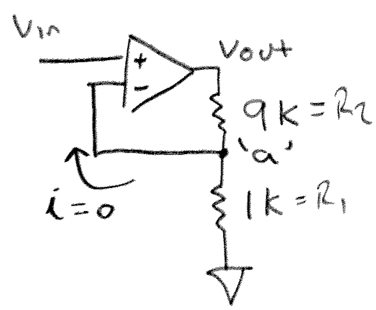
4.19

Circuit 1



Assume 1) Input currents = 0

2) Voltage between inverting and non-inverting inputs = 0

$(V_+ - V_- = 0)$

Therefore, Voltage at 'a' = Vin

$$\frac{V_{out} - V_{in}}{9k} = \frac{V_{in} - 0}{1k}$$

$$\frac{V_{out}}{9k} = \frac{V_{in}}{1k} + \frac{V_{in}}{9k}$$

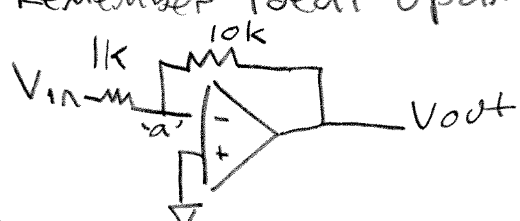
$$V_{out} = V_{in}\left(\frac{9k + 1k}{9k * 1k}\right)9k$$

$$\frac{V_{out}}{V_{in}} = 10$$

This circuit is known as the non-inverting configuration with a gain equal to $1 + \frac{R_2}{R_1}$ where R_2 is the resistor in the feedback loop

Circuit 2

Remember ideal opamp assumptions



Voltage at 'a' = 0 $\rightarrow \frac{V_{in} - 0}{1k} = \frac{0 - V_{out}}{10k}$

$$\frac{V_{out}}{V_{in}} = \frac{-10k}{1k} = -10$$

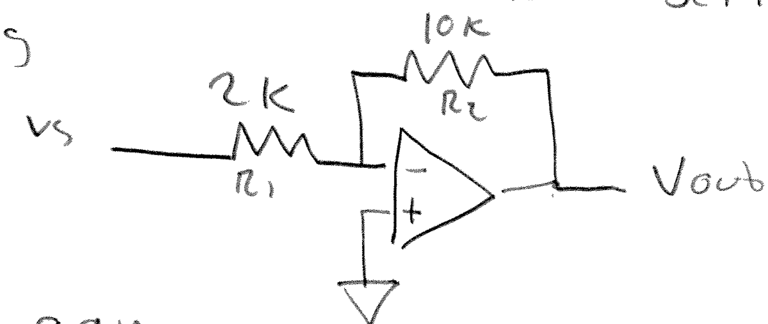
4.19 continued

Circuit 2 is known as the inverting configuration and has gain $= \frac{-R_2}{R_1}$ where R_2 is the feedback resistor

b) when connecting a practical source to circuit 1, Nothing changes because the current flowing into the opamp is assumed to be zero (an ideal opamp has infinite input impedance)

Zero input current means zero voltage drop across the $1k\Omega$ source resistor, so $V_+ = V_s$

Circuit 2 does not have this property. The source resistance is in series with R_1 ($1k\Omega$) giving

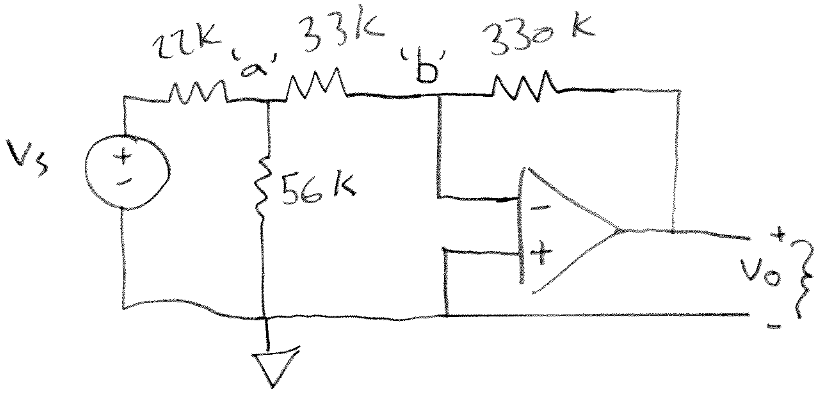


with gain $\frac{-10k}{2k} = -5$

* Note, this source resistance is very high compared to most real sources. Never the less, it shows why it is important to keep input resistances large and output resistances (which will be source resistances for the next stage) low.

