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).

**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 \( \infty \)).
3. The output terminal 3 has a very low impedance (ideally \( \infty \)).

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 \( v_1 \equiv v_2 \equiv 0 \).
2. Then \( i_{in} = \frac{v_{in} - v_1}{R_1} = \frac{v_{in} - 0}{R_1} = \frac{v_{in}}{R_1} \).
3. By characteristic (2), no current flows into the op amp, so \( i_2 = i_{in} \).
4. Then \( v_{out} = v_1 - i_2R_2 = 0 - i_2R_2 = -i_{in}R_2 = -i_{in} \left( \frac{R_2}{R_1} \right) \).
5. so the transfer function is \[ \frac{v_{out}}{v_{in}} = -\left( \frac{R_2}{R_1} \right) \]

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:

\[ v_{out} = -R \left( \frac{v_A}{R} + \frac{v_B}{R} \right) = -(v_A + v_B) \]

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 \( i_{in} = \frac{v_{in}}{R} = i_C \)

2. since \( i_C = C \frac{dv_C}{dt} \) we get

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

4. thus \( v_{out} = v_1 - v_C = 0 - v_C = -\frac{1}{RC} \int v_{in} dt \)

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](http://www.google.com/search?q=op+amp+tutorial+inverting+summer+integrator)

Or you can refer to the ECE 342 textbook: