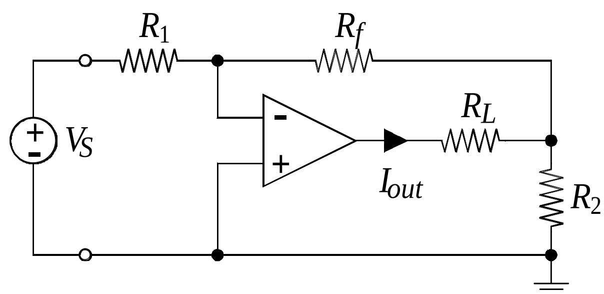
MODELING AN OP-AMP AMPLIFIER

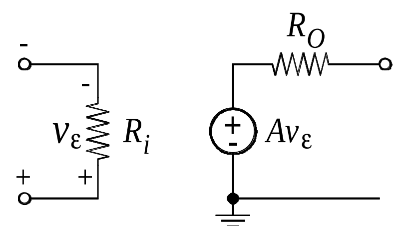
An example of creating a feedback model for an op-amp amplifier to determine its input and output topologies, the asymptotic gain, and the loop gain.

The Problem:

Given the op-amp amplifier circuit:

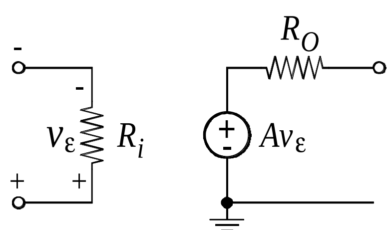


And the op-amp model:

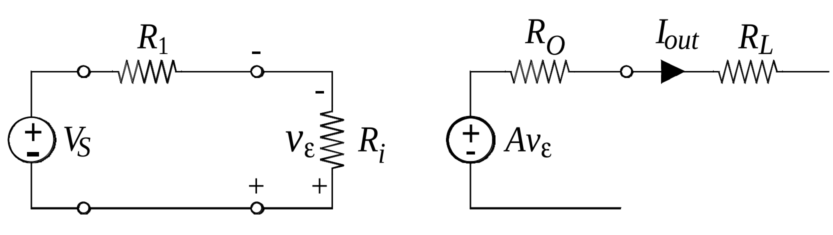


Create a model for the amplifier circuit.

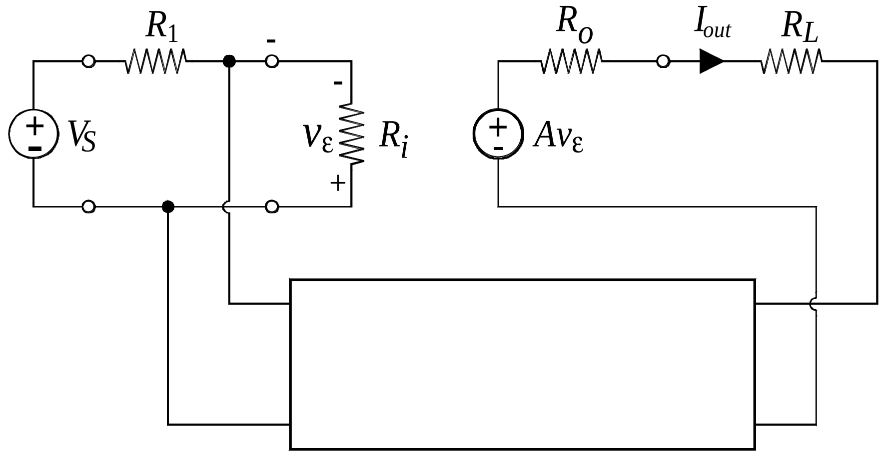
1) Draw the op-amp model:



2) Add the non-feedback parts of the circuit:



3) Draw the (empty) feedback box and connect to the circuit:

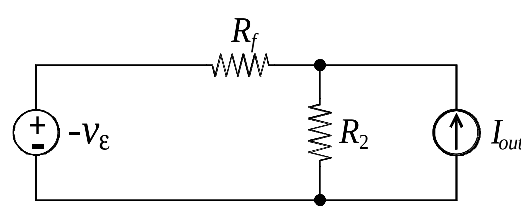


Note that the ground wires connect at the bottom of the feedback box. At this point it can be determined that the amplifier topology is parallel input, series output by observing the manner in which the feedback box is connect to the circuit.

