Using Operational Amplifiers

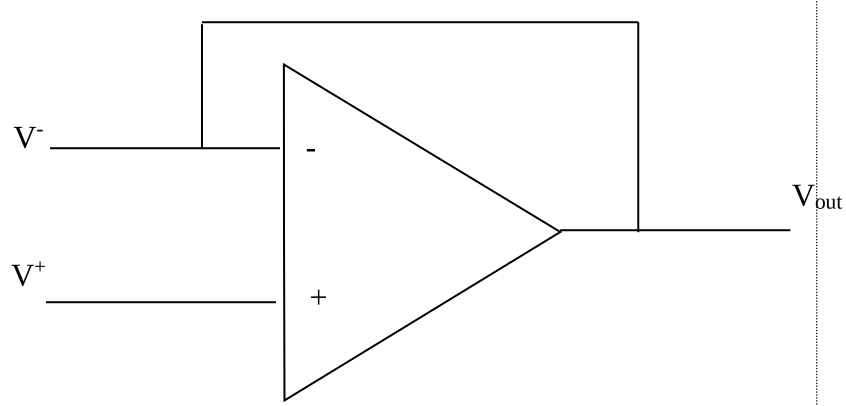
An operational amplifier or op-amp is a three port device with an input and output voltage referenced to ground. The amplifier provides a gain defined as the ratio of the output to input voltage amplitudes.

$$A = V_{out}/V_{in}$$

Op amps typically have a very high input impedance ($Z_{in} = V_{in}/I_{in} > 100K\Omega$) and a low output impedance ($Z_{out} = V_{out}/I_{out} < .1\text{-}5\ \Omega$).
The op-amp is the basic building block for:

- Amplifiers
- Integrators
- Summers
- Differentiators
- Comparators
- A/D and D/A converters
- Filters

The op amp is an active device implying that an external power supply is necessary for its operation. The figure below demonstrates an op amp circuit with feedback gain included. This closed loop configuration is necessary to give the amplifier stability in gain.



Ideal Op Amp

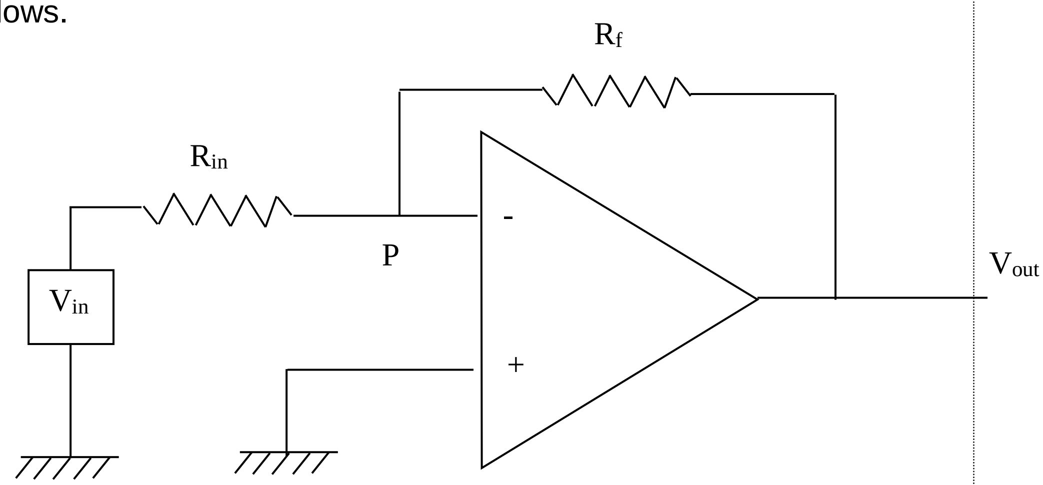
where V^- is the inverting input, V^+ is the non-inverting input, and V_{out} the output voltage. Op amps can be approximated using a simple, ideal op amp model that is based on the following assumptions:

1. Infinite impedance at the inputs, thus no current is drawn from the input circuits, I^- and I^+, and $I^- = I^{out}$ due to the feedback loop.
2. The ideal op amp has infinite gain, thus the input voltages must be equal: $V^- = V^+$.
3. The ideal op amp has zero output impedance, so V_{out} is independent of I_{out}.

Note that op amps provide a gain to the input signal. However, the gain is limited by the maximum output voltage for the op amp. If the desired gain exceeds the op amp maximum, the op amp will saturate and not perform as expected.

Several uses of op amps are demonstrated here:

Inverting Amplifier:
The inverting amplifier amplifies the input signal and inverts the signal (note the input at the inverting channel of the op amp). Analysis of the inverting amplifier proceeds as follows.



