USC University of Southern California

ECE 105: Introduction to Electrical Engineering

Lecture 9

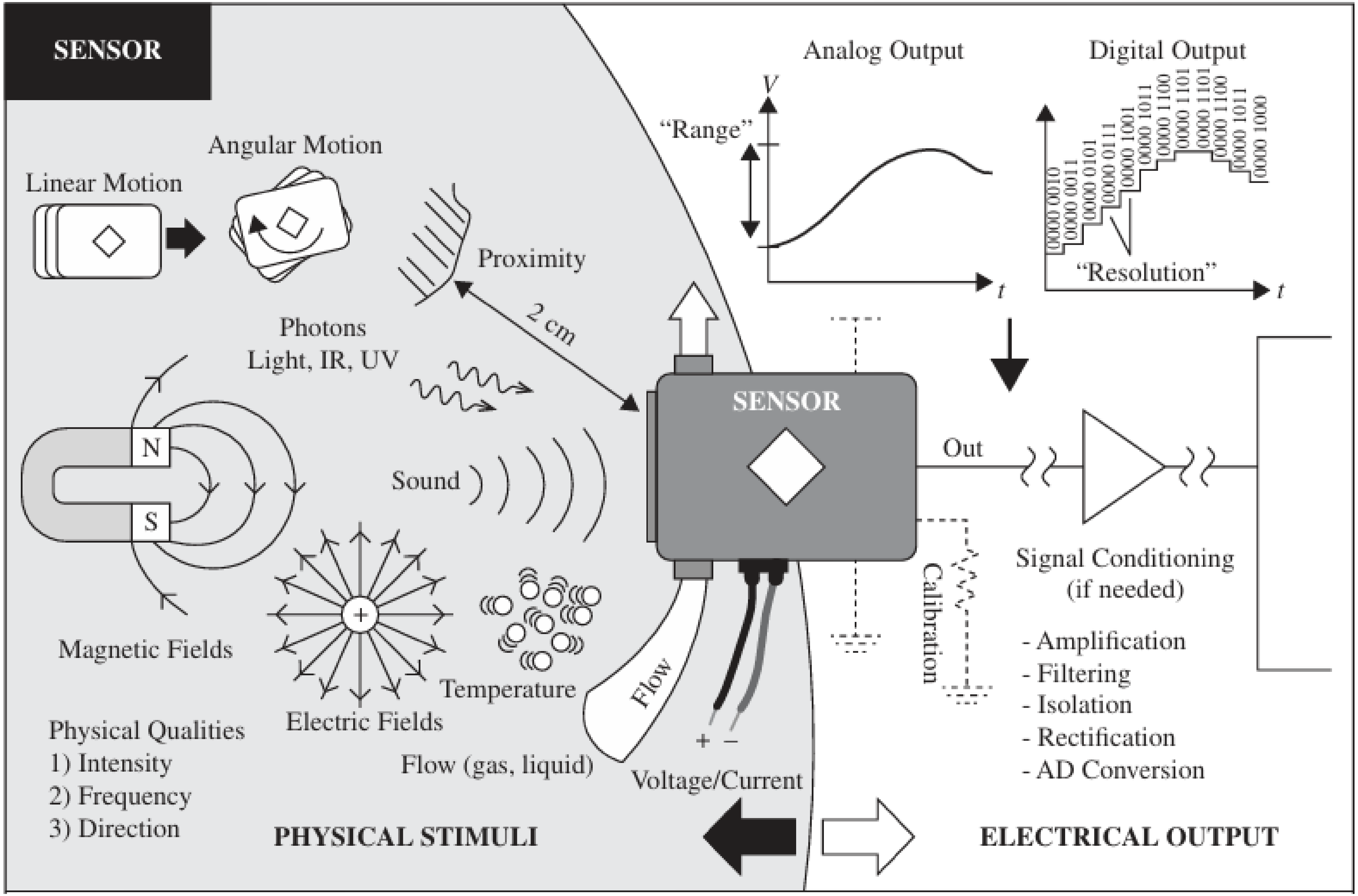
Sensors 1

Yasser Khan

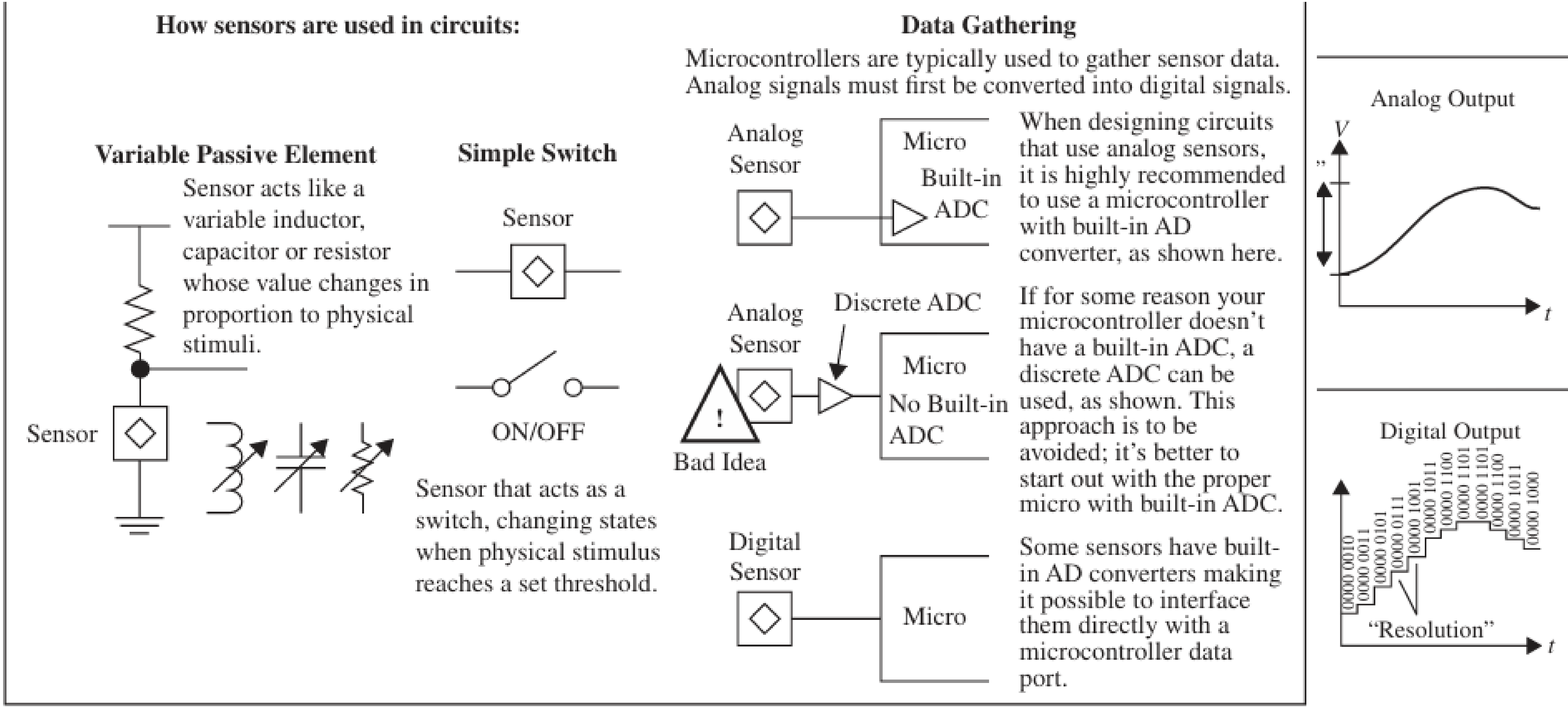
Rehan Kapadia

What is a sensor?

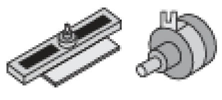
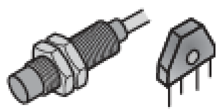
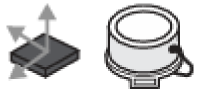
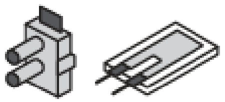
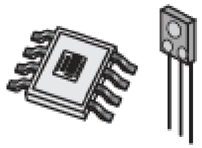
What is a sensor?



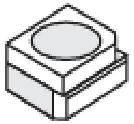
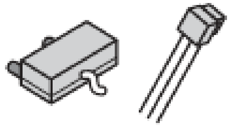
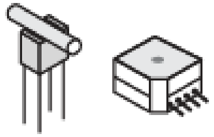
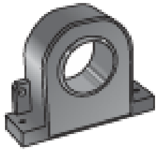
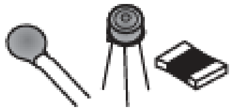
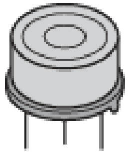
Sensors in circuits:



Types of sensors

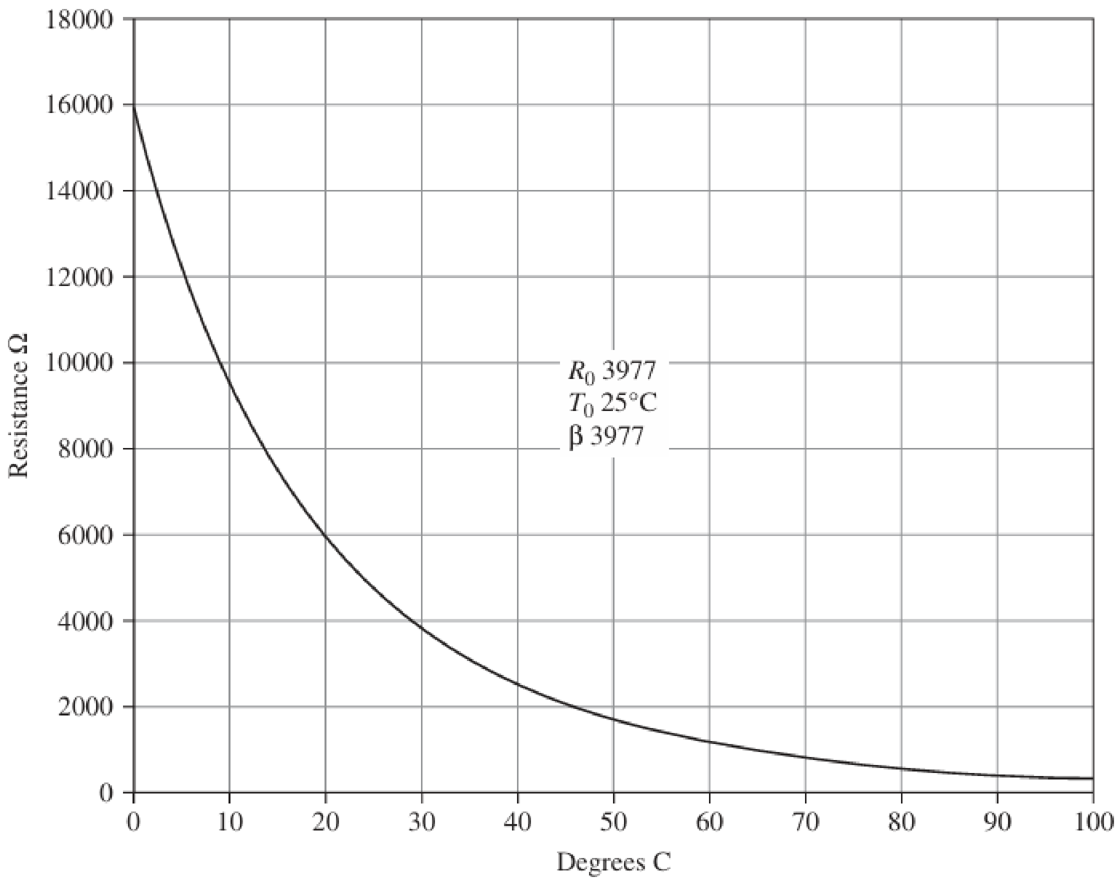
TYPES OF SENSORS			Sensors in bold are covered in this chapter.
Category of Sensor		**What It Does**	**Example Devices**
Position Measuring Devices		Designed to detect and respond to changes in angular position or in linear position of the device.	**Potentiometer** Linear Position Sensor Hall Effect Position Sensor Magnetoresistive Angular **Encoders:** **-Quadrature** -Incremental Rotary **-Absolute Rotary** -Optical
Proximity, Motion Sensors		Designed to detect and respond to movement outside of the component but within the range of the sensor.	**Ultrasonic Proximity** **Optical Reflective** **Optical Slotted** **PIR (Passive Infrared)** **Inductive Proximity** **Capacitive Proximity** Reed Switch Tactile Switch
Inertial Devices		Inertia Devices designed to changes in the physical movement of the sensor.	**Accelerometer** **Potentiometer** Inclinometer Gyroscope Vibration Sensor/Switch **Tilt Sensor** **Piezo Shock Sensor** LVDT/RVDT
Pressure/Force		Pressure Devices designed to detect a force being exerted against it.	**IC Barometer** **Strain Gauge** Pressure potentiometer LVDT Silicon transducer Piezoresistive sensor Capacitive transducer
Optical Devices		Optical Devices designed to detect the presence of light or a change in the amount of light on the sensor.	**LDR** **Photodiodes** **Phototransistors** Photo interrupters **Reflective Sensors** IrDA Transceiver Solar Cells LTV (Light to Voltage) Sensors

