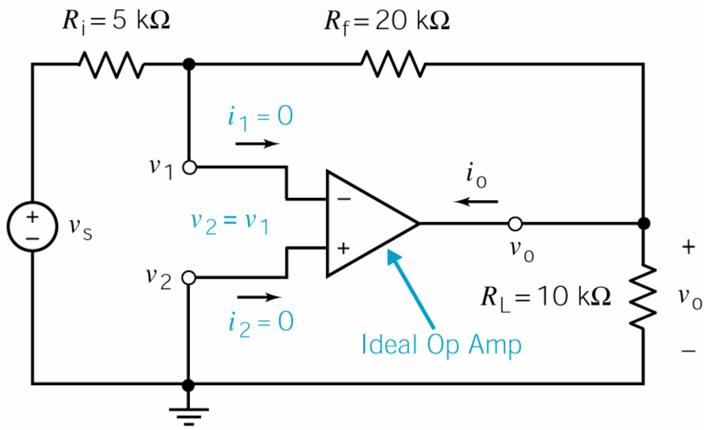
The Inverting Amplifier



v_2 is the node voltage at the reference node (ground), so $v_2 = 0$. The op amp is ideal so $v_1 = v_2$. (All op amps are ideal in this course.) Consequently,

$$v_1 = v_2 = 0$$

Apply KCL at the node connected to the inverting input of the op amp to get

$$\frac{v_s - v_1}{R_i} = i_1 + \frac{v_1 - v_o}{R_f} \quad \Rightarrow \quad \frac{v_s}{R_i} = \frac{-v_o}{R_f} \quad \Rightarrow \quad v_o = -\frac{R_f}{R_i} v_s = -4\, v_s$$

Beware: Both $\frac{v_o}{v_s} = -\frac{R_f}{R_i}$ and $\left|\frac{v_o}{v_s}\right| = \frac{R_f}{R_i}$ are sometimes called the "gain" of the inverting amplifier.

Apply KCL at the output node of the op amp to get

$$\frac{v_1 - v_o}{R_f} = i_o + \frac{v_o}{R_L} \quad \Rightarrow \quad i_o = -\left(\frac{1}{R_f} + \frac{1}{R_L}\right) v_o = -\frac{R_f + R_L}{R_f\, R_L} v_o = -\frac{R_f + R_L}{R_f\, R_L}\left(-\frac{R_f}{R_i} v_s\right)$$

or

$$i_o = \frac{R_f + R_L}{R_i\, R_L} v_s = \frac{2\times 10^4 + 10^4}{\left(2\times 10^4\right) 10^4} v_s = \left(0.6\times 10^{-3}\right) v_s$$

The power received by the op amp is

$$v_o i_o = \left(-\frac{R_f}{R_i} v_s\right)\left(\frac{R_f + R_L}{R_i R_L} v_s\right) = -\left(\frac{R_f}{R_i}\right)\left(\frac{R_f + R_L}{R_i R_L}\right) v_s^{\ 2} = -2.4\times 10^{-3} v_s^{\ 2}$$

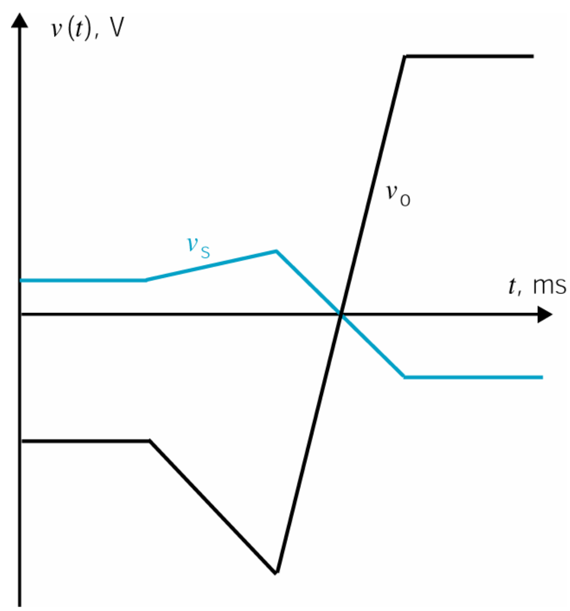
The power supplied by the op amp is

$$-v_o i_o = 2.4\times 10^{-3} v_s^{\ 2}$$

The input to this circuit is the voltage source voltage, v_s. The output is the voltage, v_o, across R_L. Recall that the input and output voltages of the circuit are related by

$$v_o = -\frac{R_f}{R_i} v_s = -4 v_s$$

Consider this plot of the input and output voltages for a particular input:



The output is seen to be 4 times as large as the input. The output is inverted with respect to the input due to the minus sign. Appropriately, the circuit is called an inverting amplifier.