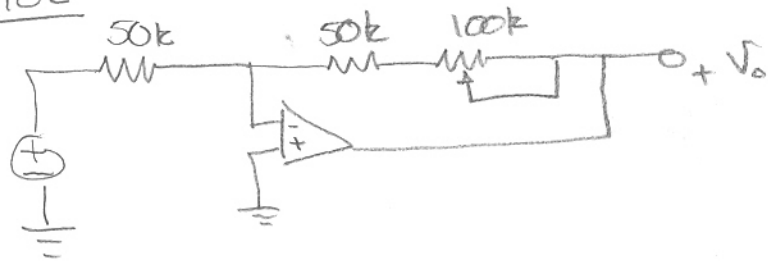


4.22



HW #5 Solutions

find range of gain V_o/V_s : $\equiv$ inverting amp w/ $R_1 = 50k\Omega$

$$R_2 = 50k\Omega + x$$

where

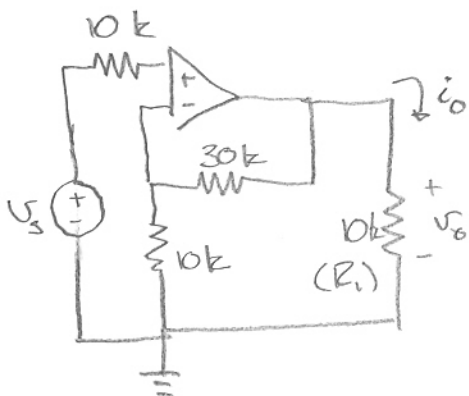
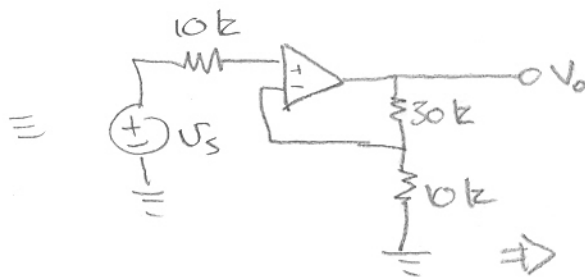
$$0 < x < 100k\Omega$$

$$\therefore \frac{V_o}{V_s} = K_v = -\left(\frac{R_2}{R_1}\right) = -\left(\frac{50k + x}{50}\right)$$

$$x=0 \Rightarrow K_v = -1, \quad x=100k\Omega \Rightarrow K_v = -3$$

$$\Rightarrow \boxed{-3 \leq K_v \leq -1}$$

4.23

(a) find V_o in terms of V_s 

(a non-inverting amplifier)

$$\Rightarrow \frac{V_o}{V_s} = \left(\frac{30k + 10k}{10k}\right) = 4$$

$$\therefore \boxed{V_o = 4V_s}$$

(b) find i_o for $V_s = 1.5V$

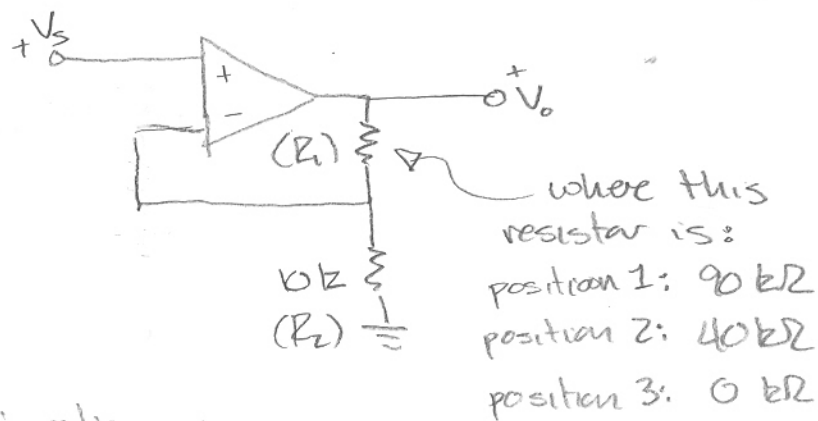
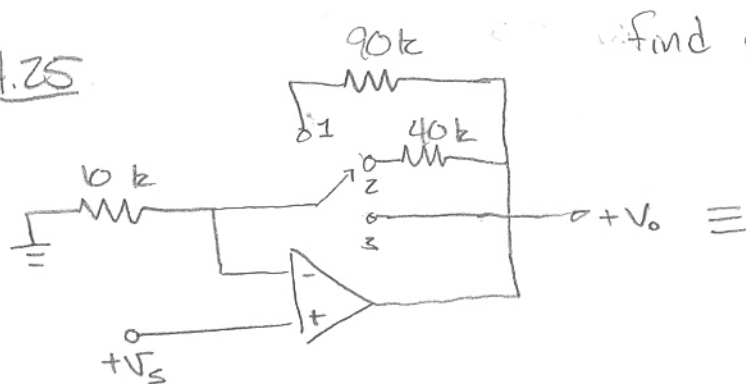
$$\Rightarrow V_o = 4(1.5V) = 6V$$

