Example 1

You are given the following op amp configuration. Find the voltage V_o

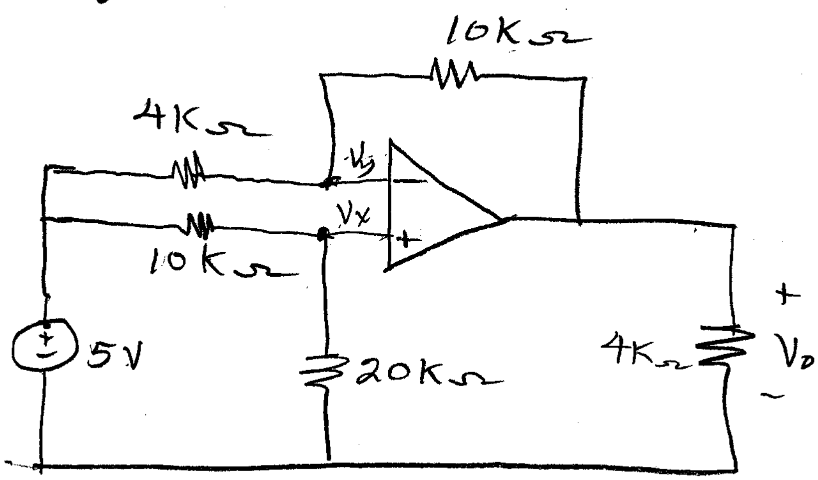


Figure 18.15: Op Amp circuit for Example 1.

At V_x

$$\frac{V_x - 5}{10K} + \frac{V_x}{20K} = 0$$

or

$$2V_x - 10 + V_x = 0$$

$$3V_x = 10 \Rightarrow V_x = \frac{10}{3} \qquad (18.21)$$

At V_y

$$\frac{V_y - 5}{4K} + \frac{V_y - V_o}{10K} = 0$$

$$5V_y - 25 + 2V_y - 2V_o = 0$$

$$7V_y = 2V_o + 25$$

$$V_y = \frac{2V_o + 25}{7} \qquad (18.22)$$

but $V_x = V_y$ so set $(18.21) = (18.23)$

$$\frac{10}{3} = \frac{2V_o + 25}{7}$$

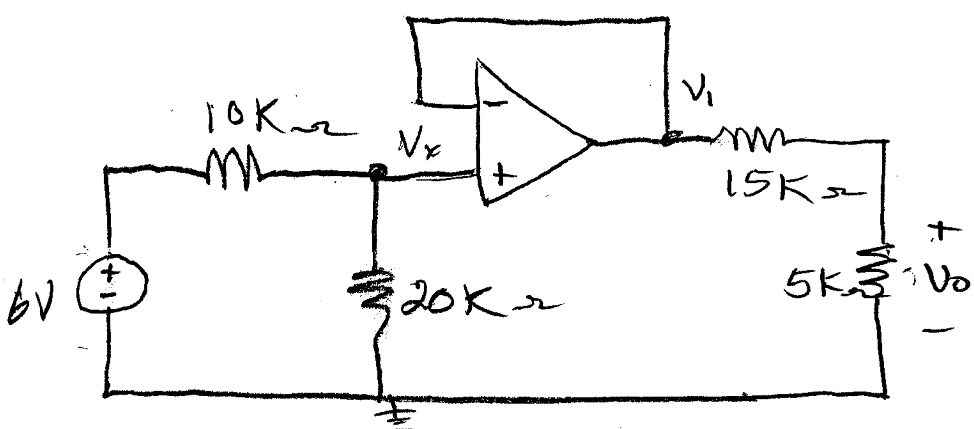
$$70 = 6V_o + 75$$

$$6V_o = 70 - 75$$

$$\boxed{V_o = -\frac{5}{6}}$$

Example 2

Find Vo for the following op amp circuit.



$$\frac{V_x - 6}{10K} + \frac{V_x}{20K} = 0$$

$$2V_x - 12 + V_x = 0$$

$$3V_x = 12 \Rightarrow V_x = 4V = V_1$$

$$V_o = \frac{V_1 \times 5K}{5K + 15K} = \frac{V_1}{4} = \frac{4}{4} = 1\ V$$

$$\boxed{V_o = 1V}$$

Example 3

You are given the op amp circuit as shown in Figure 18.16. What value of R_f will give an output of

