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Data Acquisition

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Sensors and Transducers

A **sensor** is a device that detects or measures a physical property and records, indicates, or otherwise responds to it.

A **transducer** is a material, substance, or device that converts the reaction from the active sensor into electrical signals

Often the sensor and transducer are integrated into a single unit – for example, a *thermistor's* resistance changes with temperature; it converts temperature into resistance.

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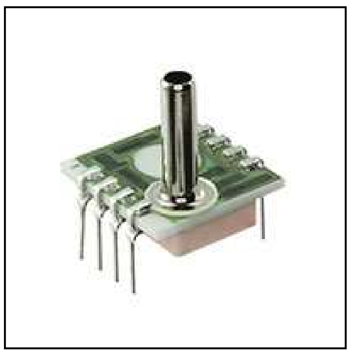
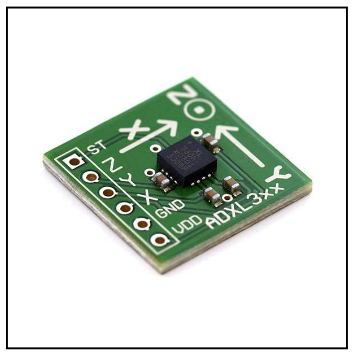
Sensor Inputs: Physical Variables

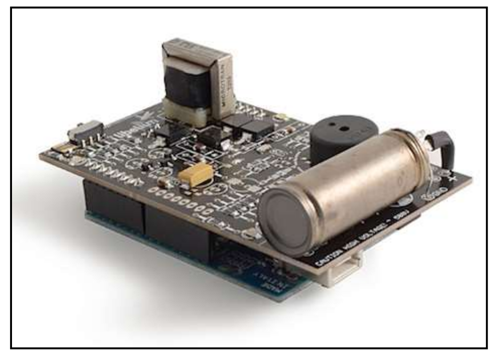
- Temperature
- Pressure
- Humidity
- Light Intensity
- Radioactivity
- Acceleration
- Altitude
- EMF strength
  - (Electromagnetic fields)



Pressure Sensor



Accelerometer



Geiger Counter

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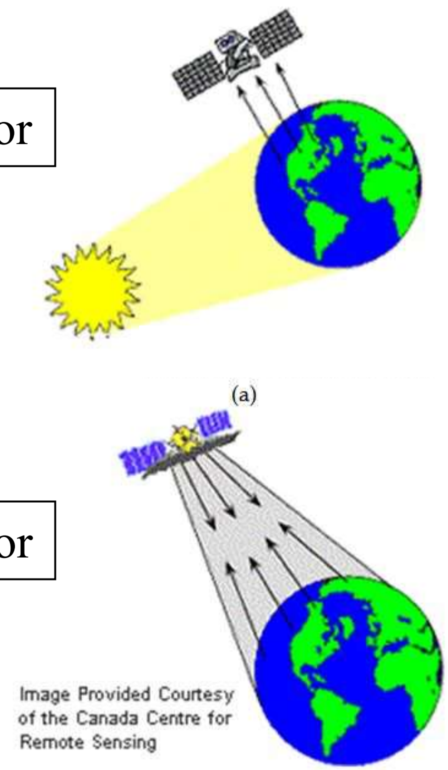
Sensor Classification

A **passive sensor** detects or responds to external stimuli from the environment

An active sensor emits a signal (light, sound, radio wave) and detects reflections or the environments reaction to the emitted signal

Passive Sensor

Active sensor



(a)

(b)

Electrical Signal Outputs

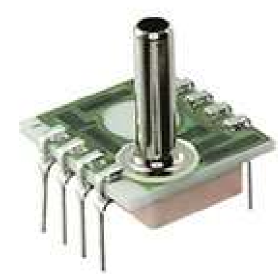
The output of a sensor will vary depending on the sensor in use. Most sensors will output electrical signals.

These signals can vary in:

- Voltage
- Current
- Pulse Amplitude & Width
- Frequency
- Signal Duration

Some sensors will output a digital signal that must be interpreted by another device such as a microcontroller or computer.

Ultrasound Transducer



Pressure Transducer

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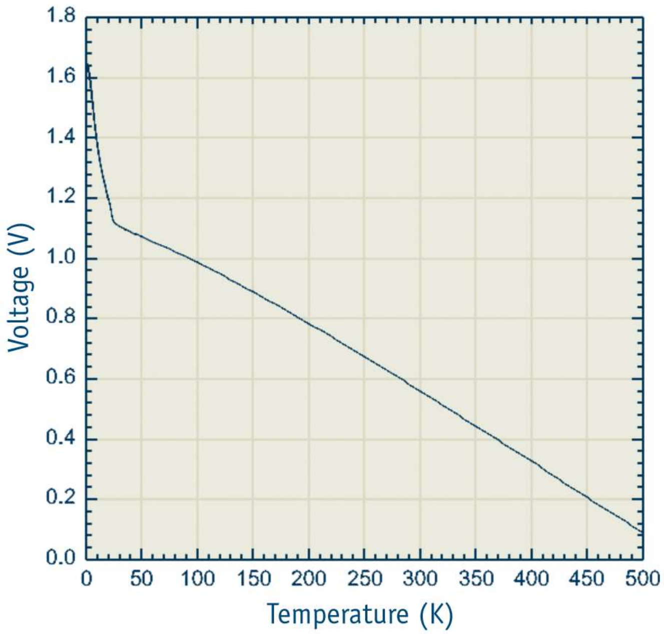
Temperature Sensors

1N457 Si Diode



There are a multitude of methods to measure temperature. It can be measured by thermistors (resistance varies with temperature), thermocouples (voltage varies with temperature), or semiconductor junction devices (current varies with temperature).

PN-junction diodes can be used to measure temperatures in the range of 20 – 500K. In this range, the forward voltage of the diode varies linearly with temperature. The forward voltage drops approximately -2.1 mV / K.

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Pressure Sensors

A conductive material called the *diaphragm* bows in or out depending on the atmospheric pressure being applied to it. This changes the distance and conductivity between it and a metal plate beneath it. A transducer reads this change in conductance as pressure. Note, temperature compensation is essential for proper pressure readings.

The MegaSat uses a pressure transducer that gauges *absolute* pressure (zero reading = perfect vacuum). It also has temperature compensation built in.

1230-015A-3L Pressure Transducer

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Humidity Sensors

How they work

The most common way humidity sensors work is by gauging how electricity jumps the air gap in a capacitor. All substances conduct electricity differently, and this includes dry vs humid air. The change in conductivity is interpreted as humidity.

MegaSat

The board uses a capacitive sensing element that is light sensitive so care must be taking to keep it out of the light.

HIH-4000-003 Humidity Sensor

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Acceleration and Orientation Sensors

There are multiple ways to make an accelerometer. The MegaSat has the simplest type. A semiflexible conductive mass spans a gap between two beams like a bridge. Underneath it lies a conductive plate. If an accelerative force causes the bridge to bend, then the capacitance between it and the plate will change. Circuitry converts this change to voltage for an acceleration reading.

A gyroscope is more complicated. The physics involved includes the conservation of angular momentum and the *Coriolis Effect.* The gyro used by the MegaSat gets it readings from the change in capacitance caused by the Coriolis Effect. Curious students may research *"vibratory MEMS rate gyroscope"* if they would like to know more.

SEN-11028 ROHS Accelerometer-Gyro combo

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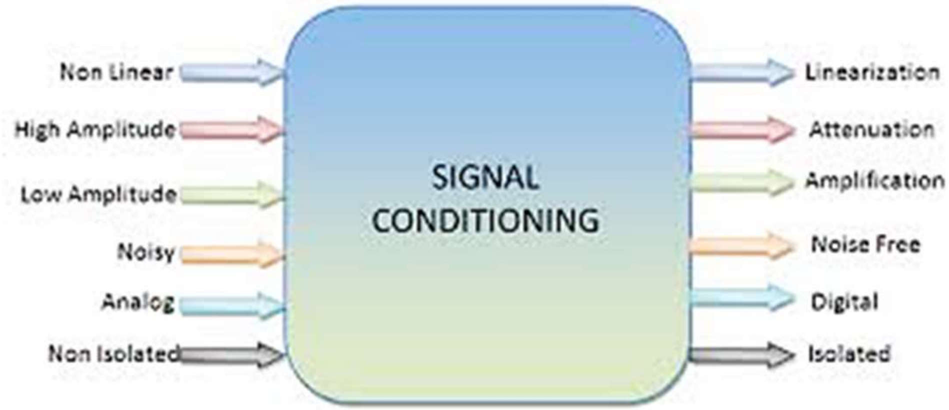
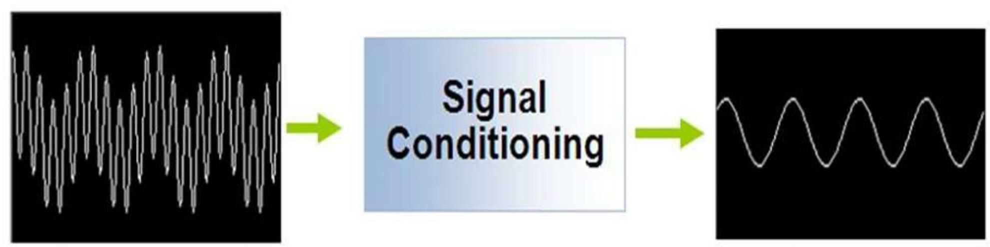
Signal Conditioning

Sensors output an electric signal, but many times the signal cannot be directly interpreted by humans or other electronics. This can be fixed with signal conditioning.

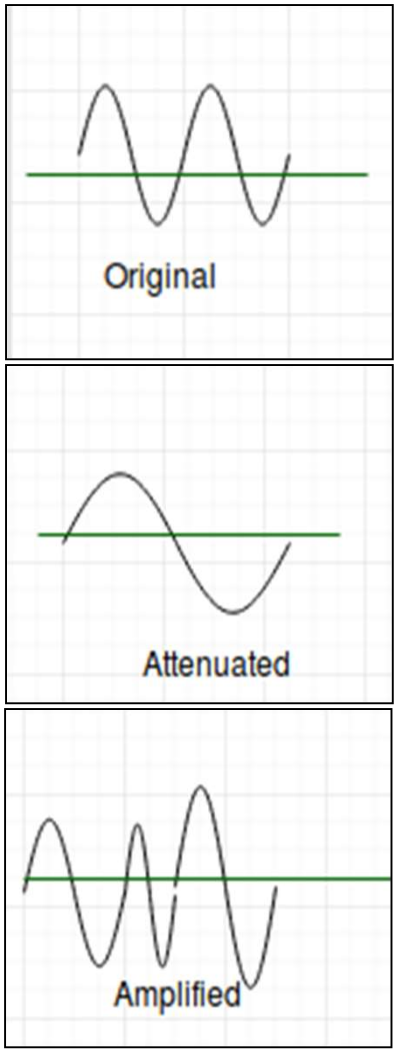




Noisy, raw signal from sensor

Filtered signal

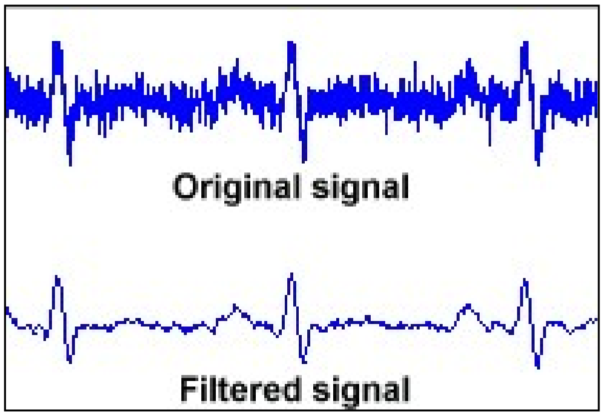
Amplification and Attenuation



When a signal is too weak to be interpreted correctly, the signal can be amplified. **Amplification** is the process of increasing the power of an electrical signal.

Sometimes, a signal is strong enough to damage equipment or other devices or exceed the desired thresholds. In such cases, it often useful to attenuate the signal. **Attenuation** is the process of reducing the power of an electrical sensor. Attenuation occurs naturally over long distances.

Electronic Filters



In the image above, the signal has had unwanted frequencies removed.

All sensors have noise in their outputs to some degree. **Noise** is undesired variations in electronic signals.

Electronic filters are circuits that remove unwanted noise from an applied signal and produce a cleaner signal. They may separate combined signals or restore distorted signals

Input and Output Impedance

Impedance is the resistance a circuit has to current flow when voltage is applied. Resistance is a component of impedance. The impendence of various components in a circuit will vary. Often, it is most useful to measure the input and output impendence of a circuit.

Input impedance is the equivalent impedance of the circuit when viewed from the input of the circuit. Similarly, **output impedance** is the equivalent impedance of a circuit when viewed from the output of the circuit.

Input and output impedance can be measured or calculated.

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Impedance Matching

An **impedance mismatch** is when the input impedance and output impedance of two connected electronics differ. Impedance mismatches introduce additional noise and power loss to the system through signal reflections and other phenomenon.

Impedance matching is the practice of designing the input or output impedance of a circuit to match its corresponding signal source or load. This is often done to maximize power transfer or minimize signal reflections.

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Level Shifting

Many digital electronics communicate on different logic voltages. For example, the Arduino Mega digital pins communicates with +5V, while the Raspberry Pi communicates with +3.3V. It is possible for a Raspberry Pi to communicate with a Mega through level shifting.

Level Shifting is the conversion of logic signals from one voltage level to another. It converts the "HIGH" voltage level of the input to a different voltage. In the example above, a level shifter would change the 3.3V logic to 5V logic or vice versa.

Span and Base Adjustment

Example:

Temperature sensor:

450 mV to 800 mV

BASE = 450 mV, ***SPAN*** = 350 mV

Signal Conditioning Output:

0V to 3V (to match ADC)

BASE = 0V, ***SPAN*** = 3V

Span refers to the voltage *span* of the device. Base refers to the lowest voltage of the device.

If the span of two components do not match than the signal could be lost.

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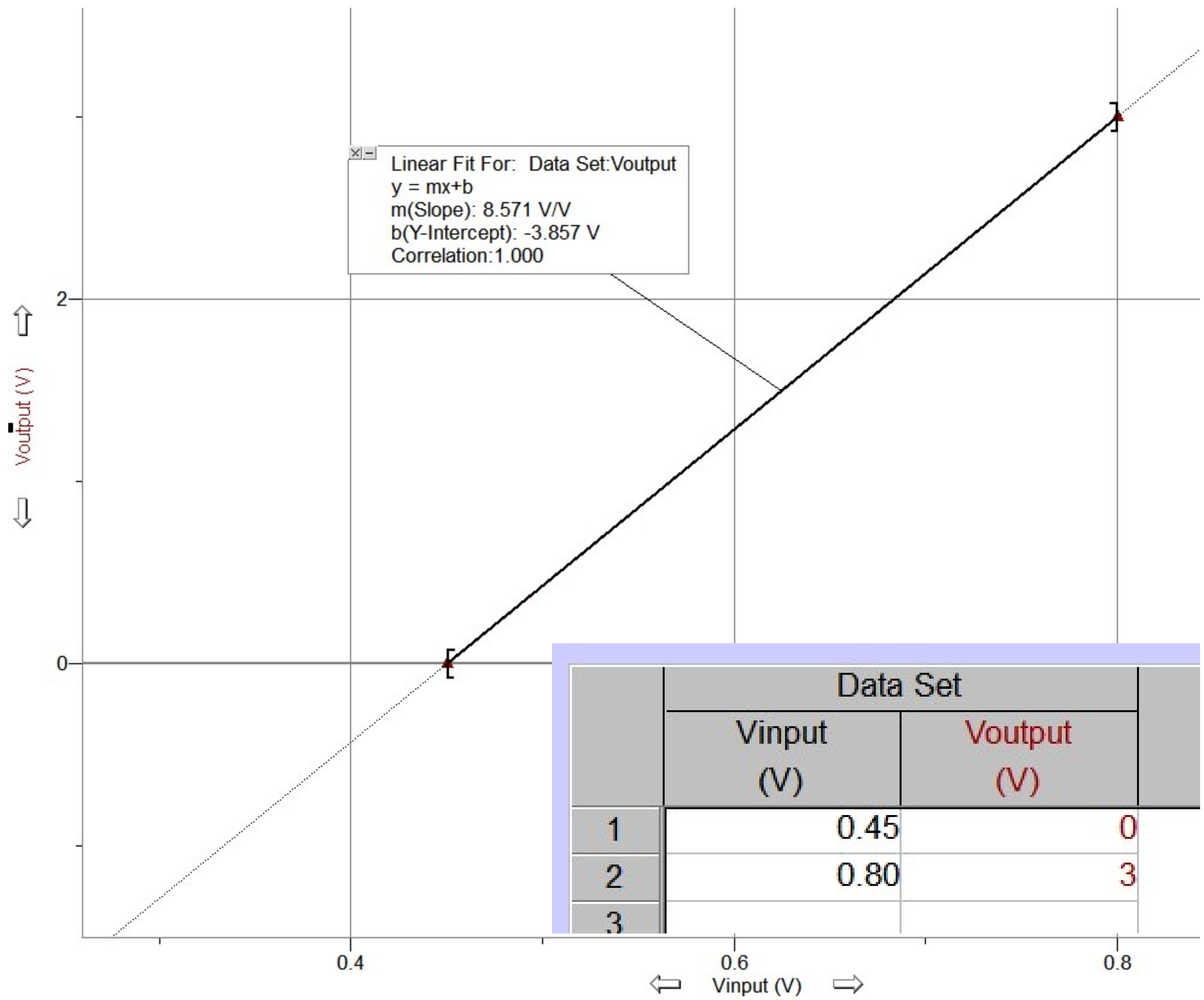
Span and Base



	Data Set	
	Vinput (V)	Voutput (V)
1	0.45	0
2	0.80	3
3		

Gain = 8.571

Offset = -3.857

Design and Build a circuit that performs this transfer function.

What do we need?

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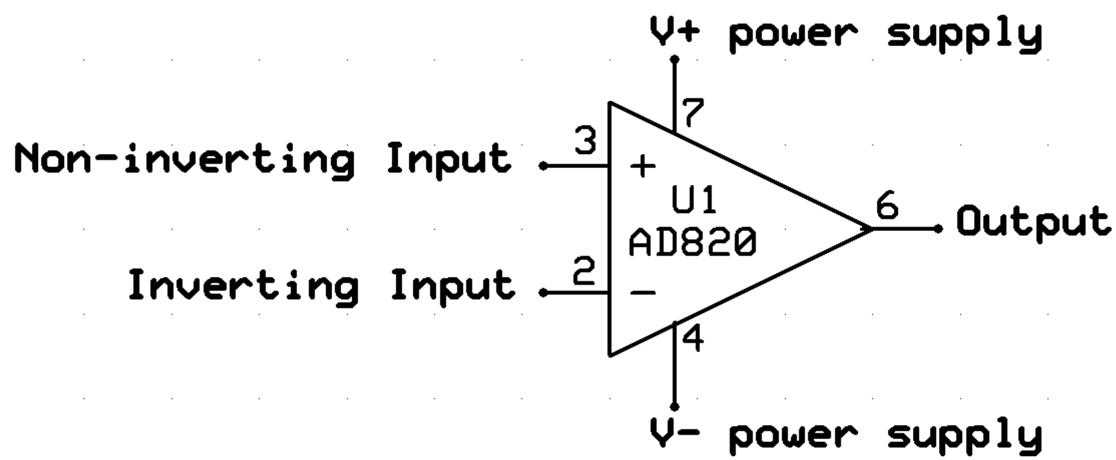
Signal Conditioning Circuit

Operational Amplifier or "Op amp"

An op amp takes 2 input signals and outputs 1



Ideal Op amp Parameters:

▪Input Z = ∞ ▪Out Z = 0

▪Gain = ∞ ▪BW = ∞ ▪Vos = 0

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Op Amp Golden Rules

I. **The output attempts to do whatever is necessary to make the voltage difference between both inputs zero.**

II. **The inputs draw no current.**

The output influences the input pins via the external **feedback** network. Use the **Rules** and **Ohm's Law** to analyze or synthesize opamp circuits.

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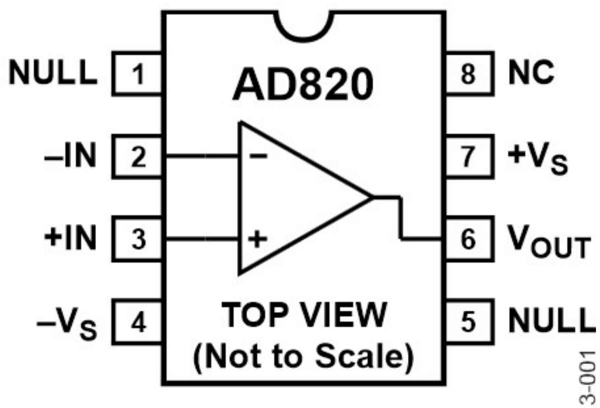
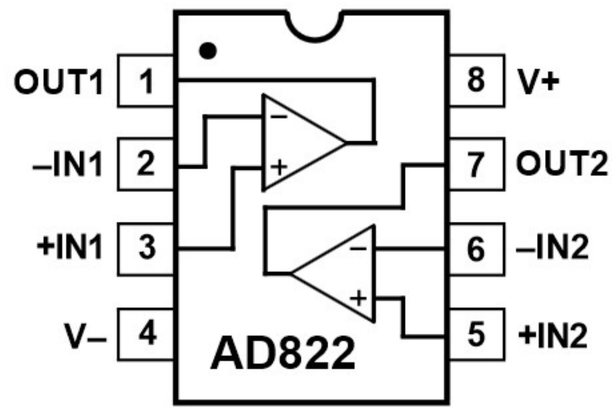
Operational Amplifier

Available in Single, Dual and Quad Packages
Bipolar power supply (typ. +/- 12V)
Single supply operation (typ. +12V, GND)

V- < Vout < V+





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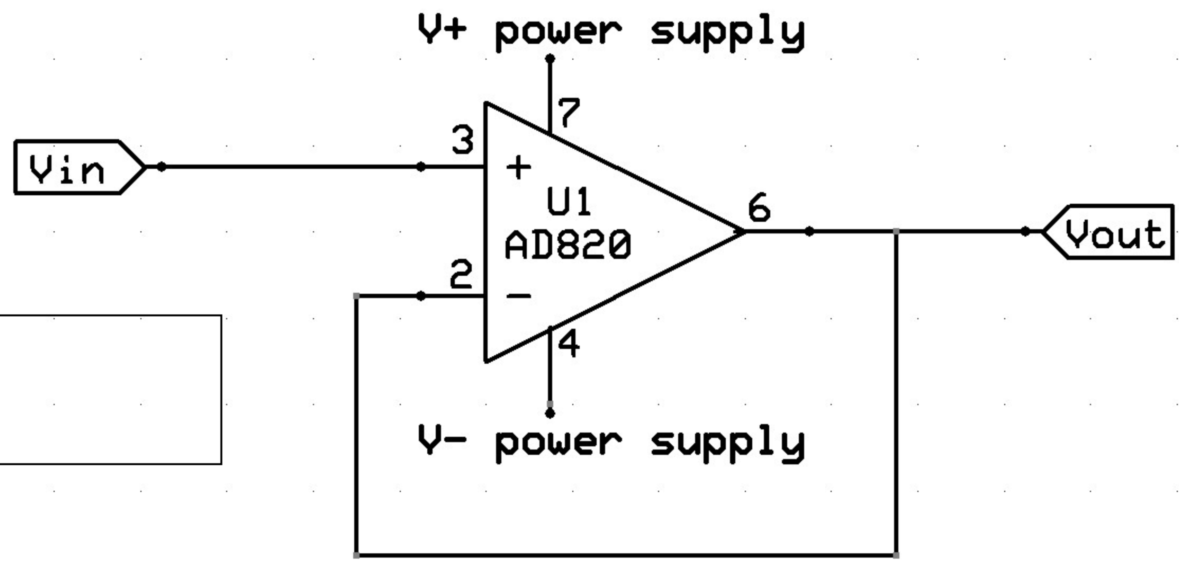
Signal Conditioning Circuit

Buffer

A buffer provides voltage or current impedance between to components to prevent the signal from affecting the performance of a component.