4) Draw the feedback circuit by itself:

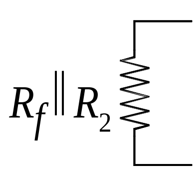
a) First, draw what the feedback box *sees* at each end:

b) Now add the feedback components:



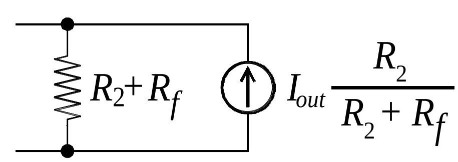
5) Determine the components for the feedback box of step 3:

a) Consider circuit 4b with the current source removed. What is *seen* at the terminals where the source was removed? Since v_ε is very small compared to Av_ε, we can set $v_\varepsilon = 0$.



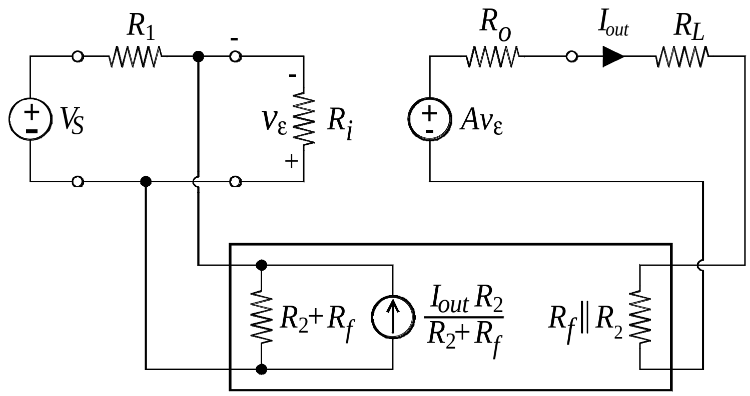
This circuit becomes the input (right hand) side of the feedback box.

b) Consider circuit 4b with the voltage source removed. What is *seen* at the terminals where this source was removed?



This is the Norton equivalent and it becomes the output (left hand) side of the feedback box.

6) Add the above circuits to the feedback box to complete the amplifier model:



In further analysis, it may be helpful if the input feedback circuit is a Norton equivalent in the case of a parallel input amplifier like this one, or a Thèvenin equivalent in the case of a series input amplifier.

7) Finding the asymptotic gain *G*¥:

The gain of the circuit is defined as $G = \dfrac{I_{out}}{V_S}$.

Under asymptotic conditions, no current flows through R_i, and since $v_\varepsilon = 0$, no current flows through (R_2+R_f) either. Therefore, all of the current from the feedback current source must flow through R_1. So the voltage across R_1 must be equal and of opposite sign to the voltage V_S. Therefore we can say:

$$V_S = -\frac{I_{out}R_2}{R_2 + R_f} R_1$$

Solving this expression for I_{out}/V_S we get the asymptotic gain:

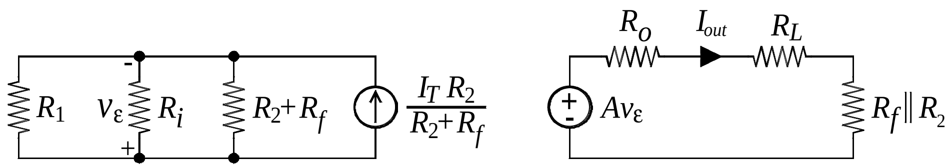
$$\boxed{G_\infty = \frac{I_{out}}{V_S} = -\frac{R_2 + R_f}{R_1 R_2}}$$

8) Finding the Loop Gain *L*:

The loop gain is the gain of the system one time through the loop. To evaluate the loop gain, a test signal is applied in the feedback loop and the resulting output is calculated. The loop gain is always a negative value. The process is as follows:

a) Turn off the voltage source V_S.

b) In the feedback network, replace I_{out} with I_T (or replace V_{out} with V_T as the case may be).



c) Calculate v_ε.

$$v_\varepsilon = -\frac{I_T R_2}{R_2 + R_f}\left[R_1 \| R_i \| \left(R_2 + R_f\right)\right]$$

d) Calculate I_{out} at R_L (or V_{out} at R_L).

$$I_{out} = \frac{Av_\varepsilon}{R_O + R_L + \left(R_f \| R_2\right)}$$

e) Solve for I_{out}/I_T.

$$I_{out} = \frac{A}{R_O + R_L + \left(R_f \| R_2\right)} \times \frac{-I_T R_2}{R_2 + R_f}\left[R_1 \| R_i \| \left(R_2 + R_f\right)\right]$$

$$\boxed{L = \frac{I_{out}}{I_T} = \frac{-AR_2\left[R_1 \| R_i \| \left(R_2 + R_f\right)\right]}{\left[R_O + R_L + \left(R_f \| R_2\right)\right]\left(R_2 + R_f\right)}}$$