



L02.03

The Operational Amplifier

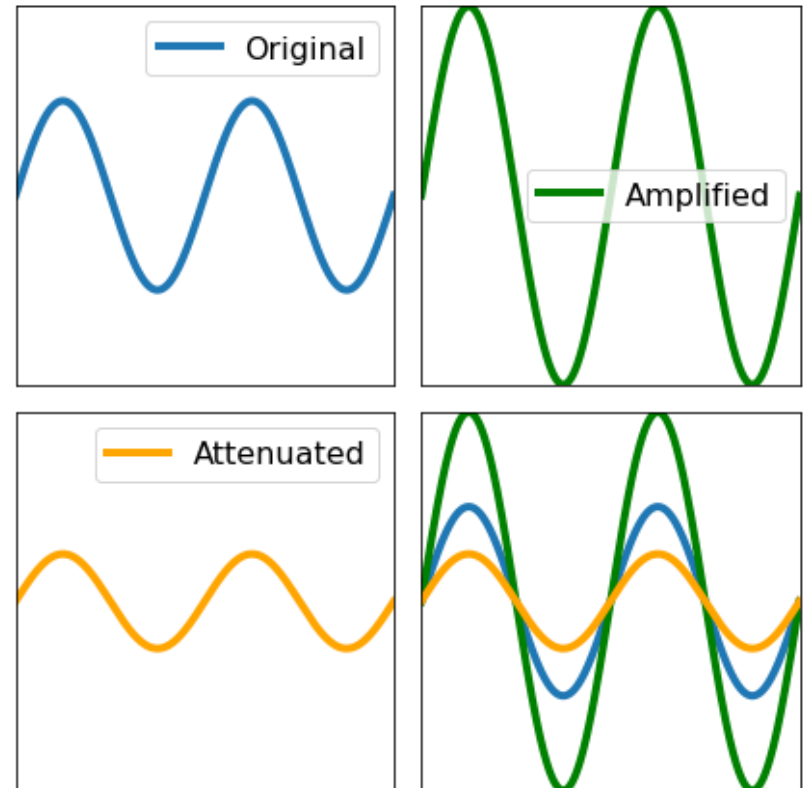


Amplification and Attenuation



- A common task in electronics is to change the size of a signal, usually voltage, smaller or larger
- Making a voltage smaller is easy; we can just use resistors to divide the voltage
 - This is called attenuation
- Needing to make a signal larger is common, but much trickier
 - This is called amplification
- The ratio of input to output is commonly referred to as gain

$$G = \frac{V_{out}}{V_{in}}$$



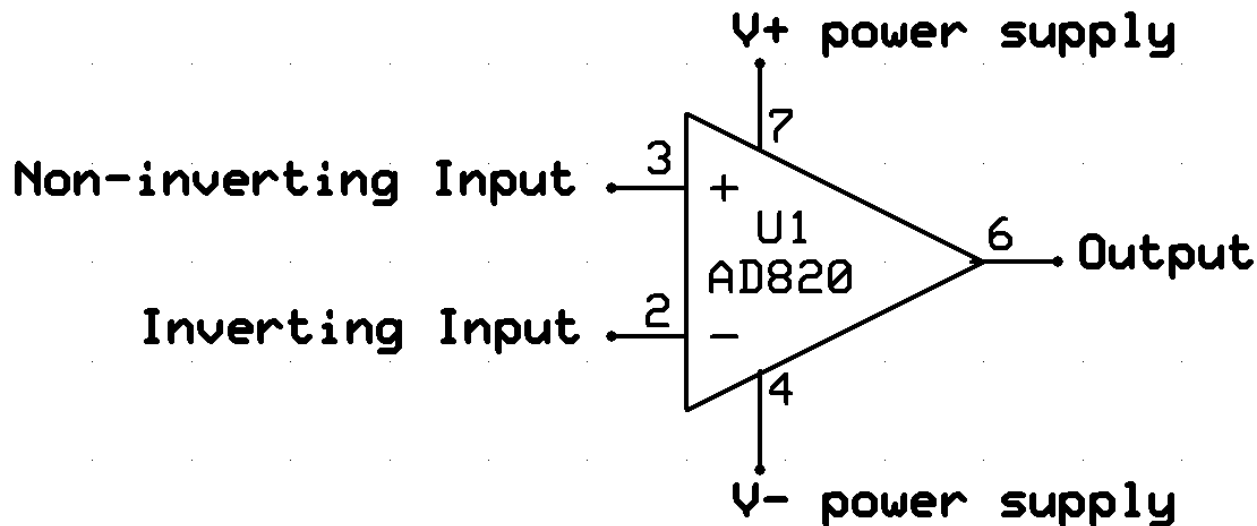


Operational Amplifier or “Op Amp”



A commonly used IC, the Op Amp, can be used to do this.

