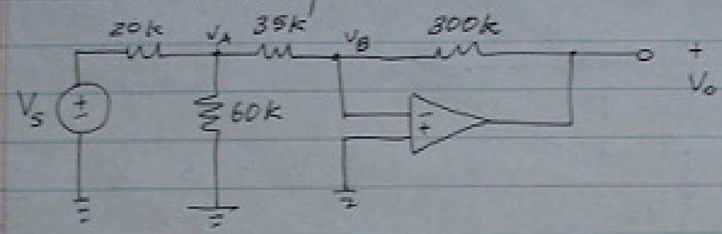
4.21, 4.24, 4.28, 4.29, 4.32, 4.33, 4.35, 4.38, 4.48, 4.54

4.21) Find V_o in terms of V_s



$V_p = V_N = 0$

$i_p = i_n = 0$

$V_B = V_N = 0$

KCL @ node A:

$$\frac{V_A - V_s}{20k} + \frac{V_A - V_B}{35k} + \frac{V_A}{60k} = 0$$

$$\frac{V_A - V_s}{20k} + \frac{V_A}{35k} + \frac{V_A}{60k} = 0$$

$$V_A\left(\frac{1}{20k} + \frac{1}{35k} + \frac{1}{60k}\right) - \frac{V_s}{20k} = 0$$

$$V_A\left(\frac{21 + 12 + 7}{420k}\right) - \frac{V_s(21)}{420k} = 0$$

$$40 V_A - 21 V_s = 0 \quad -(1)$$

KCL @ node B:

$$\frac{V_B - V_A}{35k} + \frac{V_B - V_o}{300k} = 0$$

$$\frac{-V_A}{35k} - \frac{V_o}{300k} = 0 \implies V_A = \frac{-V_o(35)}{300} \quad -(2)$$

Plugging (2) in (1)

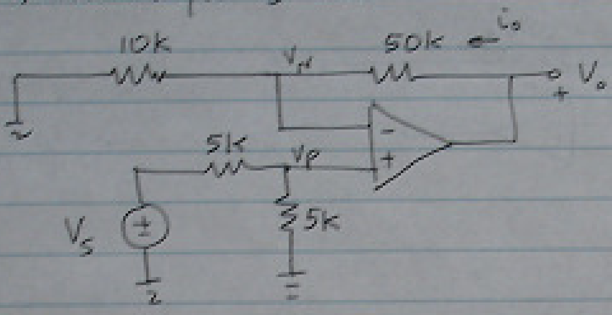
$$40\left(\frac{-35 V_o}{300}\right) - 21 V_s = 0$$

$$-\frac{14}{3} V_o = 21 V_s \implies \boxed{V_o = \frac{-9}{2} V_s}$$

18

4.24) a) Find V_o in terms of V_s

b) Find i_o for $V_s = 2V$



$V_P = V_N$

$i_N = i_P = 0$

$$V_P = \frac{5}{5+5} V_s = \frac{V_s}{2}$$

$$V_N = V_P = \frac{V_s}{2}$$

KCL @ V_N

$$\frac{V_N}{10k} + \frac{V_N - V_o}{50k} = 0$$

$$\frac{V_s}{20k} + \frac{V_s/2 - V_o}{50k} = 0$$

$$\frac{V_s}{20k} + \frac{V_s - 2V_o}{100k} = 0 \Rightarrow V_s\left(\frac{1}{20k} + \frac{1}{100k}\right) = \frac{2V_o}{100k}$$

$$V_s\left(\frac{6}{100k}\right) = \frac{2V_o}{100k}$$

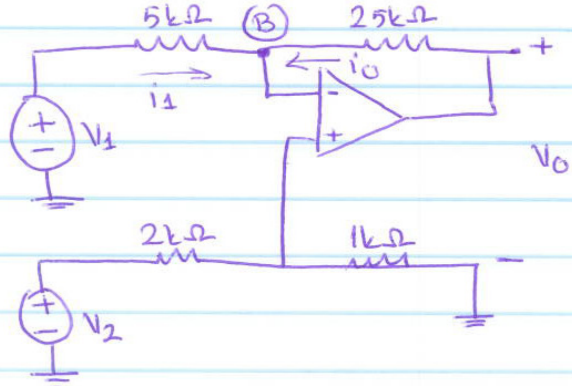
$$\Rightarrow \boxed{V_o = 3V_s}$$

$$i_o = \frac{V_o - V_N}{50k} = \frac{3V_s - \frac{V_s}{2}}{50k} = \frac{5V_s}{100k} = \frac{5(2)}{100k} = 0.1mA$$

$$\boxed{i_o = 0.1mA}$$

18 1:55

4.28)



$V_n = V_p$ and $i_n = i_p = 0$

$$V_p = \frac{1}{(1+2)} V_2 = \frac{V_2}{3} = V_n$$

KCL for node (B)

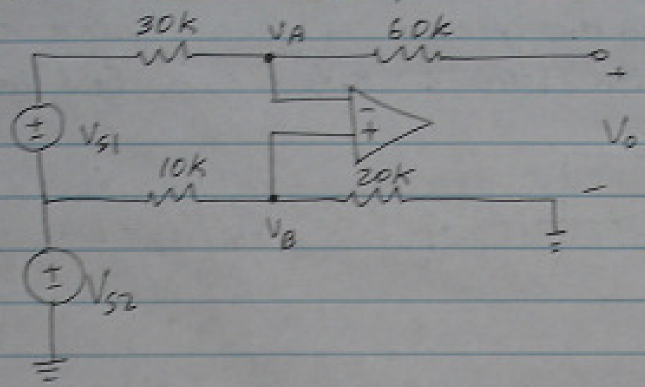
$$i_1 + i_o = 0 \Rightarrow \frac{V_1 - V_n}{5} + \frac{V_o - V_n}{25} = 0 \quad \left(V_n = V_p = \frac{V_2}{3}\right)$$

$$\Rightarrow \frac{V_1}{5} - \frac{6V_n}{25} + \frac{V_o}{25} = 0$$

$$\Rightarrow \frac{V_o}{25} = \frac{6}{25}\frac{V_2}{3} - \frac{V_1}{5} \Rightarrow \frac{V_o}{25} = \frac{2V_2}{25} - \frac{V_1}{5}$$

$$\Rightarrow \boxed{V_o = 2V_2 - 5V_1}$$

4.29 Find V_o in terms of inputs V_{s1} and V_{s2}



$V_N = V_P$

$i_N = i_P = 0$

$V_A = V_N$

$V_B = V_P$

$$V_B = \frac{20k}{20k+10k} V_{s2} = \frac{2}{3} V_{s2} = V_N = V_P$$

KCL @ node A:

$$\frac{V_A - (V_{s1} + V_{s2})}{30k} + \frac{V_A - V_o}{60k} = 0$$

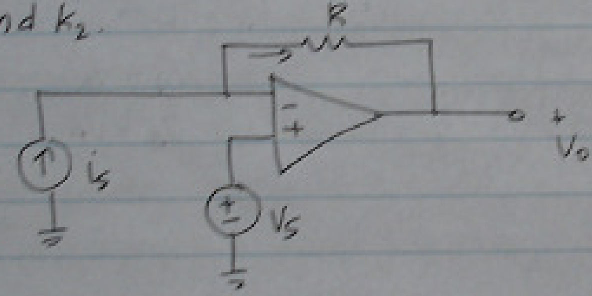
$$\frac{\frac{2}{3}V_{s2} - V_{s1} - V_{s2}}{30k} + \frac{\frac{2}{3}V_{s2} - V_o}{60k} = 0$$

$$\frac{2}{3}V_{s2} - V_{s1} - V_{s2} = \frac{1}{2}\left(V_o - \frac{2}{3}V_{s2}\right)$$

$$\frac{2}{3}V_{s2} - V_{s2} + \frac{1}{3}V_{s2} - V_{s1} = \frac{V_o}{2}$$

$$\boxed{V_o = -2V_{s1}}$$

4.32) The inputs to the circuit are a current source i_s and a voltage source V_s. When the op-Amp is in its linear range, the output voltage has the form $V_o = K_1 V_s + K_2 i_s$. Find the constants K_1 and K_2.



$V_p = V_N = V_s$

$i_N = i_p = 0$

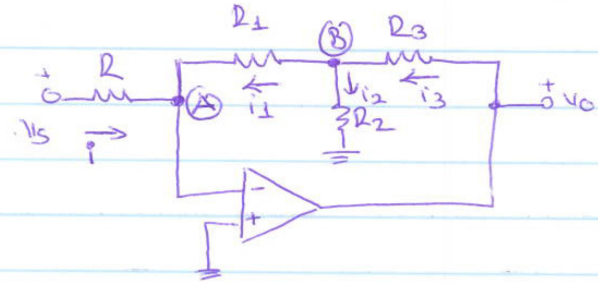
$$\frac{V_N - V_o}{R} = i_s$$

$V_o - V_s = -i_s R \implies V_o = V_s - R i_s$

$\therefore$ $K_1 = 1$, $K_2 = -R$

18 1:55

4.33)



$V_n = V_p = 0$ and $i_n = i_p = 0$

Apply KCL for Node A

$$i + i_1 = 0 \Rightarrow \frac{V_S - V_n}{R} + \frac{V_B - V_n}{R_1} = 0 \Rightarrow V_B = \frac{-R_1}{R} V_S$$

Apply KCL for Node B

$$-i_1 - i_2 + i_3 = 0 \Rightarrow \frac{-V_B}{R_1} - \frac{V_B}{R_2} + \frac{V_o - V_B}{R_3} = 0$$

$$\Rightarrow V_B\left(-\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3}\right) + \frac{V_o}{R_3} = 0 \qquad \left(V_B = \frac{-R_1}{R} V_s\right)$$

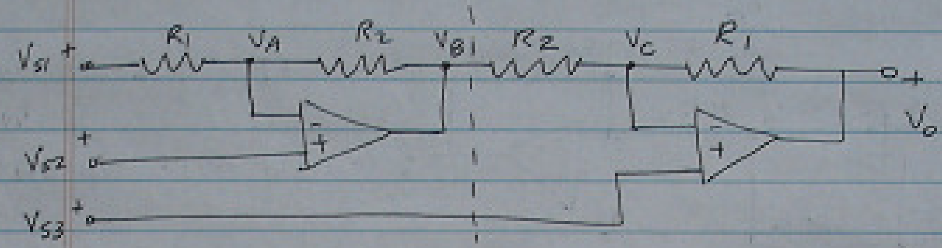
$$\Rightarrow -\frac{R_1}{R} V_s \left(-\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3}\right) + \frac{V_o}{R_3} = 0$$

$$\Rightarrow V_s \left(\frac{1}{R} + \frac{R_1}{RR_2} + \frac{R_1}{RR_3}\right) = \frac{-V_o}{R_3}$$

$$\Rightarrow V_o = -\left(\frac{R_3}{R} + \frac{R_1 R_3}{R R_2} + \frac{R_1}{R}\right) V_s$$

$$\Rightarrow V_o = -\left(\frac{R_2 R_3 + R_1 R_3 + R_1 R_2}{R R_2}\right) V_s$$