Analysis of inverting amp:
The current over R_{in} and R_f (feedback resistor) must be the same:

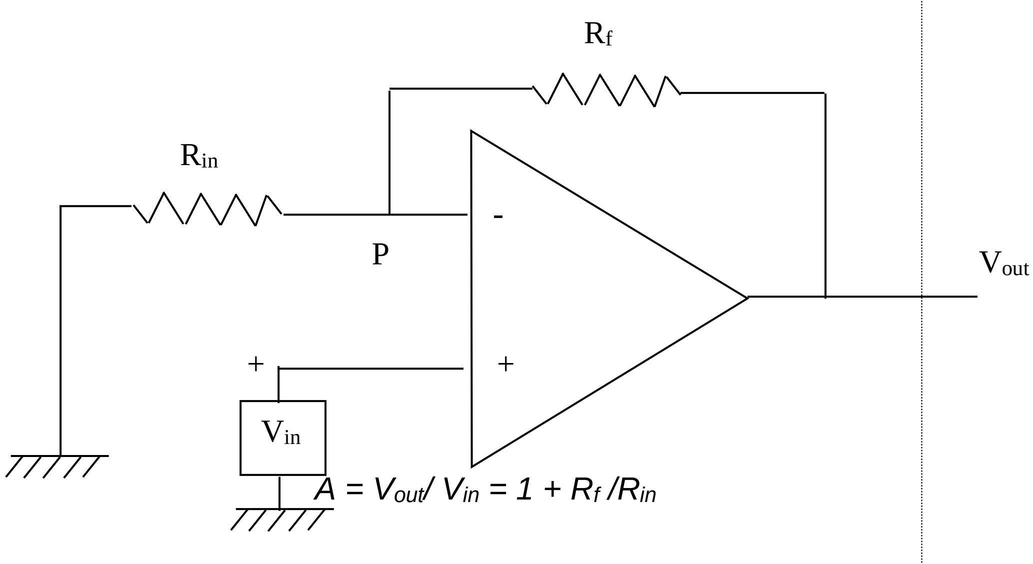
$$i_- = -i_{out}$$

and the voltage at P must equal 0. Therefore, the current over *Rin* and *Rf* can be determined and set equal:

$$V_{in}/R_{in} = -V_{out}/R_f$$

Thus, $$A = V_{out}/ V_{in} = - R_f /R_{in}$$

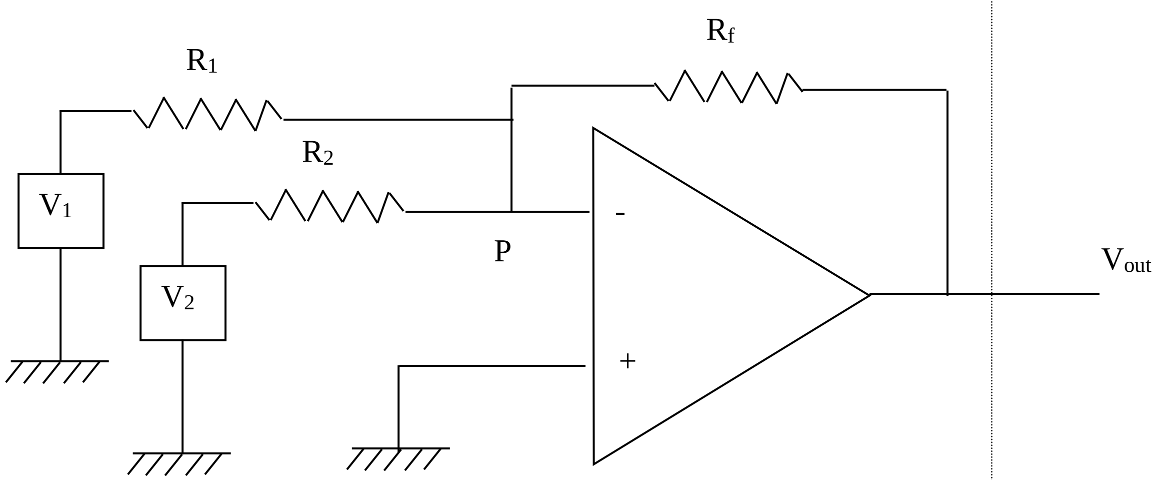
Non-inverting amplifier:



$$A = V_{out}/ V_{in} = 1 + R_f /R_{in}$$

Note that this amplifier can also be used to boost the output signal from a low output sensor, without loading the sensor since it has a high input impedance and low output impedance.

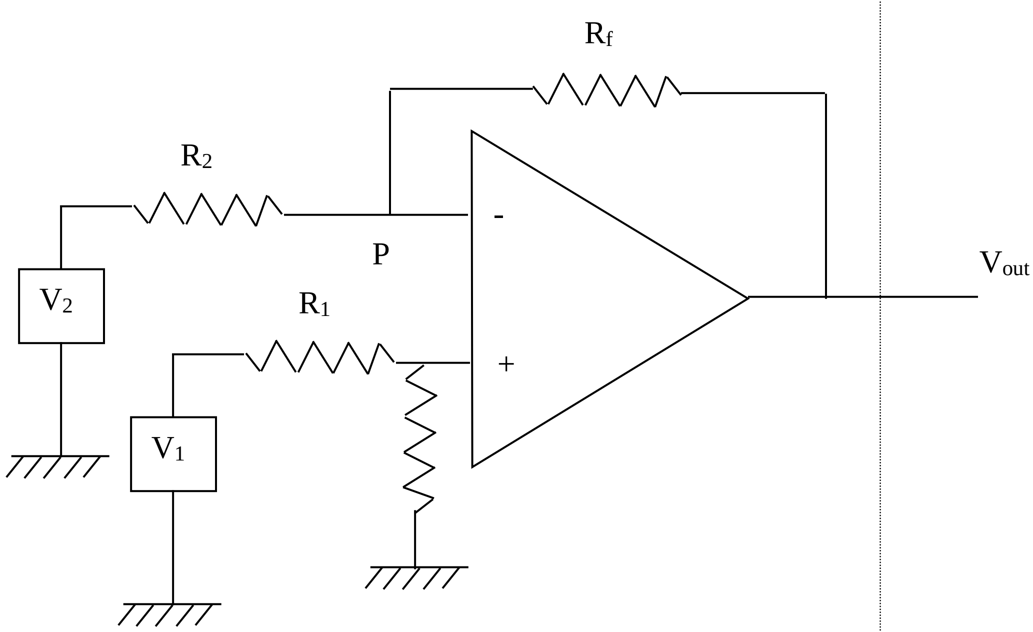
Summing amplifier:



$$V_{out} = -(V_1 + V_2)$$

with $R_1 = R_2 = R_f$

Difference amplifier:



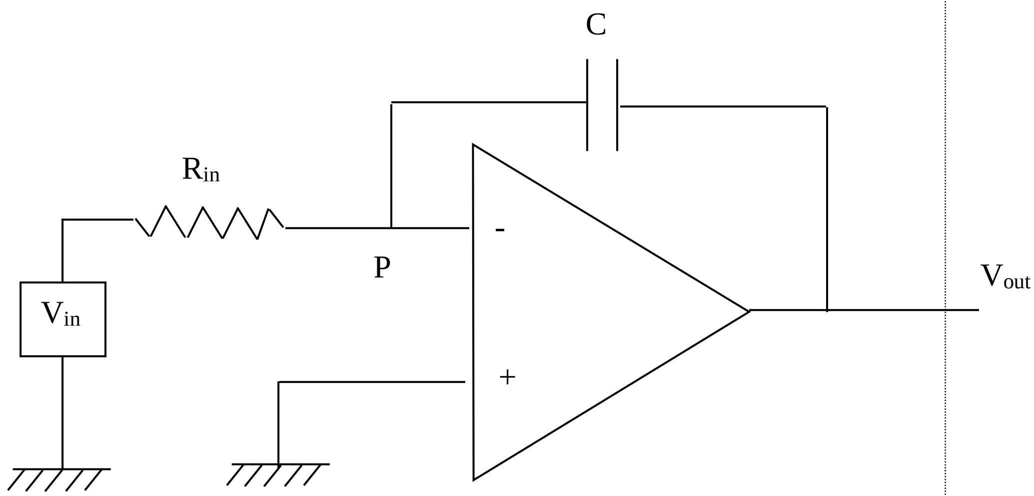
$$V_{out} = + R_f /(R_1 = R_2) *(V_1 - V_2)$$

Integrator:
The integrating amplifier is created by replacing the feedback resistor with a capacitor. The result is that the output voltage is related to the output current through the relation:

$$V_{out} = \frac{1}{C}\int_0^t i_{out}(\tau)d\tau$$

and results in an inverted, integral gain:

$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}(\tau)d\tau .$$



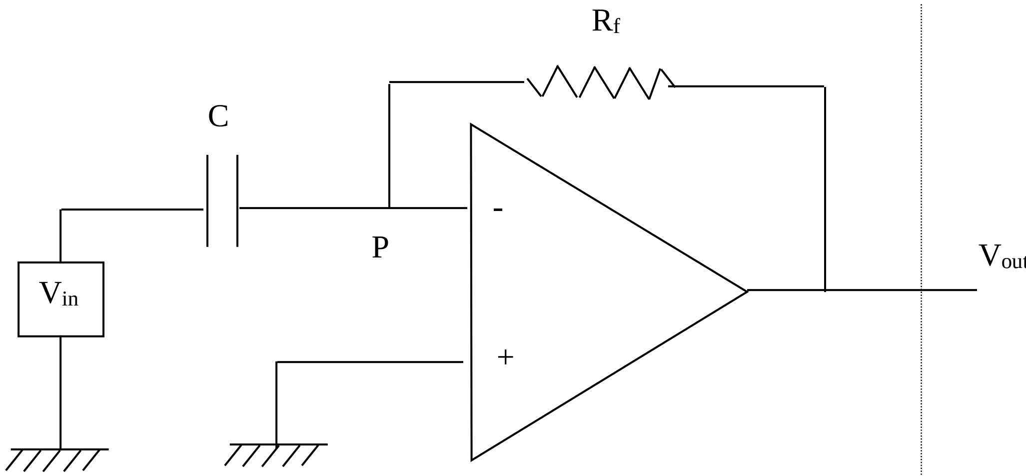
In a more practical application of this integrator, a shunt resistor is added in parallel with the capacitor to avoid a gradual drift due to any DC offset. The shunt resistor may be selected as 10x the value of the input resistor. One use for this integrator is in feedback control systems that use integral feedback.

Differentiating amplifier:
A differentiator can be created from the inverting amplifier by replacing the input resistor with a capacitor. The result is that the input voltage is related to the input current through the relation:

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

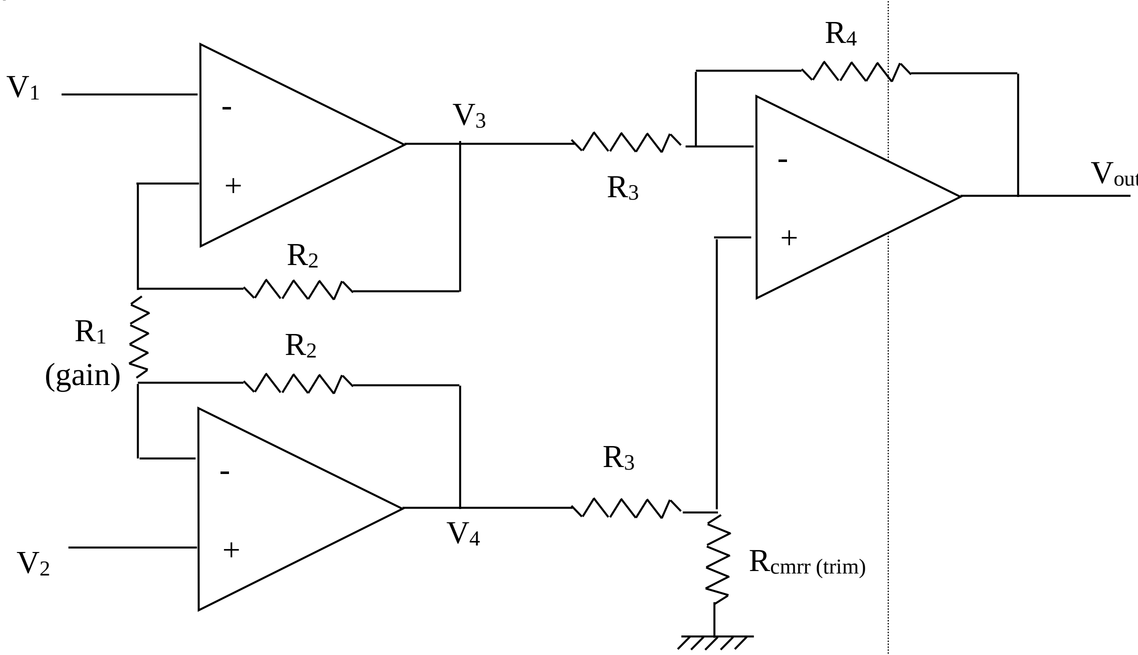
and results in an inverted, derivative gain:

$$V_{out} = -R_f C\frac{dV_{in}}{dt} .$$



Comparator:
The comparator makes use of an op amp to determine if one input signal is greater than the other. The LM339 is an example of an op amp specially designed to act as a comparator and as such can be a very useful integrated circuit component.

Instrumentation amplifier:
The instrumentation amplifier combines several op amps to provide a high input impedance with a feature called common mode rejection ratio (CMRR, different gains for difference mode or common mode) allowing low-level signals in a noisy environment to be amplified.



$$V_{out} = [R_4/R_3\,(1 + 2R_2/R_1)]*(V_2 - V_1)$$

Implementing Op amps

Op amps in practice come in many shapes and sizes, and deviate from the behavior shown in the examples above. In implementation, pay careful attention to the specifications of the device, including:

- Input voltage maximum
- Output short circuit current (maximum output current)
- Output voltage maximum
- Maximum supply voltage

Also, in implementation you will need to provide a positive and negative supply voltage. This can be performed using the lab power supplies using the following arrangement: