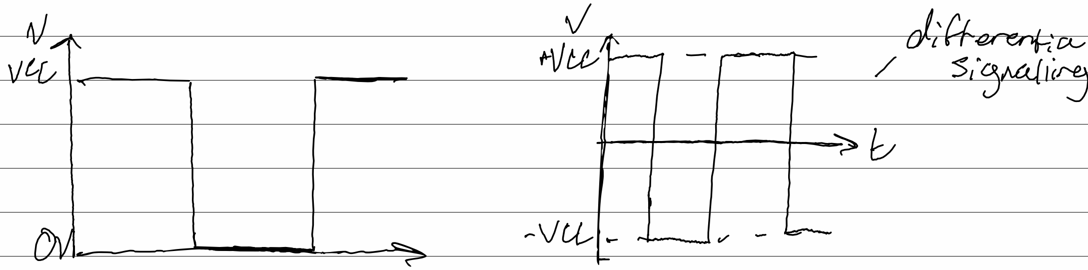
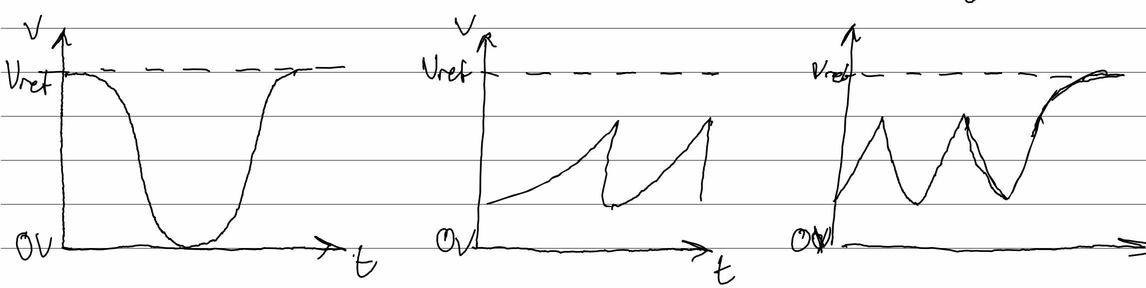
Analog Measurements

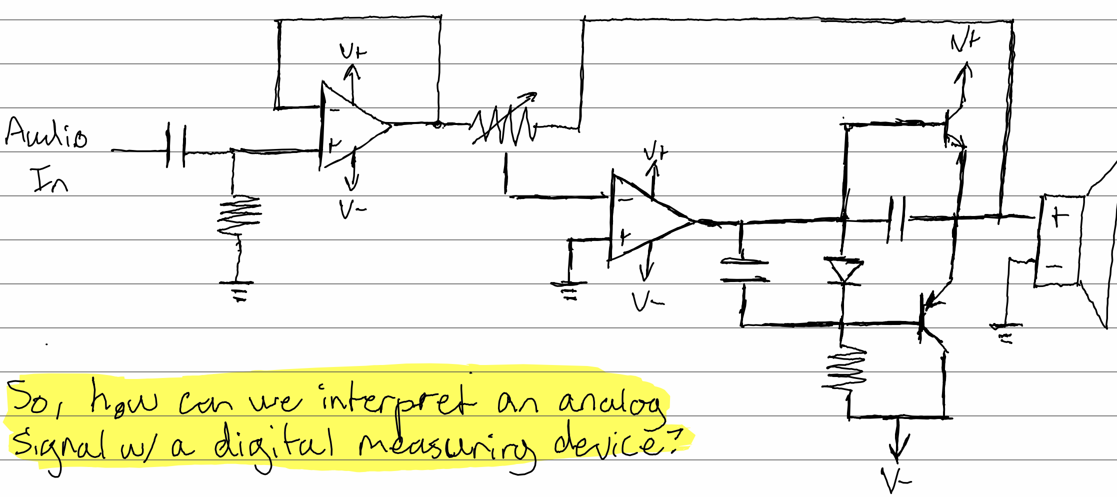
Digital Signals: Are voltages that cycle between 0V and +Vcc volts (5V = CMOS/Arduino) or +/- Vcc



Analog Signals: Are voltages that can be between 0V and Vref volts and are typically waveforms (sine, triangle, sawtooth)



Inherently, most circuits w/o a dedicated electronic controller

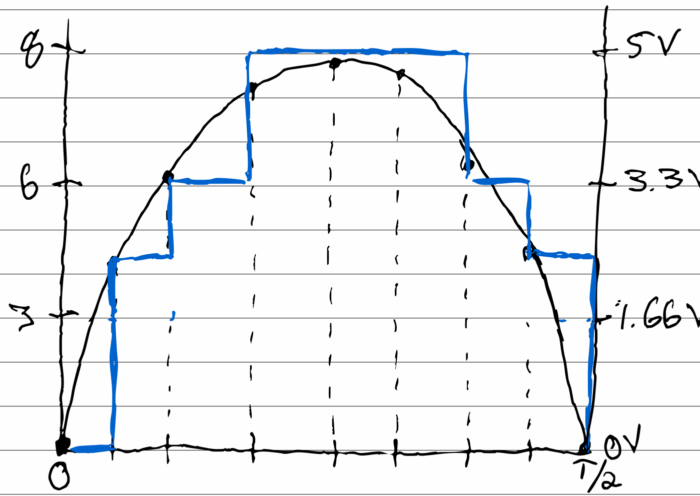


So, how can we interpret an analog signal w/ a digital measuring device?

Analog Measurements (cont.)

Analog to Digital Conversion

- Analog-to-digital converters (ADCs) sample an analog signal to create discrete points that represent the waveform



ADC value reported is a ratio of system voltage, resolution, and measured voltage.

$$\frac{\text{ADC resolution [bins]}}{\text{System Voltage [V]}} = \frac{\text{ADC Reading [bins]}}{\text{Measured Voltage [V]}}$$

In example case,

$$\frac{8\,[\text{bins}]}{5\text{V}} \cancel{=} \frac{x}{3.3\text{V}} \Rightarrow \frac{8 \cdot 3.3}{5} = x = 5.28 \Rightarrow 6$$

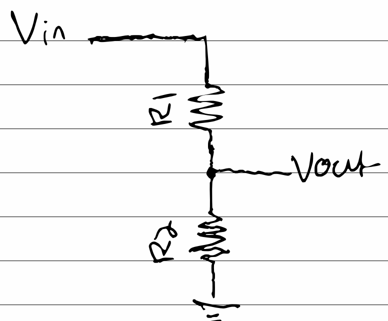
In Arduino case (10-bit ADC)

$$\frac{1024\,[\text{bins}]}{5\text{V}} \cancel{=} \frac{x}{3.3} = \frac{1024 \cdot 3.3}{5} = x = 675.84 \Rightarrow 676$$

Analog Measurements (cont.)

Voltage Divider

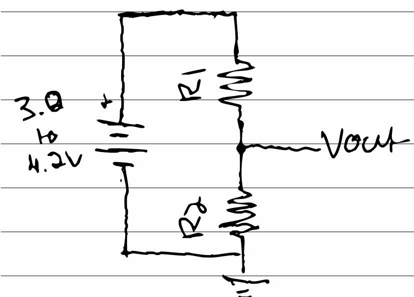
Voltage dividers lower an input voltage down to a different value depending on the value of two resistors



$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

Ex: Battery voltage monitor

$V_{io} = 3.3V$, V_{Bat} (max) $= 4.2V$. Want 4.2V to map to 3.3V



$$3.3 = 4.2V \cdot \frac{R_2}{R_1 + R_2}$$

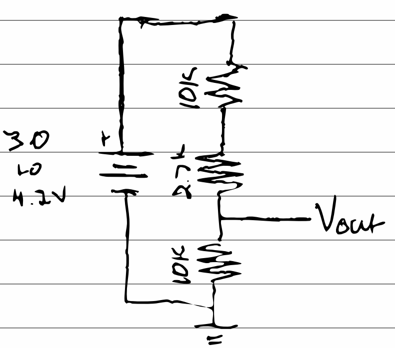
For simplicity, $R_2 = 10 K\Omega$

$$= 4.2V \cdot \frac{10 \times 10^3}{R_1 + 10 \times 10^3}$$

$$\frac{3.3}{42 \times 10^3} = \frac{1}{R_1} \Rightarrow R_1 = \frac{42 \times 10^3}{3.3} = 12.7 \times 10^3 \Omega = 12.7 K\Omega$$

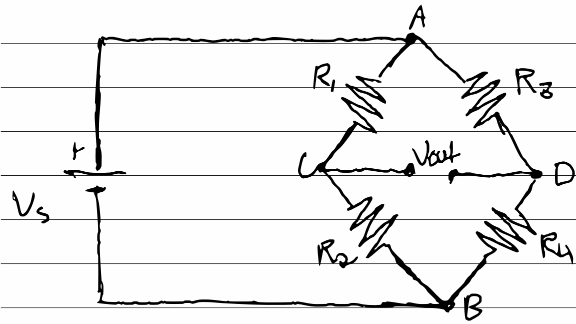
Rare!

$$12.7K = \underbrace{10K + 2.7K}_{\text{more common}}$$



Analog Measurements (cont.)

Wheatstone Bridge

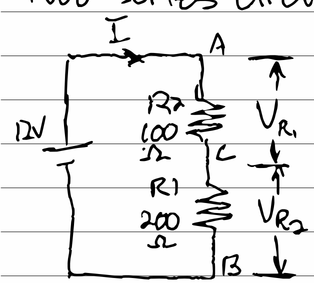


The wheatstone bridge is a way to measure and calibrate analog resistive sensors

It compares an unknown resistance to a known resistance and can allow for very low resistances (milli-ohms) to be measured.