2)

4.21



This circuit has two main features,

A) a voltage divider

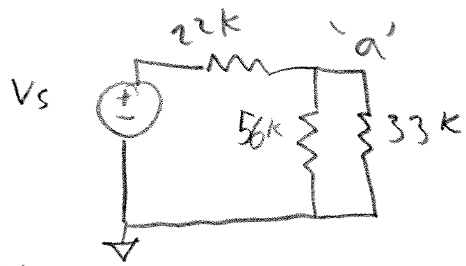
B) an inverting configuration opamp

<u>Note</u>

Node 'a' is the input to the opamp circuit

Node 'b' is zero since $V_+ = V_- = 0$

1) Voltage divider to find V'a' (56k & 33k are in parallel)



$$V_a = V_s \frac{56\|33}{56\|33 + 22} = .4855 V_s$$

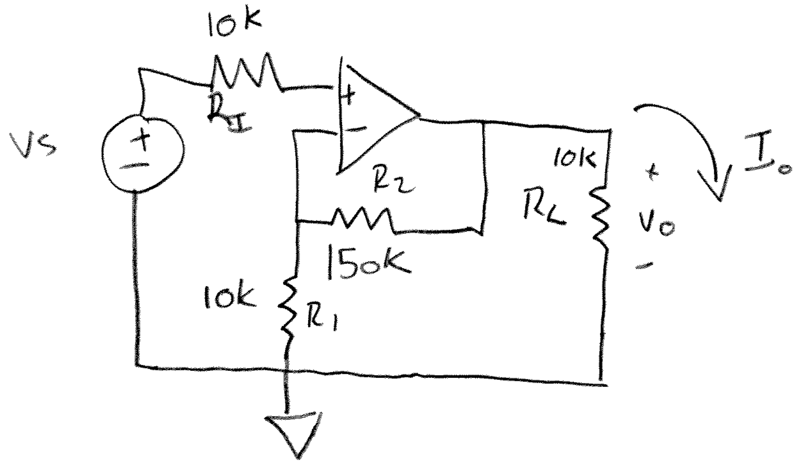
This is the input voltage to an inverting amplifier

with gain $-\frac{R_2}{R} = \frac{-330}{33} = -10$

So $V_{out} = -10 \times .4855\, V_s = -4.855\, V_s$

2

4.23



A) Remember the properties of an ideal opamp!
What is the Voltage drop across R_I? Zero!!
It does nothing,* so ignore it

Now we have the usual non-inverting configuration
Connected to a Load R_L

Note as long as 1) $V_s\left(1+\frac{R_2}{R_1}\right) < V_{supply}$

2) R_L is large enough so $I_o < I_{supply\,Max}$

The output will always be $V_s\left(1+\frac{R_2}{R_1}\right)$

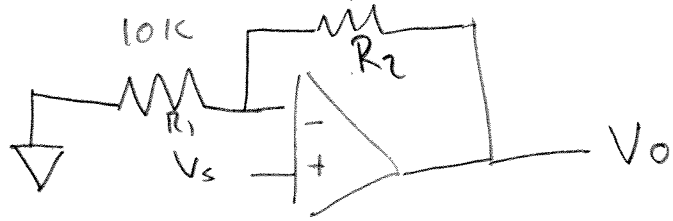
with the given Values, $\frac{V_{out}}{V_{in}} = 1 + \frac{150}{10} = \boxed{16}$

B) When $V_s = 1V$, $V_{out} = 16V$ and $I_o = \frac{16}{R_L} = \frac{16}{10k} = \boxed{1.6\,mA}$

When $V_s = 3V$, The output will TRY to be $3 \times 16V = 48V$
but the supply is limited to $\pm 24V$. The output will
Saturate at the rail Voltage $\rightarrow I_o = \frac{24}{10k} = \boxed{2.4\,mA}$

4) * Some real circuits will have a resistor to prevent
'inrush' current when powering up. Ideal assumptions ignore these currents

4.25



The circuit given in Figure 4-25 is shown here with a single value of R_2 given. You can see this is just a Non-inverting configuration with gain equation

$$\frac{V_o}{V_s} = 1 + \frac{R_2}{R_1}$$

(See 4.19 for help deriving this)

when $R_2 = 90k$, $Gain = 1 + \frac{90}{10} = 10$

$R_2 = 40k$ $\quad Gain = 1 + \frac{40}{10} = 5$

$R_2 = 0$ $\quad Gain = 1$

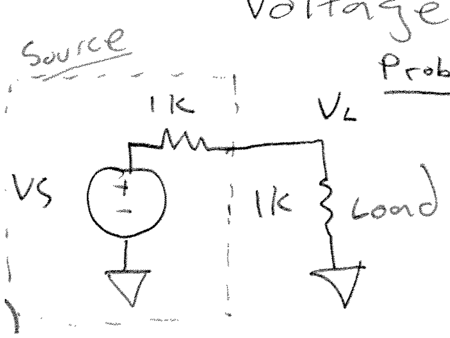
Note!