The symbol below is a standard Op Amp, only the part and pin numbers are specific to a particular model.

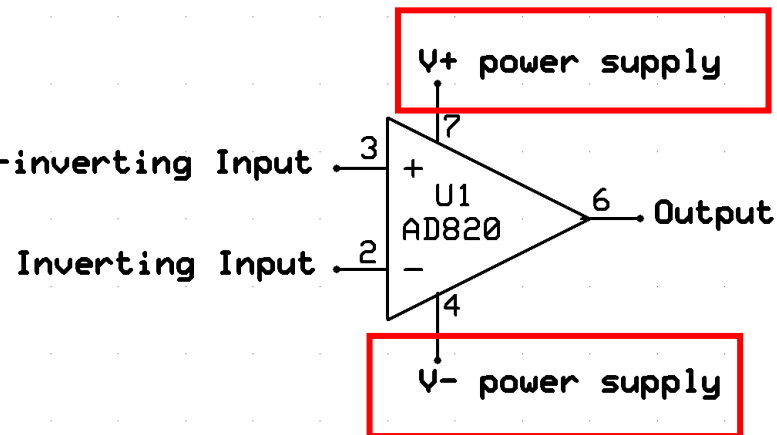




Op Amp Connections - Power



- Vcc+ Supply
- Vcc- Supply
 - Often connected to 0V or GND
 - Will sometimes be connected to a negative voltage for negative outputs
- It is common not to draw these connections on schematics to simplify drawing
- Power supplied by the output will be drawn via these connections

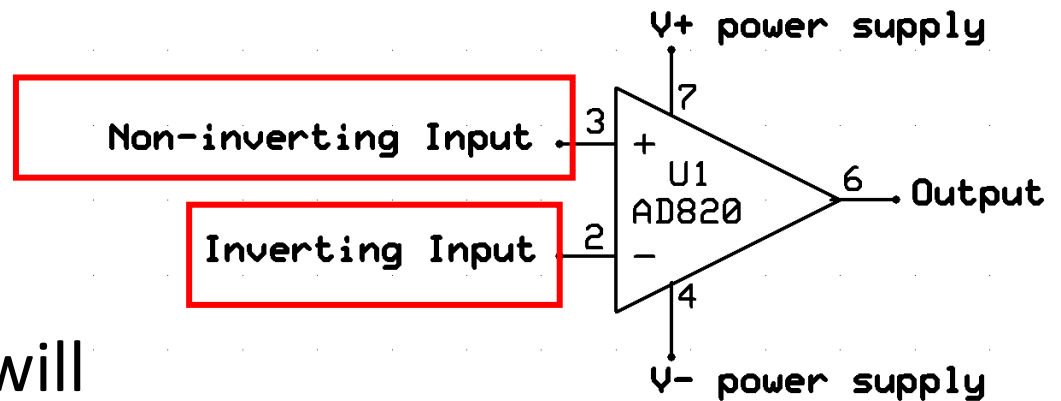




Op Amp Connections - Inputs



- V_{in+} (V_+)
 - Non-inverting input
- V_{in-} (V_-)
 - Inverting input
- The input signal V_{in} will be connected to one of these two pins

