CE 432 Robotics II

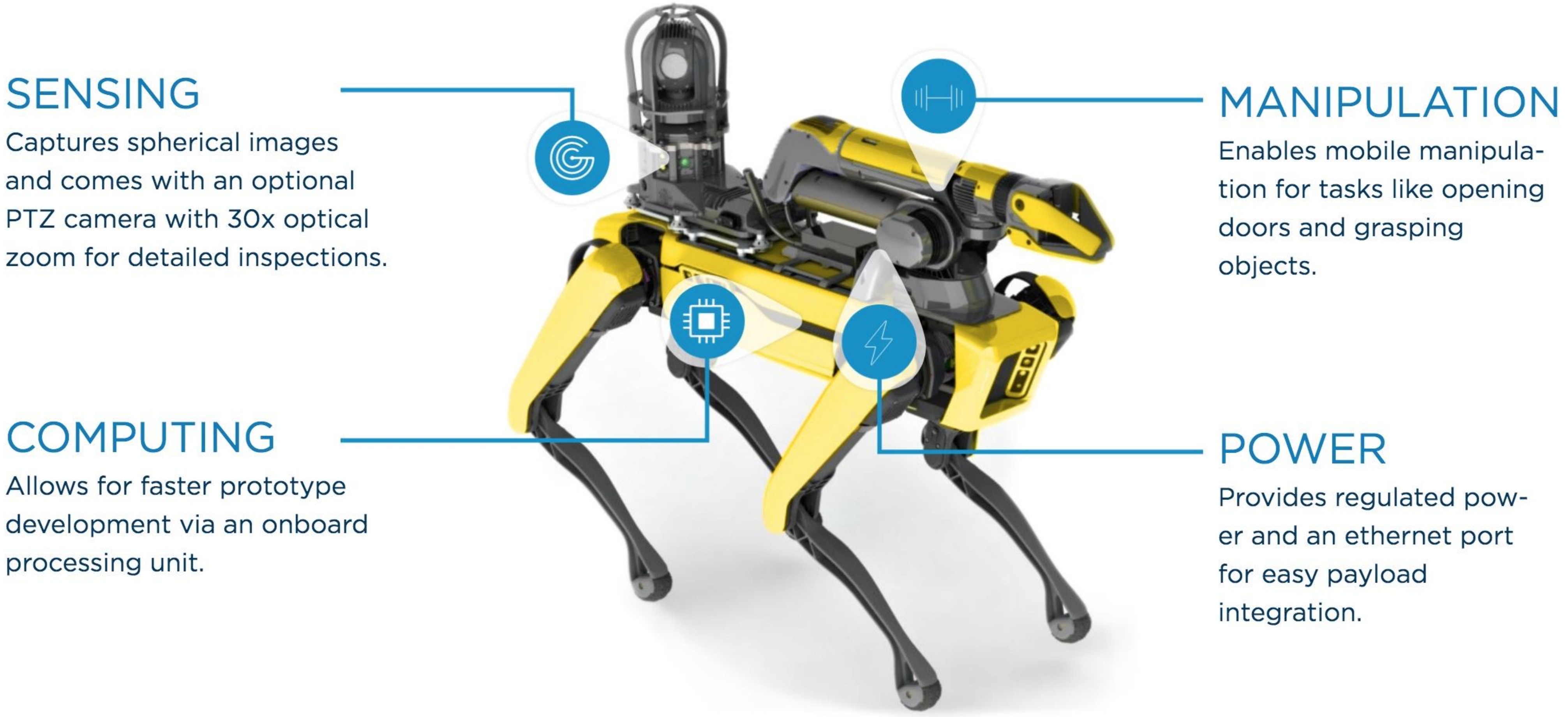
Sensors/Transducers and Actuators

Yiyan Li

Computer Engineering

Fort Lewis College

The Boston Dynamics Spot is now on sale. How much is it?



Sensors and Actuators

Common Sensors/Transducers and Actuators

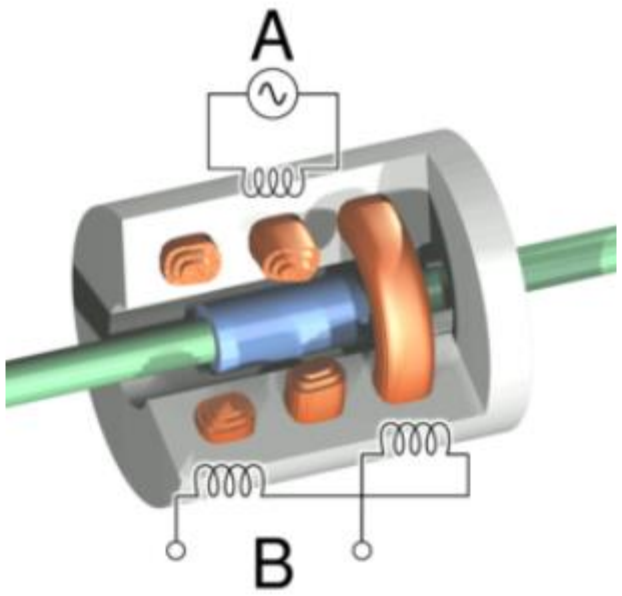
Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependent Resistor (LDR) Photodiode Photo-transistor Solar Cell	Lights & Lamps LED’s & Displays Fibre Optics
Temperature	Thermocouple Thermistor Thermostat Resistive Temperature Detectors	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Position	Potentiometer Encoders Reflective/Slotted Opto-switch LVDT	Motor Solenoid Panel Meters
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker

Active Sensors
Require an external power supply to operate, called an *excitation signal* which is used by the sensor to produce the output signal.

Passive Sensors
Does not need any additional power source or excitation voltage. Instead a passive sensor generates an output signal in response to some external stimulus.

LVDTs (Displacement, Position, Active)



Cutaway view of an LVDT. Current is driven through the primary coil at A, causing an induction current to be generated through the secondary coils at B.

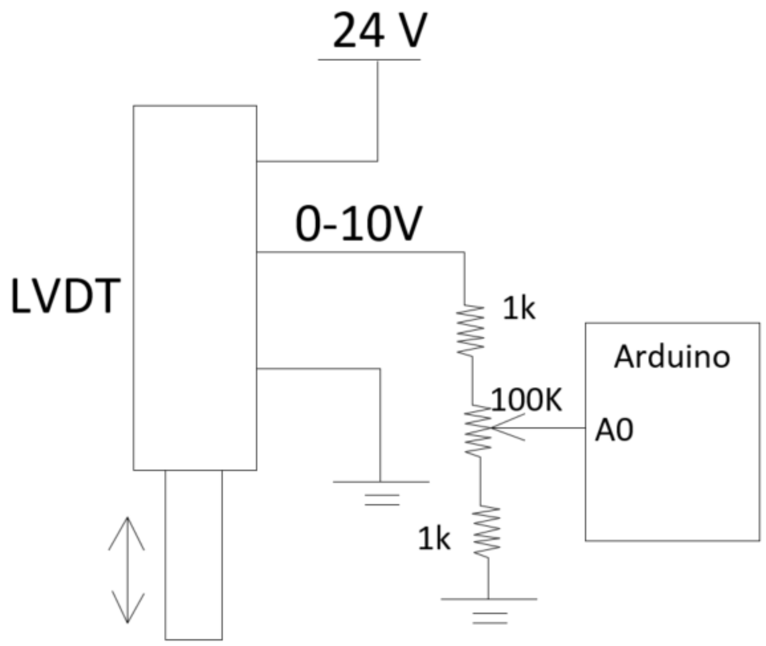
The **linear variable differential transformer (LVDT)** (also called linear variable displacement transformer, linear variable displacement transducer, or simply differential transformer) is a type of electrical transformer used for measuring linear displacement (position). A counterpart to this device that is used for measuring rotary displacement is called a rotary variable differential transformer (RVDT).

How it works:
An alternating current drives the primary and causes a voltage to be induced in each secondary proportional to the length of the core linking to the secondary. As the core moves, the primary's linkage to the two secondary coils changes and causes the induced voltages to change.

Advantages of LVDTs

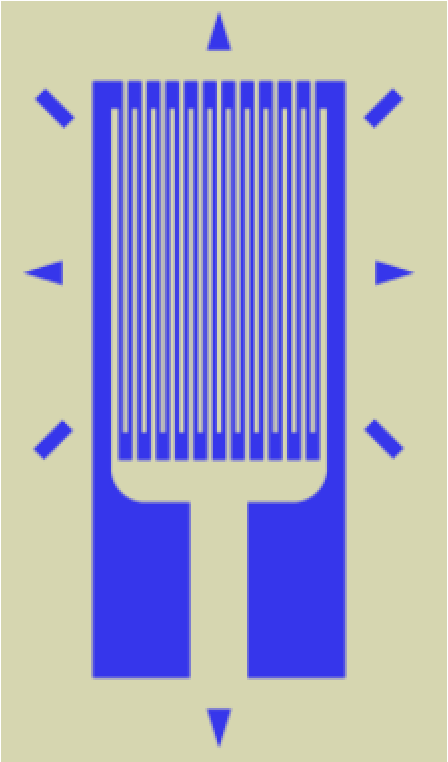
- LVDTs are robust, absolute linear position/displacement transducers;
- Inherently frictionless, they have a virtually infinite cycle life when properly used.
- As AC operated LVDTs do not contain any electronics, they can be designed to operate at cryogenic temperatures or up to 1200 °F (650 °C), in harsh environments, and under high vibration and shock levels.
- LVDTs have been widely used in applications such as power turbines, hydraulics, automation, aircraft, satellites, nuclear reactors, and many others.
- These transducers have low hysteresis and excellent repeatability.

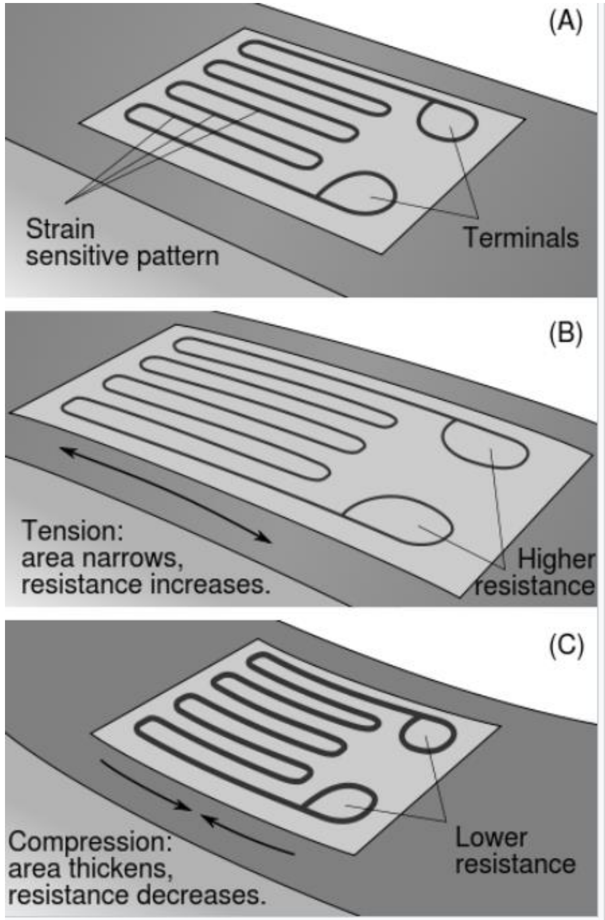
How to use LVDTs



1. Pull the core to the maximum and adjust the potentiometer to get you the 1023 digital output on the serial monitor.
2. Find the displacement range from the datasheet of the LVDT, for example, 0 – 10 cm, your digital output is 0 – 1023, so the resolution will be 10 cm / 1024 = 97.66 um.

Strain Gauges (Forces, Active)

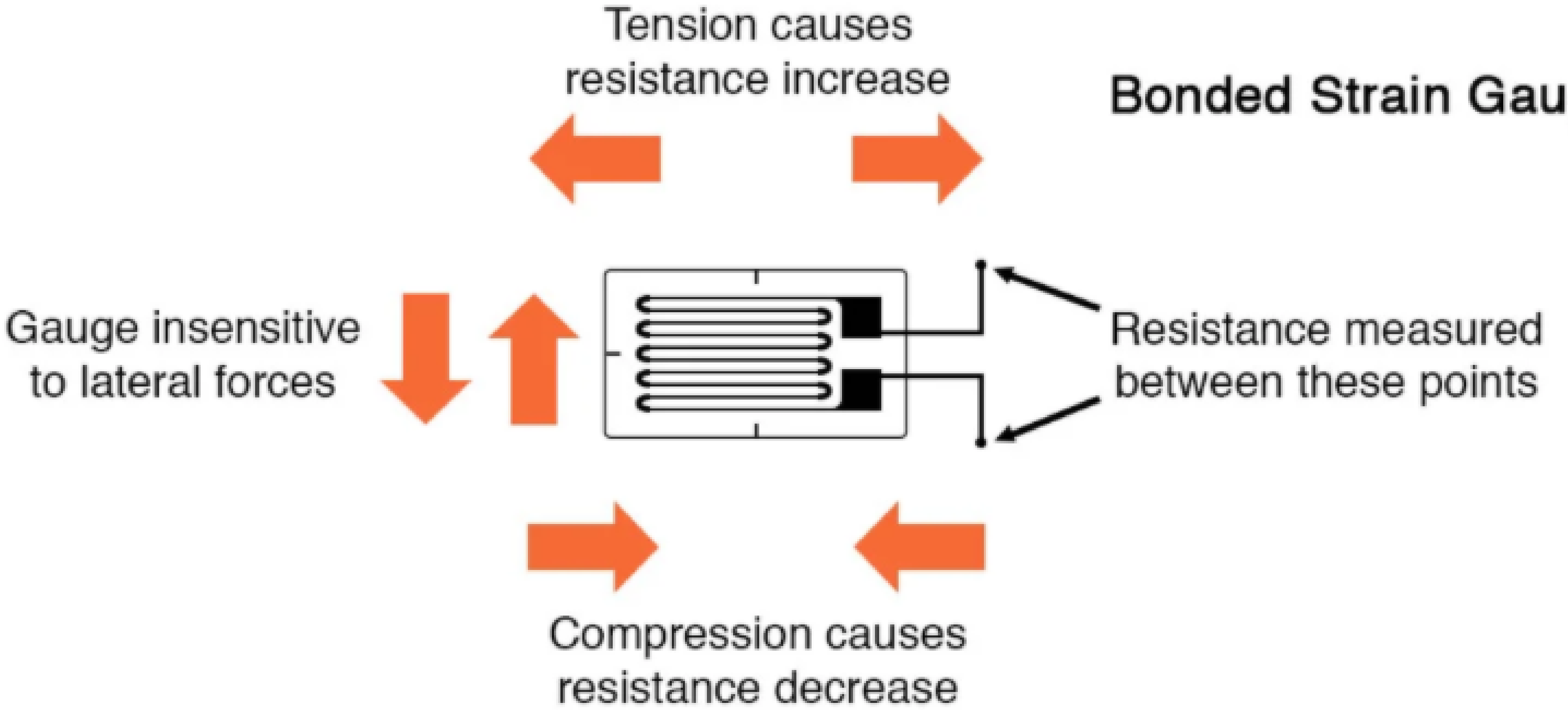




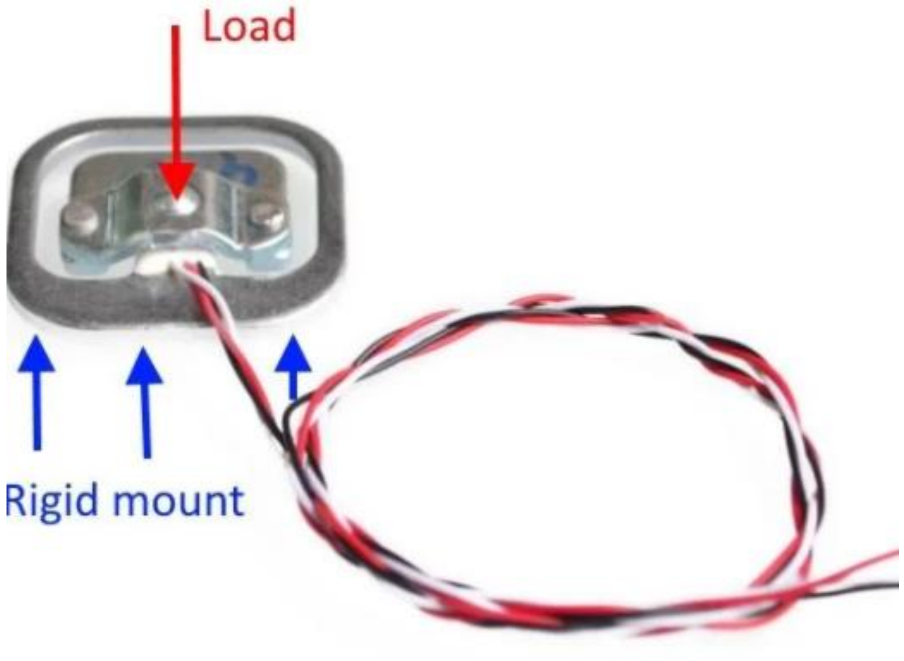
A strain gauge (also spelled strain gage) is a device used to measure strain on an object. Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a **Wheatstone bridge**, is related to the strain by the quantity known as the gauge factor.

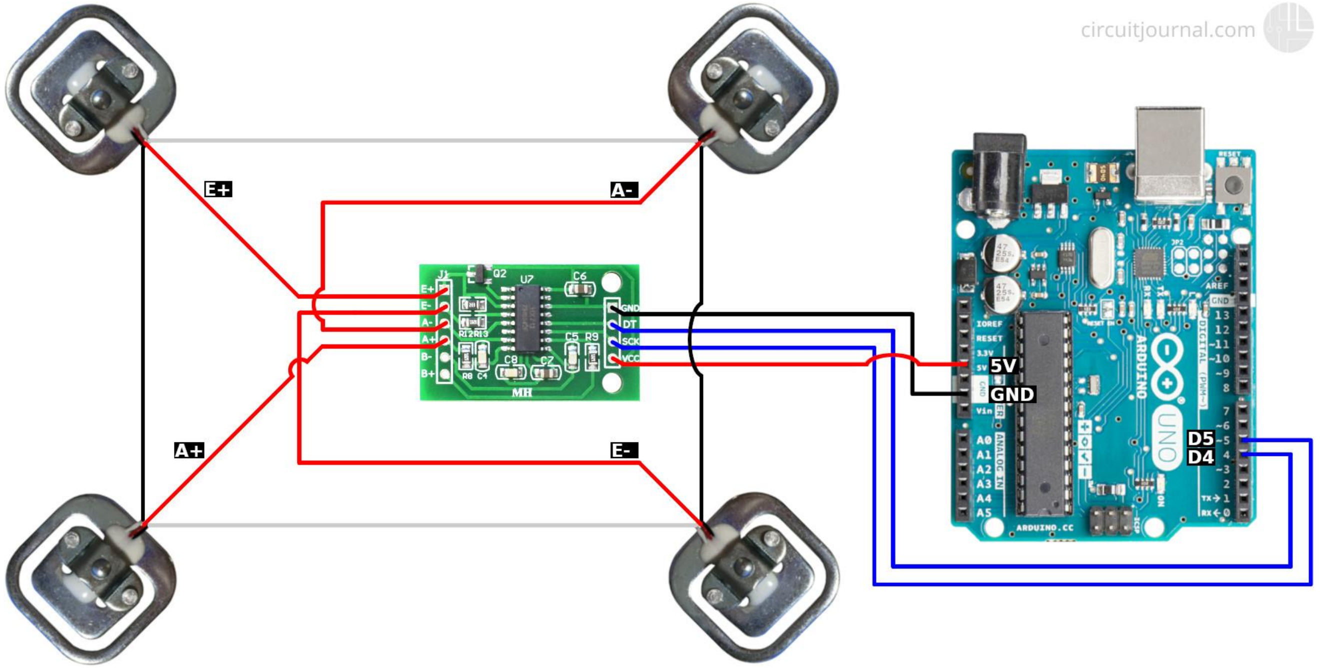
Typical foil strain gauge; the blue region is conductive and resistance is measured from one large blue pad to the other. The gauge is far more sensitive to strain in the vertical direction than in the horizontal direction. The markings outside the active area help to align the gauge during installation.

Bonded Strain Gauge

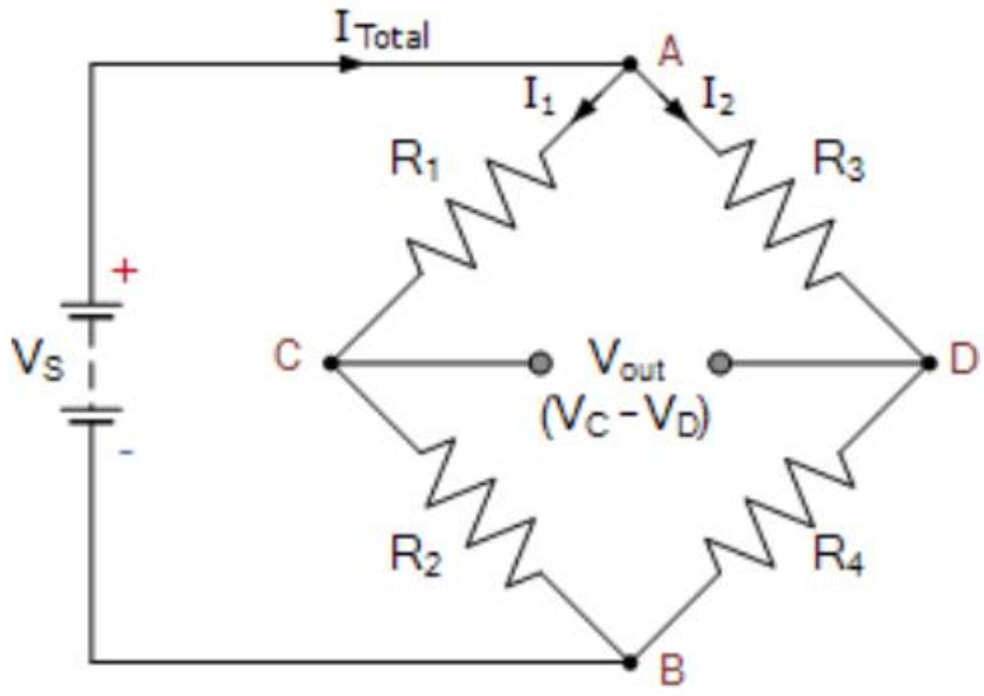


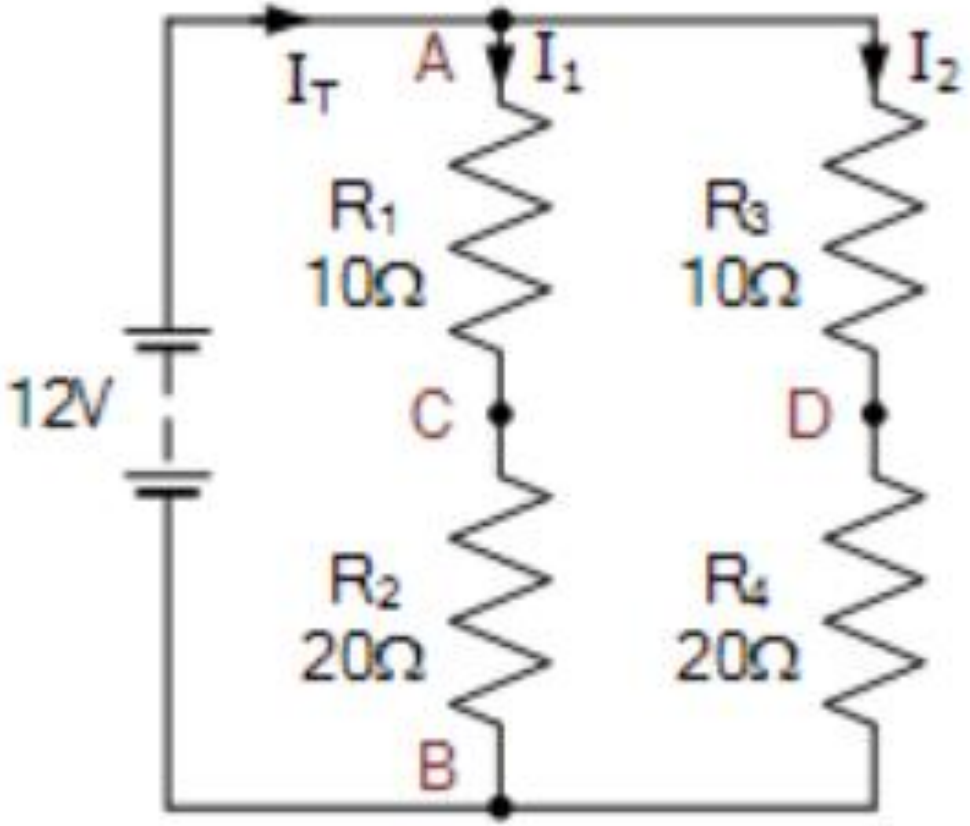
Load Cells for the strain gauge



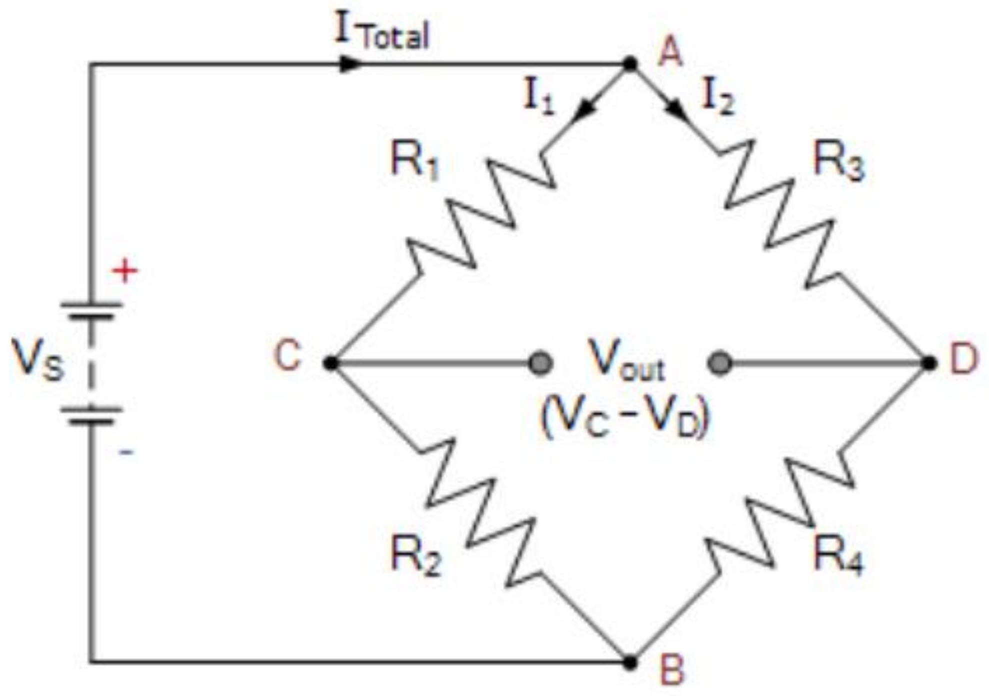


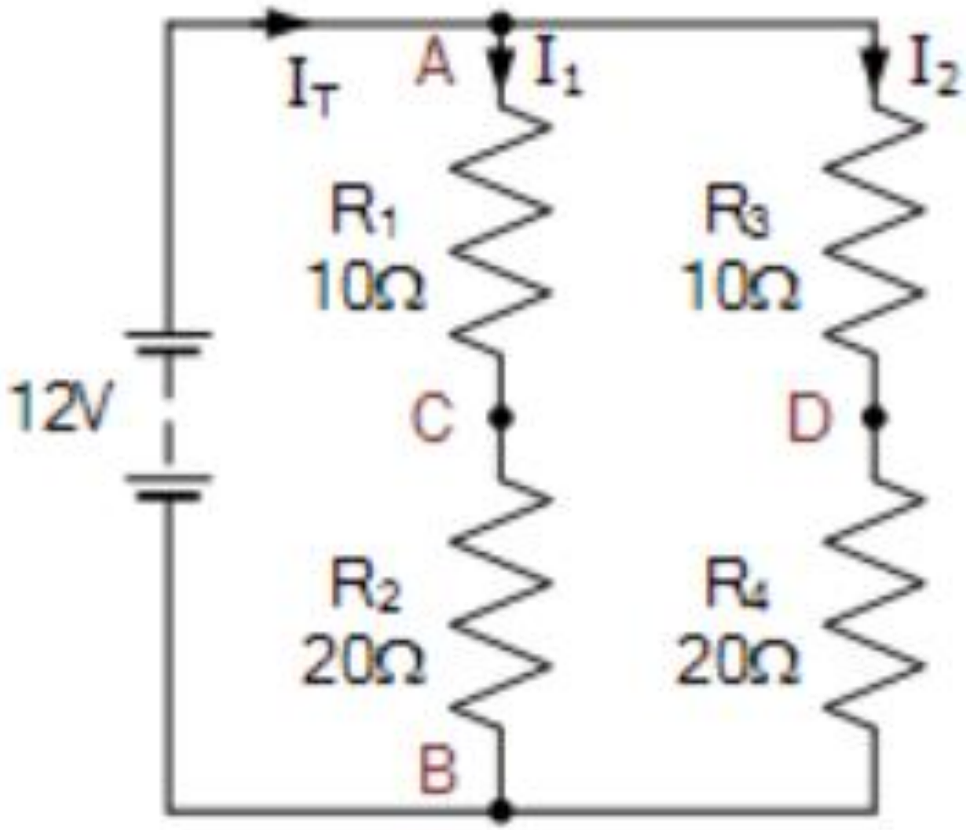
The Wheatstone Bridge





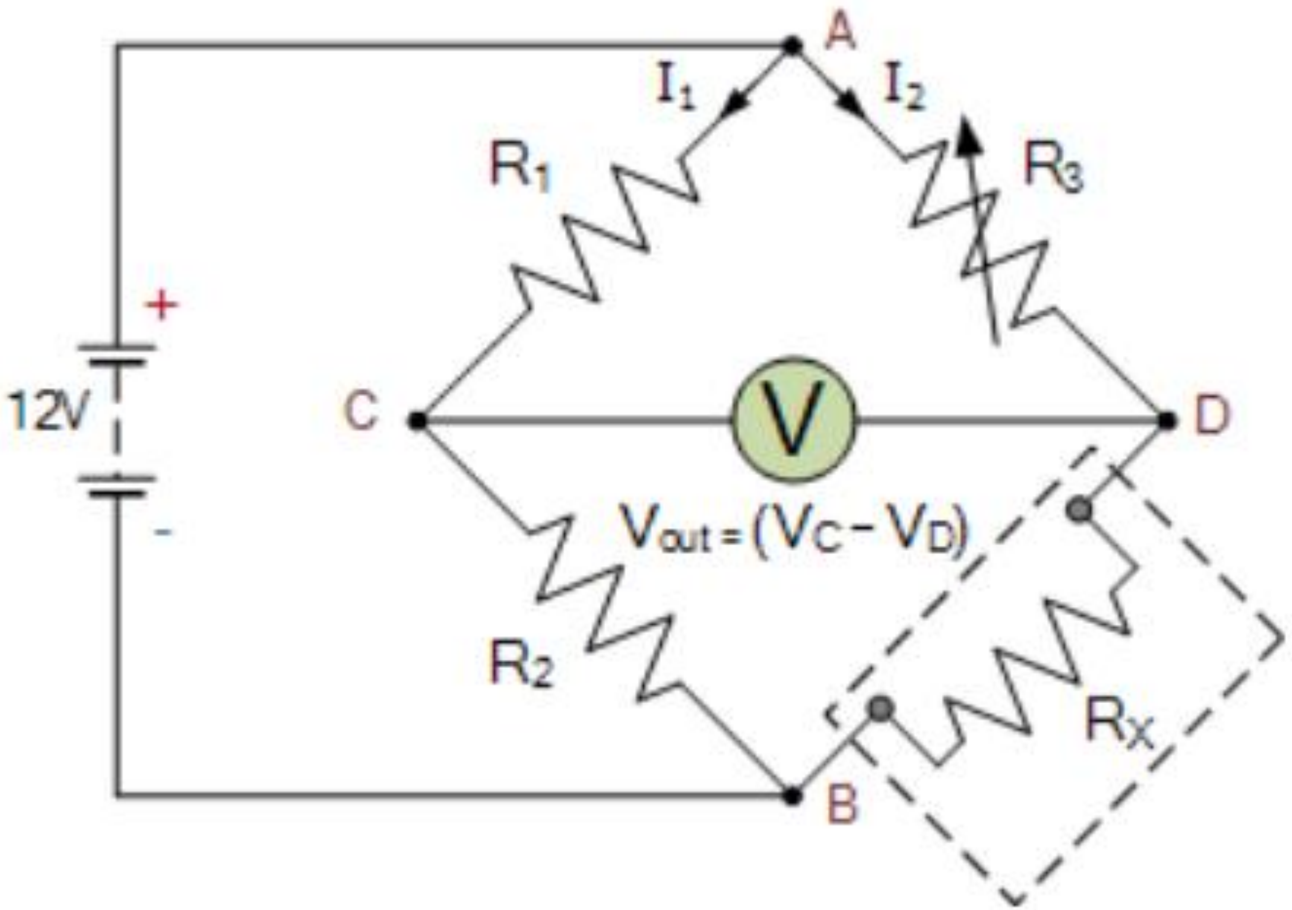
The Wheatstone Bridge





VC – VD = 0 V, the bridge is balanced

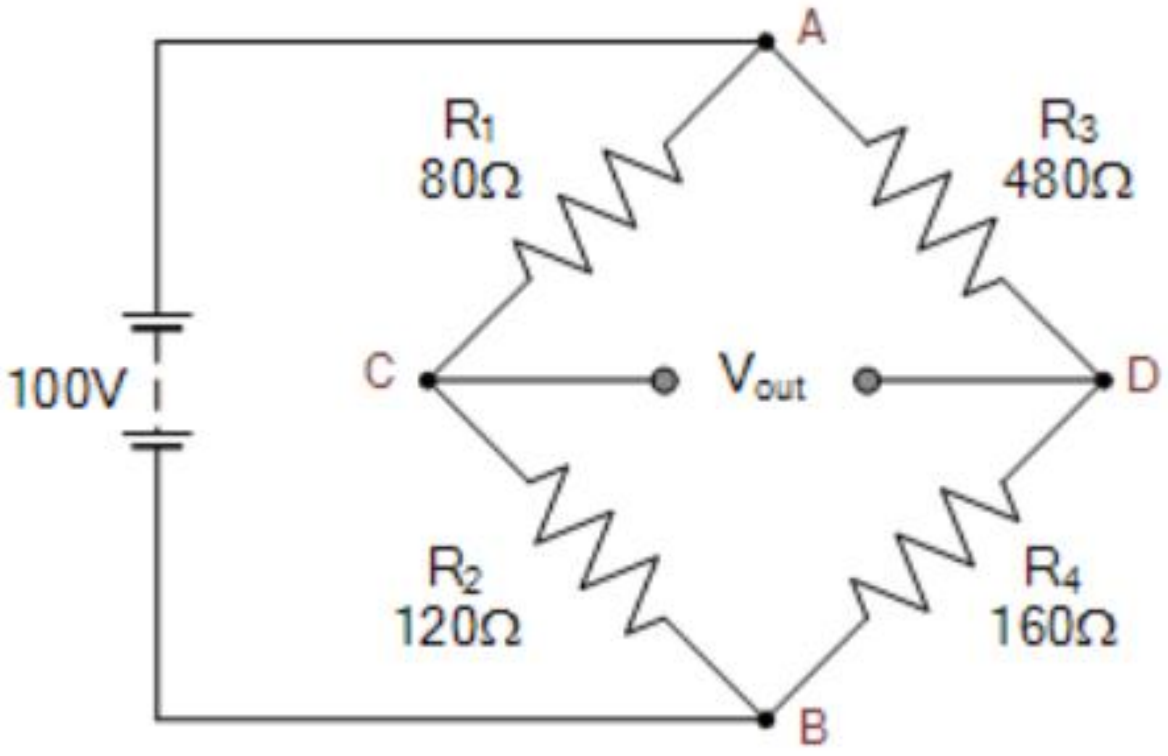
The Wheatstone Bridge



$$\frac{R_1}{R_2} = \frac{R_3}{R_x} = 1 \text{ (Balanced)}$$

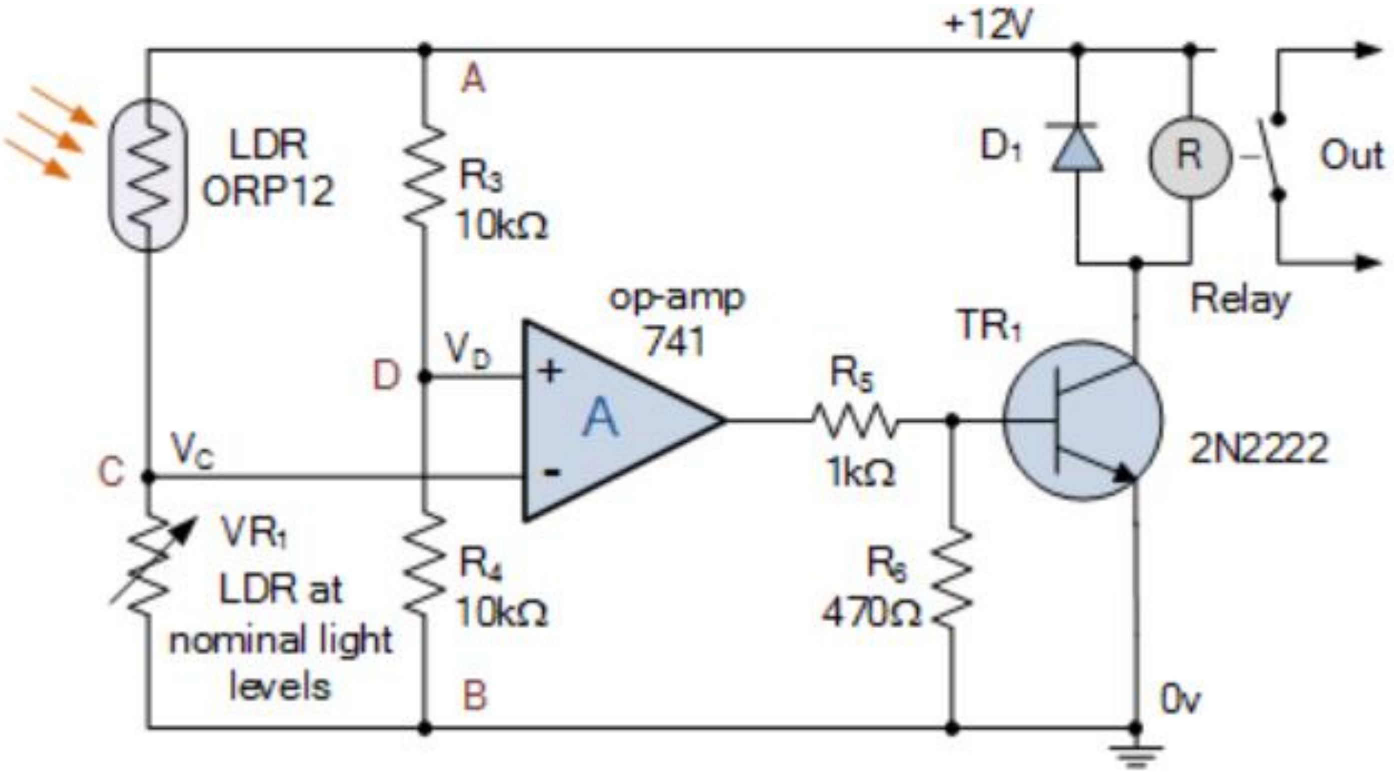
R1, R2, and R3 are known, so you can calculate for Rx.

The Wheatstone Bridge

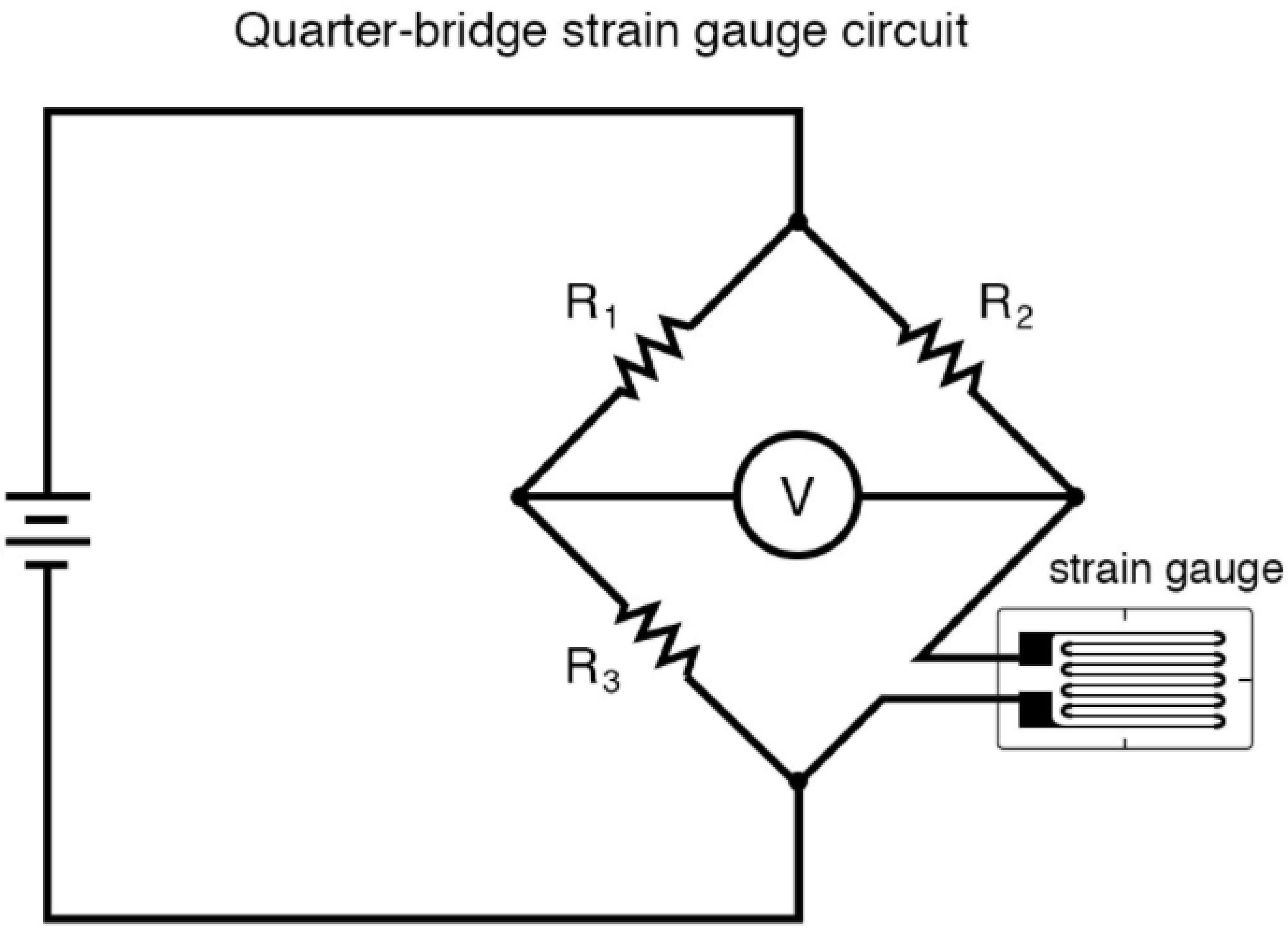


Example:
What resistance do you need for R4 to balance the bridge?

The Wheatstone Bridge

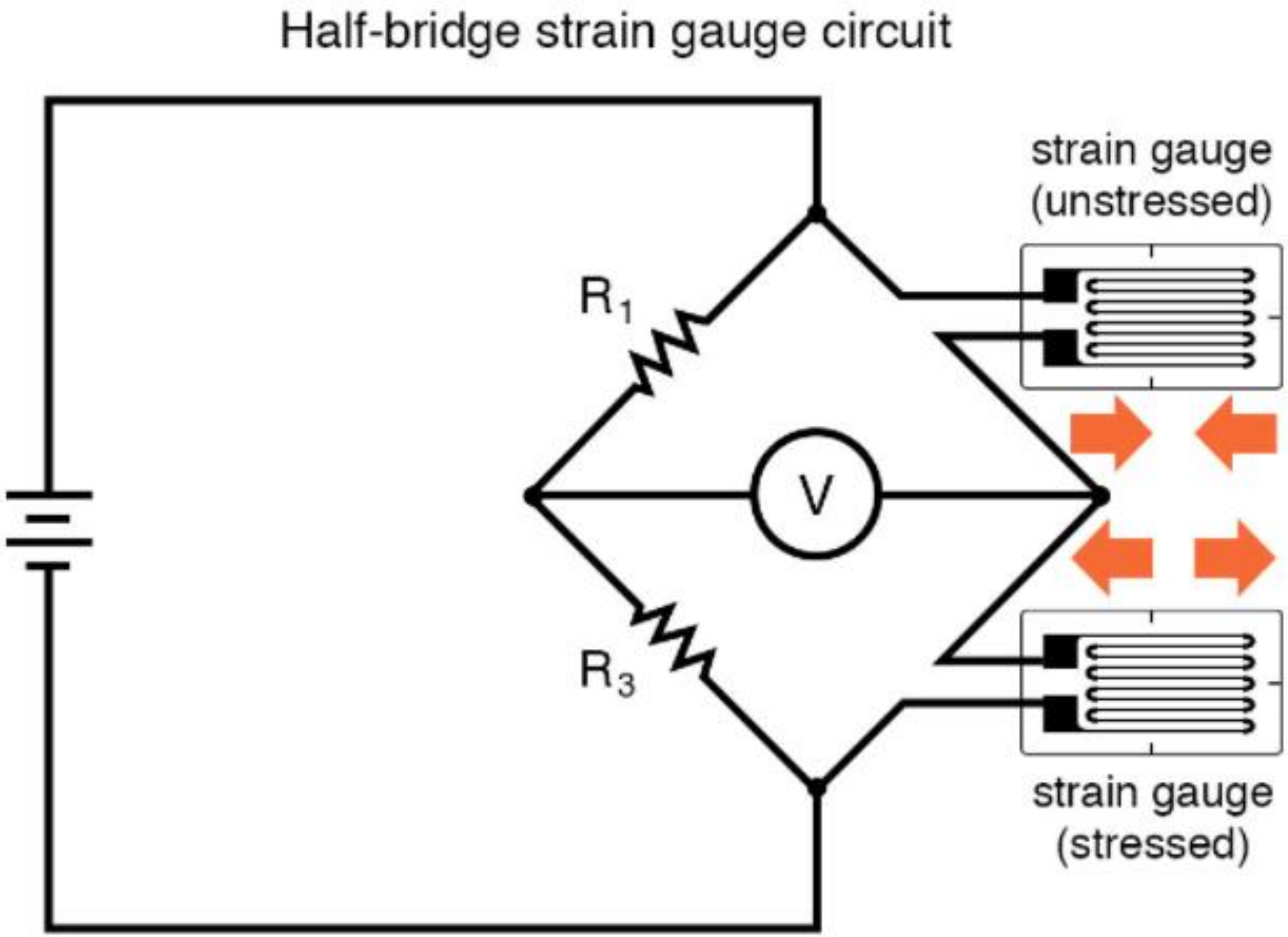


- Interpret the operation of this circuit.
- Is this a Darkness Detector or a Light Detector?



Typically, the rheostat arm of the bridge (R2 in the diagram) is set at a value equal to the strain gauge resistance with no force applied. The two ratio arms of the bridge (R1 and R3) are set equal to each other. Thus, with no force applied to the strain gauge, the bridge will be symmetrically balanced and the voltmeter will indicate zero volts, representing zero force on the strain gauge.

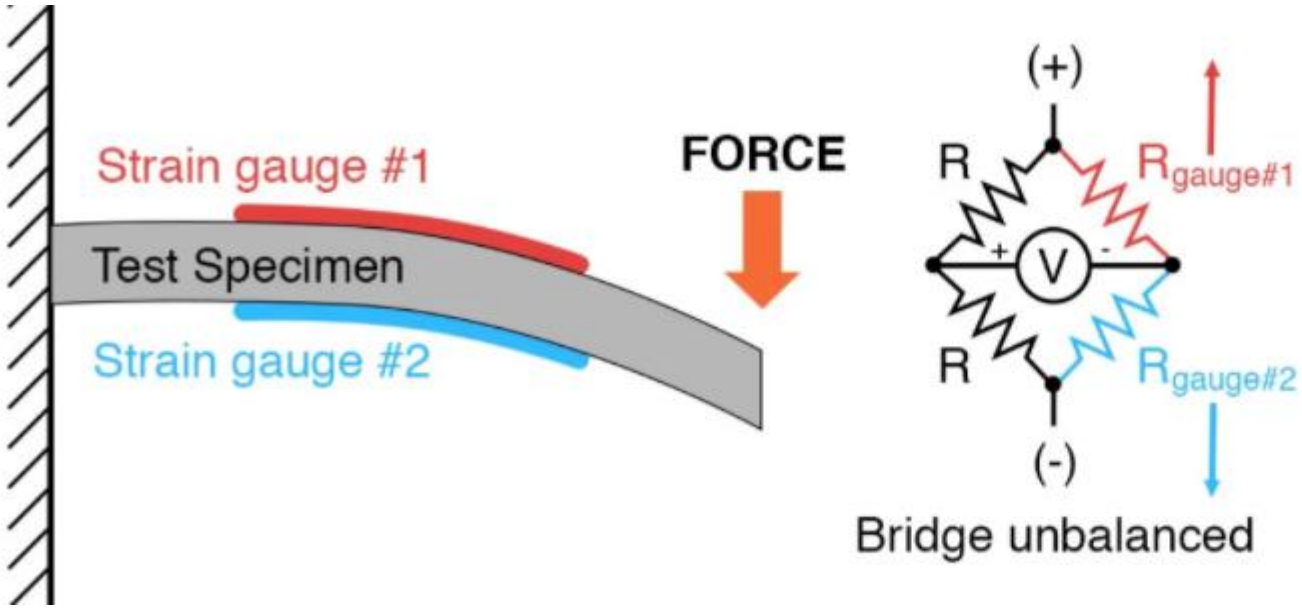
As the strain gauge is either compressed or tensed, its resistance will decrease or increase, respectively, thus unbalancing the bridge and producing an indication at the voltmeter. This arrangement, with a single element of the bridge changing resistance in response to the measured variable (mechanical force), is known as a quarter-bridge circuit.



An unfortunate characteristic of strain gauges is that of resistance change with changes in temperature. This is a property common to all conductors, some more than others.

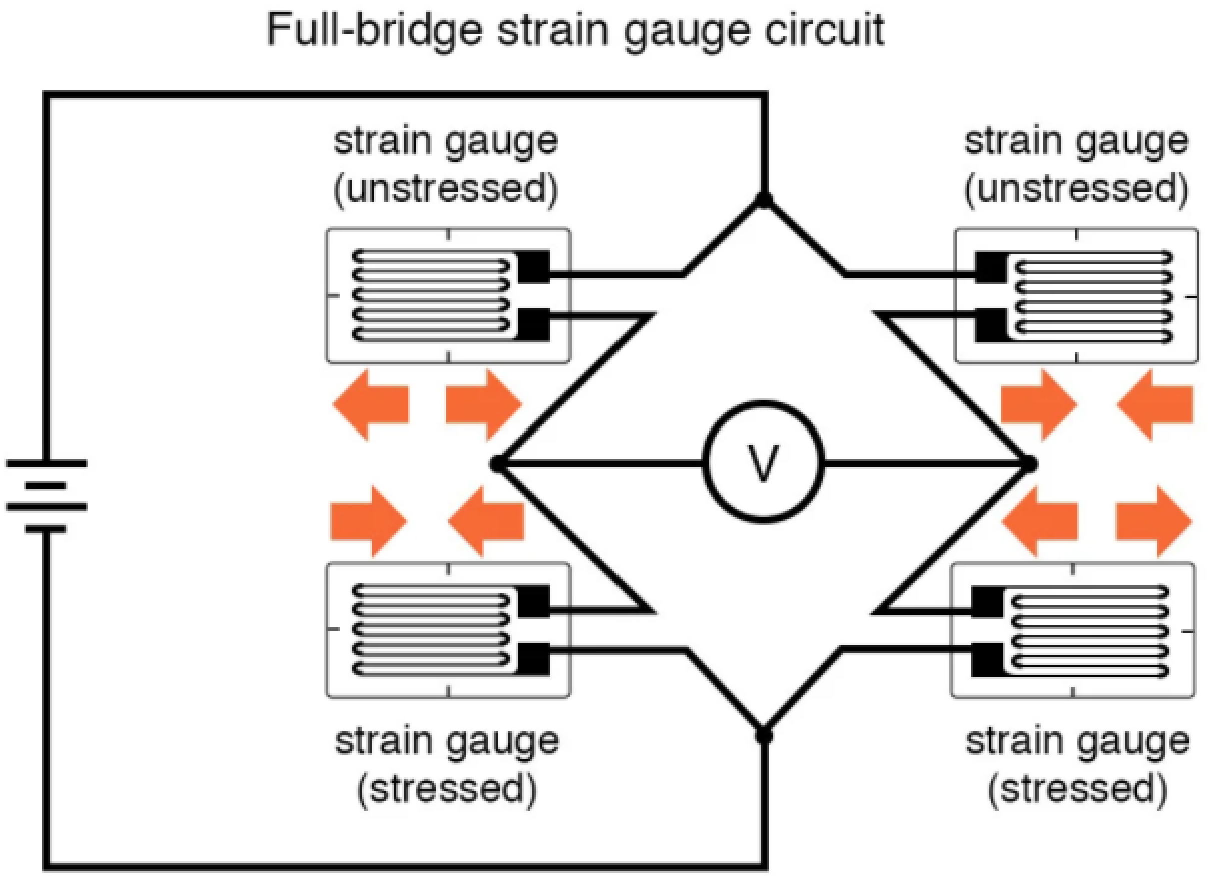
We can transcend this problem, however, by using a “dummy” strain gauge in place of R2, so that both elements of the rheostat arm will change resistance in the same proportion when temperature changes, thus canceling the effects of temperature change:

With no force applied to the test specimen, both strain gauges have equal resistance and the bridge circuit is balanced. However, when a downward force is applied to the free end of the specimen, it will bend downward, stretching gauge #1 and compressing gauge #2 at the same time:



Full-Bridge

Circuits In applications where such complementary pairs of strain gauges can be bonded to the test specimen, it may be advantageous to make all four elements of the bridge "active" for even greater sensitivity. This is called a full-bridge circuit:



When possible, the full-bridge configuration is the best to use. This is true not only because it is more sensitive than the others, but because it is linear while the others are not. Quarter-bridge and half-bridge circuits provide an output (imbalance) signal that is only approximately proportional to applied strain gauge force.

However, the voltage is normally in the milli-volt range. You need an amplifier to boost it.

海芯科技 AVIA Semiconductor

HX711

24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales

DESCRIPTION

Based on Avia Semiconductor's patented technology, HX711 is a precision 24-bit analog-to-digital converter (ADC) designed for weigh scales and industrial control applications to interface directly with a bridge sensor.

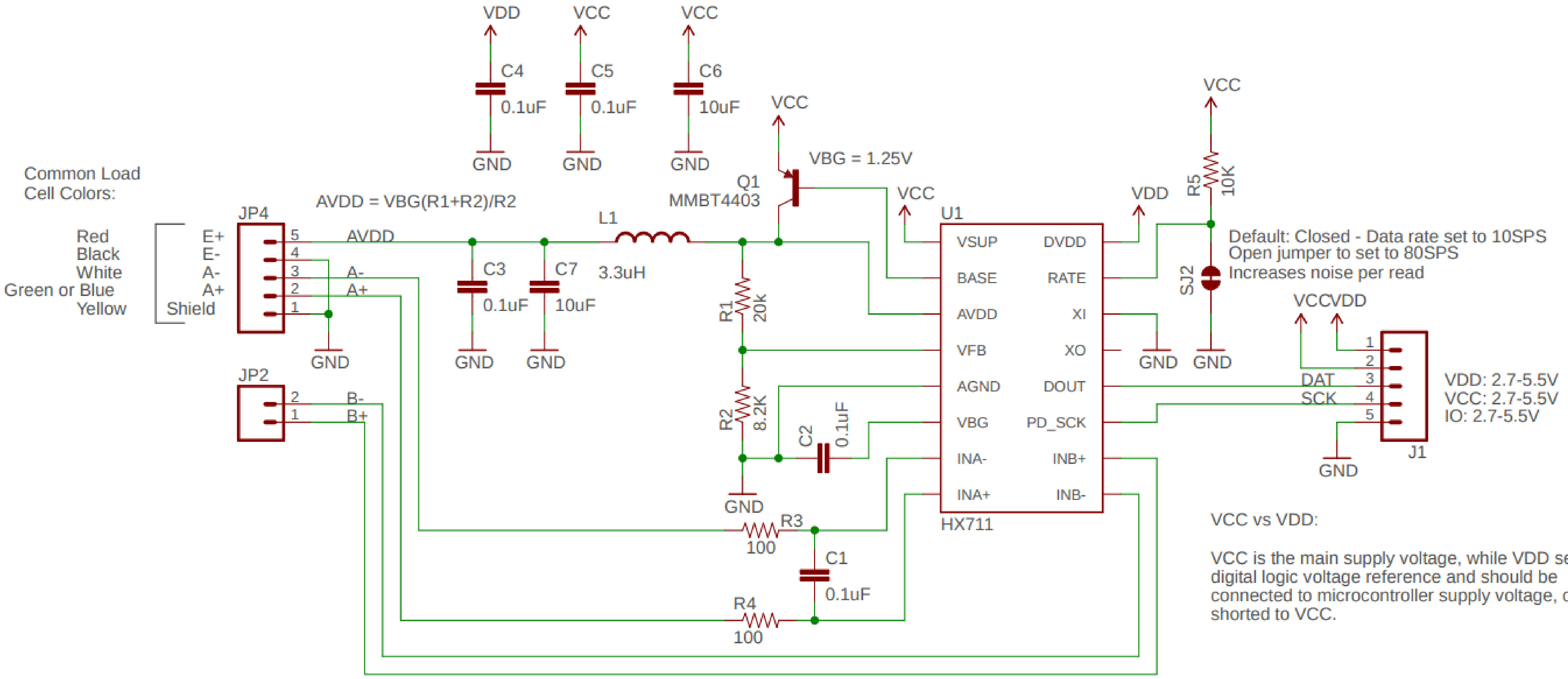
The input multiplexer selects either Channel A or B differential input to the low-noise programmable gain amplifier (PGA). Channel A can be programmed with a gain of 128 or 64, corresponding to a full-scale differential input voltage of ±20mV or ±40mV respectively, when a 5V supply is connected to AVDD analog power supply pin. Channel B has a fixed gain of 32. On-chip power supply regulator eliminates the need for an external supply regulator to provide analog power for the ADC and the sensor. Clock input is flexible. It can be from an external clock source, a crystal, or the on-chip oscillator that does not require any external component. On-chip power-on-reset circuitry simplifies digital interface initialization.

FEATURES

- **Two selectable differential input channels**
- **On-chip active low noise PGA with selectable gain of 32, 64 and 128**
- **On-chip power supply regulator for load-cell and ADC analog power supply**
- **On-chip oscillator requiring no external component with optional external crystal**
- **On-chip power-on-reset**
- **Simple digital control and serial interface: pin-driven controls, no programming needed**
- **Selectable 10SPS or 80SPS output data rate**
- **Simultaneous 50 and 60Hz supply rejection**
- **Current consumption including on-chip analog power supply regulator: normal operation < 1.5mA, power down < 1uA**
- **Operation supply voltage range: 2.6 ~ 5.5V**
- **Operation temperature range: -40 ~ +85℃**
- **16 pin SOP-16 package**

HX711 - SparkFun Load Cell Amplifier

https://www.sparkfun.com/products/13879?_ga=2.11294516.1032769351.1561666174-261824161.1560885208



VCC vs VDD:

VCC is the main supply voltage, while VDD sets the digital logic voltage reference and should be connected to microcontroller supply voltage, or shorted to VCC.

There is no programming needed for the internal registers. All controls to the HX711 are through the pins.

APPLICATIONS

- **Weigh Scales**
- **Industrial Process Control**

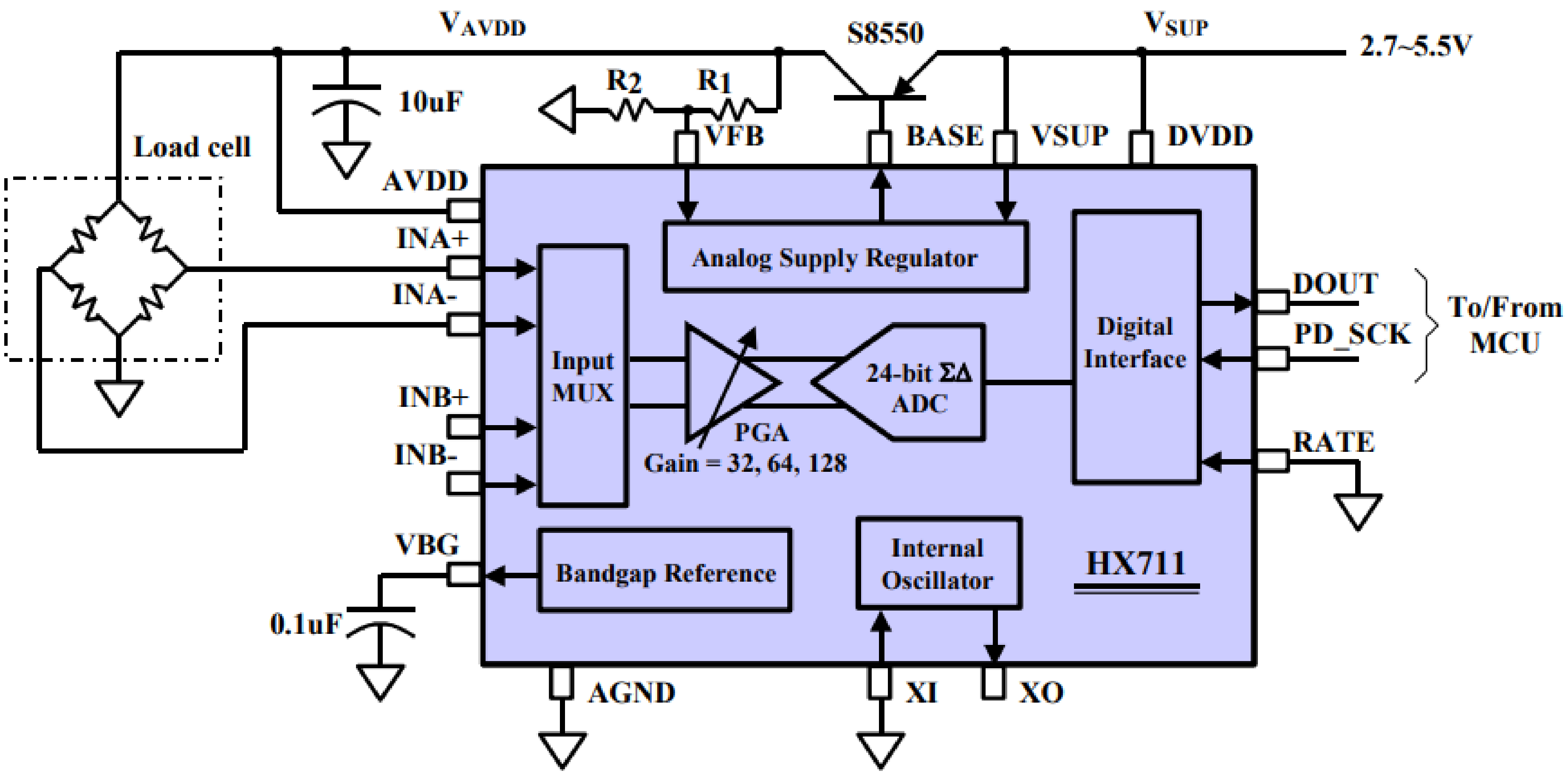
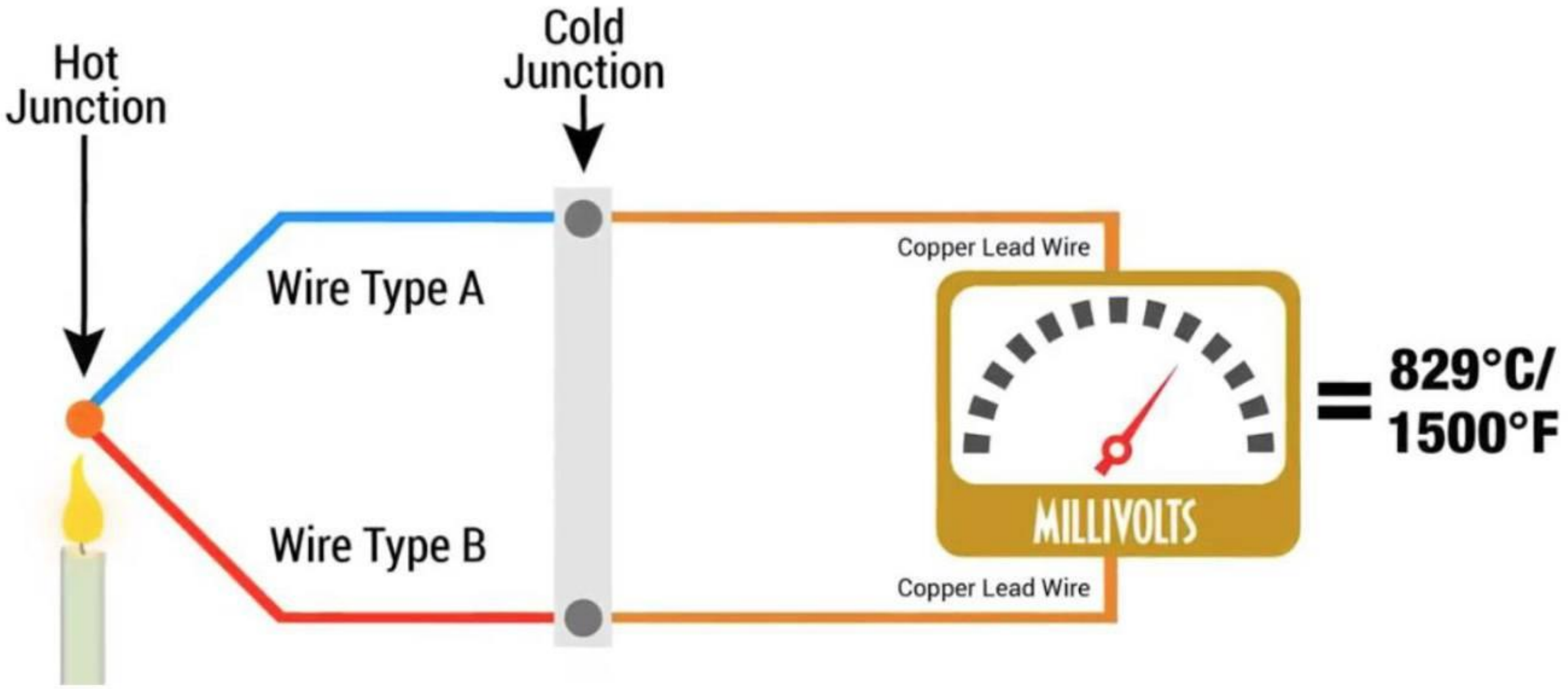


Fig. 1 Typical weigh scale application block diagram

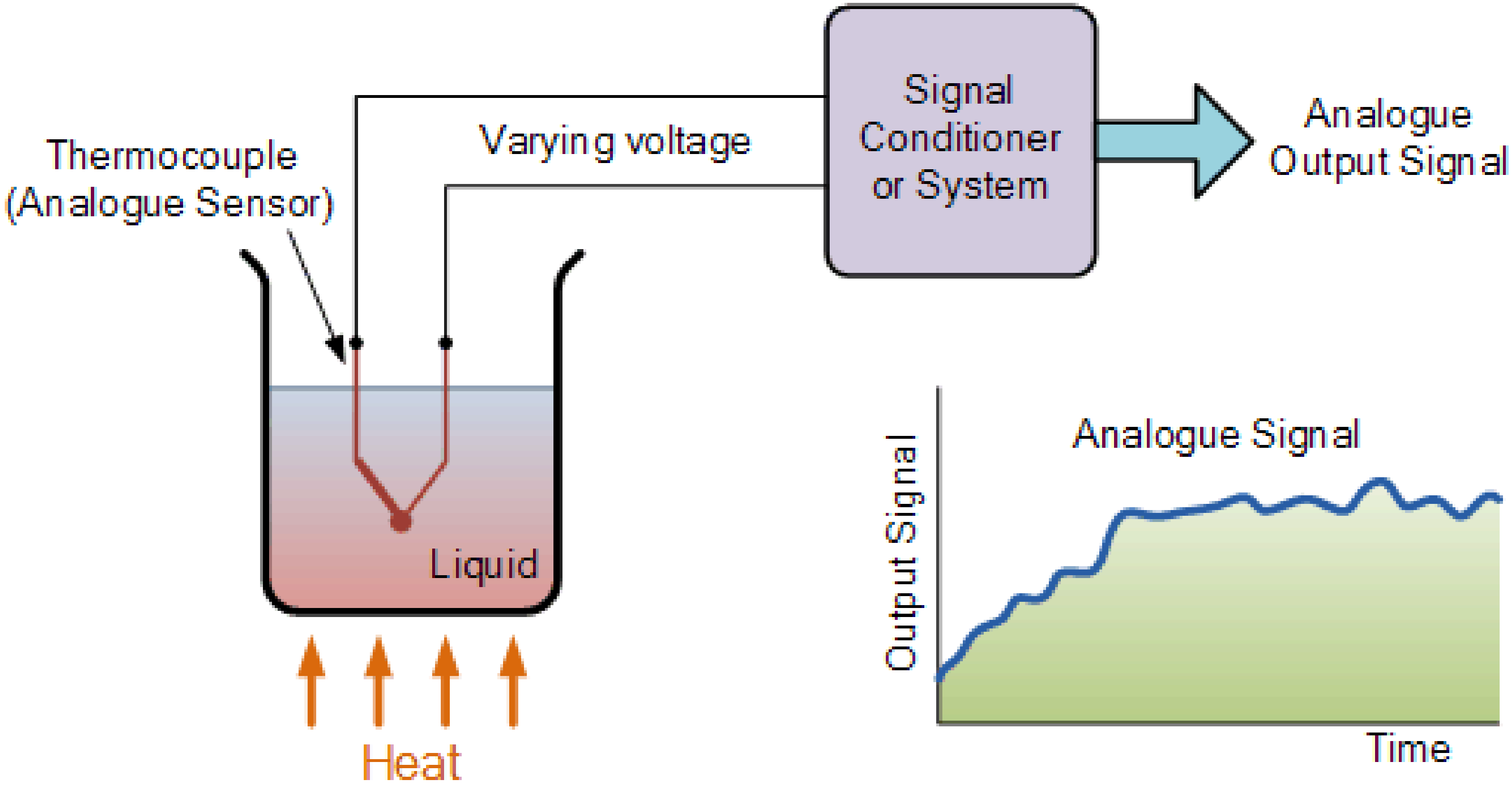
```
#include "HX711.h"
// HX711 circuit wiring
const int LOADCELL_DOUT_PIN = 2;
const int LOADCELL_SCK_PIN = 3;

HX711 scale;

void setup() {
  Serial.begin(57600);
  scale.begin(LOADCELL_DOUT_PIN, LOADCELL_SCK_PIN);
}

void loop() {

  if (scale.is_ready()) {
long reading = scale.read();
Serial.print("HX711 reading: ");
Serial.println(reading);
  } else {
Serial.println("HX711 not found.");
  }
  delay(1000);
  }
```

Thermocouples (Temperature, Passive)



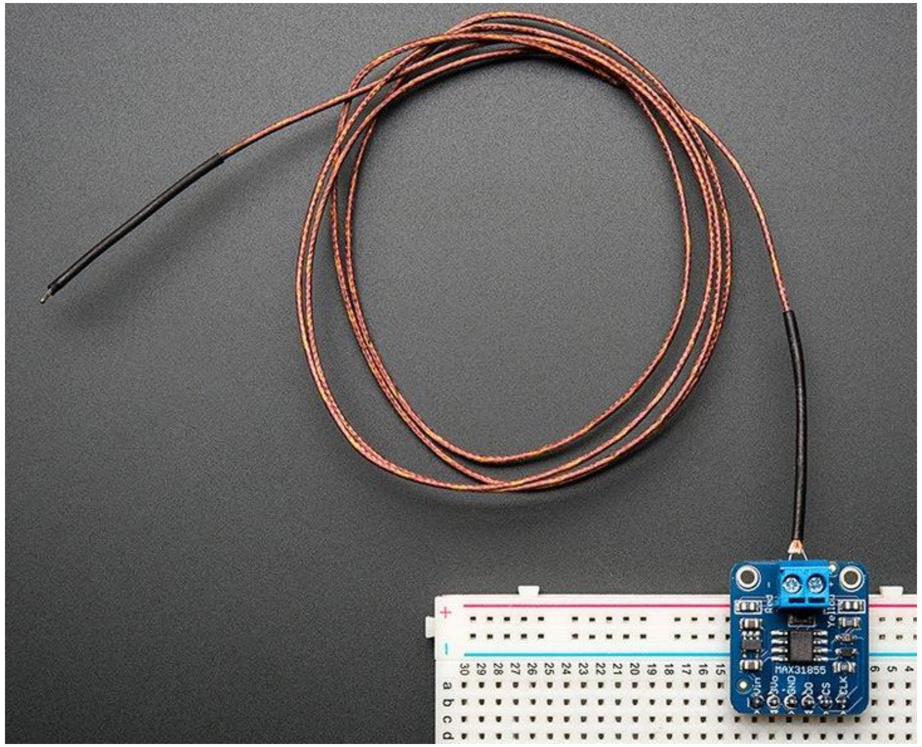
Analog and Digital Sensors

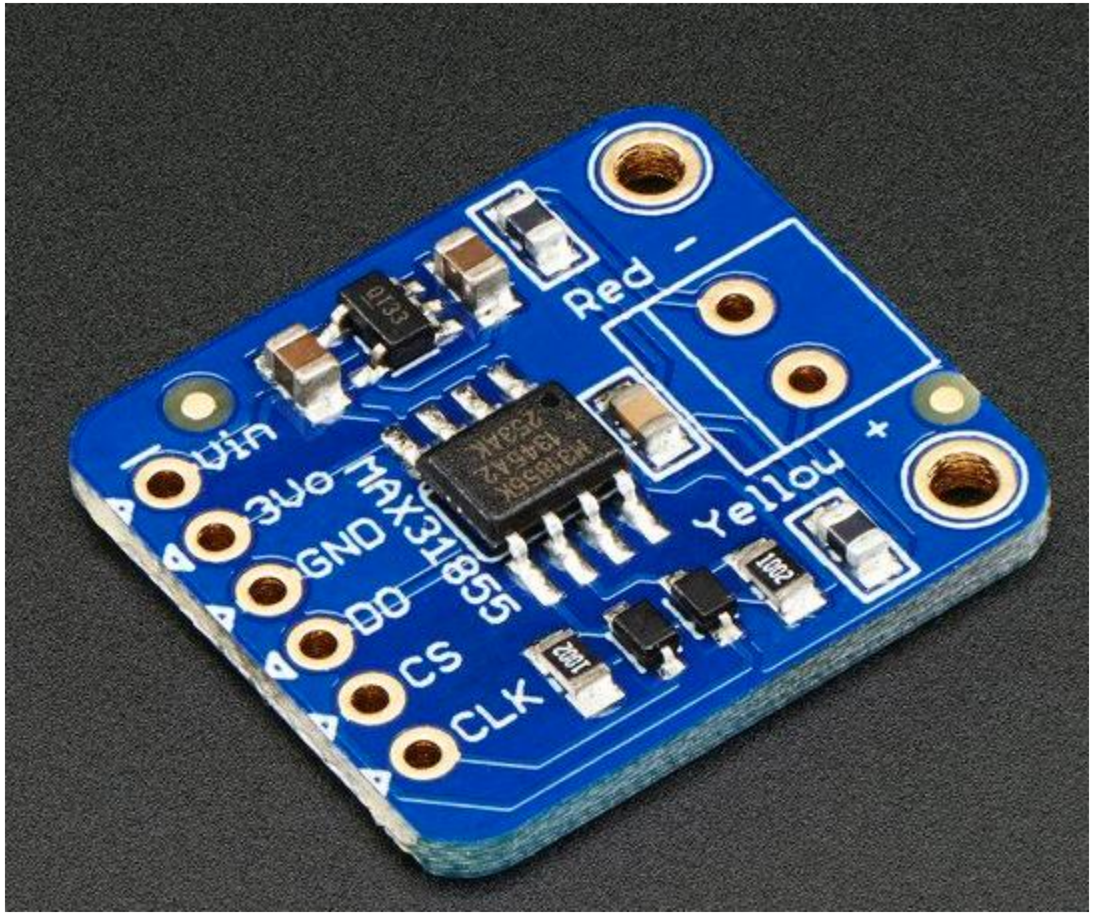
Thermocouple used to produce an Analogue Signal



