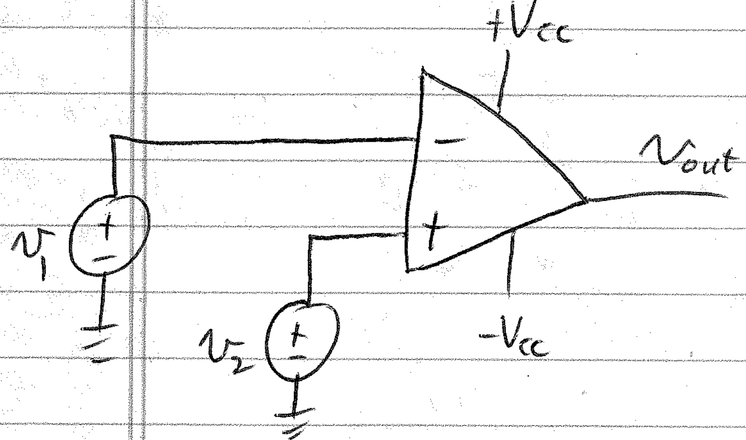
Both on: $v_{out} = v_{out\,2} + v_{out\,1}$

$$v_{out} = \left(1+\frac{R_f}{R_i}\right)\left(\frac{R_4}{R_3+R_4}\right)v_2 - \frac{R_f}{R_i}v_1$$

$$= \left(\frac{R_f+R_i}{R_i}\right) \quad '' \quad '' \quad '' \quad ''$$

Same as before.

Sometimes we do not use the linear region, but want to go straight to saturation:



$v_{out} = A(v_2 - v_1)$

$\lim_{A\to\infty}$ but output limited to $\pm V_{cc}$

$v_{out} = V_{cc}\,\mathrm{sgn}(v_2 - v_1)$

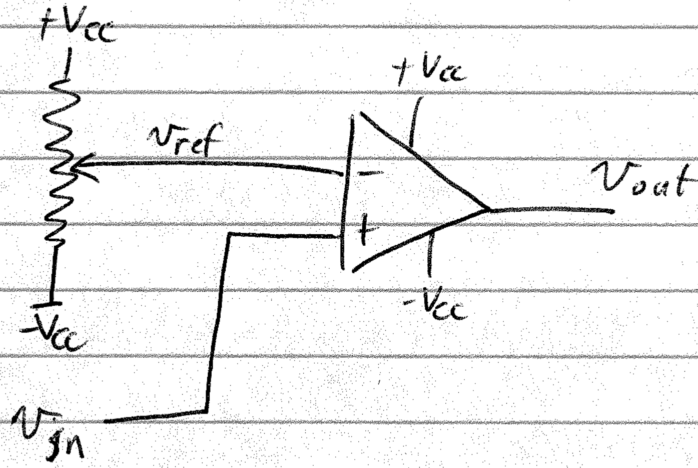
"signum" or "sign" function "sign of $(v_2 - v_1)$"

or $v_{out} = V_{cc}\dfrac{(v_2-v_1)}{|v_2-v_1|}$ ← absolute value

$$v_{out} = \begin{cases} +V_{cc} & \text{if } v_2 > v_1 \\ -V_{cc} & \text{if } v_2 < v_1 \\ 0 & \text{if } v_2 = v_1 \end{cases}$$

Called a Comparator that compares v_2 & v_1

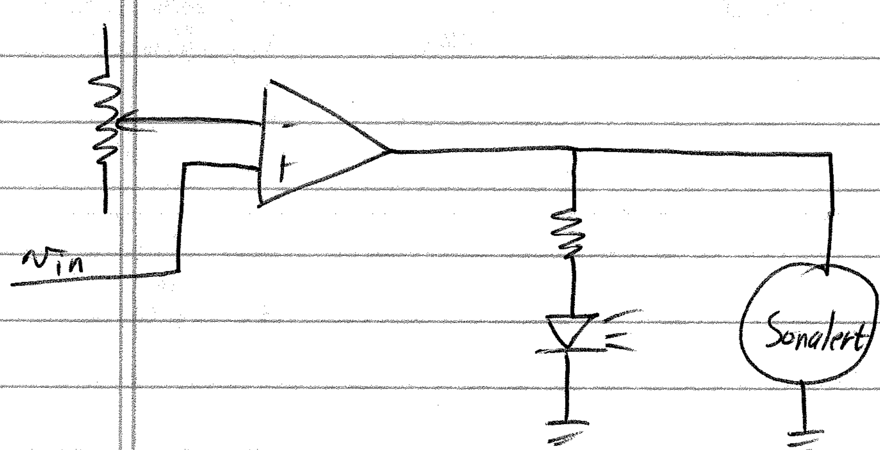
This is a great place to use a potentiometer:



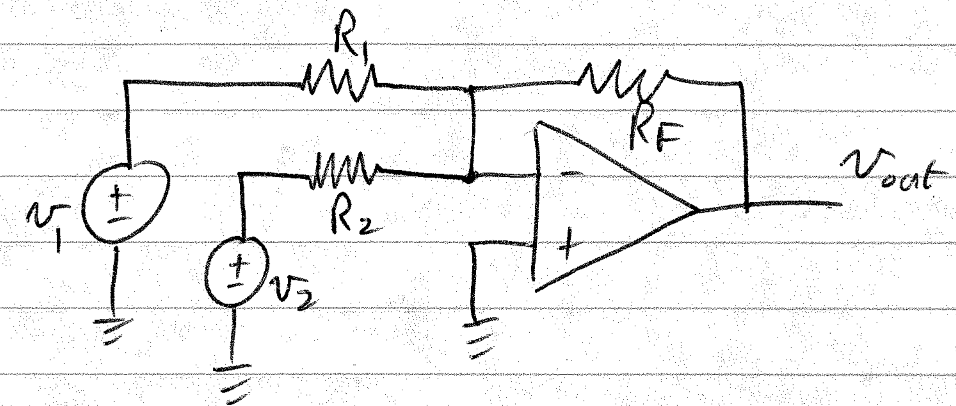
$$v_{out} = \begin{cases} +V_{cc} & v_{in} > v_{ref} \\ -V_{cc} & v_{in} < v_{ref} \end{cases}$$

Adjust the potentiometer to change the threshold value (v_{ref}) by voltage division.

This could, for example, light an LED or sound an alarm:



Consider this:



Find v_{out} as a function of $v_1 + v_2 + R$'s:

1) Feedback? Yes

2) $\underline{v_p = 0 = v_N}$

3) KCL @ inverting input:

$$\frac{\cancelto{0}{v_N} - v_2}{R_2} + \frac{\cancelto{0}{v_N} - v_1}{R_1} + \frac{\cancelto{0}{v_N} - v_{out}}{R_F} = 0$$

$$\frac{v_{out}}{R_F} = -\frac{v_2}{R_2} - \frac{v_1}{R_1}$$

$$v_{out} = -\frac{R_F}{R_2}v_2 - \frac{R_F}{R_1}v_1$$

$$v_{out} = -\left(\frac{R_F}{R_2}v_2 + \frac{R_F}{R_1}v_1\right)$$ Weighted Sum of $v_1 + v_2$