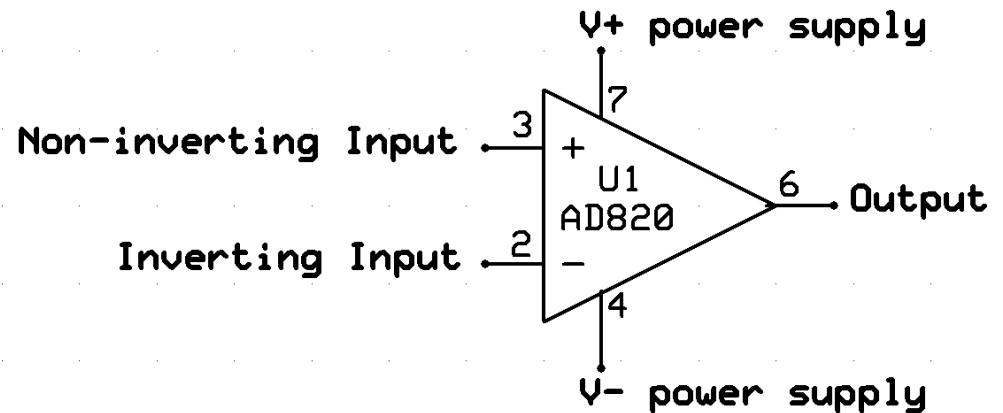




Op Amp Connections - Output

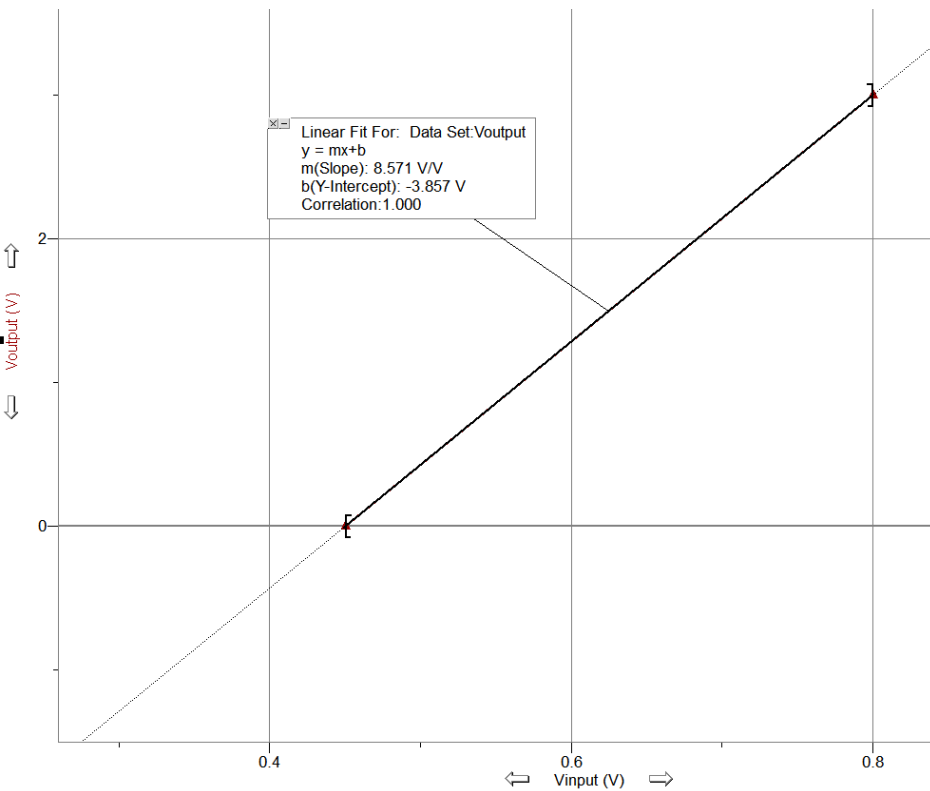


- V_{out}
 - The amplifying circuit will be set to change this the desired behavior
 - Connects back to one of the inputs to create a feedback loop
 - Maximum Out $V_{out} = V_{cc+}$
 - Minimum $V_{out} = V_{cc-}$





Transfer Function



- Op Amps create a linear relation between V_{out} and V_{in} , with V_{out} on the Y-axis and V_{in} on the X-axis
- The slope is called gain
- The intercept is called the offset
- You look at your input voltages, determine your desired output voltages, and then plot the line to determine your desired transfer equation



Op Amp Golden Rules



To determine the circuit needed to give us the transfer equation we use following rules:

- I. Infinite Open Loop Gain. (V_{out} will vary to meet the other rules)**
- II. No voltage difference between the inputs. ($V_+ = V_-$)**
- III. No current flow in or out of the inputs ($I_+ = I_- = 0A$)**

By combining these with Ohm's law and Kirchoffs Law, we can determine the resistor arrangement we need to give us the performance we want.