$$V_o = 5 - 4V_a \quad ?$$

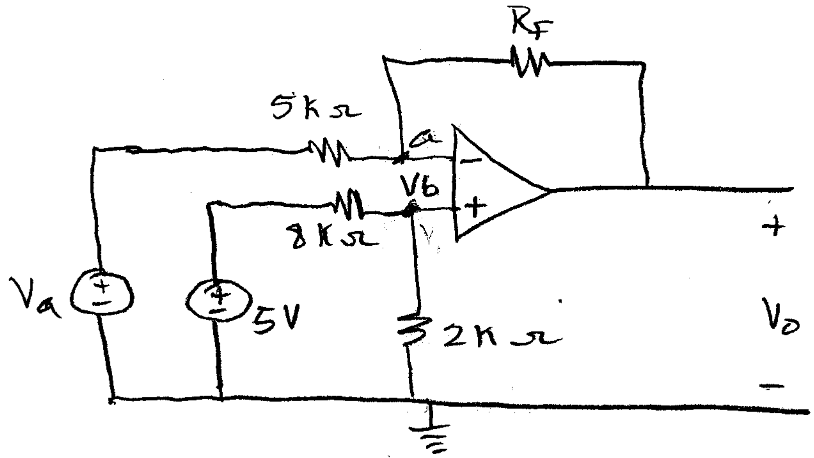


Figure 18.16: Circuit for Example 3.

At V_b

$$V_b = \frac{5 \times 2K}{2K + 8K} = 1\,V$$

At "a"

$$\frac{1 - V_a}{5K} = \frac{V_o - 1}{R_f}$$

$$V_o - 1 = \frac{R_f(1 - V_a)}{5K}$$

$$V_o = \frac{R_f(1 - V_a)}{5K} + 1$$

So.

$$\frac{R_f(1-V_a)}{5K}+1 = 5-4V_a$$

or

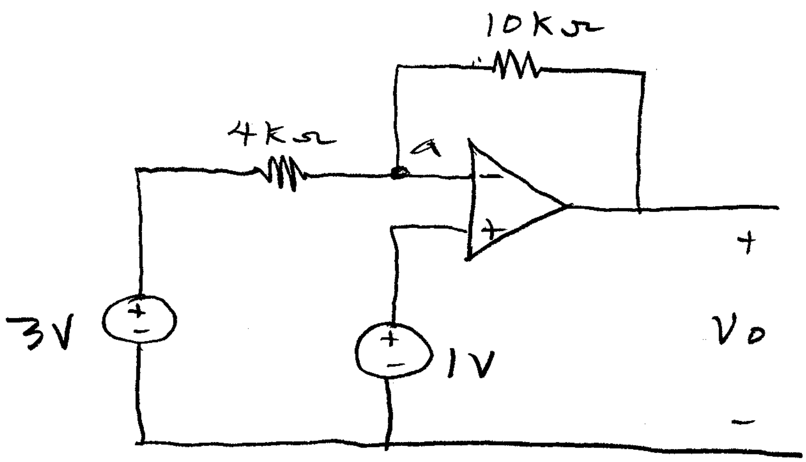
$$R_f\,\frac{(1-V_a)}{5K} = 4(1-V_a)$$

$$R_f(1-V_a) = 4\times 5K(1-V_a)$$

$$\therefore \boxed{R_f = 20k\,\Omega}$$

Example 4:

You are given the op amp circuit of Figure 18.17. Determine V_o.



At "a"

$$\frac{1-3}{4\cancel{K}} = \frac{V_o-1}{10\cancel{K}}$$

$$(-0.5)10+1 = V_o$$

$$\boxed{V_o = -4\,V}$$

Example 5

Determine the output current i_x for the following op amp circuit.

$\frac{.5 \times 10k}{13k}$

$\frac{5}{13}$

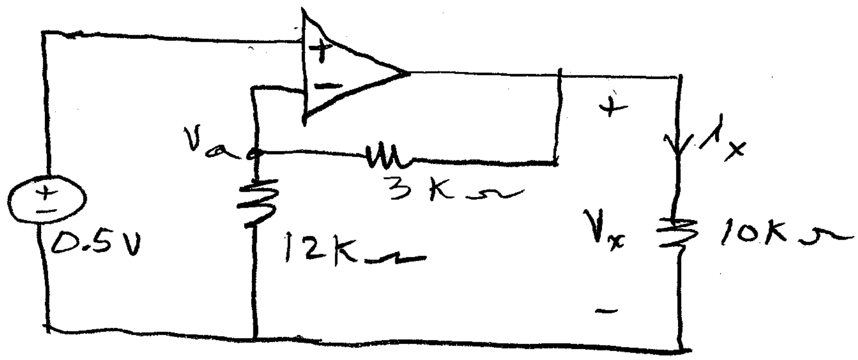


Figure 18.17: Circuit for example 5.