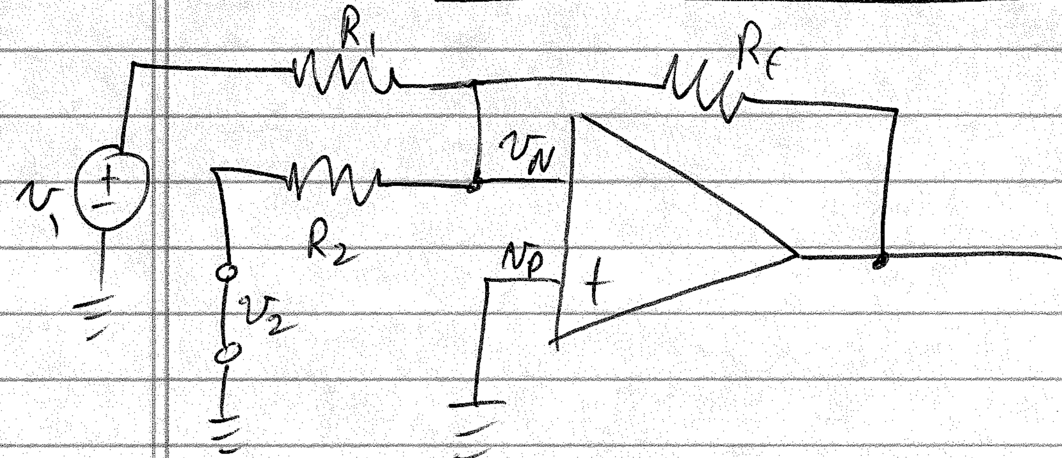
If $R_1 = R_2$:

$$v_{out} = -\frac{R_F}{R_1}(v_2 + v_1)$$ Sum of $v_1 + v_2$

Called a Summing Amp <u>or</u> Summer

This can be extended out to N inputs.

Note; if any input goes to zero (ground) then it has no influence on the rest of the circuit <u>because v_N is a virtual ground</u>.



$v_2 = 0$ and $v_N = 0$, so no current flows thru R_2, so no effect and we can ignore it.

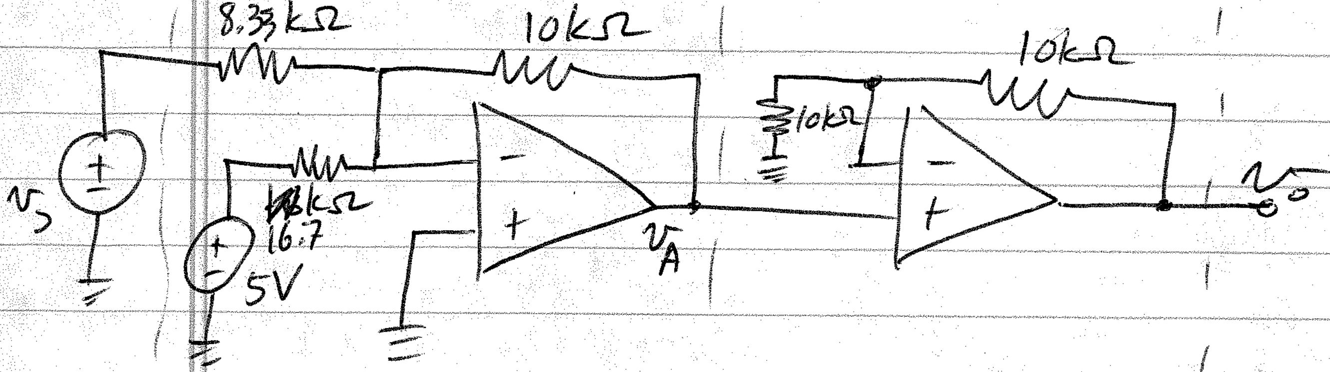
This is more likely how an audio mixing board operates, combining multiple inputs to a single output.

You can also arrange non-inverting summers, as in Ex 4-17 of the text (pgs. 192+193)

Pg. 195 has a table of common linear Op-Amp configurations, Non-Inv, Inv, Summer, Subtractor (Differential), They show "Block Diagram" symbols as well, which we will not use but you should be aware of.

A really useful property of opamps is that "connecting the output of one OpAmp ckt to an input of another Op Amp ckt does not change the operation of either."

For example



1st Stage 2nd Stage

Recognize 1st stage?