4.35) Find V_o in terms of the inputs V_{s1}, V_{s2}, and V_{s2}



For op-Amp 1 : $V_p = V_N = V_{s2}$, $i_p = i_N = 0$

$V_A = V_{s2}$

KCL @ A:

$$\frac{V_A - V_{s1}}{R_1} + \frac{V_A - V_B}{R_2} = 0$$

$$\frac{V_{s2} - V_{s1}}{R_1} + \frac{V_{s2} - V_B}{R_2} = 0$$

$$\frac{-V_B}{R_2} = -\frac{V_{s2}}{R_1} + \frac{V_{s1}}{R_1} - \frac{V_{s2}}{R_2} \Rightarrow V_B = R_2\left(\frac{V_{s2}}{R_1} - \frac{V_{s1}}{R_1} + \frac{V_{s2}}{R_2}\right)$$

For op-amp 2 : $V_p = V_N = V_{s3}$, $i_p = i_N = 0$

KCL @ C

$$\frac{V_C - V_B}{R_2} + \frac{V_C - V_o}{R_1} = 0$$

$$\frac{V_{s3} - V_B}{R_2} + \frac{V_{s3}}{R_1} \frac{-V_o}{R_1} = 0$$

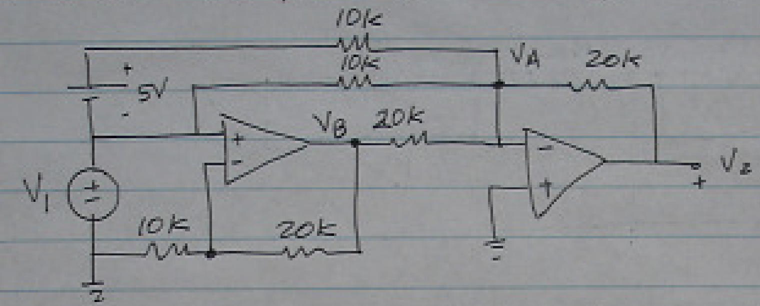
$$\frac{V_{s3}}{R_2} - \frac{V_{s2} \cancel{R_2}}{\cancel{R_2} R_1} + \frac{V_{s1} \cancel{R_2}}{\cancel{R_2} R_1} + \frac{V_{s2}}{R_2} + \frac{V_{s3}}{R_1} = \frac{V_o}{R_1}$$

$$V_o = V_{s3}\frac{R_1}{R_2} - V_{s2} + V_{s1} + V_{s2}\frac{R_1}{R_2} + V_{s3}$$

$$\boxed{V_o = V_{s1} - \left(1 + \frac{R_1}{R_2}\right)V_{s2} + \left(1 + \frac{R_1}{R_2}\right)V_{s3}}$$

18 1:5

4.38) Find the output V_2 in terms of the input V_1



Op-Amp 2: $V_P = V_N = 0$

$i_P = i_N = 0$

Op-Amp 1: $V_P = V_N = V_1$

KCL @ A:

$$\frac{V_A + 5 + V_1}{10K} + \frac{V_A - V_1}{10K} + \frac{V_A - V_B}{20K} + \frac{V_A - V_2}{20K} = 0$$

$$\frac{V_1}{10K} + \frac{5}{10K} - \frac{V_1}{10K} - \frac{V_B}{20K} - \frac{V_2}{20K} = 0$$

$$V_B - V_2 = 10 \qquad -(1)$$

KCL @ B:

$$\frac{V_B - V_1}{20K} + \frac{V_B - V_A}{20K} = 0$$

$$\frac{V_B}{20K} - \frac{V_1}{20K} + \frac{V_B}{20K} = 0$$

$$\frac{V_B}{10K} = \frac{V_1}{20K} \Rightarrow V_B = \frac{V_1}{2} \qquad -(2)$$

plugging in (2) in (1)