Set up the equations the solve for V_{out}



Signal Conditioning Circuit

Example 1: Buffer



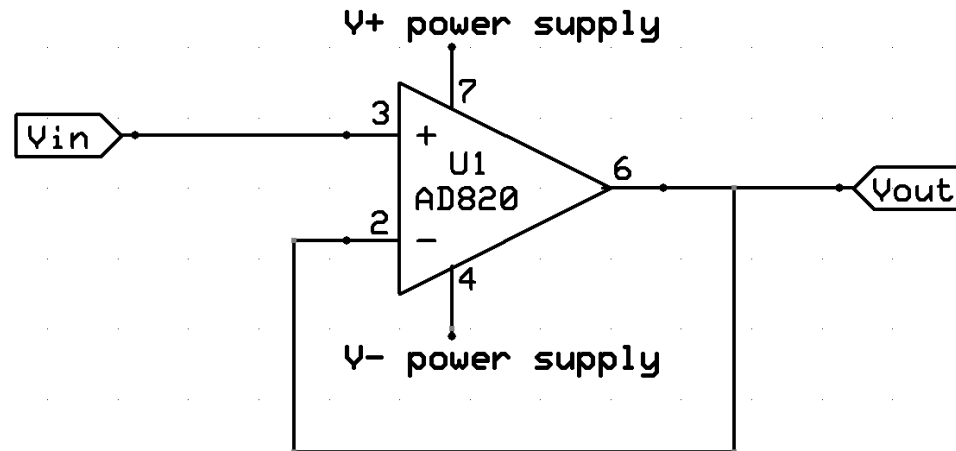
Simplest Case:
Connect the V_{out} back to
either input

$$V_{in} = V_{+}$$

$$V_{+} = V_{-} \text{ (Rule II)}$$

$$V_{-} = V_{out} \text{ (Directly Connected)}$$

$$\text{Therefore: } V_{in} = V_{out}$$





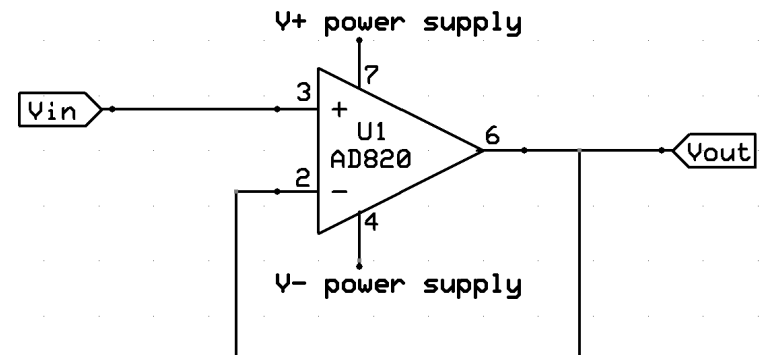
Signal Conditioning Circuit Buffer usage



This may seem like a silly example, but it is actually quite useful.

The input is isolated from the output by the Op Amp.

Current on V_{out} comes from the supply, not V_{in} . So a low-power V_{in} could be used to drive a high-power output.



Gain of Buffer
 $V_{in} = V_{out}$
Gain=1



Non-Inverting Amplifier Example



Now, let's add some resistors.
Let's draw the currents across
those resistors and into V_-

$$V_{in} = V_+ = V_- \text{ (Rule II)}$$

$$I_- = 0 \text{ (Rule III)}$$

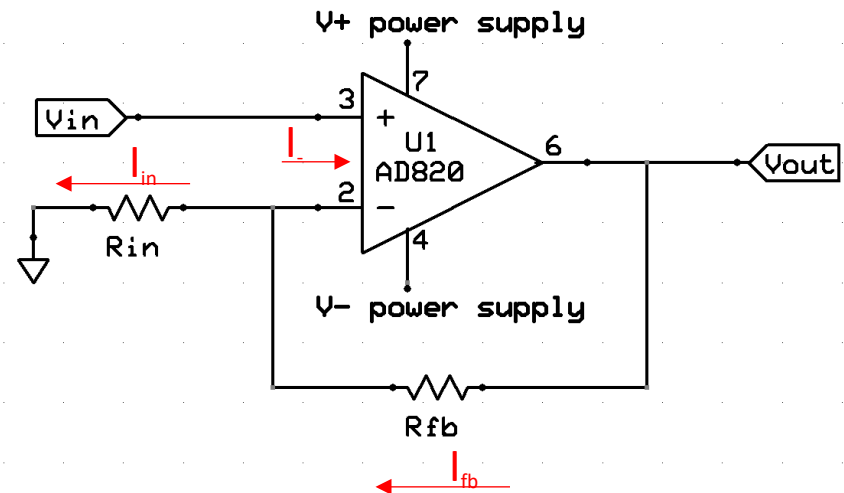
$$I_{in} = I_{fb} \text{ (KCL)}$$

Now, Ohm's law for R_{in} and R_{fb}

$$I_{in} = \frac{V_- - 0V}{R_{in}}$$

$$I_{fb} = \frac{V_{out} - V_-}{R_{fb}}$$

$$\frac{V_{out} - V_-}{R_{fb}} = \frac{V_- - 0V}{R_{in}}$$





Non-Inverting Amplifier Example



Now Combine:

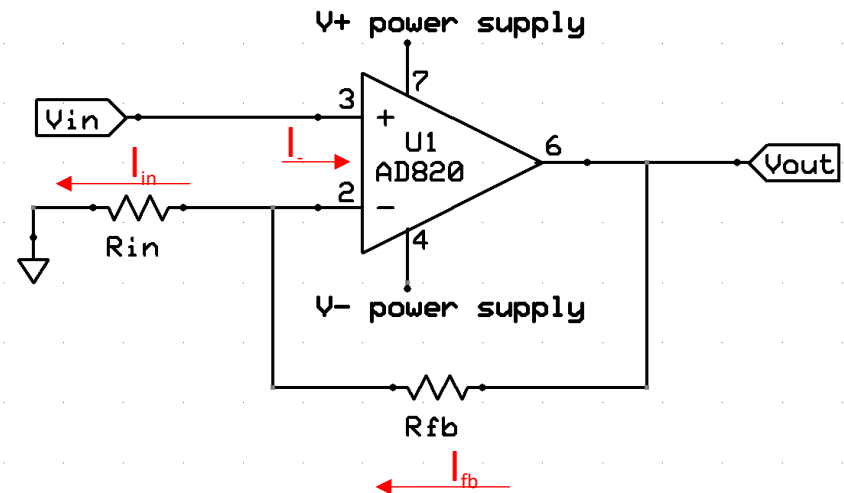
$$\frac{V_{out} - V_-}{R_{fb}} = \frac{V_- - 0V}{R_{in}}$$

Finally $V_{in} = V_-$

$$\frac{V_{out} - V_{in}}{R_{fb}} = \frac{V_{in} - 0V}{R_{in}}$$

And solving for V_{out} gives us:

$$V_{out} = \left(1 + \frac{R_{fb}}{R_{in}}\right)$$





Non-Inverting Amplifier Usage



Non-inverting Op Amps have V_{in} connected to the positive terminal.

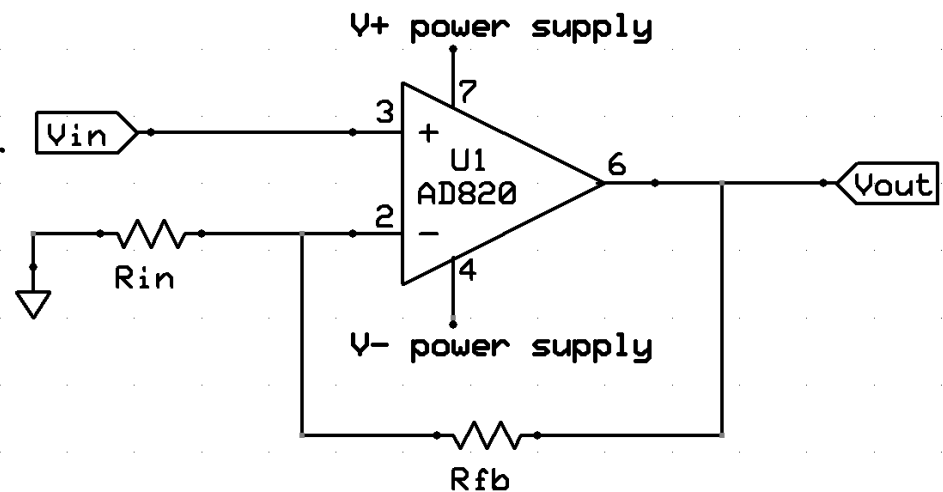
It does not flip the signal, so it is “Non-inverting”.

