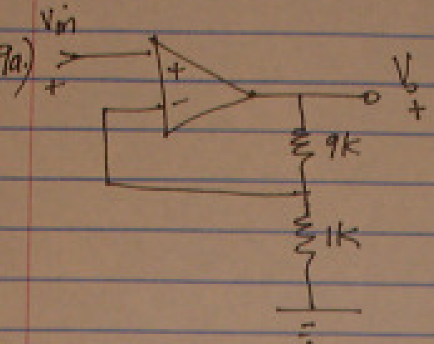
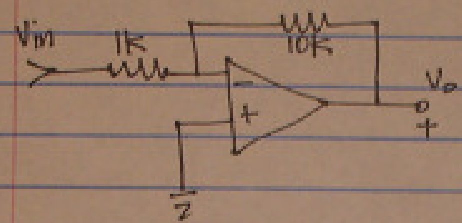
4.19a)



$\Rightarrow$ Non-inverting Amplifier

$$k = \frac{R_1 + R_2}{R_2}$$

$$= \frac{9k + 1k}{1k} = 10$$

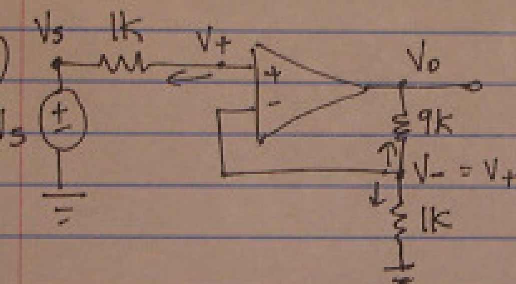


$\Rightarrow$ Inverting Amplifier

$$k = \frac{-R_2}{R_1} = \frac{-10k}{1k}$$

$$= -10$$

b)



$$V_+ = V_-$$

$$V_- = \frac{1k}{10k} V_o$$

$$V_+ = \frac{V_o}{10}$$

KCL At V_+: $\dfrac{V_+ - V_s}{1k} + \dfrac{V_+ - V_o}{9k} + \dfrac{V_+}{1k} = 0$

At V_o: $\dfrac{V_o - V_-}{9k} = 0$

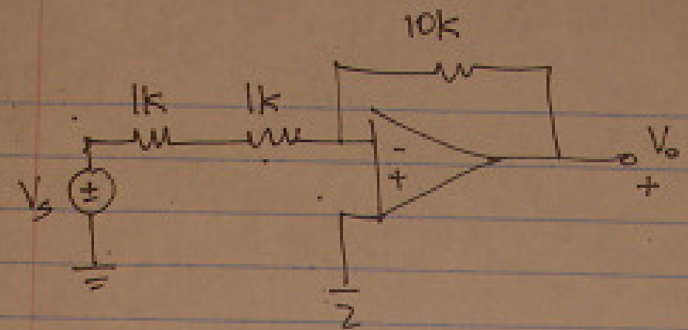
$$9k(V_+ - V_s) + V_+ - V_o + V_+ = 0$$

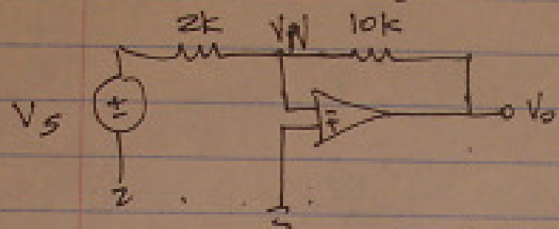
$$9kV_+ + V_+ + V_+ - V_s - V_o = 0$$

$$11\cancel{k}V_+ - V_s - V_o = 0$$

$$11\cancel{k}\frac{V_o}{10} - V_o = V_s \Rightarrow \frac{V_o}{10} = V_s$$

$$\Rightarrow \boxed{\frac{V_o}{V_s} = 10}$$





$V_p = V_N = 0$

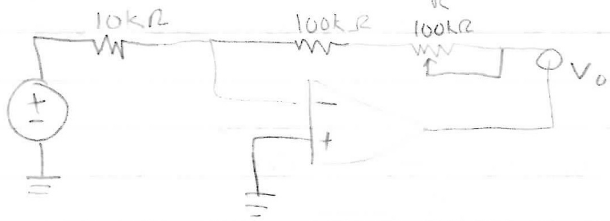
At V_N: $\dfrac{V_N - V_s}{2k} + \dfrac{V_N - V_o}{10k} = 0$

$$\frac{-V_s}{2k} + \frac{-V_o}{10k} = 0$$

$$\frac{V_o}{10k} = \frac{-V_s}{2k} \Rightarrow \boxed{\frac{V_o}{V_s} = -5}$$

Adding the source circuit only changes the gain in circuit 2 because it loads the circuit by adding another resistor in series with the 1k resistor at the ~~positive to~~ negative terminal.