The last case ($R_2 = 0$) can be generalized by letting $R_1 = \infty$, $Gain = 1 + \frac{0}{\infty} = 1$

This is a <u>Unity Gain Buffer</u>

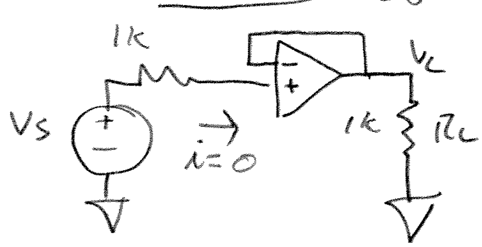
and is used to link stages in a circuit together. It provides high input impedance and low output impedance which prevents voltage droop due to loading

Problem



$$V_L = \frac{V_s}{2}$$

Solution Use a unity gain Buffer



$$V_L = V_s$$

4.27

$$V_o = -(V_1 + 10V_2 + 100V_3)$$

$R_{Feedback} = 100k$

Negative sign is due to inverting configuration
ignore to find input resistors

$$V_o = -(K_1V_1 + K_2V_2 + K_3V_3)$$

$$K_i = \frac{R_F}{R_i}$$

$$K_1 = 1 = \frac{100k}{R_1} \Rightarrow R_1 = 100k$$

$$K_2 = 10 = \frac{100k}{R_2} \Rightarrow R_2 = 10K$$

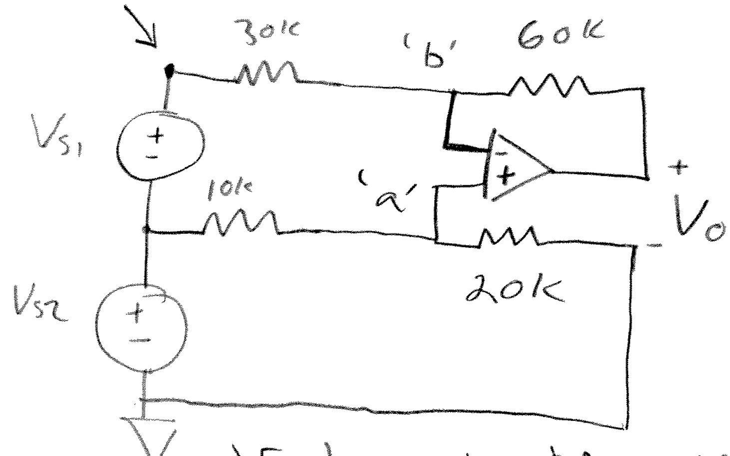
$$K_3 = 100 = \frac{100k}{R_3} \Rightarrow R_3 = 1k$$

:)

4.29

with Switch open

$V_{s1}+V_{s2}$



1) Find inverting & Non-inverting input Voltages

$$V_{'a'} = V_{s2}\frac{20k}{10k+20k} = \frac{2}{3}V_{s2} = V_{'b'}$$

2) KCL @ 'b' (remember, No current enters opamp)

$$\frac{V_{s1}+V_{s2}-V_b}{30k} = \frac{V_b-V_o}{60k}$$

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

$$\frac{V_{s1}+\frac{1}{3}V_{s2}}{30k} - \frac{\frac{2}{3}V_{s2}}{60k} = \frac{-V_o}{60k}$$

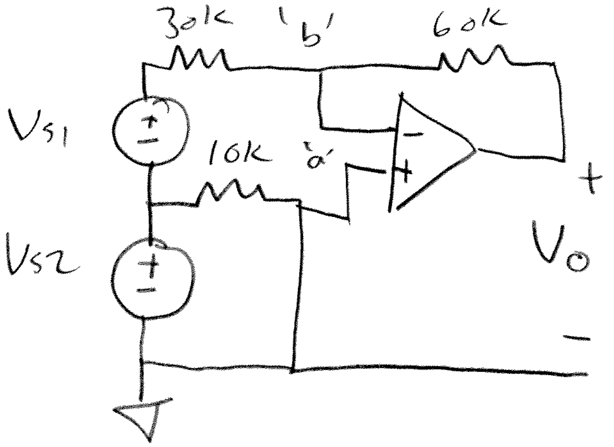
$$\frac{2V_{s1}+\frac{2}{3}V_{s2}-\frac{2}{3}V_{s2}}{60k} = \frac{-V_o}{60k} \rightarrow V_o = -2V_{s1}$$

7)

4.29

continued

with Switch closed

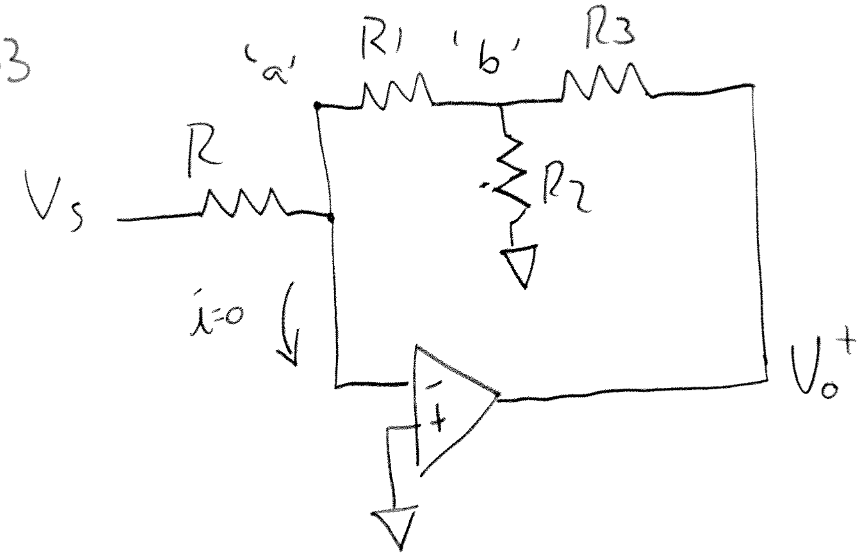


Now $V_{'a'} = V_{'b'} = 0\text{ V}$

KCL @ b

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

4.33



Notice $V_{'a'} = 0$

KCL @ 'a'

$$\frac{V_s}{R} = \frac{-V_b}{R_1} \rightarrow V_b = \frac{-R_1}{R} V_s$$

KCL @ 'b'

$$\frac{-V_b}{R_1} - \frac{V_b}{R_2} + \frac{V_o - V_b}{R_3} = 0$$

$$\frac{R_1 V_s}{R R_1} + \frac{R_1}{R R_2} V_s + \frac{R_1}{R R_3} V_s + \frac{V_o}{R_3} = 0$$

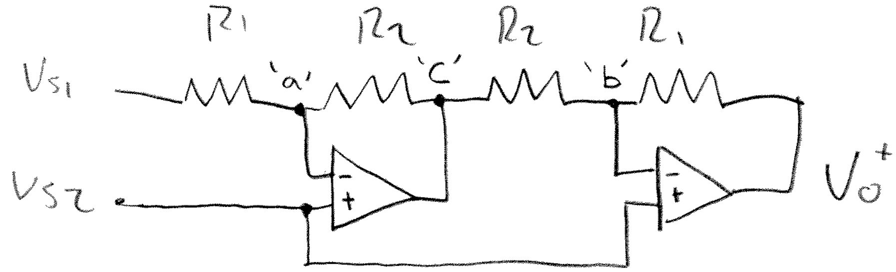
$$-V_s\left(\frac{1}{R} + \frac{R_1}{R R_2} + \frac{R_1}{R R_3}\right) = \frac{V_o}{R_3}$$

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

* This Looks slightly different ← Than the book's answer, but they are the same expression