Implementation

Thermocouple Amplifier MAX31855 breakout board



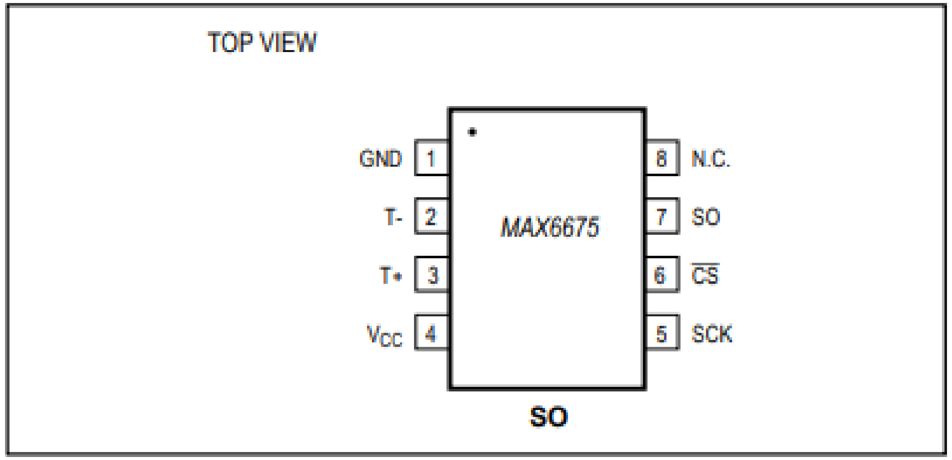


Absolute Maximum Ratings

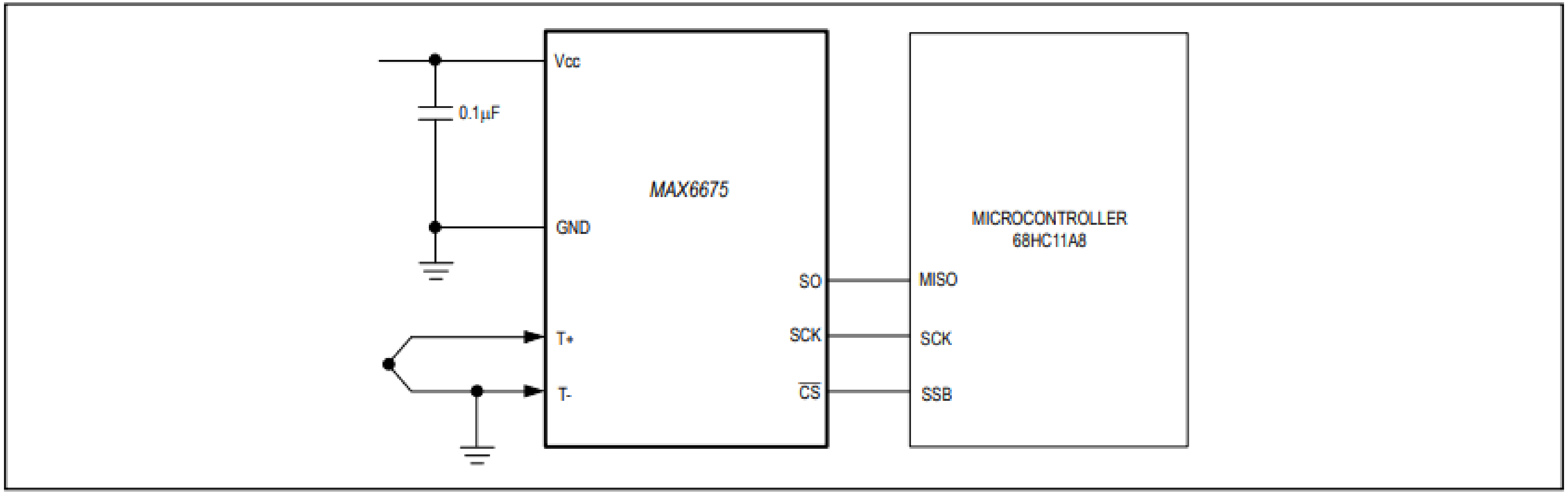
Supply Voltage (V_{CC} to GND) .... -0.3V to +6V
SO, SCK, $\overline{CS}$, T-, T+ to GND ....-0.3V to V_{CC} + 0.3V
SO Current 50mA
ESD Protection (Human Body Model) .... ±2000V
Continuous Power Dissipation (T_A = +70°C)
8-Pin SO (derate 5.88mW/°C above +70°C) 471mW
Operating Temperature Range .... -20°C to +85°C
Storage Temperature Range .... -65°C to +150°C
Junction Temperature .... +150°C
SO Package
Vapor Phase (60s) ....+215°C
Infrared (15s) ....+220°C
Lead Temperature (soldering, 10s) .... +300°C

SPI is a trademark of Motorola, Inc.

Pin Configuration



Typical Application Circuit



Two questions regarding Thermocouples:

1. Are Thermocouples waterproof?

The thermocouple you've linked isn't waterproof. You can buy thermocouple probes in sealed housings from several sources.

2. Can you design an amplifier circuit and use an ADC IC to build a temperature monitor? How?

AD8494/AD8495/AD8496/AD8497

FUNCTIONAL BLOCK DIAGRAM

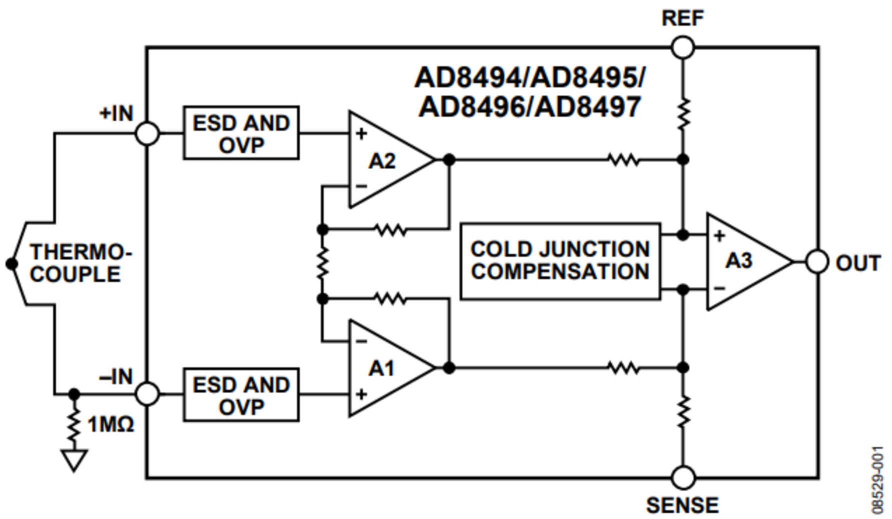
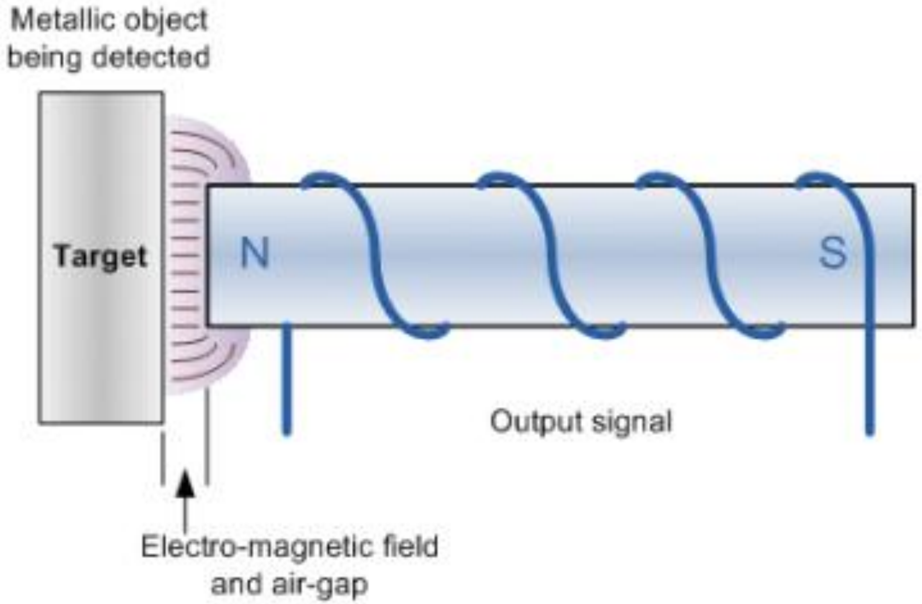


Figure 1.

The 1M ohm resistor guarantees the output rails high when the inputs are unconnected. PNP transistors inside the amplifier get their input pulled up but no certainty that which input is larger or smaller, which makes output uncertain with an open input.

Position Sensors



As their name implies, **Position Sensors** detect the position of something which means that they are referenced either to or from some fixed point or position. These types of sensors provide a "positional" feedback.

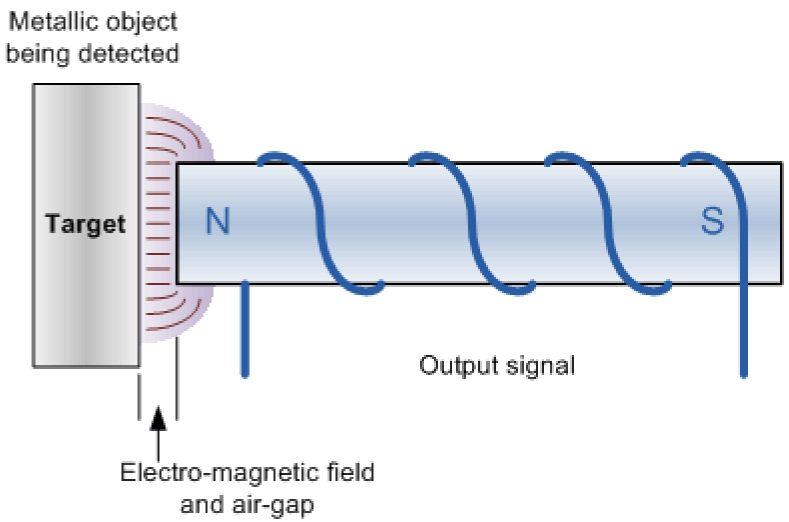
Position Sensors can detect the movement of an object in a straight line using **Linear Sensors** or by its angular movement using **Rotational Sensors**.

Inductive Proximity Sensors.
Another type of inductive position sensor in common use is the **Inductive Proximity Sensor** also called an *Eddy current sensor*. While they do not actually measure displacement or angular rotation they are mainly used to detect the presence of an object in front of them or within a close proximity, hence their name "proximity sensor".

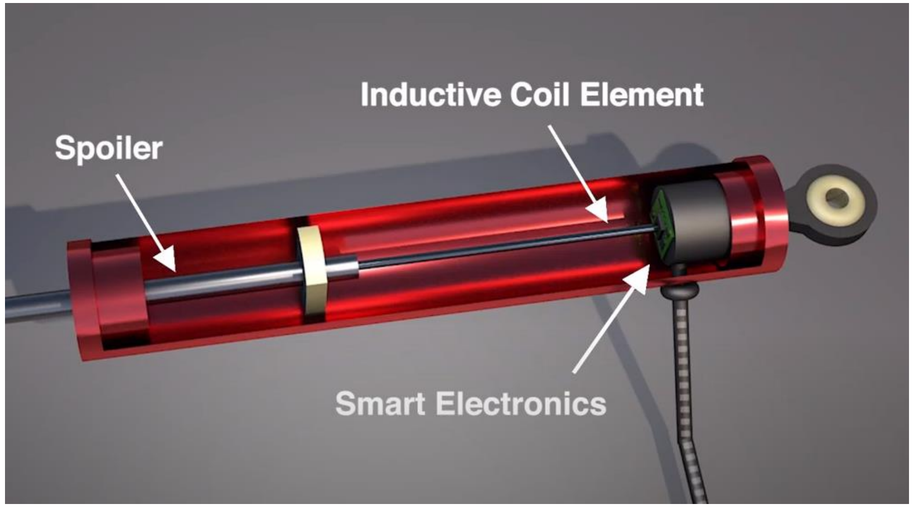
Proximity sensors, are non-contact position sensors that use a magnetic field for detection with the simplest magnetic sensor being the reed switch. In an inductive sensor, a coil is wound around an iron core within an electromagnetic field to form an inductive loop.

When a ferromagnetic material is placed within the eddy current field generated around the inductive sensor, such as a ferromagnetic metal plate or metal screw, the inductance of the coil changes significantly. The proximity sensors detection circuit detects this change producing an output voltage. Therefore, inductive proximity sensors operate under the electrical principle of **Faraday's Law of inductance**.

Inductive Proximity Sensors



Linear Variable Inductive Transducers (LVIT) (Displacement, Position, Passive)



LVDTs and LVITs offer an extremely long life expectancy in harsh environments and critical applications. These sensors feature friction-free, non-contact inductive magnetic coupling for extremely long cycle life and virtually infinite resolution. Various off the shelf and custom packaging options are available for the most demanding application requirements.

