The Operational Amplifier

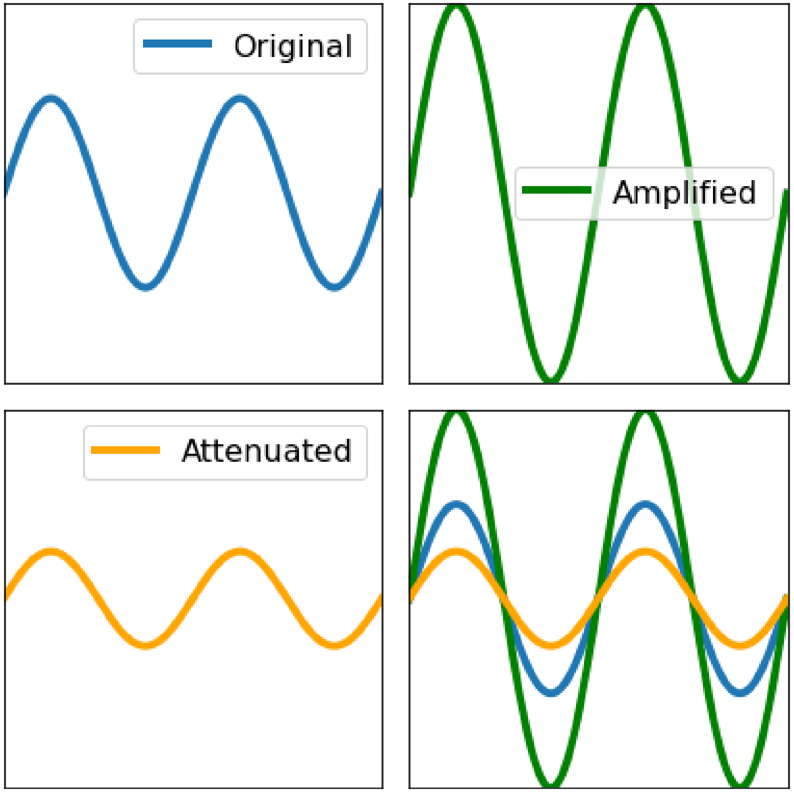
Basics of Amplifying Circuits

L02.06

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**

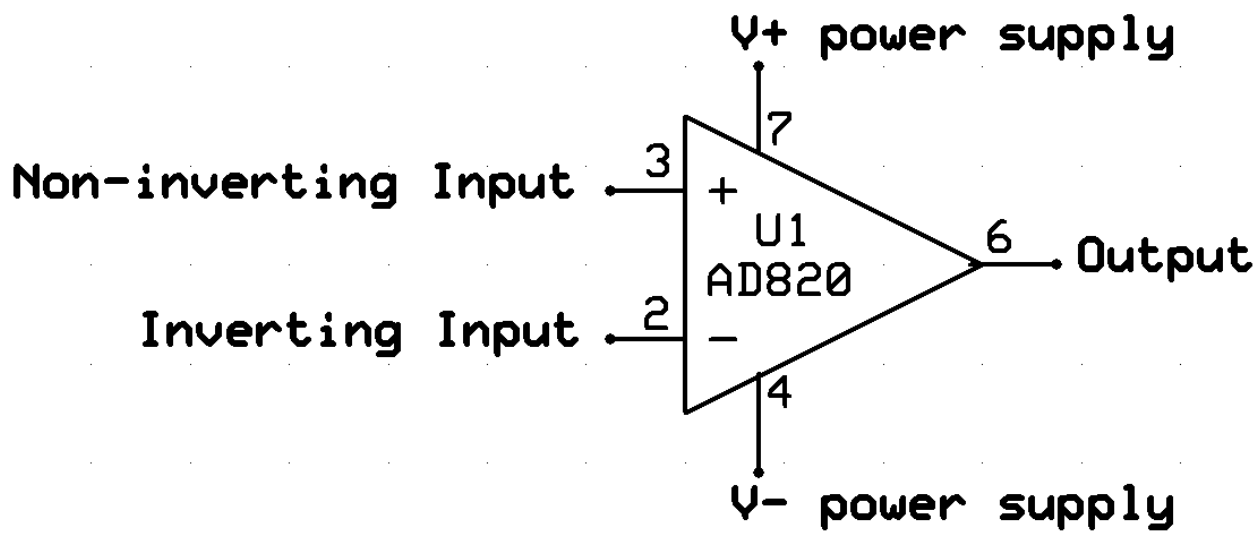
$$G = \frac{V_{out}}{V_{in}}$$



Operational Amplifier or “Op Amp”