$V_a = 0.5\ V$

but

$$V_a = 0.5 = \frac{V_x \times 12K}{(12+3)K} = \frac{4}{5} V_x$$

$$V_x = \frac{2.5}{4}$$

$$i_x = \frac{V_x}{10K} = 0.0625\ mA$$

Example 6

Voltage Follower.

You are given the circuit of Figure 18.18.

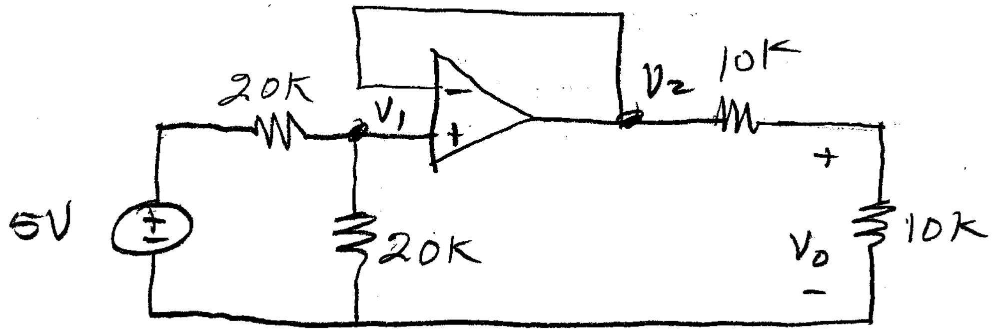


Figure 18.18: Circuit for Example 6.

The voltage V_2 follows V_1. Since

$$V_1 = \frac{5 \times 20k}{20k + 20k} = 2.5\,V$$

$$V_2 = V_1 = 2.5\,V$$

$$V_o = \frac{V_2 \times 10k}{10k + 10k} = \frac{V_2}{2}$$

$$\boxed{V_o = 1.25\,V}$$

<u>Example 7</u>

For the op amp circuit of Figure 18.19 find i_x and i_y.

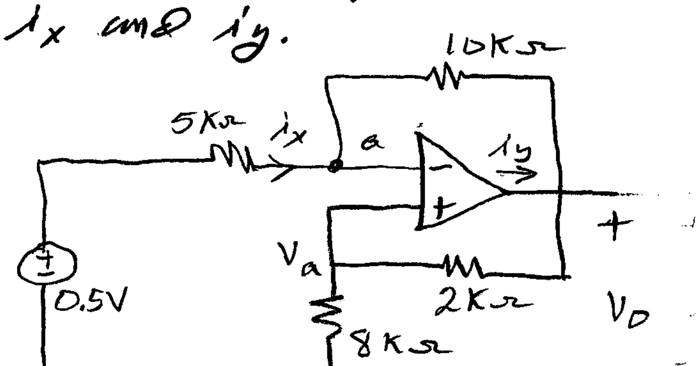


Figure 18.19: Circuit for Example 7.

$$V_a = \frac{V_o \times 8K}{8K + 2K} = 0.8\,V_o \qquad (1)$$

At "a"

$$i_x = \frac{0.8\,V_o - V_o}{10K} = -0.02\,V_o \text{ mA}$$

At "a"

$$\frac{.8\,V_o - .5}{5\cancel{K}} = \frac{V_o - .8\,V_o}{10\cancel{K}}$$

$$1.6\,V_o - 1 = +.2\,V_o$$

$$1.4\,V_o = 1$$

$$\boxed{V_o = \frac{1}{1.4}\text{ V}}$$

$$\boxed{i_x = -\frac{.02}{1.4}\text{ mA} = -0.01428\text{ mA}}$$

$$i_g = \frac{V_o - .8\,V_o}{10K} + \frac{V_o}{10K}$$

$$= \frac{.2\,V_o + V_o}{10K} = \frac{1.2\,V_o}{10K} = \frac{(1.2)\left(\frac{1}{1.4}\right)}{10K}$$

$$\boxed{i_g = 0.0857\text{ mA}}$$

Example 8

Find the voltage gain for the following op amp circuit.