Types of sensors

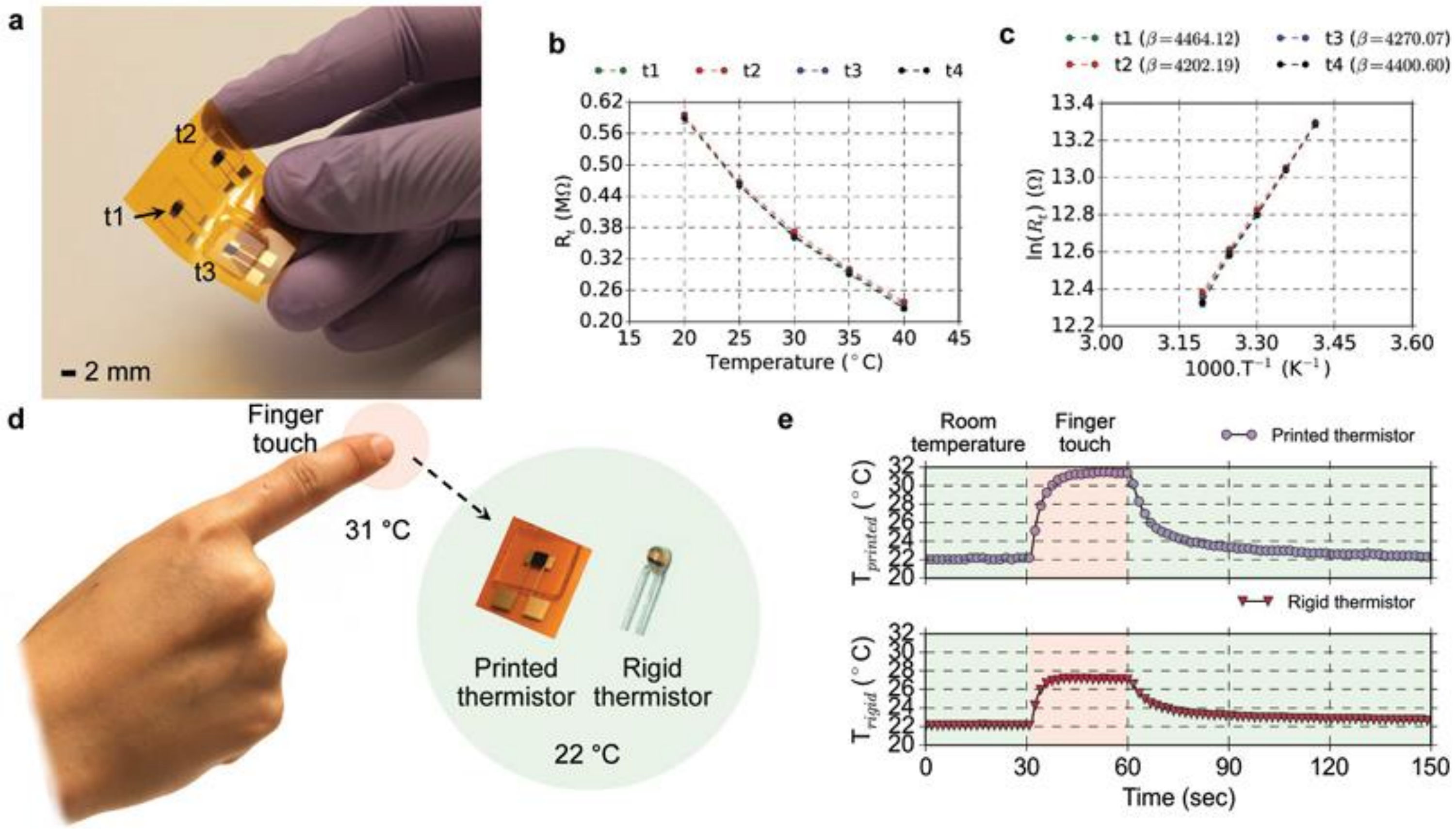
Image, Camera Devices		Image, Camera Devices designed to detect and change a viewable image into a digital signal.	CMOS Image Sensor
Magnetic Devices		Magnetic Devices designed to detect and respond to the presence of a magnetic field.	**Hall Effect sensor** Magnetic Switch Linear Compass IC Reed Sensor
Media Devices		Media Devices designed to detect and respond to the presence or the amount of a physical substance on the sensor.	**Gas** Fluid Flow **Smoke** **Humidity, Moisture** Dust Float Level
Current and Voltage Devices		Current Devices designed to detect and respond to changes in the flow of electricity in a wire or circuit.	Hall Effect current sensor DC current sensor AC current sensor Voltage Transducer
Temperature		Temperature Devices designed to detect the amount of heat using different techniques and in different mediums.	**Thermistor NTC** **Digital IC** **Thermistor PTC** **Analog IC** **Resistance Temp Detectors (RTD)** **Thermocouple** **Thermopile** **Infrared Thermometer/Pyrometer**
Specialized		Specialized Devices designed to provide detection, measurement, or response in specialized situations, which also may include multiple functions.	**Audio Microphone** **Geiger-Müller Tube** **Chemical**

Temperature sensor

Sensor calibration

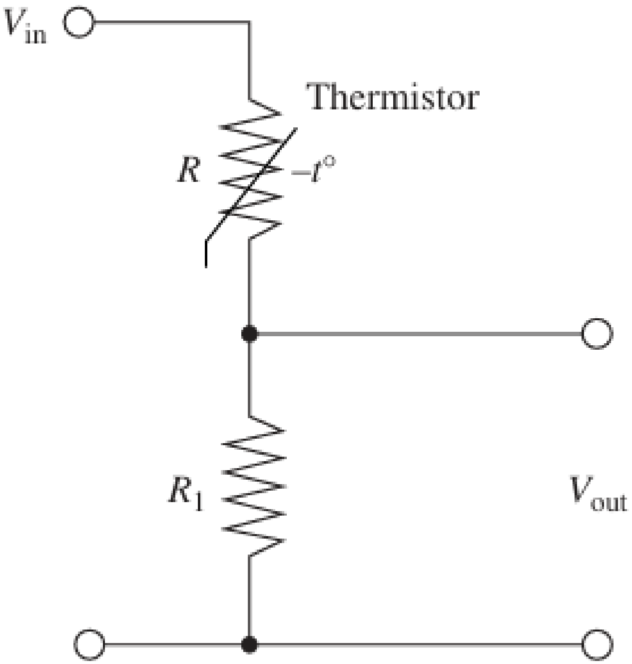


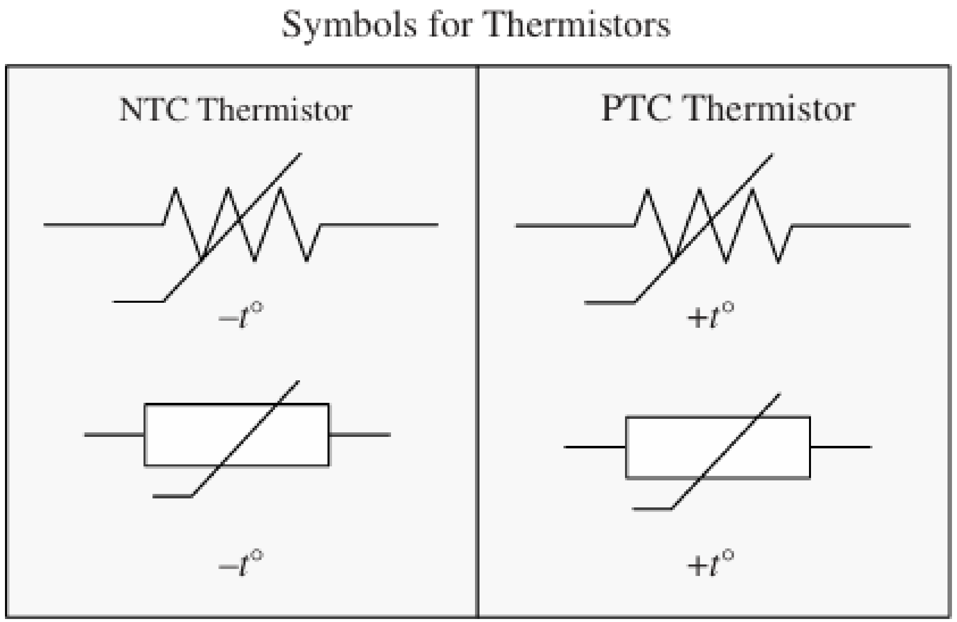
Sensor calibration



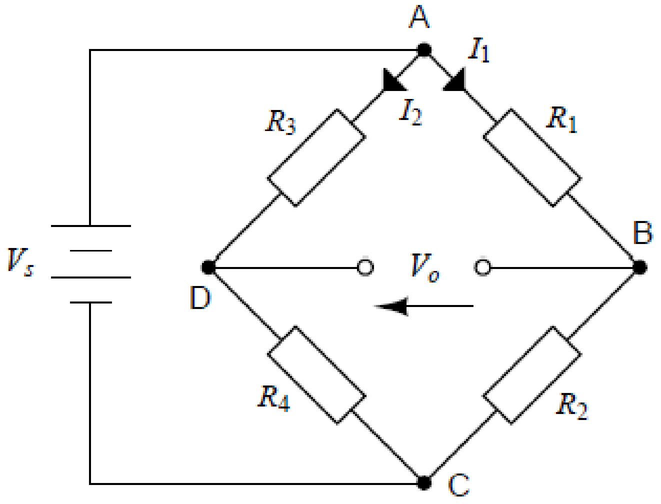
$$R_t = R_0 \exp \beta \left(\frac{1}{T} - \frac{1}{T_0} \right)$$

Using sensors in circuits





Wheatstone bridge



$$V_{AB} = \frac{V_s R_1}{R_1 + R_2}$$

$$V_{AD} = \frac{V_s R_3}{R_3 + R_4}.$$

Then $V_o = (V_s - V_{AD}) - (V_s - V_{AB}) = V_{AB} - V_{AD}$ which works o

$$V_o = V_s\left(\frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right)$$

$$V_o = V_s \frac{R_1 R_4 - R_2 R_3}{(R_1 + R_2)(R_3 + R_4)}.$$

If V_o is zero we can work back from this to the resistor ratios shown before. However, what if one resistor is a sensor with a resistance that has changed by some value δR_1? The new value for the resistor is then $R_x = R_1 + \delta R_1$ and if this is substituted into Equation the result is:

$$V_o = V_s \frac{(R_1 + \delta R)R_4 - R_2 R_3}{(R_1 + \delta R + R_2)(R_3 + R_4)}.$$