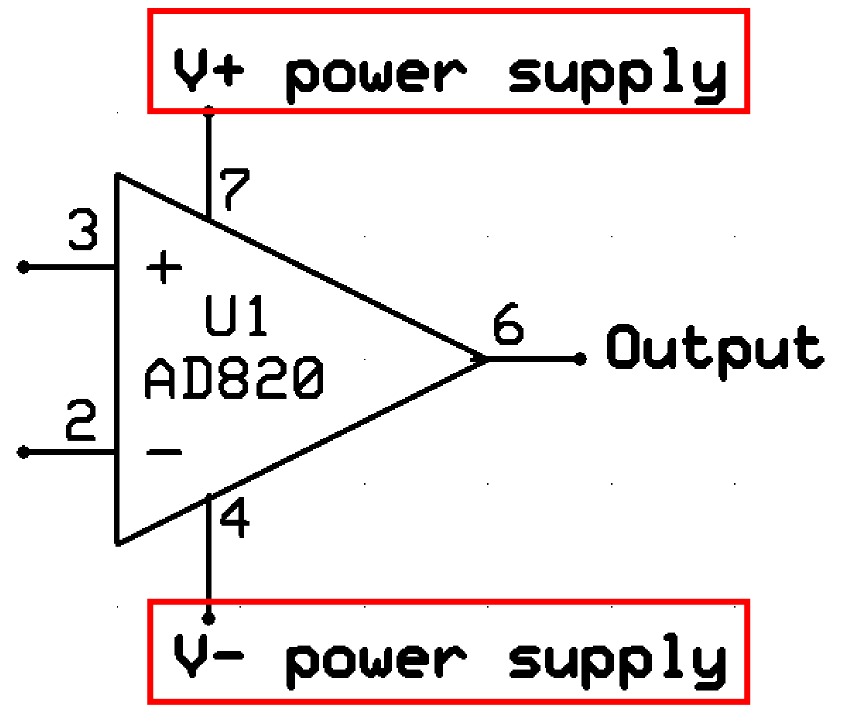
An IC, the Op Amp, can be used to do this.

The symbol below is a standard Op Amp; only the part and pin numbers are specific to a part (AD820) number.



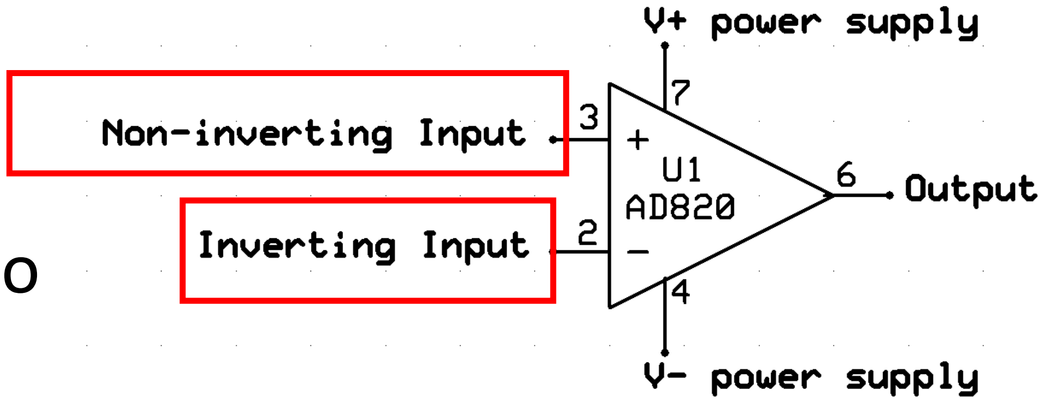
Op Amp Connections - Power

- 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 going out the output pin will come from these connections instead of the input pins