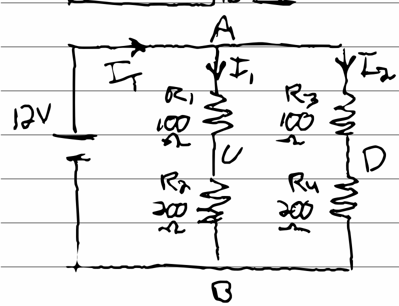
Amplifier circuits downstream of the bridge's output (Vout) can allow a digital controller to read real analog values.

This circuit is a hybrid series-parallel circuit as there are two series circuits of two resistors each, in parallel



$$I = \frac{V_S}{R_T} = \frac{12V}{300\Omega} = 0.04A$$

$$V_C = V_{R_1} = I \cdot R_2 = 0.04 \cdot 200 = 8V$$



Since $(R_1+R_2)=(R_3+R_4)$, $I_T = 0.08A$

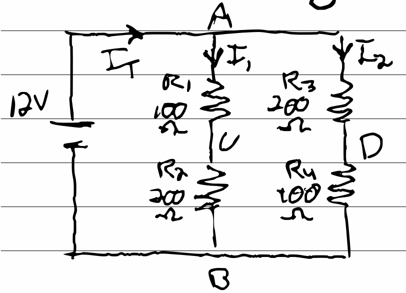
$I_T = I_1 + I_2 \Rightarrow I_1 = 0.04A$, $I_2 = 0.04A$

$V_C = V_D = 8V$, then $V_C - V_D = 0V$

The circuit is <u>balanced</u>!

Analog Measurements (cont.)

Wheatstone Bridge (cont.)



Since resistor totals are the same, current will remain the same.

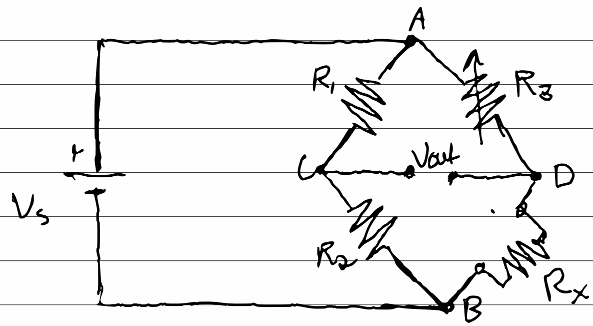
$V_D = I_2 \cdot R_4 = 0.04 \cdot 100 = 4\,V$

$V_C \neq V_D \therefore V_{DC} = V_C - V_D = 8 - 4 = 4\,V$

$\therefore$ Bridge is <u>unbalanced</u>

The resistance ratio of these parallel arms, ACB/ADB results in a voltage difference across C and D.

So, we can keep R1 and R2 known, easy constants, make R3 variable, and use R4 to be an unknown but non-zero value.



We can set the system into a known steady, "calibrated" state, and use the variable resistor, R3, to "balance" the bridge.

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} = 1 \Rightarrow \text{"Balanced"}$$

$$V_{out} = (V_C - V_D) = \cancel{V_{in}}\left(\frac{R_2}{R_1+R_2} - \frac{R_x}{R_3+R_x}\right) = 0 \rightarrow \text{when balanced}$$

Where R_1 and R_2 are known or preset values.

$$\frac{R_2}{R_1+R_2} = \frac{R_x}{R_3+R_x}$$

$$R_2(R_3+R_x) = R_x(R_1+R_2)$$

$$R_2R_3 + \cancel{R_2R_x} = R_xR_1 + \cancel{R_xR_2}$$

$$\boxed{\frac{R_2R_3}{R_1} = R_x.}$$

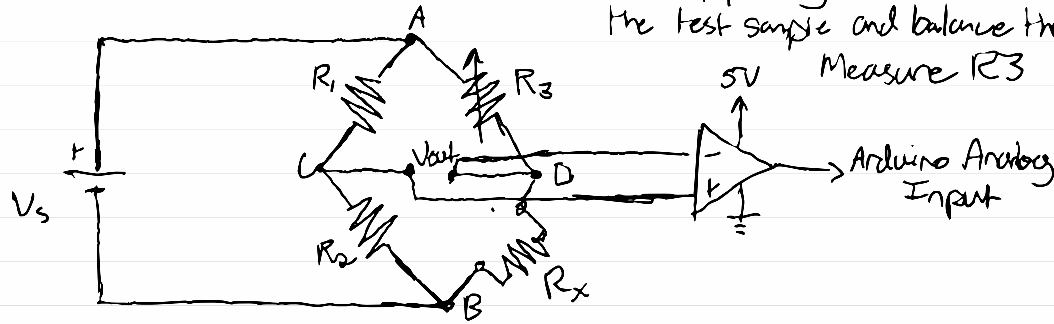
Analog Measurements (cont.)

Wheatstone Bridge (cont.)

Ex: Load cell (Strain guage)

Start by placing the loadcell on the test sample and balance the bridge

Measure R3



- Arduino will dectet the voltage difference across C and D through the OP-Amp and analog input
- Can calculate R_x using circuit theory.
- Correlate R_x w/ sensor Ohms/mil or Ohms/mm value to calculate the elongation.