Gain Buffer
Vin = Vout

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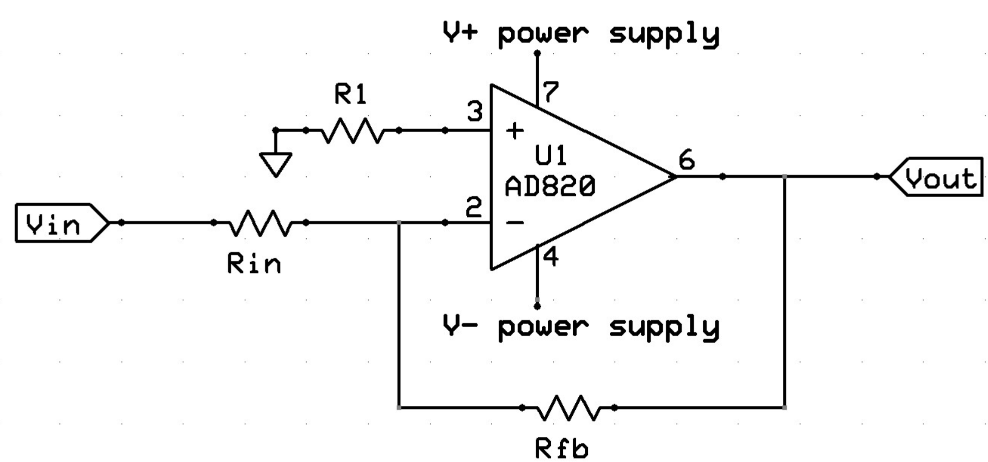
Signal Conditioning Circuit

Inverting Amplifier

Inverted op amps have Vin connected to the negative terminal. This is useful for converting a smaller sensor signal into a much larger voltage.

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



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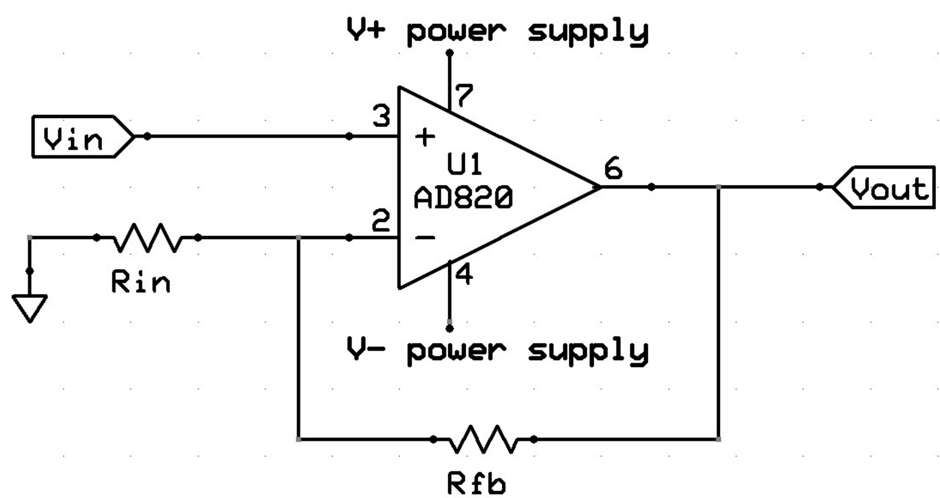
Signal Conditioning Circuit

Non-Inverting Amplifier

Non-inverted op amps have Vin connected to the positive terminal. This is commonly used in electronics to isolated circuits from each other.