Now if we begin with a balanced bridge where all the resistors, including the sensor, have the same value, that is $R_1 = R_2 = R_3 = R_4 = R$ then can be simplified to:

$$V_o = V_s \frac{\delta R}{4R + 2\delta R} \approx V_s \frac{\delta R}{4R}.$$

Precise thermistor measurement steps

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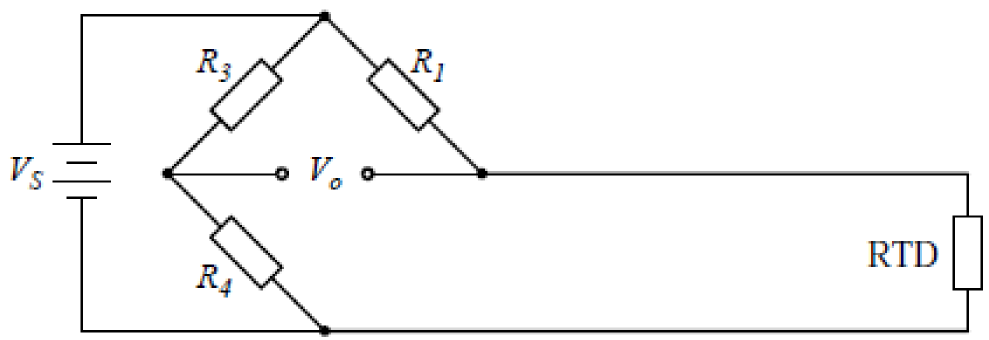


$$R_T = R_0[1 + AT + BT^2 + (T - 100)CT^3]$$

for temperatures $-200\,°C < T < 0\,°C$ and:

$$R_T = R_0[1 + AT + BT^2]$$

for $0\,°C < T < 661\,°C$.

These equations contain higher order coefficients and these can be found by calibrating the individual resistor. The accepted values for a ‘pt100’ RTD with a standard temperature coefficient are:

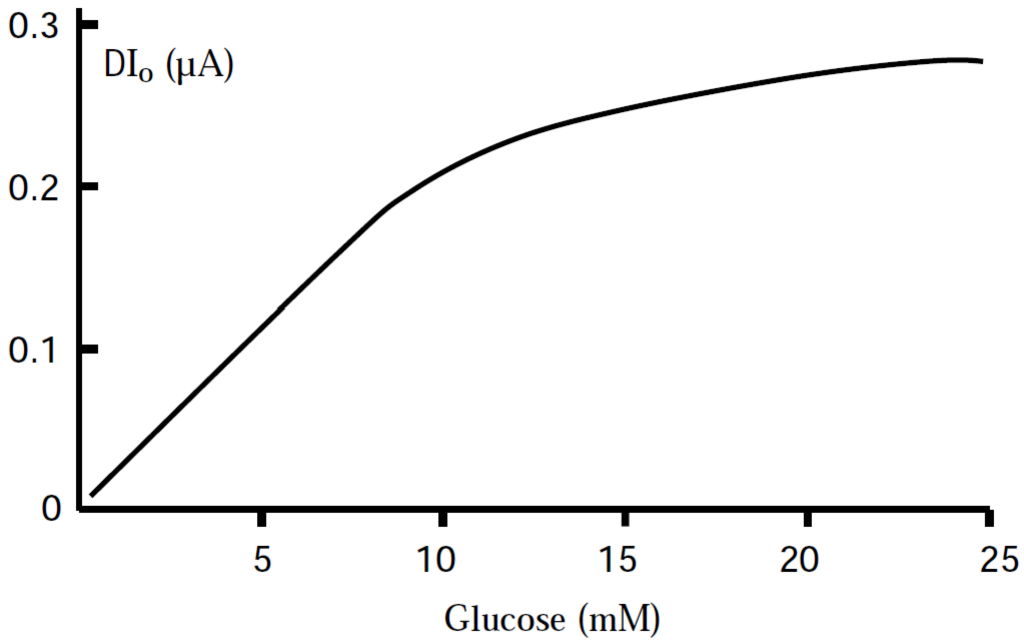
$$A = 3.908310^{-3} K^{-1}$$

$$B = -5.77510^{-7} K^{-2}$$

$$C = -4.18310^{-12} K^{-4}.$$

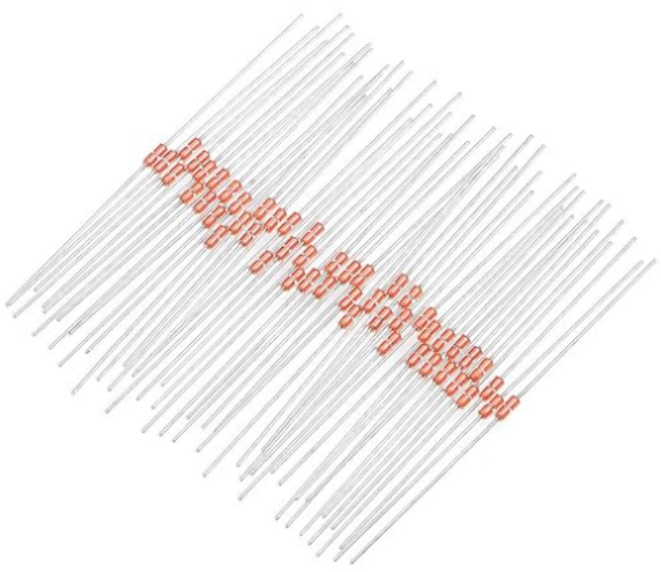
Sensitivity

$$S_{out} = f(S_{in})$$



$\delta S_{out}/\delta S_{in}$

Let's build our temperature sensor circuit



Roll over image to zoom in

uxcell 50PCS NTC Thermistors Resistors MF58 3950B 10K Ohm Glass Sealed Temperature Sensors

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Brand	uxcell
Item dimensions L x W x H	3.54 x 2.36 x 0.39 inches
Measurement Type	Ohmmeter
Manufacturer	uxcell

About this item

- FEATURES: MF58 10K Ohm NTC Thermistors with B Value: 3950(+/-1%)
- DESIGN: Glass sealed packaging with firm structure, small size and light weight, applicable in severe environments
- PERFORMANCE: High precision resistance, B values with high reliability and stability, high sensitivity
- APPLICATION: Suitable for related equipment with temperature measurement and controls thermal protection circuits in various family appliances
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What else is needed to create this circuit?

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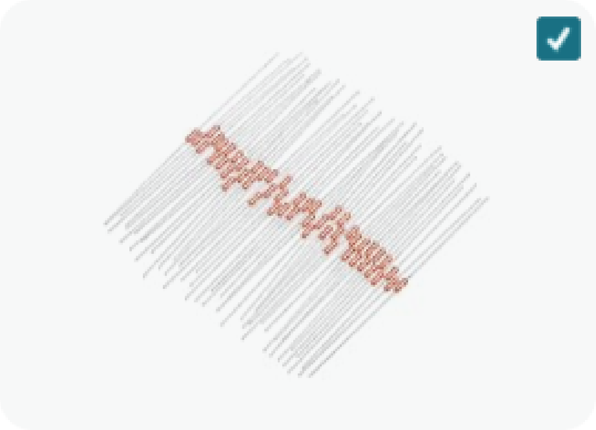
Frequently bought together



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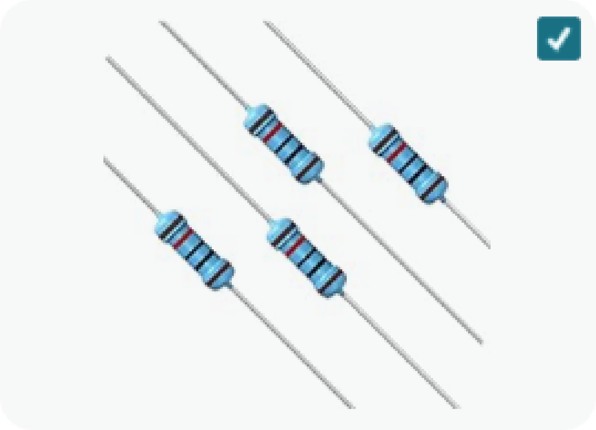

This item: uxcell 50PCS NTC Thermistors Resistors MF58 3950B 10K Ohm Glass Sealed…

100 PCS 10K ohm Resistor 1/4w (0.25 Watt) ±1% Tolerance Metal Film Fixed Resistors, Over 200…

Demo board setup

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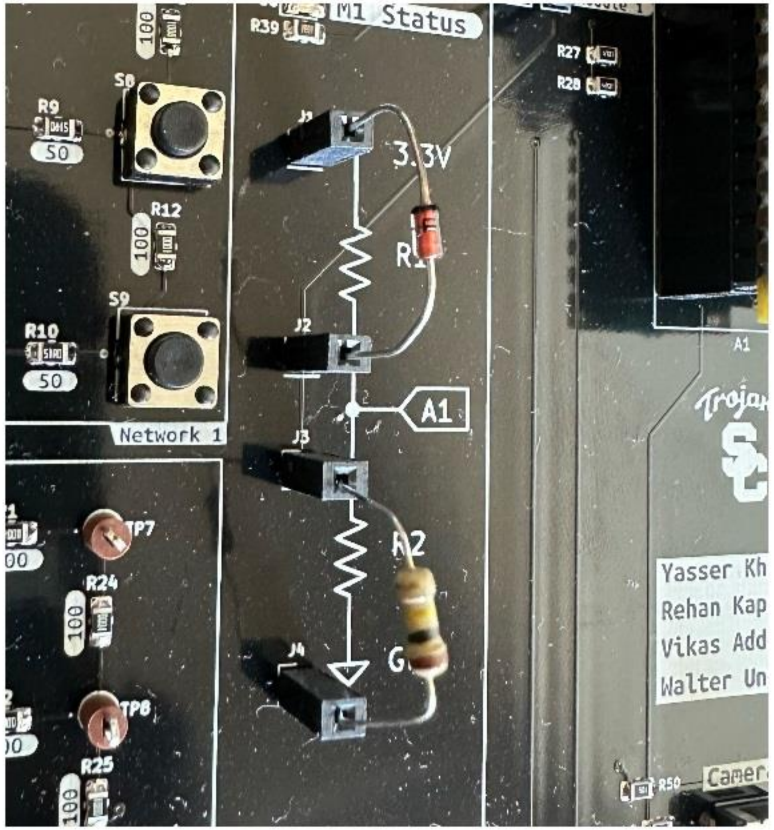

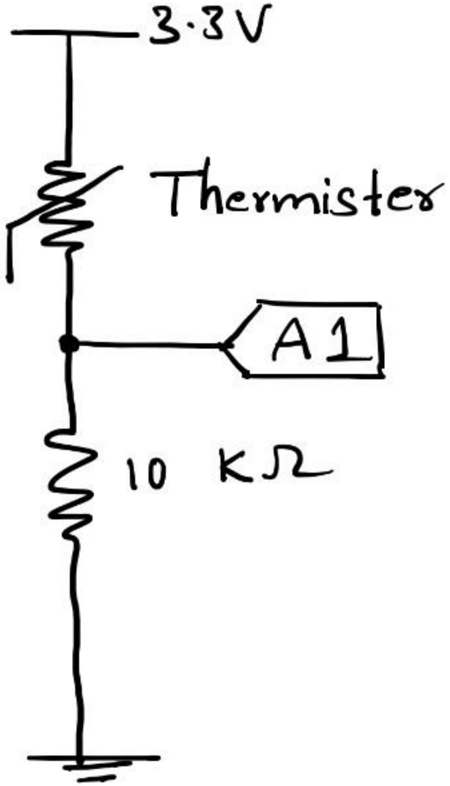

Sensor circuit

Arduino sketch

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voltage_divider | Arduino IDE 2.3.2