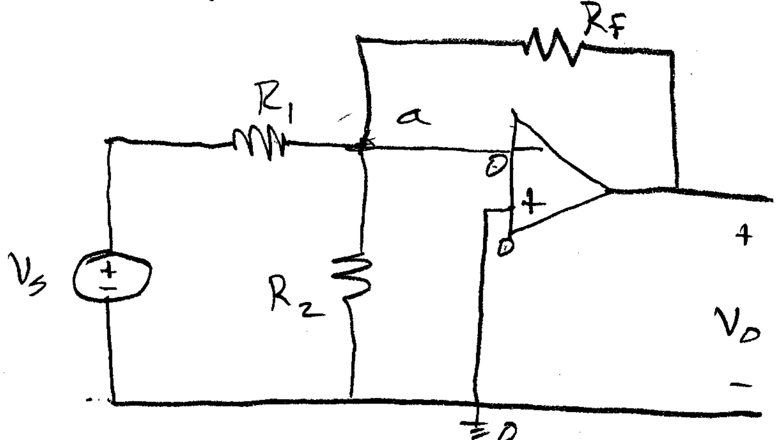


Figure 18.20: Circuit for Example 8.

At "a"

$$\frac{0 - V_s}{R_1} = \frac{V_o - 0}{R_f}$$ (the current thru $R_2 = 0$)

$$\boxed{\frac{V_o}{V_f} = -\frac{R_f}{R_1}}$$

In earlier times, one of the most important roles of the op amp was its use as an integrator, that is, the ability to electrically perform the function of mathematically integrating a signal. This was the backbone of the analog computer. Whereas analog computers have expired, the operation of integration is still important in signal processing. We now look at the process of integration with the op amp.

Example 9

Consider the op amp circuit shown in Figure 18.21

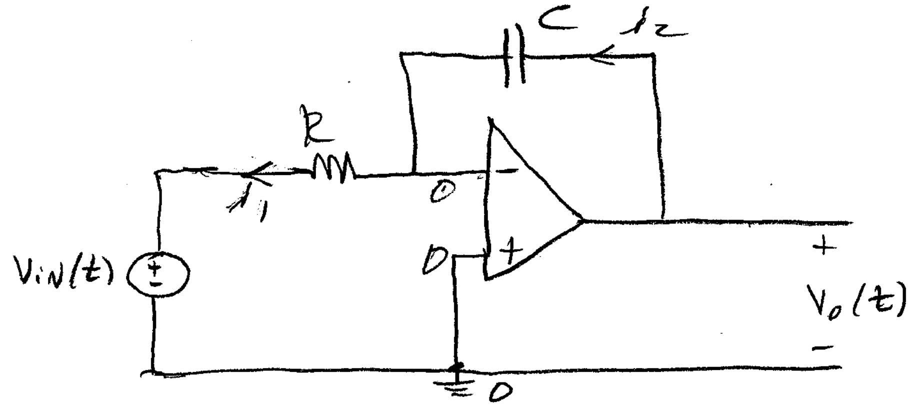


Figure 18.21: Op Amp circuit used as an integrator.

From the diagram we see that

$$i_1 = i_2$$ (no current enters the inverting terminal)

or

$$\frac{0 - V_{in}(t)}{R} = C\frac{dV_o(t)}{dt}$$

and

$$\frac{dV_o(t)}{dt} = -\frac{V_{in}(t)}{RC} \qquad (18.23)$$

We separate variables and integrate;

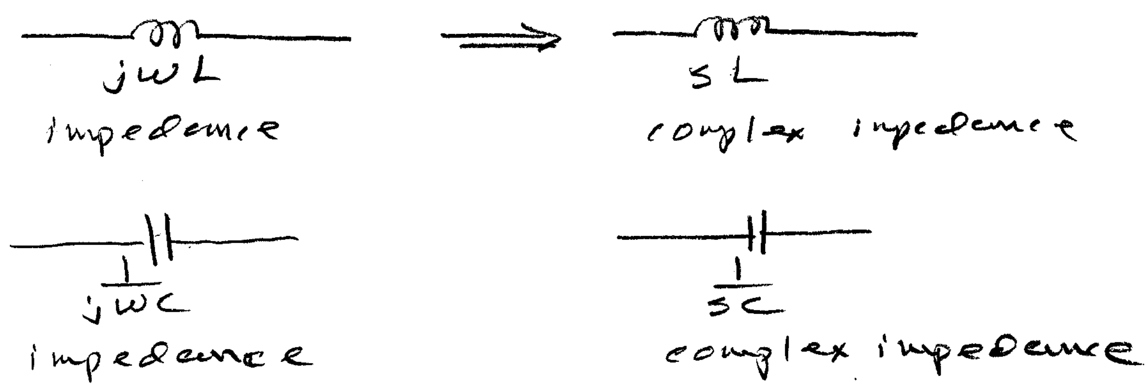
$$\int_{\tau=0}^{\tau=t} dV_o(\tau) = -\frac{1}{RC}\int_{\tau=0}^{\tau=t} V_{in}(\tau)\,d\tau$$

$$\boxed{V_o(t) - V_o(0) = -\frac{1}{RC}\int_{\tau=0}^{\tau=t} V_{IN}(\tau)\,d\tau} \qquad (18.24)$$

Initial condition, $V_o(0)$, can be applied to the op amp by applying an initial voltage to the capacitor.