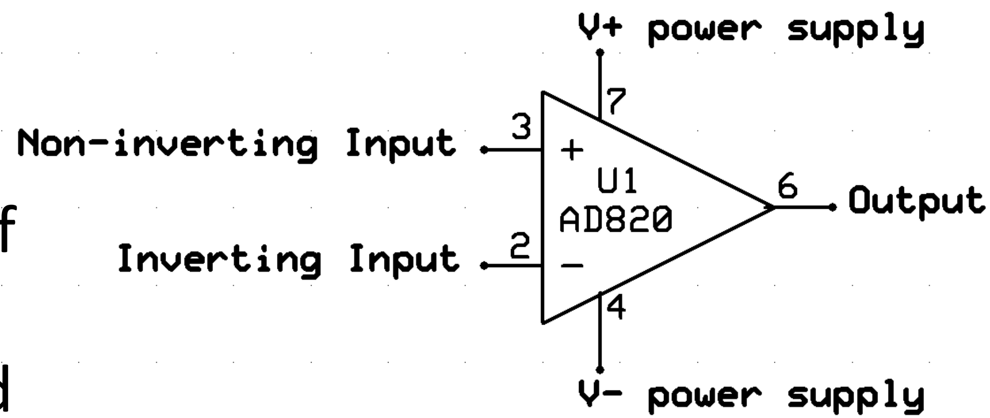
Op Amp Connections - Inputs

- V_{in+} (V_+)
  - Non-inverting input
- V_{in-} (V_-)
  - Inverting input
- The signal you want to amplify (V_{in}) will be connected to one of these two pins
  - The + or – is used depending on application

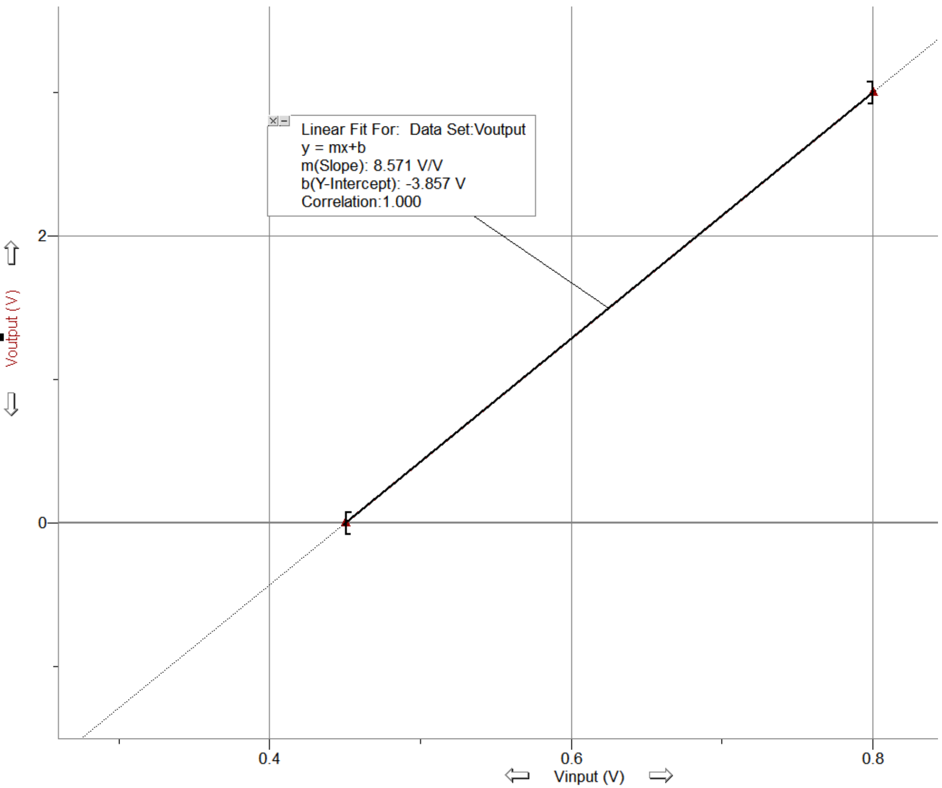


Op Amp Connections - Output

- V_{out} is the changed output voltage signal
  - The amplifying circuit is built to change this to the desired behavior
- In addition to sending the output somewhere else, it will be connected to one of the inputs (+ or -)
- The voltage value is limited by the voltage supplied at the power pins
  - Maximum Out V_{out}=V_{cc+}
  - Minimum V_{out}=V_{cc-}

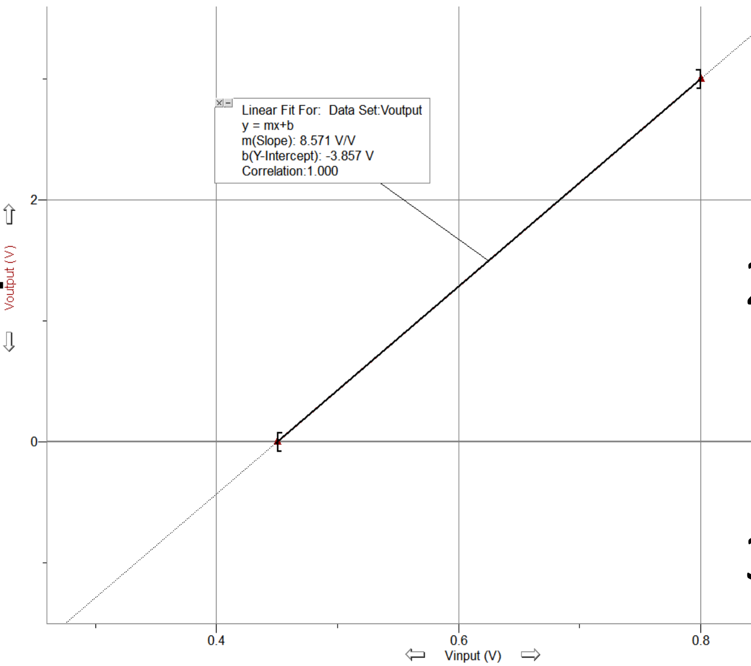


Transfer Function



- 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 equation of the line with V_{out} on Y and V_{in} on X is called the **TRANSFER FUNCTION**
- The slope is called **GAIN**
  - Can be positive or negative
  - Since it is Volts/Volts, Gain is a unitless number
- The intercept is called the **OFFSET**
  - For the simplest amplifier, the offset is 0
  - Since it is a shift in the output, Offset has units of Volts

Determining the Amplifier Circuit



1. Determine your Minimum and Maximum V_{IN}

   For example, this would be the Voltage at the highest and lowest temperatures you are trying to measure

2. Determine the Min and Max V_{out}

   Ex. The minimum voltage and maximum voltage on the meter you are using to measure the output

3. Plot the line of $V_{out}(y)$ vs $V_{in}(x)$to determine gain and offset

4. Build an amplifier that will give that gain and offset

Op Amp Golden Rules

To determine the circuit needed, we use the following rules:

I. **Infinite Open Loop Gain. (V_{out} will change 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)**

These are how a perfect ideal Op Amp will function

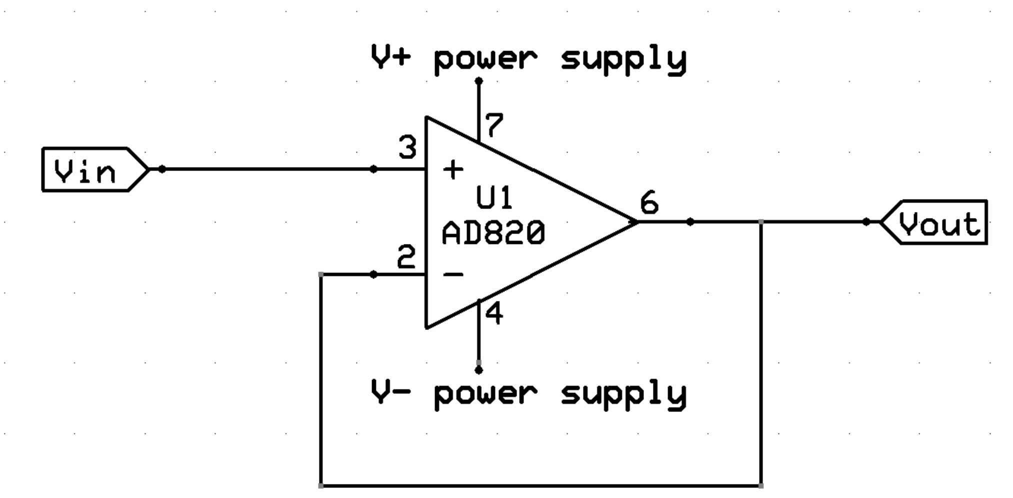
Connecting the input and output pins with resistors, we can manipulate the behavior of the output voltage.