Summer: $v_A = -\frac{10k\Omega}{8.33k\Omega} v_s - \frac{10k\Omega}{16.7k\Omega}(5V)$

$= -1.2 v_s - 0.6(5V)$

$\underline{v_A = -1.2 v_s - 3V}$

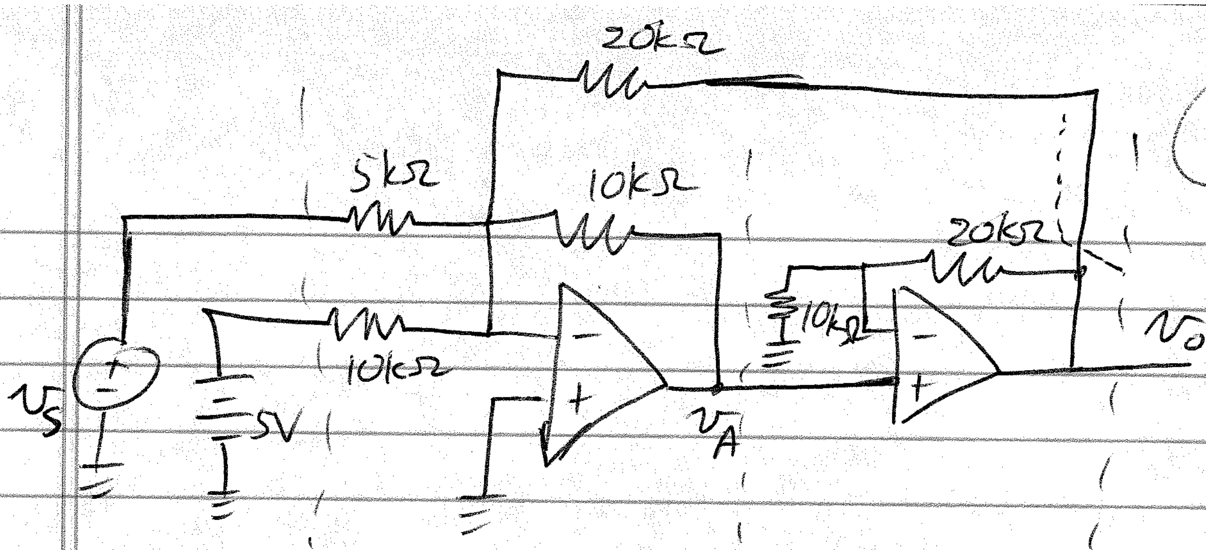
Recognize 2nd Stage?

Non Inverting: $v_o = \left(1 + \frac{10k}{10k}\right) v_A$

$= 2 v_A = -2.4 v_s - 6V$

This output is same as obtained.

by the example in text, Ex 4-18,



This looks a little scary because of the "big" feedback from v_o back to the input, but don't let it fool you.

Stage 1: $v_A = -\frac{10k\Omega}{10k\Omega} 5V - \frac{10k\Omega}{5k\Omega} v_S - \frac{10k\Omega}{20k\Omega} v_O$

$$\underline{v_A = -5V - 2v_S - \tfrac{1}{2} v_O}$$

Now,
Stage 2: $v_o = +\left(1 + \frac{20k\Omega}{10k\Omega}\right) v_A$
$= +3 v_A$

$$v_o = 3\left[-5V - 2v_S - \tfrac{1}{2} v_o\right]$$
$$= -15V - 6v_S - \tfrac{3}{2} v_o$$
$$\tfrac{5}{2} v_o = -15V - 6v_S$$
$$5v_o = -30V - 12v_S$$
$$\underline{\underline{v_o = -6V - 2.4 v_S}}$$

Why use one or the other? No good reason I can think of. The text version has nice even R values, although I could probably play with mine to get easier ones. I think it was chosen to prove the point that where an input comes from, even a later stage output, does not matter, just write the equations and solve.