ECE 386

Op Amp Mini-Tutorial

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The operational amplifier is a complicated transistor circuit, but can be modeled as a simple device. Its near-ideal performance makes it a popular device in electronic circuits. Therefore it is useful to understand the basics of op amps. Figure 1 shows the symbol of an op amp (the power supplies are usually not shown).
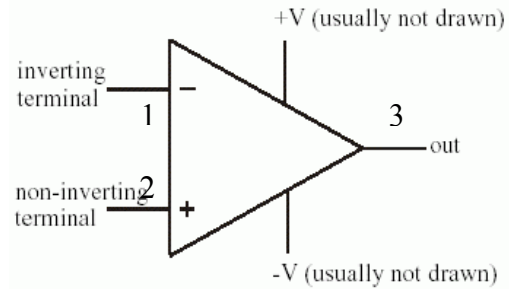

Figure 1: Op Amp circuit symbol

Op Amp in open loop

In open-loop (as shown in Figure 1), the basic characteristics are:

(1) The output voltage $v_3 = A(v_2 - v_1)$ where A is very large.

(2) The input terminals 1 and 2 have very high impedances (ideally ∞)

(3) The output terminal 3 has a very low impedance (ideally ∞)

How do we interpret characteristic (1)? Well the op amp is almost always used in closed-loop. The output terminal 3 is connected in feedback, and is therefore forced to be finite. Therefore v_2 is forced to be equal to v_1.

Characteristic (2) implies that the current flowing into the op amp will always be very small (ideally zero).

Characteristic (3) implies that the current flowing out of the op amp can be very large (ideally arbitrarily large).

The Inverting Amplifier

Let's analyze the result of connecting a resistor in feedback between the output terminal and the inverting input terminal as shown in Figure 2:
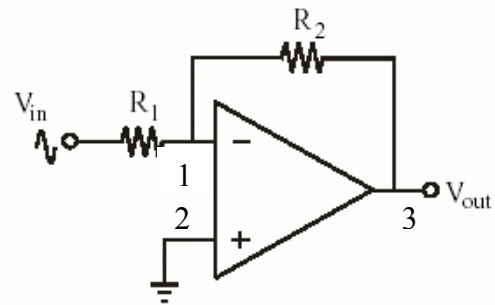

1. if v_{out} is finite, then $v_1 \cong v_2 \equiv 0$.

2. then $i_{in} = \dfrac{v_{in} - v_1}{R_1} = \dfrac{v_{in} - 0}{R_1} = \dfrac{v_{in}}{R_1}$

3. by characteristic (2), no current flows into the op amp, so $i_2 = i_{in}$

Figure 2: Op Amp as inverting amp

4. then $v_{out} = v_1 - i_2 R_2 = 0 - i_2 R_2 = -i_{in} R_2 = -\left(\dfrac{v_{in}}{R_1}\right) R_2 = -v_{in}\left(\dfrac{R_2}{R_1}\right)$

5. so the transfer function is $\dfrac{v_{out}}{v_{in}} = -\left(\dfrac{R_2}{R_1}\right)$

This is an inverting amplifier, where the gain can be greater than, less than, or equal to unity.

The Inverting Summer

Notice that since in the previous configuration, $i_2 = i_{in}$, we can input multiple currents and effectively sum them, as shown for the case of two inputs in Figure 3.
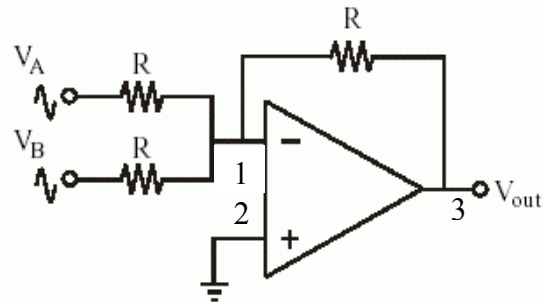
Here we have:

$$v_{out} = -R\left(\dfrac{v_A}{R} + \dfrac{v_B}{R}\right) = -(v_A + v_B)$$

Figure 3: Op Amp as inverting summer

By adjusting the resistance values, we can also obtain a weighted sum.

The Inverting Integrator

By connecting a capacitor in feedback as shown in Figure 4, we can implement an integrator. The following analysis yields the voltage integration:
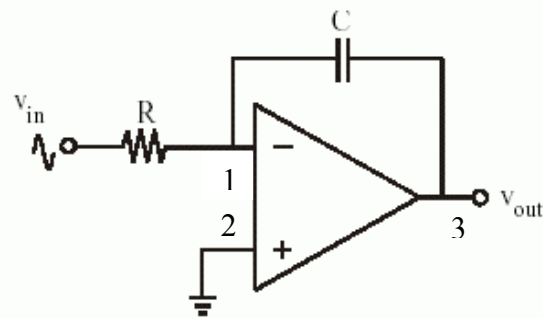
1. we still have $i_{in} = \dfrac{v_{in}}{R} = i_C$

2. since $i_C = C\dfrac{dv_C}{dt}$ we get

Figure 4: Op Amp as integrator

3. $v_C = \dfrac{1}{C}\int i_C dt = \dfrac{1}{C}\int i_{in} dt = \dfrac{1}{C}\int\left(\dfrac{v_{in}}{R}\right)dt = \dfrac{1}{RC}\int v_{in} dt$

4. thus $v_{out} = v_1 - v_C = 0 - v_C = -\dfrac{1}{RC}\int v_{in} dt$

Which is an integrator whose slope is inverted and weighted by $R \cdot C$.

Since we will not use op amps again directly in ECE 386, no further discussion will be given here. For more information:

You can refer to one of several good tutorial websites discussing op amps, from here:
http://www.google.com/search?q=op+amp+tutorial+inverting+summer+integrator

Or you can refer to the ECE 342 textbook:
Sedra/Smith. Microelectronic Circuits, 4th Ed, 1998.