Ohm's law over $R_L = 10k\Omega$

$$(V_o - 0) = i_o (10k) \Rightarrow i_o = \frac{6}{10k} \Rightarrow \boxed{i_o = 0.6mA}$$

4.25

find gain at each switch position:

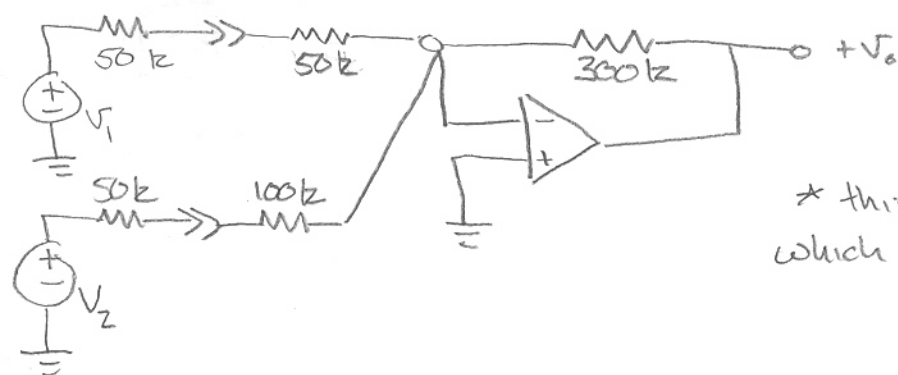


This equivalent circuit is a non-inverting amp:

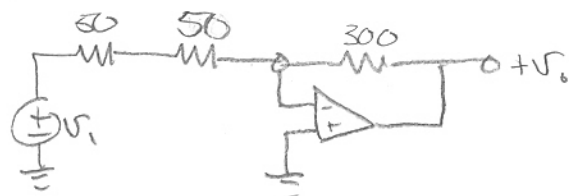
$$\frac{V_o}{V_s} = K = \frac{R_1 + R_2}{R_2} \quad \text{where } R_2 = 10k\Omega \text{ and } R_1 \text{ varies}$$

position 1: $K = \frac{100}{10} = 10$
 position 2: $K = \frac{10 + 40}{10} = 5$
 position 3: $K = \frac{10 + 0}{10} = 1$

4.26 find V_o in terms of V_1 and V_2



* this is a summer circuit which we solve w/ linearity:



$$K_1 = \frac{V_o}{V_1} = -\left(\frac{300}{100}\right) = -3$$

$$V_o = -3V_1$$

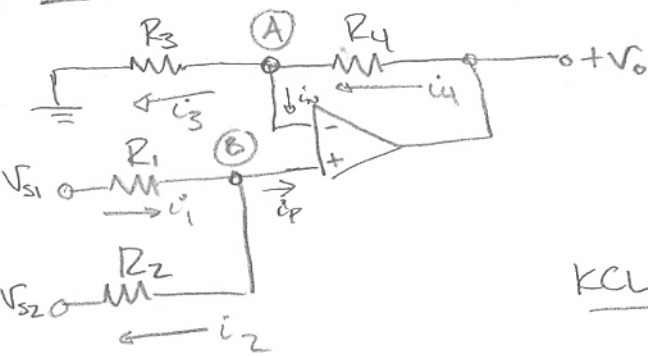


$$K_2 = \frac{V_o}{V_2} = -\left(\frac{300}{150}\right) = -2$$

$$V_o = -2V_2$$

$$\Rightarrow V_{o, \text{TOTAL}} = -3V_1 - 2V_2$$

4.36 Find V_o in terms of V_s



op. amp rules:

$$V_N = V_P \quad i_P = i_N = 0$$

$$V_N = V_A, V_P = V_B$$

$$\Rightarrow V_A = V_B$$

KCL @ B: $i_1 = i_N + i_2 = i_1 = i_2$

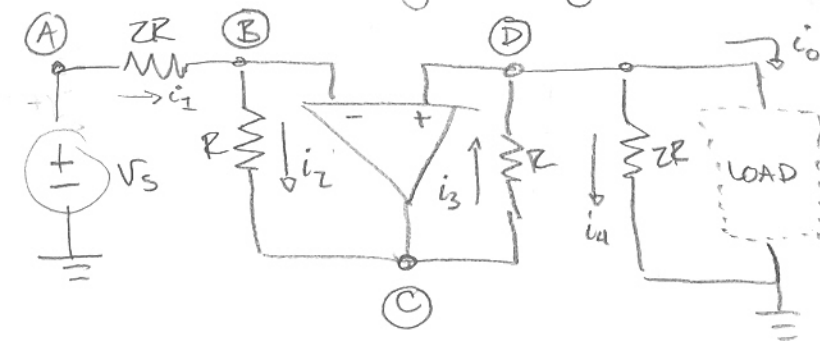
$$\Rightarrow \frac{V_{s1} - V_B}{R_1} = \frac{V_B - V_{s2}}{R_2} \Rightarrow V_B = \frac{R_2 V_{s1} + R_1 V_{s2}}{R_1 + R_2} = V_A$$

KCL @ A: $i_4 = i_N + i_3 \Rightarrow i_4 = i_3$

$$\frac{V_o - V_A}{R_4} = \frac{V_A - 0}{R_3} \Rightarrow V_o = \left(\frac{R_4}{R_3} + 1 \right) V_A = \left(\frac{R_4}{R_3} + 1 \right) V_B$$

$$\Rightarrow V_o = \left(\frac{R_4}{R_3} + 1 \right) \left(\frac{R_2 V_{s1} + R_1 V_{s2}}{R_1 + R_2} \right)$$

4.34 Use node voltage analysis to show $i_o = -V_s / 2R$ regardless of load.



NODE A: $\Rightarrow V_A = V_s$

Node B: $i_1 - i_2 = 0$

$$\frac{V_A - V_B}{2R} - \frac{V_B - V_C}{R} = 0 \Rightarrow \left(\frac{1}{2R} \right) V_A - \left(\frac{1}{2R} + \frac{1}{R} \right) V_B + \left(\frac{1}{R} \right) V_C = 0$$

$$\Rightarrow \left(\frac{1}{2R} \right) V_A = \left(\frac{3}{2R} \right) V_B - \left(\frac{1}{R} \right) V_C \quad (1)$$

Node D: $i_3 - i_4 - i_o = 0$

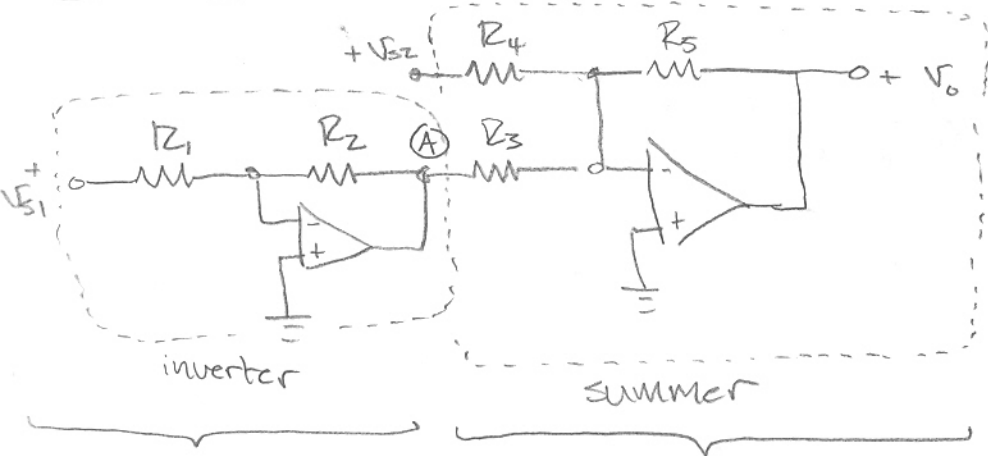
$$\frac{V_C - V_D}{R} - \frac{V_D - V_C}{2R} - i_o = 0 \Rightarrow -\frac{1}{R} V_C + \left(\frac{3}{2R} \right) V_D = -i_o \quad (2)$$