Very Broad Applications

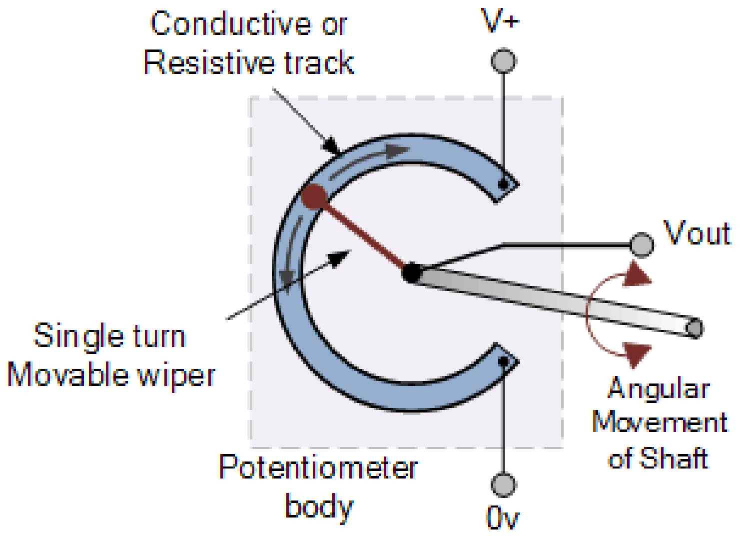
Assembly Machine

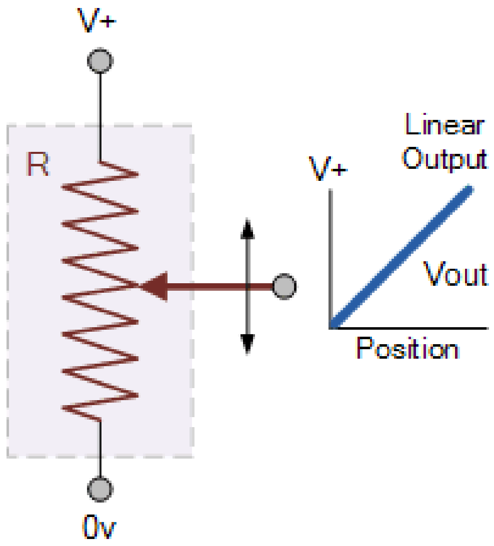
Agriculture Steering Position Feedback

Automotive Suspension Testing

The Potentiometer (Position, Resistance, Passive)

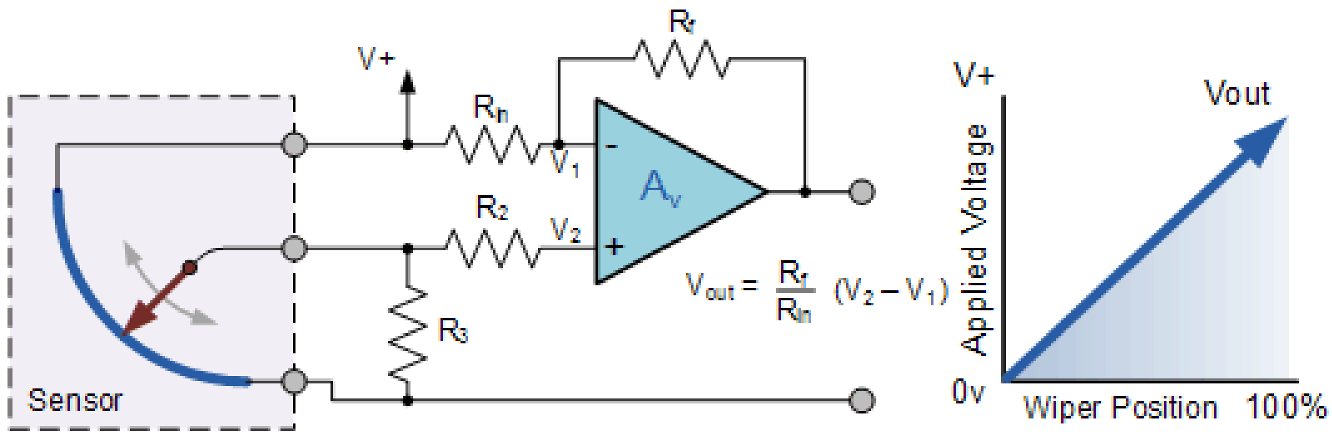
Potentiometer Construction





The most commonly used of all the "Position Sensors", is the *potentiometer* because it is an inexpensive and easy to use position sensor. It has a wiper contact linked to a mechanical shaft that can be either angular (rotational) or linear (slider type) in its movement, and which causes the resistance value between the wiper/slider and the two end connections to change giving an electrical signal output that has a proportional relationship between the actual wiper position on the resistive track and its resistance value. In other words, resistance is proportional to position.

Example of a simple Positional Sensing Circuit

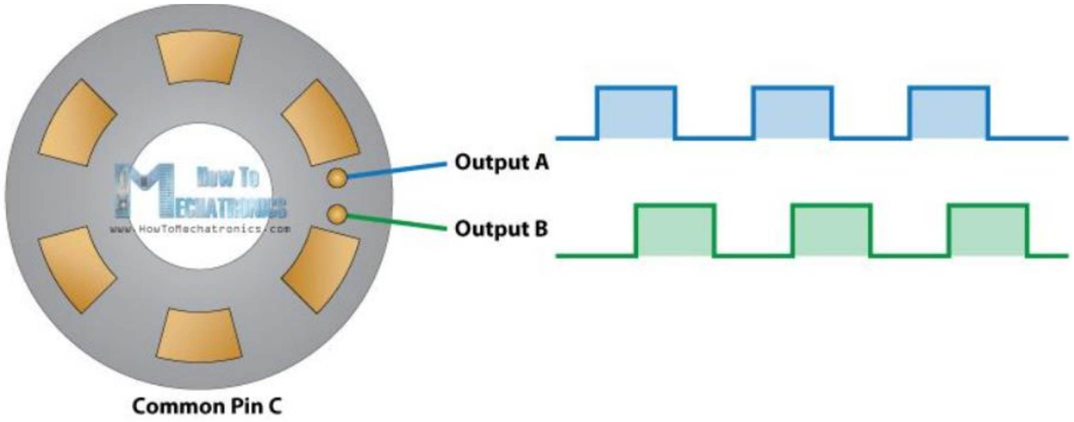


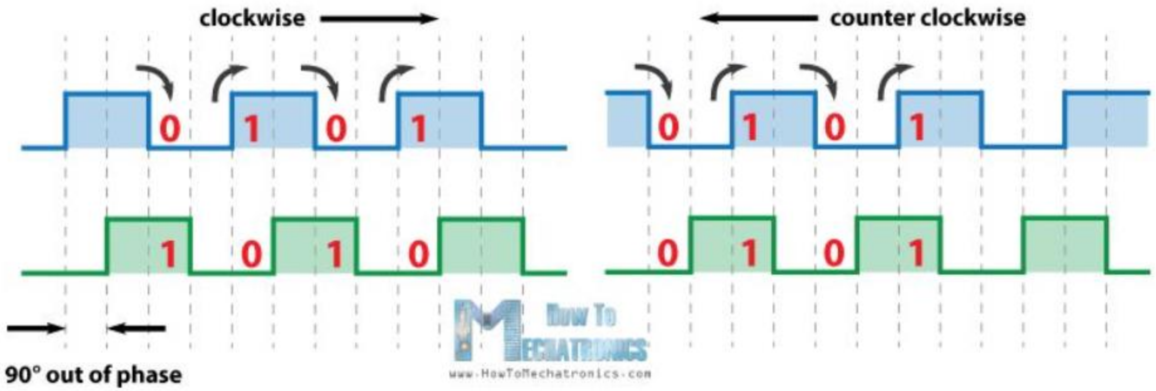
While resistive potentiometer position sensors have many **advantages**: low cost, low tech, easy to use etc, as a position sensor they also have many disadvantages: wear due to moving parts, low accuracy, low repeatability, and limited frequency response.

But there is one main **disadvantage** of using the potentiometer as a positional sensor. The range of movement of its wiper or slider (and hence the output signal obtained) is limited to the physical size of the potentiometer being used.

Rotary Encoders (Position, Active)
Rotary Encoders are another type of position sensor which resemble potentiometers mentioned earlier but are non-contact optical devices used for converting the angular position of a rotating shaft into an analogue or digital data code. In other words, they convert mechanical movement into an electrical signal (preferably digital).

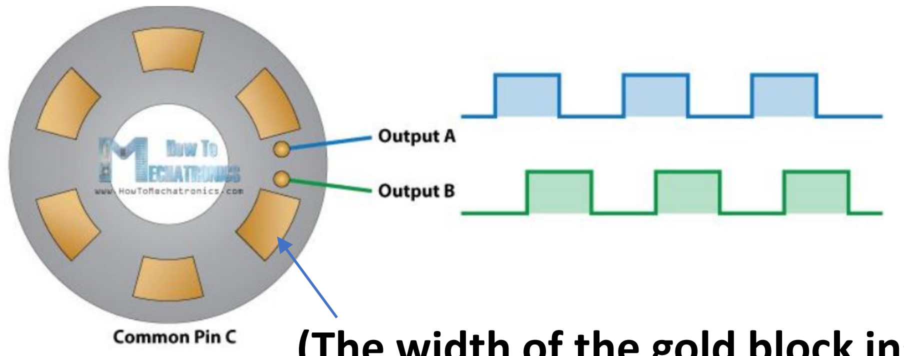
All optical encoders work on the same basic principle. Light from an LED or infra-red light source is passed through a rotating high-resolution encoded disk that contains the required code patterns, either binary, grey code or BCD. Photo detectors scan the disk as it rotates and an electronic circuit processes the information into a digital form as a stream of binary output pulses that are fed to counters or controllers which determine the actual angular position of the shaft.





There are two basic types of rotary optical encoders, **Incremental Encoders** and **Absolute Position Encoders**.

Arduino code to detect the clock-wise or counter clock-wise rotation of the encoder



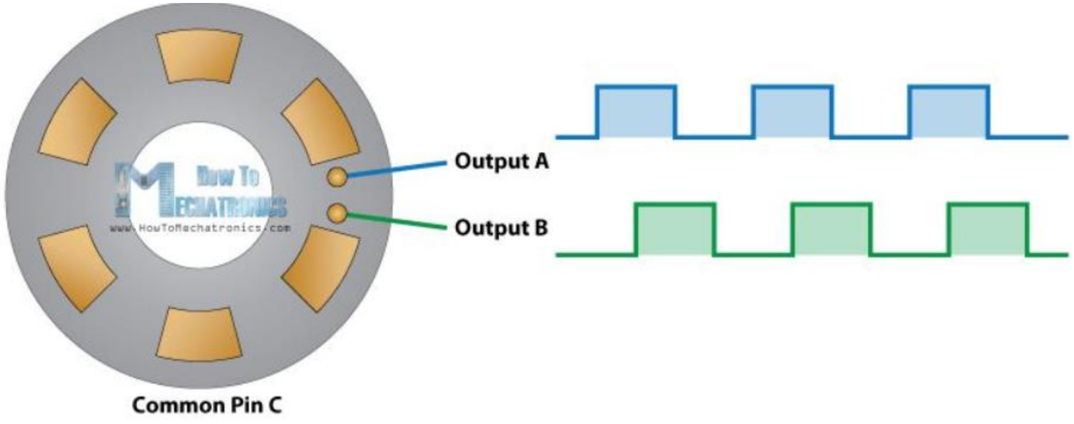
Algorithm I:

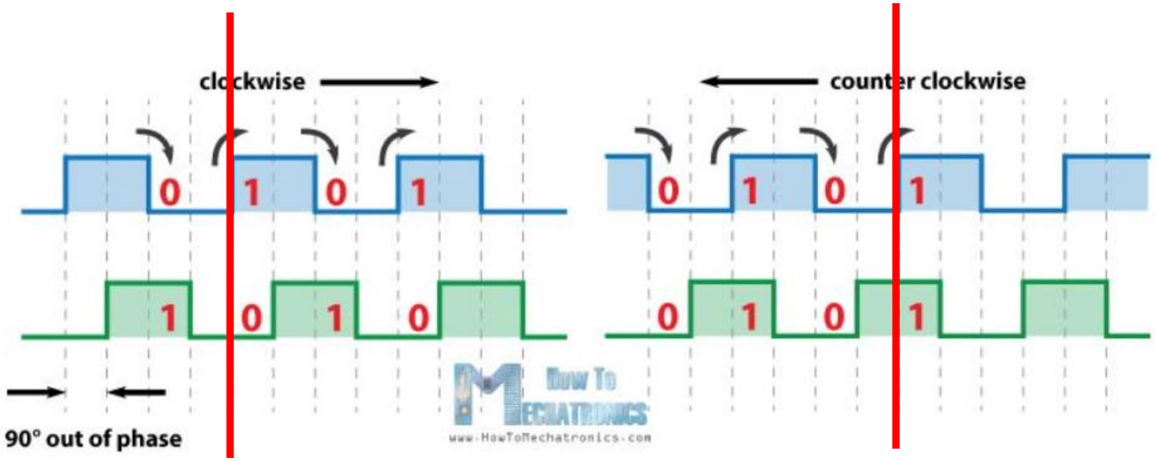
Counter Clock-Wise: after A changed its state, A and B are in the same state.

Clock-Wise: after A changed its state, A and B are in different states.

(The width of the gold block inside the encoder can cover two light sources at the same time)

```
void loop() {
  aState = digitalRead(outputA); // Reads the "current" state of the outputA
  // If the previous and the current state of the outputA are different, that means a Pulse
has occured
  if (aState != aLastState){
    // If the outputB state is different to the outputA state, that means the encoder is
rotating clockwise
    if (digitalRead(outputB) != aState) {
      counter ++;
    } else {
      counter --;
    }
    Serial.print("Position: ");
    Serial.println(counter);
  }
  aLastState = aState; // Updates the previous state of the outputA with the current state
}
```





Algorithm II:

Counter Clockwise: When A changes from LOW to HIGH, B is HIGH.

Clockwise: When A changes from LOW to HIGH, B is LOW.

Absolute Position Encoder

Absolute Position Encoders are more complex than quadrature encoders. They provide a unique output code for every single position of rotation indicating both position and direction. Their coded disk consists of multiple concentric "tracks" of light and dark segments. Each track is independent with its own photo detector to simultaneously read a unique coded position value for each angle of movement. The number of tracks on the disk corresponds to the binary "bit"-resolution of the encoder so a 12-bit absolute encoder would have 12 tracks and the same coded value only appears once per revolution.

4-bit Binary Coded Disc