IF $R = R_1 = R_2 = R_3 \rightarrow k = -1(1+1+1) = -3$

4.35



$$V_{'a'} = V_{'b'} = V_{s2}$$

<u>KCL @ 'a'</u>

$$\frac{V_{s1} - V_{s2}}{R_1} = \frac{V_{s2} - V_c}{R_2}$$

$$\frac{V_{s1} - V_{s2}}{R_1} - \frac{V_{s2}}{R_2} = \frac{-V_c}{R_2}$$

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

<u>KCL @ 'b'</u>

$$\frac{V_c - V_{s2}}{R_2} = \frac{V_{s2} - V_o}{R_1}$$

$$-R_1\left(\frac{V_c - V_{s2}}{R_2} - \frac{V_{s2}}{R_1}\right) = V_o$$

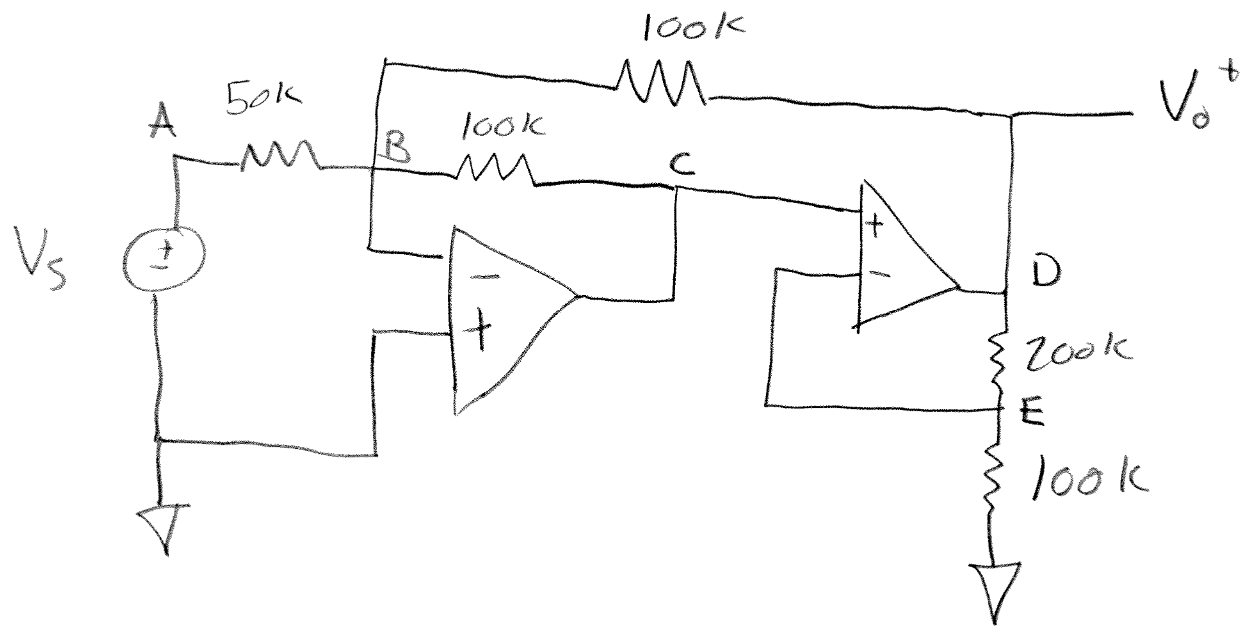
<u>Sub V_c</u>

$$-R_1\left[\frac{-R_2\left(\frac{V_{s1}-V_{s2}}{R_1} - \frac{V_{s2}}{R_2}\right) - V_{s2}}{R_2} - \frac{V_{s2}}{R_1}\right] = V_o$$

$$\cancel{-R_1}\left[\frac{-\cancel{(V_{s1} - V_{s2})}}{\cancel{R_1}} + \frac{\cancel{V_{s2}}}{\cancel{R_2}} - \frac{\cancel{V_{s2}}}{\cancel{R_2}} - \frac{\cancel{V_{s2}}}{\cancel{R_1}}\right] \rightarrow \boxed{V_{s1} = V_o}$$

o)

4.39



<u>Notice</u> $V_a = V_s$

$V_D = V_o$

$V_B = 0$

$V_E = V_c$

KCL @ B

$$\frac{V_s}{50k} = \frac{-V_c}{100k} - \frac{V_o}{100k}$$

$$-\left(\frac{V_s}{50k} + \frac{V_o}{100k}\right)100k = V_c$$

$$-2V_s - V_o = V_c$$

Now that we have V_c (and V_E) solve for the current flowing from V_e to ground

This is the same current flowing from V_o to ground

$$I_E = \frac{V_E}{100k} = \frac{-V_s}{50k} - \frac{V_o}{100k}$$

Then, $V_o = 0 + I_E(200k + 100k)$

$$V_o = -\left(\frac{V_s}{50k} + \frac{V_o}{100k}\right) 300k$$

$$V_o + 3V_o = -6V_s \rightarrow V_o = -\frac{3}{2}V_s$$

4.45

Use 1 inverting opamp with gain -2 for input Vs2

Then use a summer with gain (-3, -1, -5)