$$(1) \left(\frac{3}{2R} \right) V_B - \left(\frac{1}{R} \right) V_C = \frac{V_A}{2R}$$

$$- \left[(2) \left(\frac{3}{2R} \right) V_B - \left(\frac{1}{R} \right) V_C = -i_o \right]$$

$$0 = \frac{V_A}{2R} + i_o \Rightarrow i_o = -\frac{V_A}{2R} = -\frac{V_s}{2R} = i_o$$

4.36 find V_o in terms of V_{s1} & V_{s2}

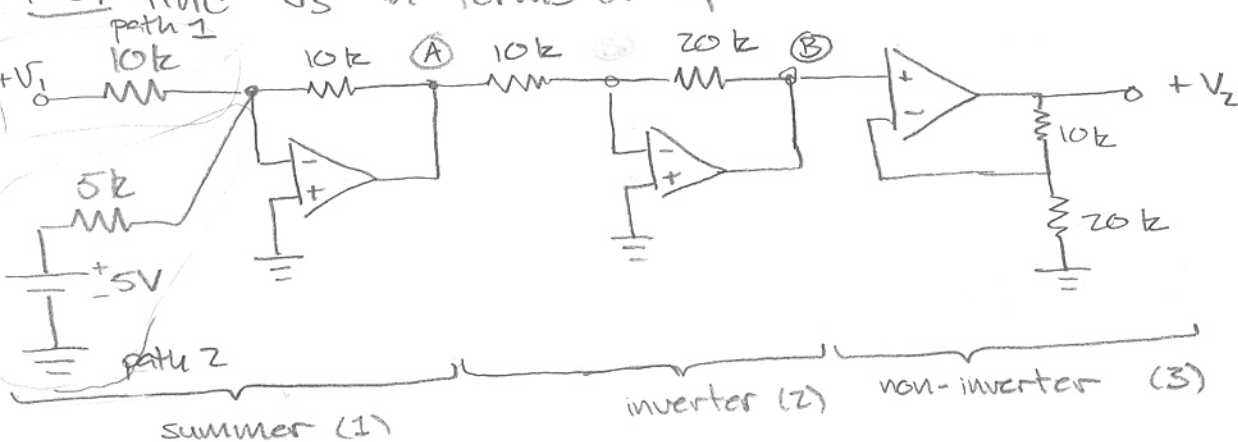


$$\frac{V_A}{V_{s1}} = -\left(\frac{R_2}{R_1}\right)$$

$$V_o = -\left(\frac{R_5}{R_4}\right)V_{s2} - \left(\frac{R_5}{R_3}\right)V_A$$

$$\Rightarrow \boxed{V_o = -\left(\frac{R_5}{R_4}\right)V_{s2} + \left(\frac{R_5 R_2}{R_3 R_1}\right)V_{s1}}$$