File Edit Sketch Tools Help

Arduino Nano 33 BLE

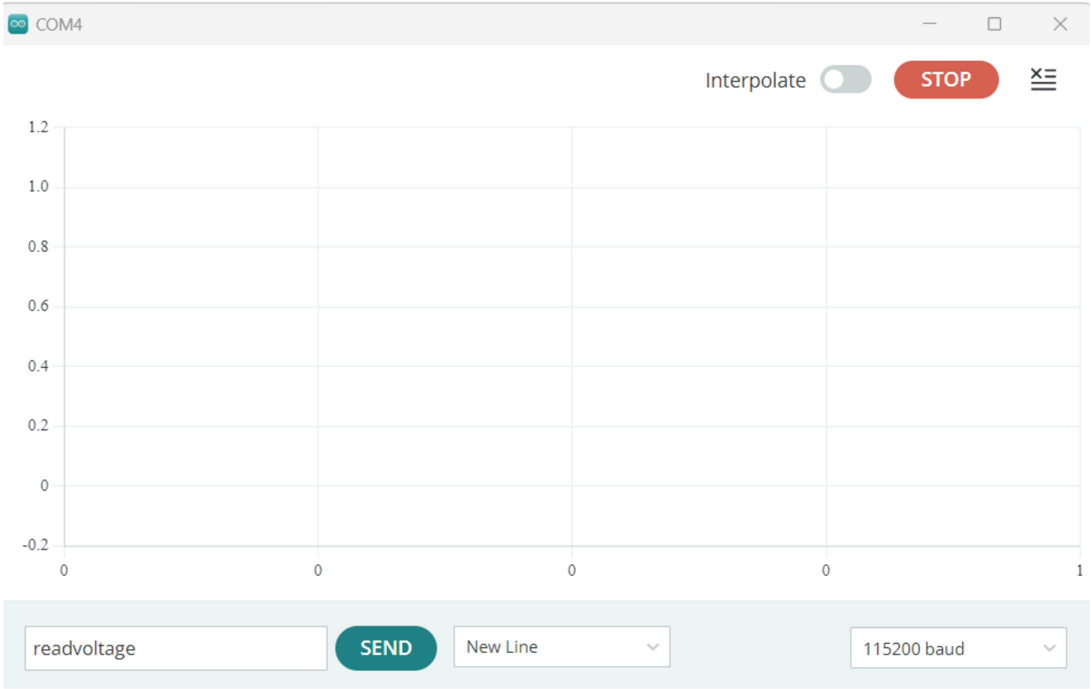
voltage_divider.ino

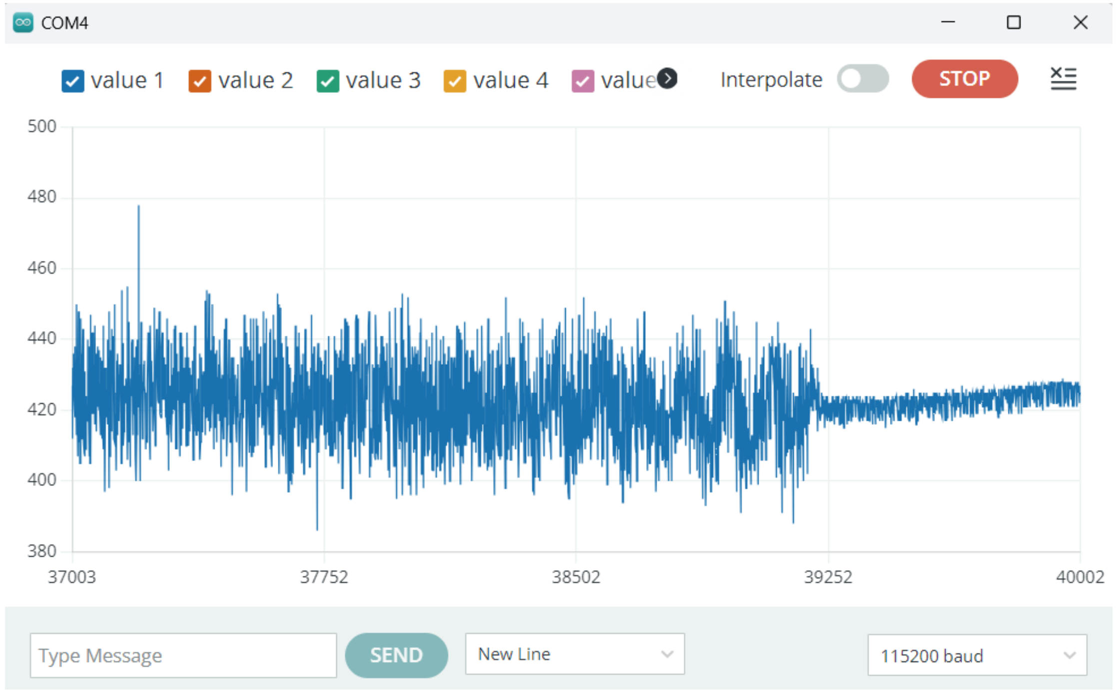
```
#include <Arduino.h>

#define m1_vd_input ? // 1. change here, m1_vd_input ? which ADC is connected to your voltage divider
#define adc_resolution 1024

bool readingEnabled = false;
int counter = 0;

void setup() {
  Serial.begin(115200);
  while (!Serial); // Wait for the serial port to be ready (for certain boards like Leonardo)
}

void loop() {
  // Check if any serial input is available
  if (Serial.available() > 0) {
    String command = Serial.readStringUntil('\n'); // Read the command from the serial monitor

    // Check if the entered command is 'readvoltage'
    if (command == "readvoltage") readingEnabled = true;
  }

  while(readingEnabled){
    Serial.println(analogRead(m1_vd_input));
    counter = counter + 1;
    if(counter == ?){ // 2. change here, counter == ? for getting 10s
      counter = 0;
      readingEnabled = false;
      Serial.println("Ready to enter next command");
      break;
    }
    delay(1);
  }
}
```