Most often when we use op amps we use complex impedence rather than actually carrying out integration as above.

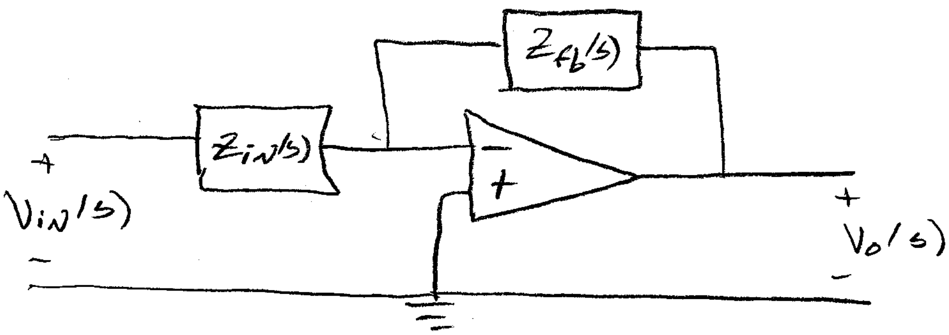
For example



And mathematically

$$\mathcal{L}\left[\int f(\tau)\,d\tau\right] = \frac{F(s)}{s}$$ with 0 initial condition

We recall



$$\frac{V_o(s)}{V_{in}(s)} = -\frac{Z_{fb}(s)}{Z_{in}(s)}$$

If $Z_{fb}(s)$ corresponds to the complex impedance of a capacitor

$$Z_{fb}(s) = \frac{1}{sC}$$

and $Z_{in}(s)$ is the complex impedance of a resistor;

$$Z_{in}(s) = R$$

So

$$V_o(s) = -\frac{V_{in}(s)}{RC\, s}$$

in the time domain

$$V_o(t) = -\frac{1}{RC}\int V_{in}(t)\,dt$$

which is the result we got earlier.

Example 10

We saw earlier on page 14 how an op amp can be set-up to add input signals. This example illustrates how to set-up an op amp so it averages the input signals. Consider the circuit of Figure 18.22.

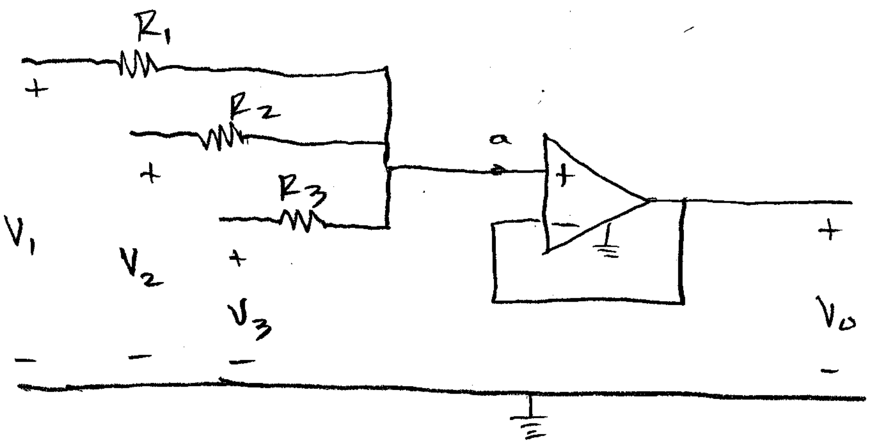


Figure 18.22: Op Amp used for Averaging.

The voltage at "a" is V_o so we can write

$$\frac{V_1 - V_o}{R_1} + \frac{V_2 - V_o}{R_2} + \frac{V_3 - V_o}{R_3} = 0$$

OR

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = V_o\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

OR

$$R_2R_3V_1 + R_1R_3V_2 + R_1R_2V_3 =$$

$$V_o\left[R_2R_3 + R_1R_3 + R_1R_2\right]$$

OR

$$V_o = \frac{R_2 R_3 V_1 + R_1 R_3 V_2 + R_1 R_2 V_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}$$

If $R_1 = R_2 = R_3 = R$

$$V_o = \frac{(V_1 + V_2 + V_3)\cancel{R^2}}{3\cancel{R^2}}$$

OR

$$\boxed{V_o = \frac{(V_1 + V_2 + V_3)}{3}}$$