4.37 find V_2 in terms of V_1



$$(1): V_A = -\left(\frac{10k}{10k}\right)V_1 \text{ from path 1}$$

$$V_A = -\left(\frac{10k}{5k}\right)(+5V) \text{ from path 2}$$

$$\Rightarrow V_A = (-V_1 - 10)$$

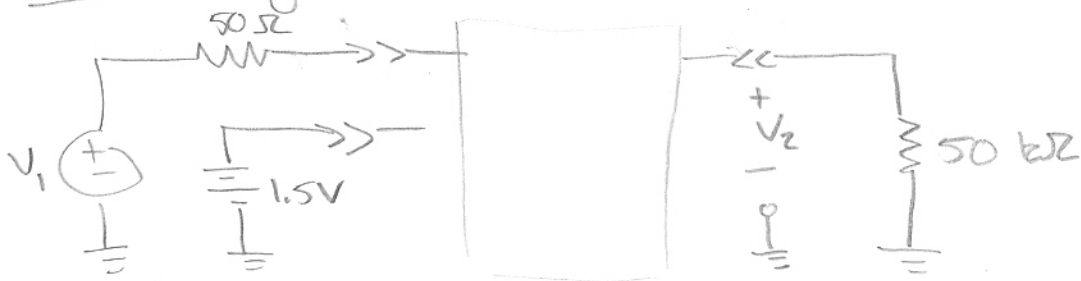
$$(2): V_B = -\left(\frac{20}{10}\right)V_A = -2V_A$$

$$(3): V_2 = \left(\frac{10+20}{10}\right)V_B = \left(\frac{3}{2}\right)V_B$$

$$\Rightarrow V_2 = \left(\frac{3}{2}\right)(-2)(-V_1 - 10)$$

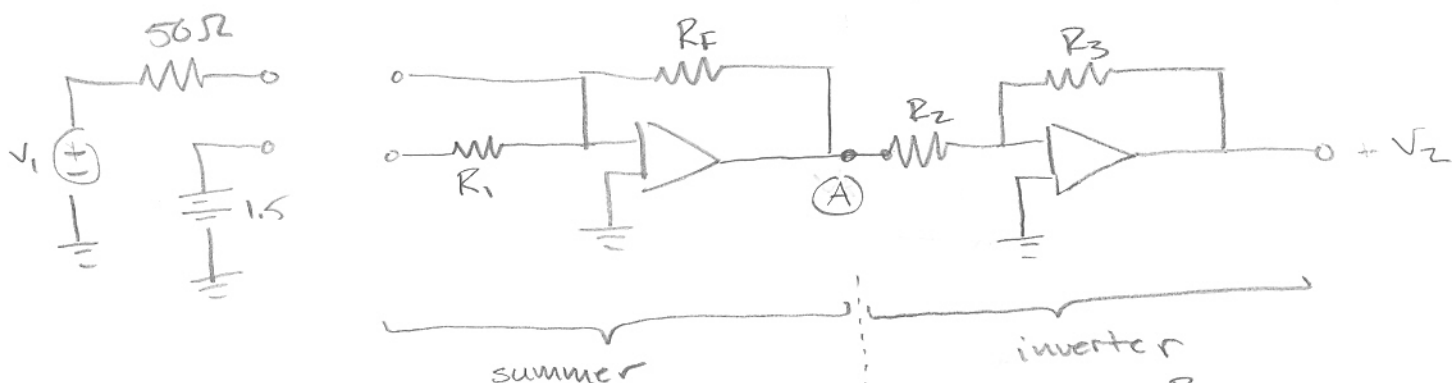
$$\therefore \boxed{V_2 = 3V_1 + 30 \text{ volts}}$$

4.47 Design interface so that $V_2 = (50V_1 + 3)V$



$V_2 = 50V_1 + 3$ indicates a summer.

positive values of a sum indicate an inverter (see 4.26)



$$V_A = -\left(\frac{R_F}{50}\right)V_1 - \left(\frac{R_F}{R_1}\right)(1.5)$$

$$V_2 = -\left(\frac{R_3}{R_2}\right)V_A$$

$$\Rightarrow V_2 = -\left(\frac{R_3}{R_2}\right)\left(-\left(\frac{R_F}{50}\right)V_1 - \left(\frac{R_F}{R_1}\right)(1.5)\right) = 50V_1 + 3$$

$$\Rightarrow \frac{R_3 R_F}{50 R_2} = 50 \quad \text{and} \quad \frac{R_3 R_F}{R_1 R_2} (1.5) = 3$$

which we can solve w/ any feasible choice

ex: (a possible solution)

$$\frac{R_3}{R_2} = 1, \quad \frac{R_F}{50} = 50, \quad \frac{R_F}{R_1} = 2$$

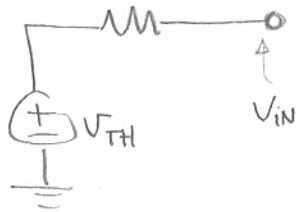
$$R_3 = R_2 = 1\Omega$$

$$R_F = 2500\Omega$$

$$R_1 = 1250\Omega$$

4.55 Consider the transducer modelled a thevenin equivalent.

the output for P is $V = (0.05P - 0.75) \text{ mV}$.



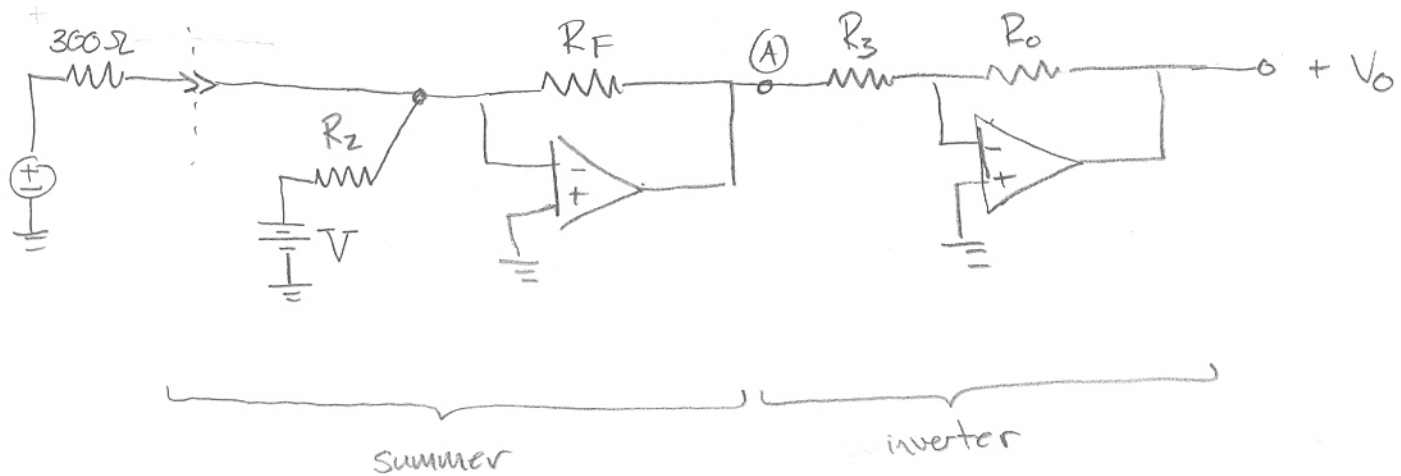
$$V_{TH} = (0.05P - 0.75 \text{ mV})$$

$$P = 20 \text{ mmHg} \Rightarrow 0.25 \text{ mV}$$

$$P = 200 \text{ mmHg} \Rightarrow 9.25 \text{ mV}$$

$\therefore$ We need to add 0.75 mV to the measurement
(i.e. add a constant)

$\Rightarrow$ Note a summer output is negative, so we'll need an inverter



$$V_A = -\left(\frac{R_F}{300}\right)V_{TH} - \left(\frac{R_F}{R_Z}\right)V$$

$$V_O = -\left(\frac{R_O}{R_3}\right)V_A$$

$$\Rightarrow V_O = -\frac{R_O}{R_3} \left(-\frac{R_F}{300} V_{TH} - \frac{R_F}{R_Z} V \right) \quad \text{where } V \text{ is an un-chosen battery voltage.}$$

ex sol'n

$$\text{if } R_F = 300 \Rightarrow V_O = \frac{R_O}{R_3} V_{TH} + \frac{300}{R_Z} V$$

$$\text{let } R_O = R_3 \Rightarrow V_O = V_{TH} + \frac{300}{R_Z} V$$

$$\frac{300}{R_Z} = 0.75 \Rightarrow R_Z = 400 \Omega \quad \text{for } V = +1 \text{ volt}$$