Output

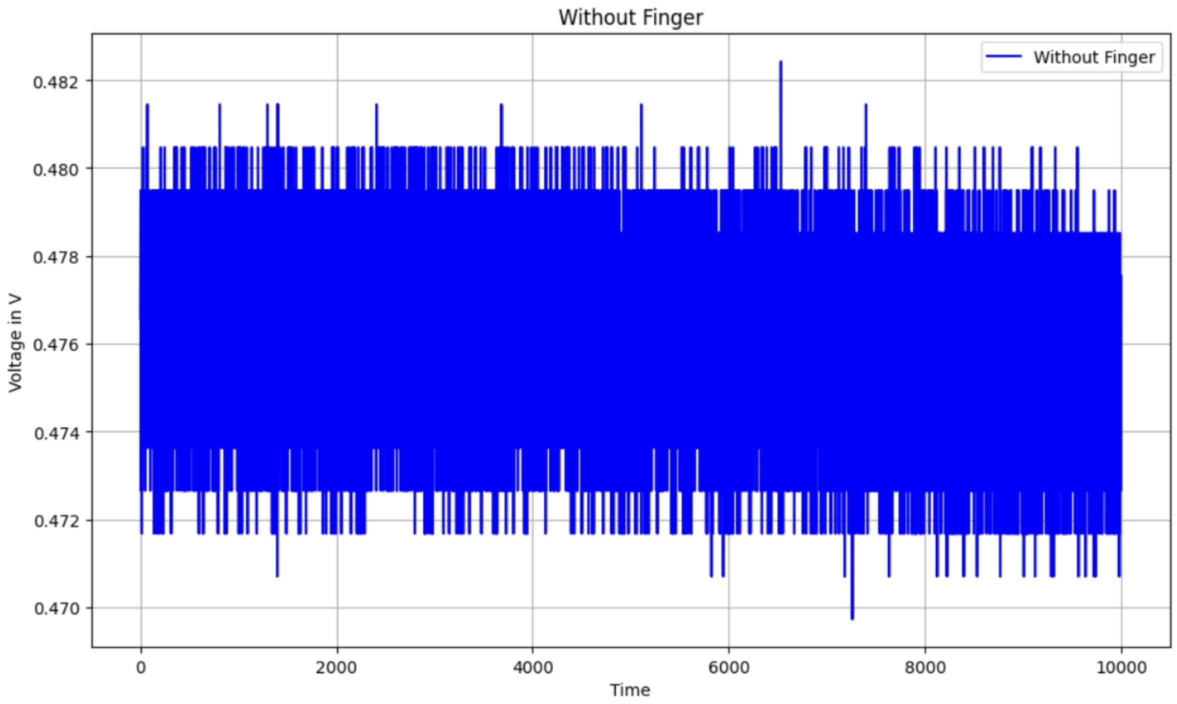
indexing: 3/32 Ln 26, Col 20 Arduino Nano 33 BLE on COM4

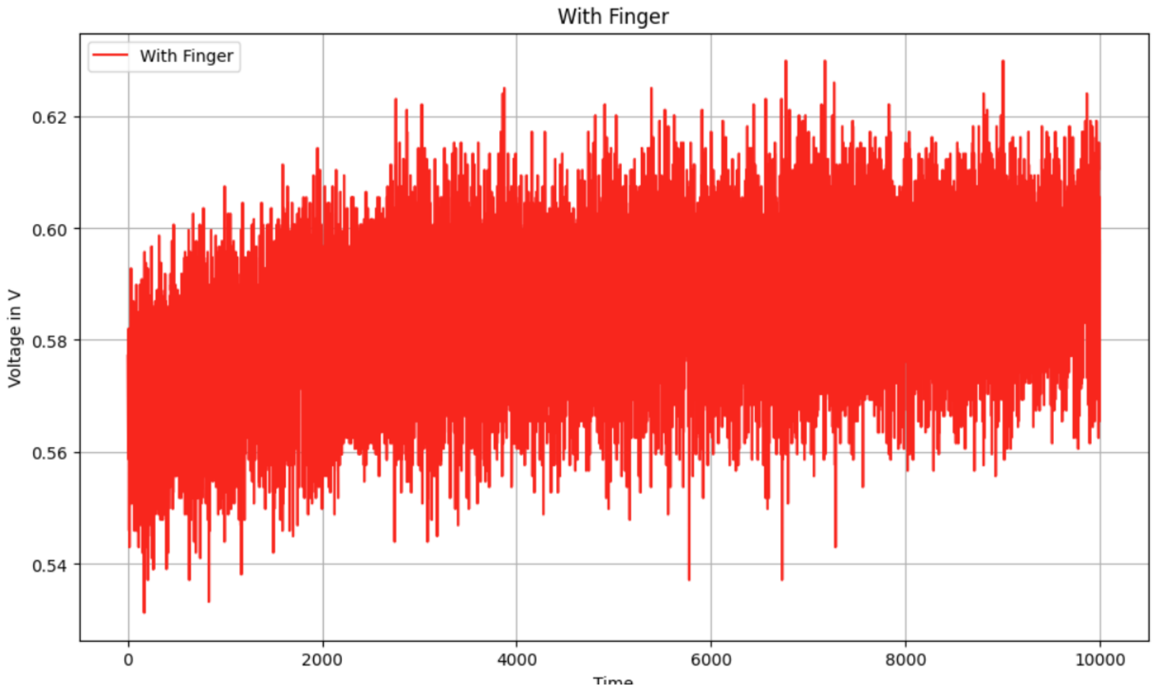
Serial plotter





Temperature plots





Noise

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Noise is a random fluctuation of the output of a sensor which is essentially unrelated to the input parameter. Common sources of noise include temperature fluctuations, electromagnetic interference, instability of the bioactive sensitive element or of the electronic circuitry, mechanical vibrations and fluid flow artifacts such as bubbles. Noise can be quantified as the root mean square x_{rms} of a sample $(x_1, x_2, \ldots x_n)$ of output signals for a given time period:

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}}.$$