We could do a similar analysis to derive the equations more amplifiers but will just show some common types along with their transfer equations

$$G = 1 + \frac{R_{fb}}{R_{in}}$$

$$\text{Gain} > 0$$

$$V_{out} = V_{in} \left[1 + \frac{R_{fb}}{R_{in}} \right]$$





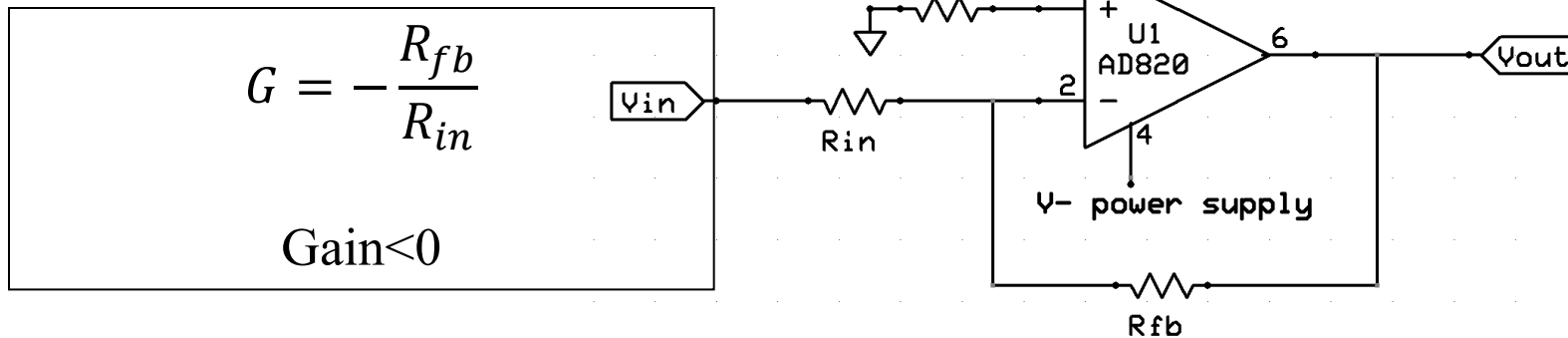
Inverting Amplifier

Inverted op amps have V_{in} connected to the negative terminal.

Signal is inverted over 0V.(flipped).

$$V_{out} = -V_{in} \left[\frac{R_{fb}}{R_{in}} \right]$$

Note: the gain is negative so it is important to consider the sign of V_{in} and if V_{s-} is negative or zero



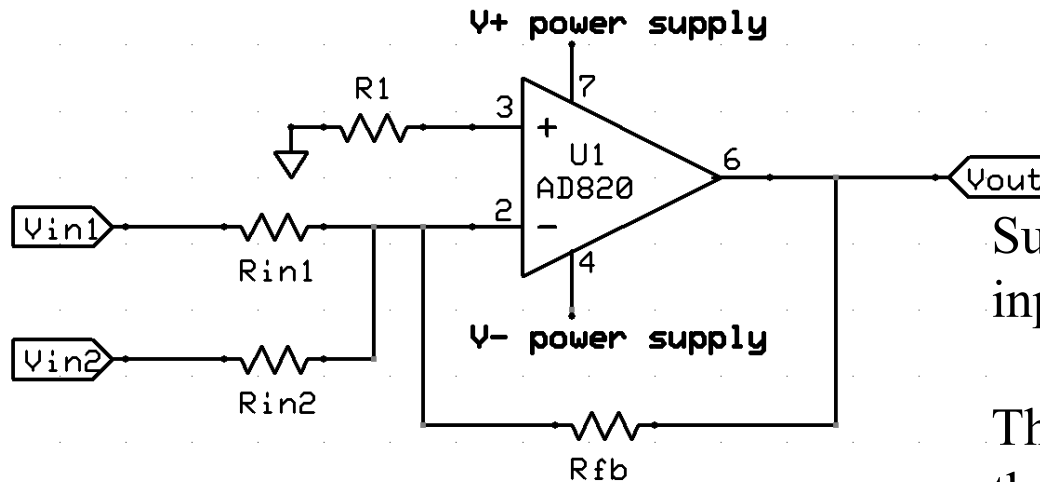
$$G = -\frac{R_{fb}}{R_{in}}$$

Gain < 0



Summing Amplifier

$$V_{out} = -[V_{in1} \frac{R_{fb}}{R_{in1}} + V_{in2} \frac{R_{fb}}{R_{in2}}]$$



Summing op amps have multiple inputs connected to a single input.

The output is a weighted sum of the inputs.