4-22 What is the range of the gain $\frac{V_o}{V_s}$?



Max & Min occur when R is either 0Ω or 100kΩ

When R is 0Ω, its just an inverter circuit

$$K = \frac{V_o}{V_s} = \frac{100k}{10k} = 10$$

When R is 100kΩ, the two 100kΩ resistors can be combined

$$K = \frac{V_o}{V_s} = \frac{200k}{10k} = 20$$

$\boxed{\text{range: } 10-20}$

4.23

Part (a) Begin by noting that $v_s = v_p = v_n$ due to the Op-Amp laws. KCL at the v_n node yields

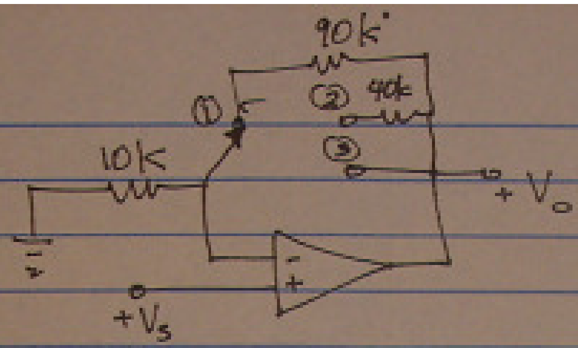
$$\frac{v_n}{10k\Omega} = \frac{v_o - v_n}{150k\Omega},$$
$$\Rightarrow v_o = 16v_s.$$

Part (b) The relation between i_o and v_o is given by Ohm's law;

$$i_o = \frac{v_o}{10k\Omega} = 1.6v_s \times 10^{-3}.$$

For $v_s = 1V$ we have $i_o = 1.6mA$ and for $v_s = 3V$ we have v_o saturate at $24V$, resulting in $i_o = 2.4mA$.

4.25



$V_p = V_N$

$V_p = V_N = V_s$

At V_1: $\dfrac{V_1}{10k} + \dfrac{V_1 - V_0}{90k} = 0$

$V_1 = V_N = V_s$

$$\frac{9V_s + V_s}{\cancel{90k}} = \frac{V_o}{\cancel{90k}}$$

$$\boxed{\frac{V_o}{V_s} = 10}$$

At V_2: $\dfrac{V_2}{10k} + \dfrac{V_2 - V_o}{40k} = 0$

$V_2 = V_N = V_s$

$$\frac{V_s}{10k} + \frac{V_s - V_o}{40k} = 0$$

$$\frac{4V_s + V_s}{\cancel{40k}} = \frac{V_o}{\cancel{40k}}$$

$$\boxed{\frac{V_o}{V_s} = 5}$$

At V_3: $V_3 = V_0$ $\quad V_3 = V_p$

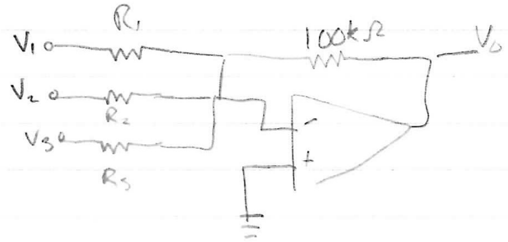
$\Rightarrow V_0 = V_p = V_s \Rightarrow \boxed{\dfrac{V_o}{V_s} = 1}$

26

4-27

$V_o = -[V_1 + 10V_2 + 100V_3]$

$V_F = 100k\Omega$



$K_1 = 1 = -\frac{R_F}{R_1} = -\frac{100k}{R_1}$

$\boxed{R_1 = 100k\Omega}$

$K_2 = 10 = \frac{-100k}{R_2}$

$\boxed{R_2 = 10k\Omega}$

$K_3 = -100 = \frac{-100k}{R_3}$

$\boxed{R_3 = 1k\Omega}$

4.30

Begin by solving for v_p using KCL (and noting that $i_p = 0$);

$$\frac{v_p - v_{s1}}{R_1} + \frac{v_p - v_{s2}}{R_2} = 0,$$
$$\Rightarrow v_p = \frac{v_{s1}R_2 + v_{s2}R_1}{R_1 + R_2}.$$

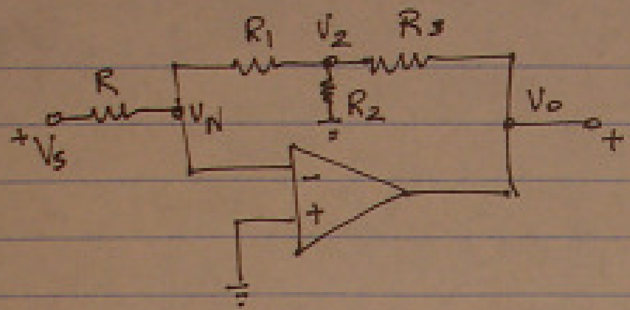
Now note that by voltage division,

$$v_n = v_o\frac{R_3}{R_3 + R_4},$$
$$\Rightarrow v_o = v_n\frac{R_3 + R_4}{R_3}.$$

Finally, from the Op-Amp law $v_n = v_p$, we have

$$v_o = \frac{v_{s1}R_2 + v_{s2}R_1}{R_1 + R_2} \times \frac{R_3 + R_4}{R_3}.$$

4.33a)



$V_p = V_N = 0$

KCL at V_N: $\dfrac{V_N - V_S}{R} + \dfrac{V_N - V_2}{R_1} = 0$

$\dfrac{-V_S}{R} + \dfrac{-V_2}{R_1} = 0 \Rightarrow V_2 = \dfrac{-R_1 V_S}{R}$

KCL @ V_2: $\dfrac{V_2 - V_N}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_2 - V_0}{R_3} = 0$

$V_2\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right) = \dfrac{V_0}{R_3}$

$-\dfrac{R_1}{R}\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right)V_S = \dfrac{V_0}{R_3}$

$$\boxed{\dfrac{-R_1 R_3}{R}\left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right) = \dfrac{V_0}{V_S}}$$

b) $K = -3$

$-\left(\dfrac{R_1 R_2 + R_2 R_3 + R_1 R_3}{R R_2}\right) = -3$

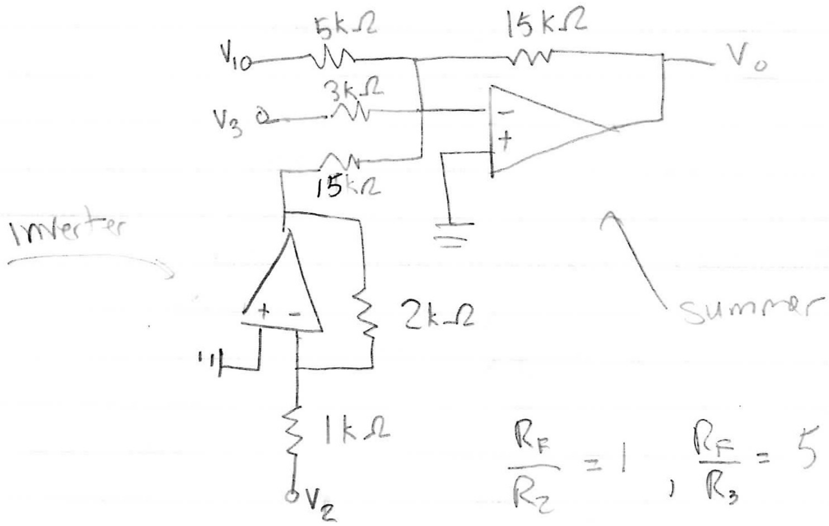
for eg: $R_1 = 1K$

$R_2 = 1K$

$R_3 = 1K$

$R = 1K$

4-45 Using no more than two op amps, design a circuit with I/O $V_o = -3V_1 + 2V_2 - 5V_3$



$$\frac{R_F}{R_2} = 1, \quad \frac{R_F}{R_3} = 5 \quad \frac{R_F}{R_1} = 3$$

$R_F = 15k\Omega$, $R_2 = 15k\Omega$, $R_3 = 3k\Omega$, $R_1 = 5k\Omega$

4.56

The transducer is modeled as an ideal voltage source in series with a resistance. Denote the potential supplied by the source as v_i and the corresponding internal resistance R_i. Note that $v_i = 400$ corresponds to a pressure of 32 psi, while $v_i = 1000$ corresponds to a pressure of 7 psi. We desire an output voltage, denoted v_o, of $-5V$ when the pressure is 7 psi, and an output of $5V$ when the pressure is 32 psi. Hence, it is desired to realize the input-output voltage relation described by the plot in Figure 1. The corresponding equation is

$$v_o = 5 \times \frac{7}{3} - 100 \times \frac{500}{3} v_i. \tag{1}$$

Note that the coefficients are factored as above to accomodate the available five volt bias source and to contain the Op-Amp gains within their operational range of $[0, 2000]$, as specified by the design constraints. Clearly, the factorization is non-unique.

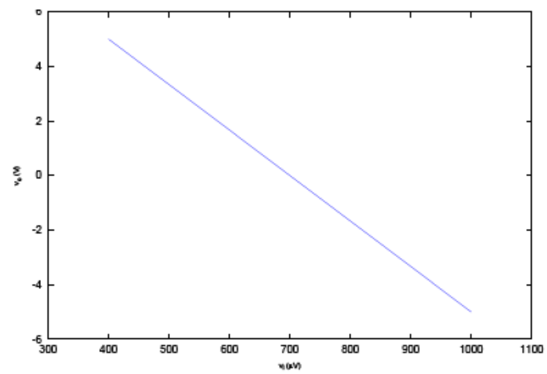


Figure 1: Graph of desired input-output relation.

Remark: In grading this problem, students who have attained the above expression (1) or an equivalent form and have additionally drawn a circuit that appears to realize their equation should receive full credit. The reader is discouraged from attempting to confirm that each individual student's design is completely correct due to the ridiculous amount of time that would be required to do so.

One possible realization of Equation (1) is given in Figure 2. The chosen resistances are only unique up to scalar multiples. The use of a non-inverter eliminates the effect of the transducer's internal resistance, so it is superior to an inverter circuit in this case. Additionally, note that resistance values close to those listed may be used without significantly changing the input-output relation. Confirmation of this is left as an exercise for the student.

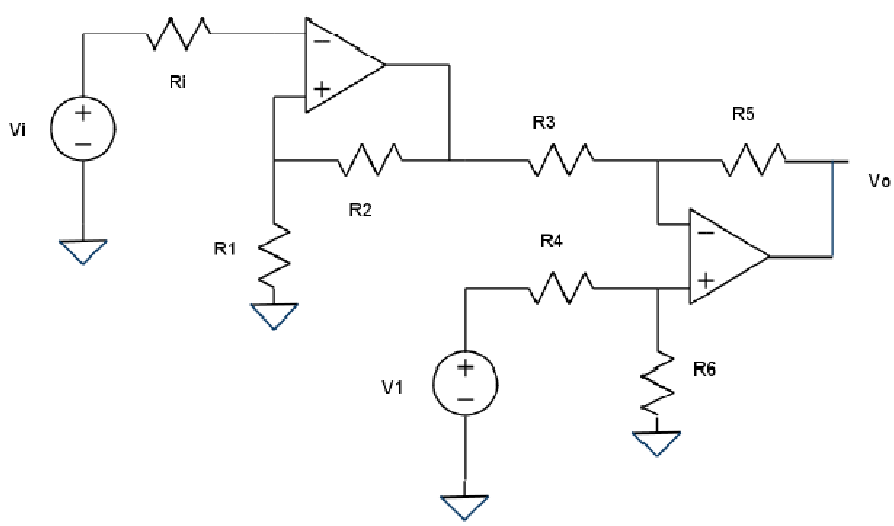


Figure 2: Final design, combining a non-inverter with a subtractor. The values for resistances are $R_i = 500 \pm 75\Omega$, $R_1 = 3\Omega$, $R_2 = 497\Omega$, $R_3 = 1\Omega$, $R_4 = 296\Omega$, $R_5 = 100\Omega$, and $R_6 = 7\Omega$. The bias source is $V_1 = 5V$.

4.58) $k = \frac{60\,mV}{pH}$

Output requirements: $V_o = 1V$ @ $pH = 4$

$V_o = 1.75\,V$ @ $pH = 7$

$$k = \frac{\text{Desired range}}{\text{Available range}} = \frac{\overset{4}{1} - \overset{7}{1.75}}{V_{TR}(4) - V_{TR}(7)}$$

$$= \frac{-0.75}{V_{TR}(4) - V_{TR}(7)}$$

Proportionality constant $= 60\,mV/pH$

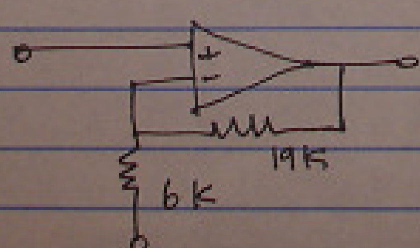
@ pH 4 $= 0.24V$

@ pH 7 $= 0.42V$

$$k = \frac{-0.75}{0.24 - 0.42} = \frac{-0.75}{-0.18} = \frac{25}{6}$$

$V_o = kV_{TR} + V_b$

$1 = \frac{25}{6}(0.24) + V_b \Rightarrow V_b = 0$



$k = \frac{R_1 + R_2}{R_2} = \frac{25}{6}$

$R_2 = 6K$

$R_1 = 19K$