$$\frac{V_1}{2} - V_2 = 10$$

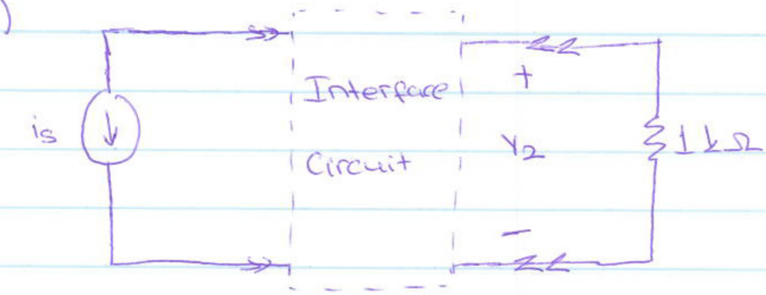
$$\boxed{V_2 = \frac{V_1}{2} - 10}$$

$\frac{V_1}{10} + \frac{V_1 - V_B}{20}$

$V_1\left(\frac{1}{10} + \frac{1}{20}\right) = V$

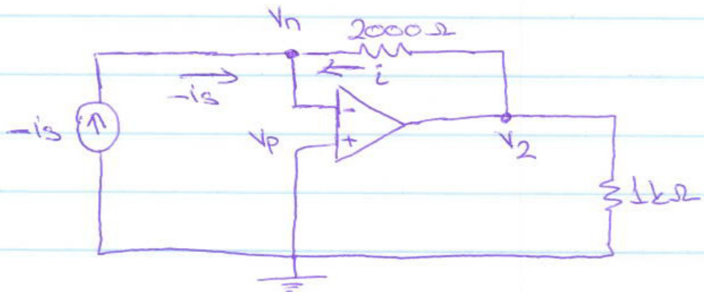
$V_1\left(\frac{3}{20}\right) = V_1$

4.48)



$v_2 = 2000\, i_s$

You can find different solution. Here is the one by inspiring from 4.32.



Let's check if it works

$v_n = v_p = 0$ and $i_n = i_p = 0$

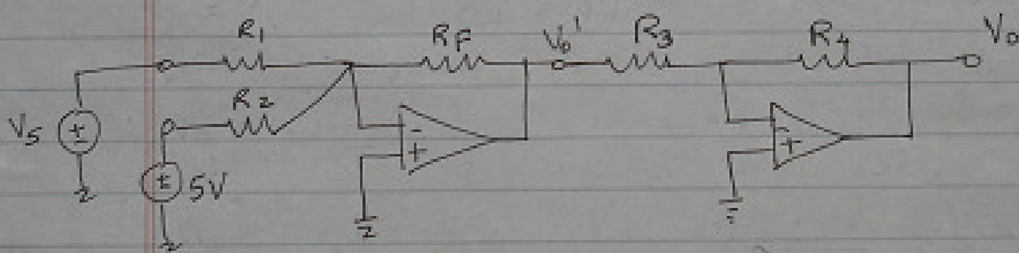
$-i_s + i = 0 \Rightarrow -i_s + \frac{v_2}{2000} = 0 \Rightarrow v_2 = 2000\, i_s$ ✓

4.54) The output voltage of a semi-conductor temp. sensor is $V_S = (10T + 500)\,mV$, where T - temp (°C). The sensor is to be used to measure temperatures in the range −40°C to 110°C. Design an interface circuit that translates this temperature range to a 0V to 3V output voltage range. Use a standard 5V reference source to obtain any required bias voltage.

$-40°C \le T \le 110°C \implies 0.1V \le V_S \le 1.6V$

Output voltage desired $\quad 0 \le V_o \le 3V$

Example : one possible design



$$V_o' = \frac{-R_F}{R_1} V_S - \frac{R_F}{R_2}(5V)$$

$$V_o = \frac{-R_4}{R_3} V_o'$$

$R_F = 1k$, $R_1 = R_2 = R_4 = 1k \quad R_3 = 3k$

$V_o' = -V_S - 5$

$$V_o = \frac{-1}{3}(-V_S - 5) = \frac{V_S + 5}{3}$$

if $V_S = 0.1 \implies V_o = \frac{5.1}{3} = 1.7V$

if $V_S = 1.6V \implies V_o = \frac{6.6}{3} = 2.2V$

18 1