The Op Amp Rules, Ohm's law, and Kirchhoff's Laws allow us to write a system of equations to figure out the specific resistor values we need.

You usually start with the general type of amplifying circuit needed, or just look up a standard design.

Signal Conditioning Circuit Example 1: Buffer

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



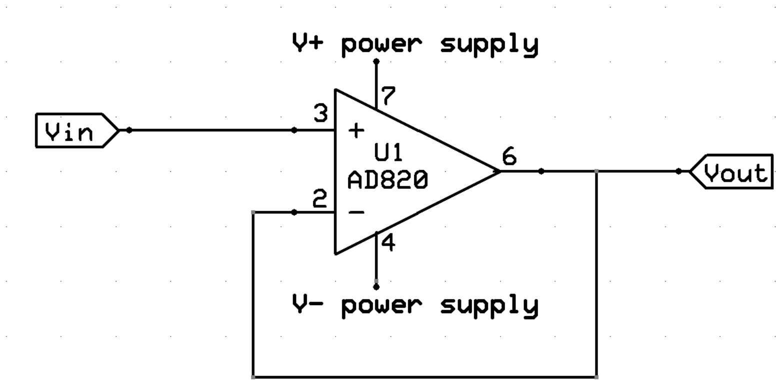
$V_{in}=V_+$
$V_+=V_-$ (Rule II)
$V_-=V_{out}$ (Directly Connected)

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 Vin could be used to drive a high-power output.



Gain of Buffer
Vin = Vout
Gain=1

Non-Inverting Amplifier Example

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

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

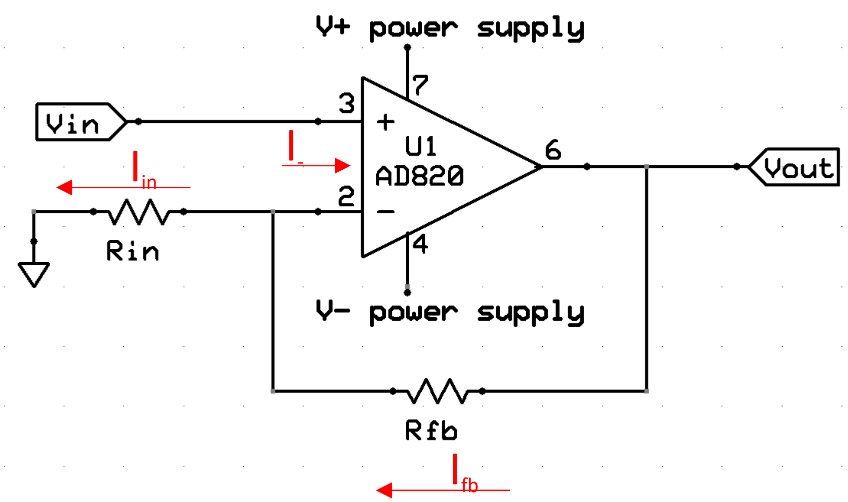
$I_-=0$ (Rule III)
$I_{in}=I_{fb}$ (KCL)

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:

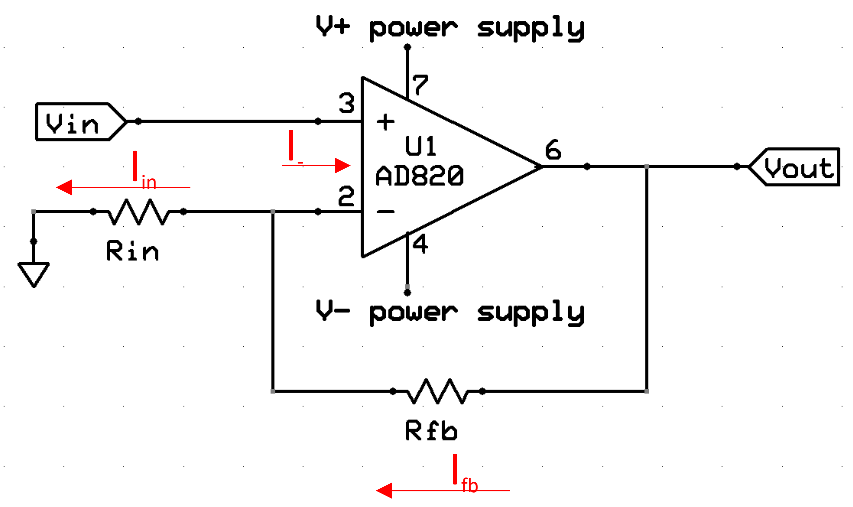
$$\frac{V_{out} - V_-}{R_{fb}} = \frac{V_- - 0V}{R_{in}}$$

Finally $V_{in} = V_-$

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

And solving for V_{out} gives us:

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



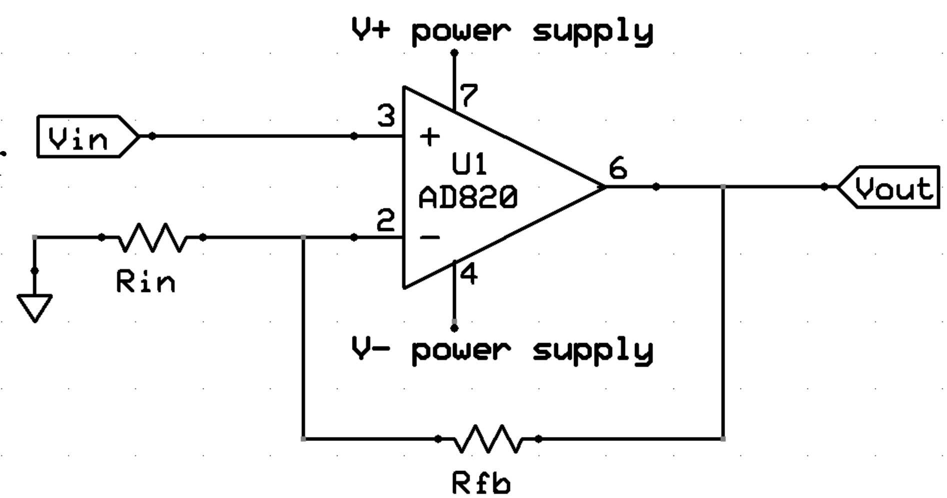
Non-Inverting Amplifier Usage

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

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

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

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



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

Gain > 0

Inverting Amplifier

Inverted op amps have Vin connected to the negative terminal.

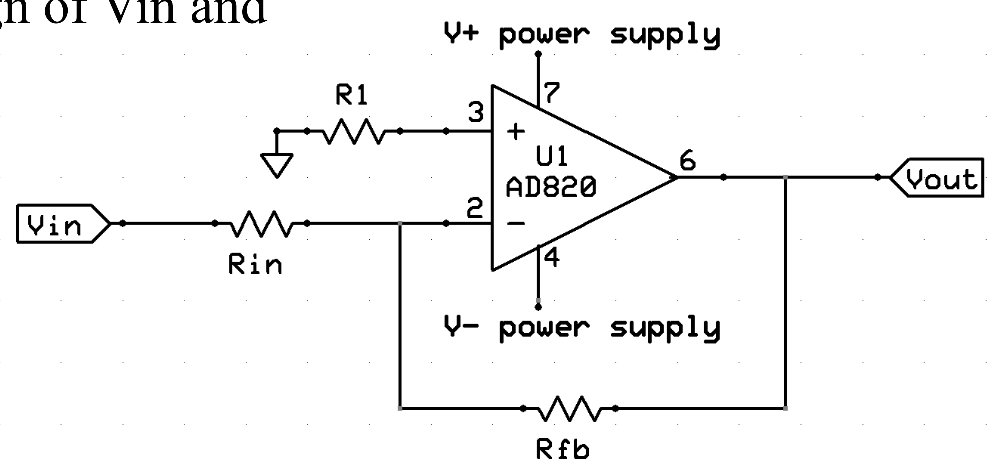
Signal is inverted over 0V.(flipped).

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

Note: the gain is negative so it is important to consider the sign of Vin and if Vs- is negative or zero

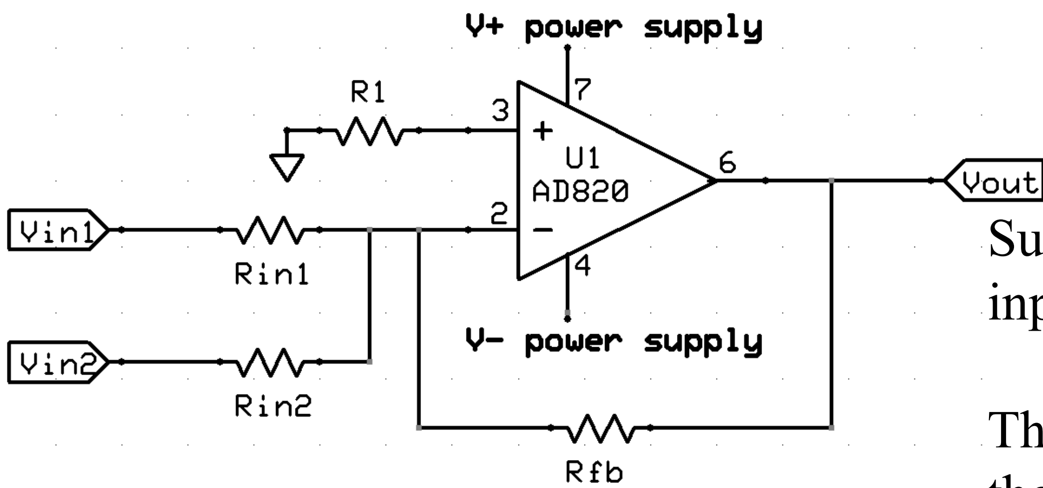
$$G = -\frac{R_{fb}}{R_{in}}$$

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.

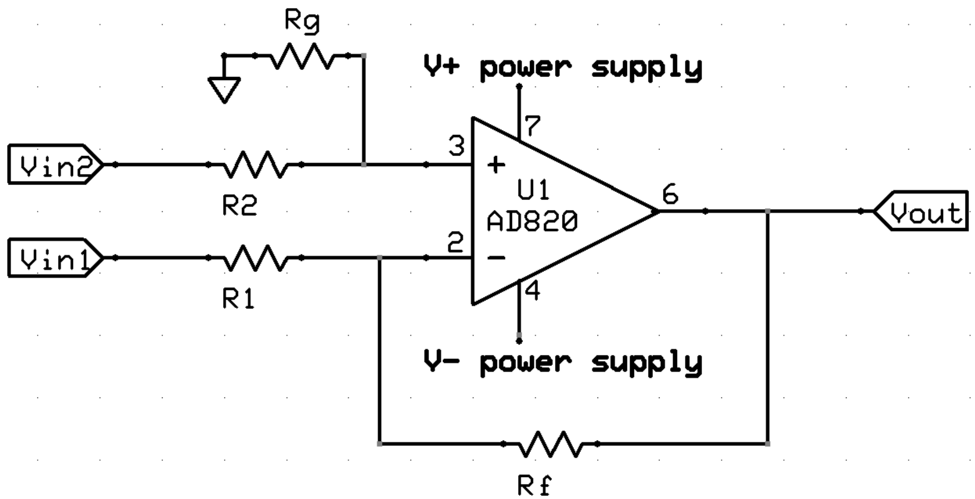
Can be inverting (shown here) or noninverting,

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.

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, which allows you to filter out undesirable signals (like quickly changing noise from radio)

- It is also common to send the output of one amplifier to the input of another to achieve the desired output

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 are not, in particular, the power pins are different