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



Signal Conditioning Circuit

Summing Amplifier

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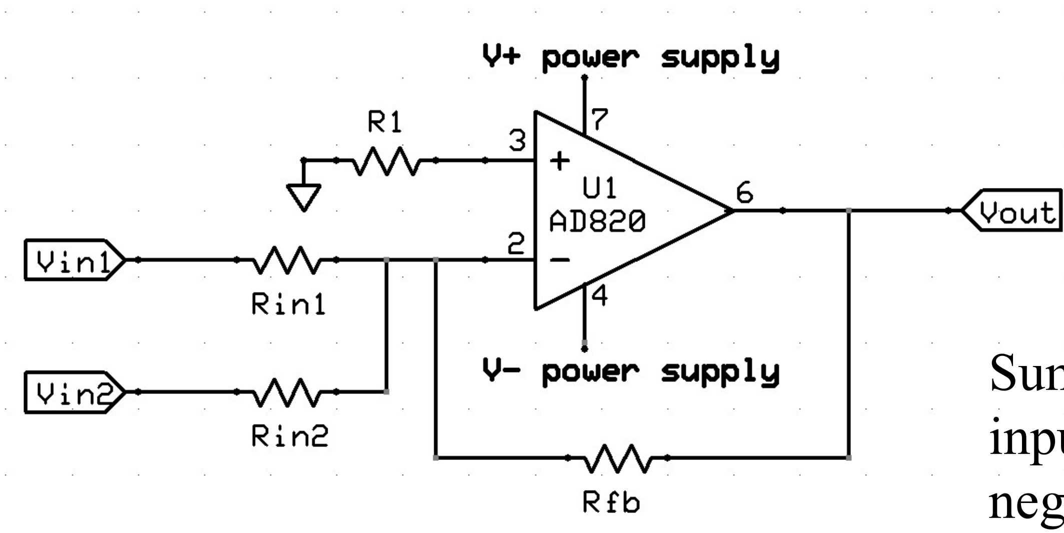
$$V_{out} = -[V_{in1}\frac{R_{fb}}{R_{in1}} + V_{in2}\frac{R_{fb}}{R_{in2}}]$$



Summing op amps have multiple inputs are connected into the negative terminal

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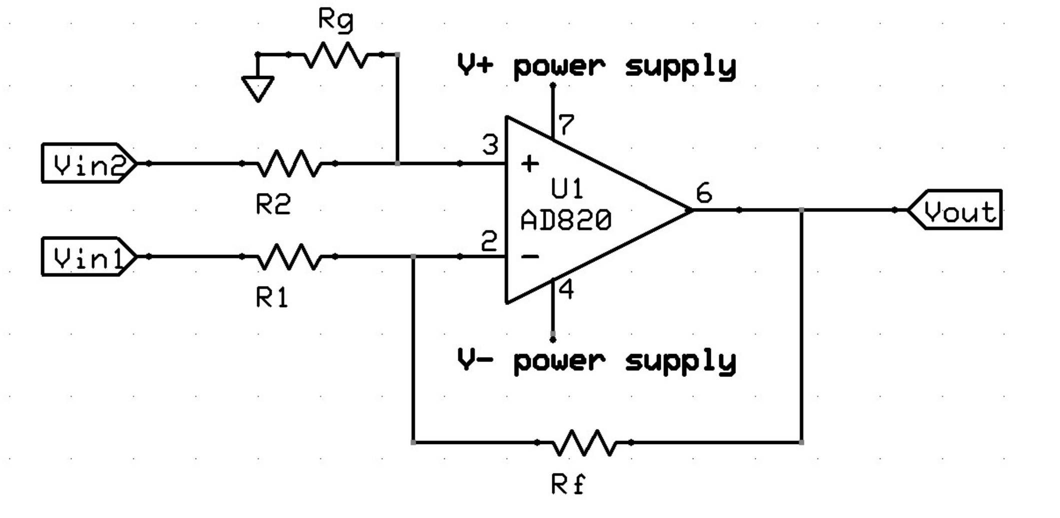
Signal Conditioning Circuit

Difference Amplifier

$$V_{out} = (V_{in2} - V_{in1})\left(\frac{Rf}{R1}\right) \quad \textbf{if} \; \frac{Rf}{R1} = \frac{Rg}{R2}$$



A difference op amp has an input into both the negative and positive terminals.

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Data Acquisition Flow