output voltage V_o of the amplifier circuit shown in Fig. Q5. Assume that all op-amps are ideal and none of the op-amps saturate.

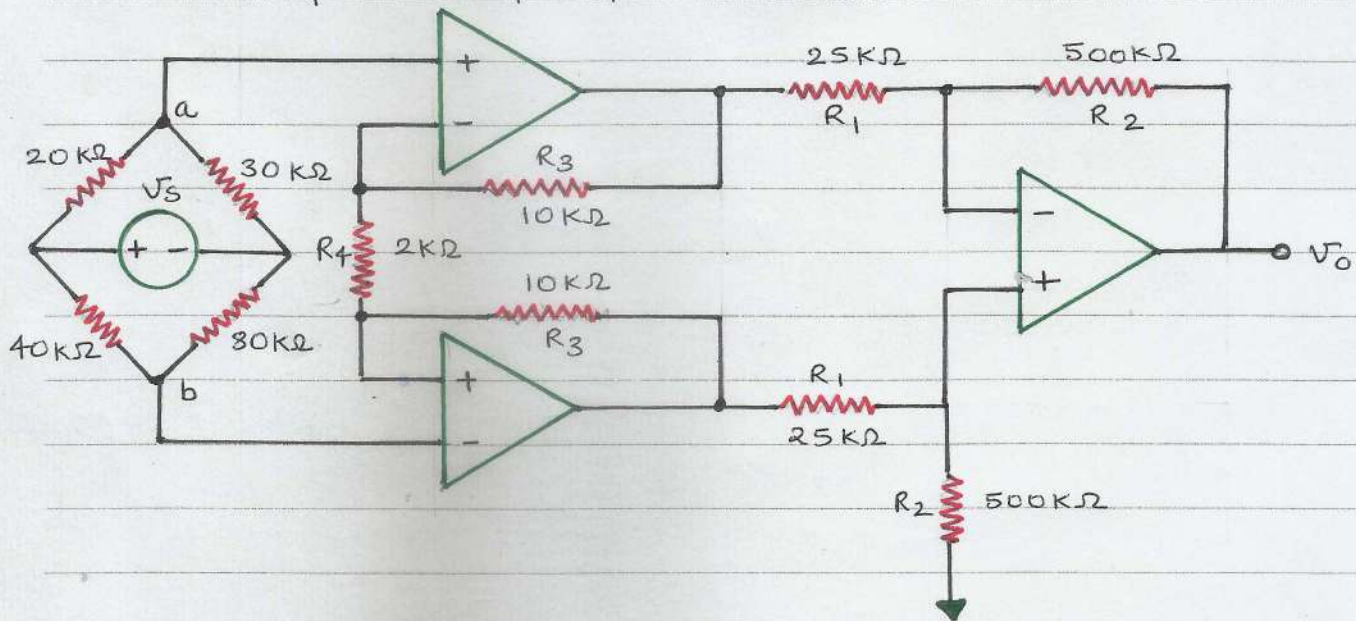
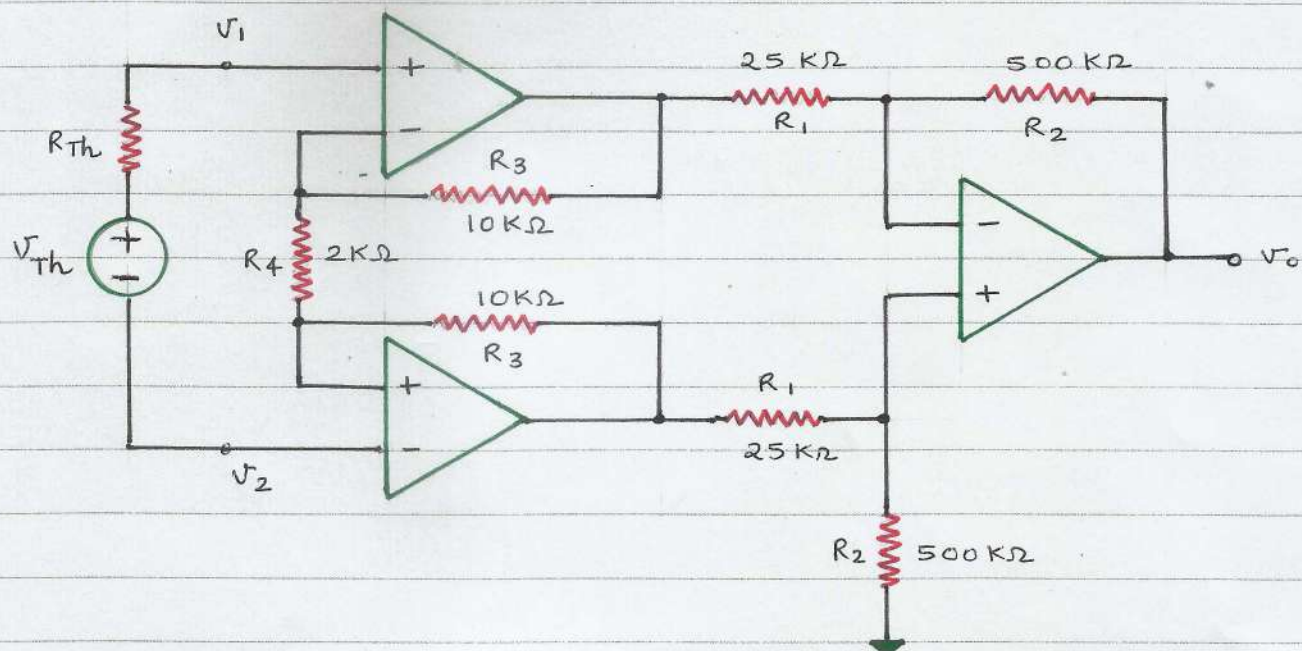


Fig. Q5

Sol. Thevenizing bridge circuit across a-b.



$$\begin{aligned}
 R_{Th} &= 20\text{K}\Omega \parallel 30\text{K}\Omega + 40\text{K}\Omega \parallel 80\text{K}\Omega \\
 &= \frac{20 \times 30}{50} + \frac{40 \times 80}{120} \text{K}\Omega \\
 &= \frac{60}{5} + \frac{80}{3} \text{K}\Omega = \frac{116}{3} \text{K}\Omega
 \end{aligned}$$

$$V_{th} = V_1 - V_2 = \frac{30}{30+20} V_S - \frac{80}{80+40} V_S$$

(current flows from the 1st stage op-amps)

$$= \frac{30}{50} V_S - \frac{80}{120} V_S$$

$$= \frac{3}{5} V_S - \frac{8}{12} V_S = \frac{3}{5} V_S - \frac{2}{3} V_S$$

$$= -\frac{1}{15} V_S = V_1 - V_2$$

$$V_0 = \left(\frac{R_2}{R_1} \right) \left(1 + \frac{2R_3}{R_4} \right) (V_2 - V_1)$$

$$= \left(\frac{500K}{25K} \right) \left(1 + \frac{2 \times 10K}{2K} \right) \times \frac{V_S}{15}$$

$$\therefore V_2 - V_1 = \frac{V_S}{15}$$

$$= 20 \times 11 \times \frac{V_S}{15} = \frac{220}{15} V_S = \frac{44}{3} V_S = 14.667 V_S$$