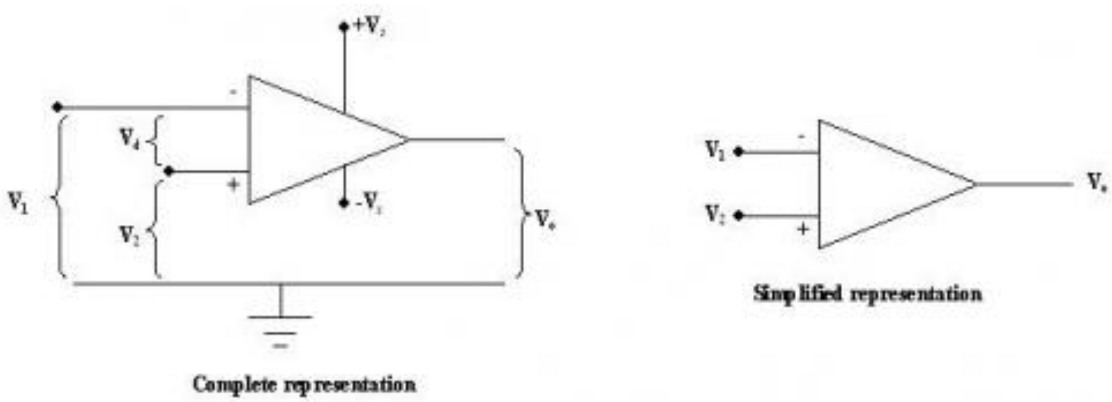
Operational amplifiers (op amps)

Much of modern electronics involves the use of Operational Amplifiers or Op Amps. So, what are Op Amps?

· The name Op Amp was originally given to an amplifier that could be easily modified by external circuitry to perform mathematical operations such as +, scaling, , etc. in analog computer applications.· Now, they are basic building blocks in amplification, signal conditioning, filters, function generators, and switching circuits.·

An Op Amp amplifies the difference $V_d = V_1 – V_2$ between two inputs:



Complete representation

Simplified representation

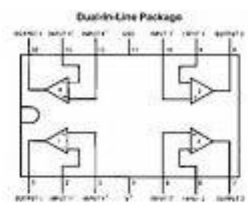
- $A_{OL} = V_o/V_d$ is called the **Open Loop Gain**. Typically, A_{OL} $[10^4, 10^7]$.
- V_1 is called the **inverting input** and is labeled with a negative sign.
- The input signal V_1 is ***magnified and phase inverted*** at output.
- V_2 is called the **non-inverting input** and is labeled with a positive sign. The contribution of V_2 to the output is ***phase-preserved***.
- The maximum output voltage from an Op Amp is called the ***saturation voltage***. This voltage is approximately 2 Volts smaller than the supply voltage. The Op Amp is typically linear over the range $–(V_s - 2) < V_o < (V_s – 2)$.

Characteristics of Ideal Op Amps

- A_{OL} = - ¥
- Input impedance R_d between terminals 1 and 2 is ¥ Þ input current = 0.
- Output impedance is 0 Þ V_o is independent of load.

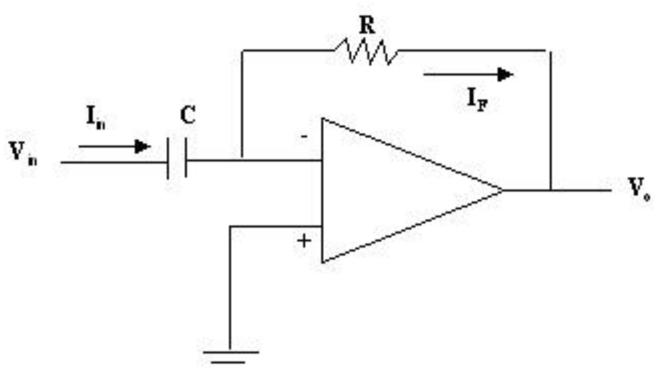
<u>**Your Friend, the LM324**</u>

There are many different integrated circuits containing op amps, but the one you will use most often is the LM324. This chip is a low power quad op amp, which means that there are actually four op amps contained in one chip. LM324s are available for you to use in W294. The spec sheet for this circuit can be found on the data sheets page of this website.



For descriptions of some useful circuits involving op amps, see the links below.

Differentiating amplifier



• Introduction of the capacitor C in the inverting input of the Op Amp will lead to time differentiation of the input signal:

For an ideal Op Amp, V_d » 0 Þ inverting (-) terminal is a virtual ground.

Þ V_{in} appears across the capacitor and

$$I_{in} = C\frac{dV_{in}}{dt}$$

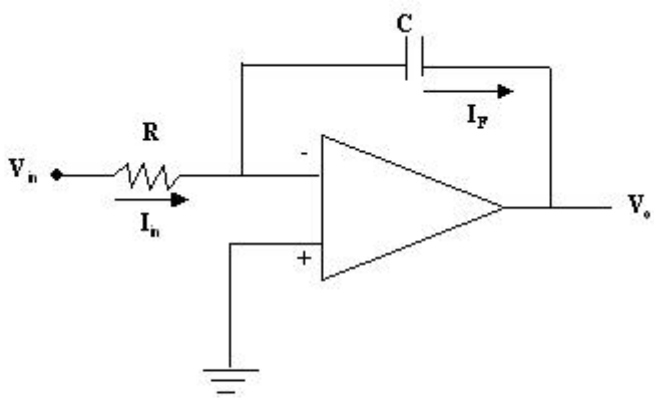
Then, by continuity of current, I_{in} » I_F

$$\Rightarrow \quad C\frac{dV_{in}}{dt} = \frac{0-V_o}{R} \quad \Rightarrow \quad V_o = -RC\frac{dV_{in}}{dt}$$

with a characteristic response time of 1/RC.

Note: This circuit is of limited use since high frequency noise can produce derivatives of comparable magnitude to that of the derivative of the input signal

Integrating amplifier



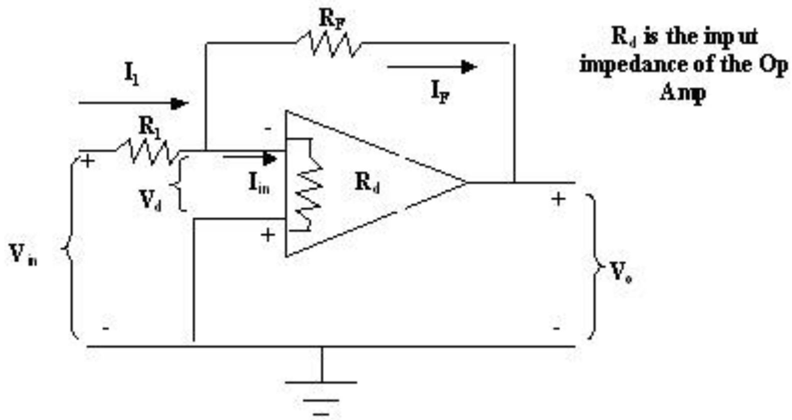
Introduction of a capacitor in the feedback path of an Op Amp produces an output signal which is the integral of the input:

For an ideal Op Amp, Vd » 0 Þ inverting (-) terminal is a virtual ground Þ Iin = Vin/RWith negligible current into the Op Amp, current continuity yields Iin = IF

$$\Rightarrow \quad \frac{V_{in}}{R} = I_{in} = I_F = -C\frac{dV_o}{dt} \quad \Rightarrow \quad V_o = -\frac{1}{RC}\int V_{in}dt$$

with a characteristic response time of 1/RC.

Inverting amplifier



- Non-inverting (+) input connected to ground or common.
- Signal is applied through input resistor R1.
- Negative current feedback is implemented by connecting feedback resistor RF. Negative feedback gives any circuit containing the amplifier, characteristics that are dependent almost entirely on circuit elements external to the Op Amp. This is shown below:

$$I_1 = I_{in} + I_F$$

$$\Rightarrow \quad \frac{V_{in} - V_d}{R_1} = \frac{V_d}{R_d} + \frac{V_d - V_o}{R_F}$$

$$\Rightarrow \quad \frac{V_{in} - V_d}{R_1} + \frac{V_o - V_d}{R_F} = \frac{V_d}{R_d}$$

By definition of the open loop gain, AOL = Vo/Vd Þ Vd = Vo/AOL

$$\Rightarrow \quad \frac{V_{in} - \left(\frac{V_o}{A_{OL}}\right)}{R_1} + \frac{V_o - \left(\frac{V_o}{A_{OL}}\right)}{R_F} = \frac{1}{R_d}\left(\frac{V_o}{A_{OL}}\right)$$

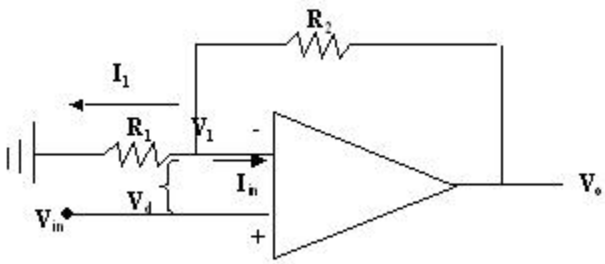
In the limit of an ideal Op Amp, i.e.

$$A_{OL} \to -\infty, \ \frac{V_{in}}{R_1} + \frac{V_o}{R_F} = 0 \quad \Rightarrow \quad \frac{V_o}{V_{in}} = -\frac{R_F}{R_1} = A_F \ (Voltage\ Amplification)$$

This can also be seen from the second ideal characteristic of an Op Amp, namely, Iin = 0. If Iin = 0 then Vd = 0 and IF = I1 Þ Vin = I1R1 and –Vo = IFRF

$$\Rightarrow \frac{V_o}{V_{in}} = -\frac{I_F R_F}{I_1 R_1} = -\frac{R_F}{R_1} = A_F \text{ (Voltage Amplification)}$$

Non-inverting amplifier



- Ground the resistance R_1.
- Apply the input signal at the non-inverting (+) terminal of the Op Amp.

Assuming the current to the inverting (-) terminal of the Op Amp is 0, i.e. assuming I_{in} = 0, and V_d » 0 Þ V_{in} » V_1.Continuity of current yields:

$$\frac{V_o - V_1}{R_2} = \frac{V_1}{R_1} \Rightarrow \frac{V_o - V_1}{V_1} = \frac{R_2}{R_1} \Rightarrow \frac{V_o}{V_1} - 1 = \frac{R_2}{R_1}$$

and so

$$\boxed{\frac{V_o}{V_1} = \frac{V_o}{V_{in}} = \frac{R_2}{R_1} + 1 = A_v \text{ (Voltage Amplification)}}$$

(Note: Be sure to compare this formula with the gain formula for your Precision Instrumentation Amplifier INA114 chip in Experiment #3B)