Can be inverting (shown here) or noninverting,



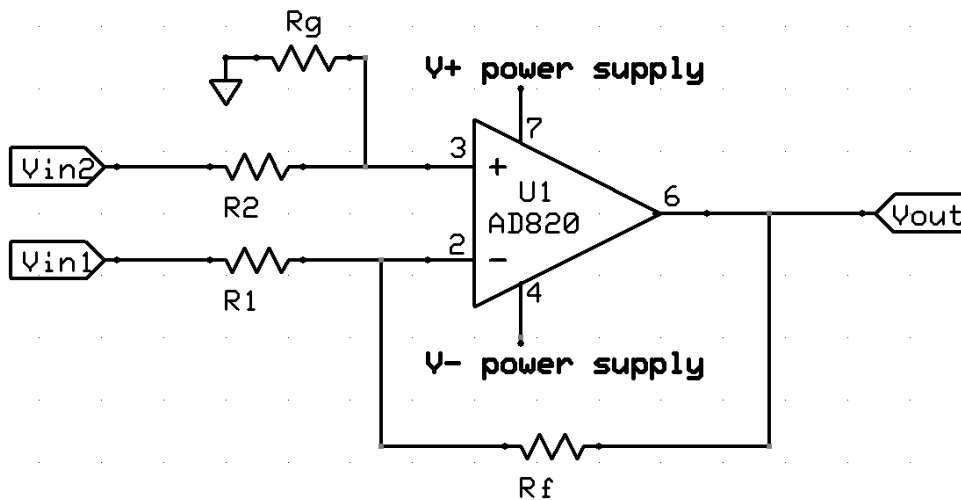
Difference Amplifier



$$V_{out} = -\left(\frac{R_f}{R_1}\right)V_{in1} + \left(\frac{R_g}{R_2 + R_g}\right)\left(\frac{R_1 + R_f}{R_1}\right)V_{in2}$$

Which is commonly simplified by setting $R_1=R_2$ and $R_f=R_g$ giving:

$$V_{out} = \left(\frac{R_f}{R_1}\right)(V_{in2} - V_{in1})$$



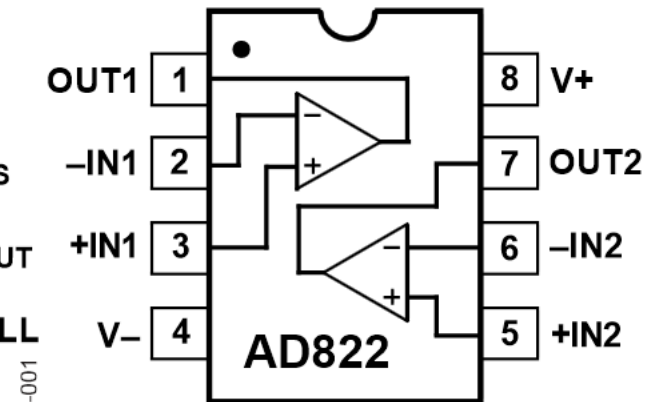
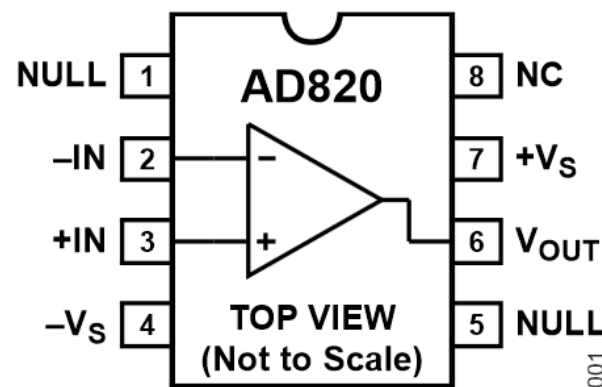
It amplifies the difference between the two signals.



Operational Amplifier ICs



- Commonly come in Single(1x), Dual(2x), and Quad(4x) Packages
- In those cases, the amplifiers share a common set of power supply pins and have individual input and output pins
- To the right, we can see the single and dual versions of a common Op Amp
 - Notice the physical package is the same but the pins, in particular the power pins, are in different spts



3-001



Other Amplifier Variations



- A common variation is to add an offset to previous examples, which shifts the entire signal by a constant amount up and down
 - We will do this in the Temperature Calibration Activity
- By adding capacitors and or inductors you can make the gain of a circuit depend on a frequency, this allows you to filter undesirable signals (like high frequency RF noise) out
- It is also common to send the output of one amplifier to the input of another. Giving multiples stages of amplification.