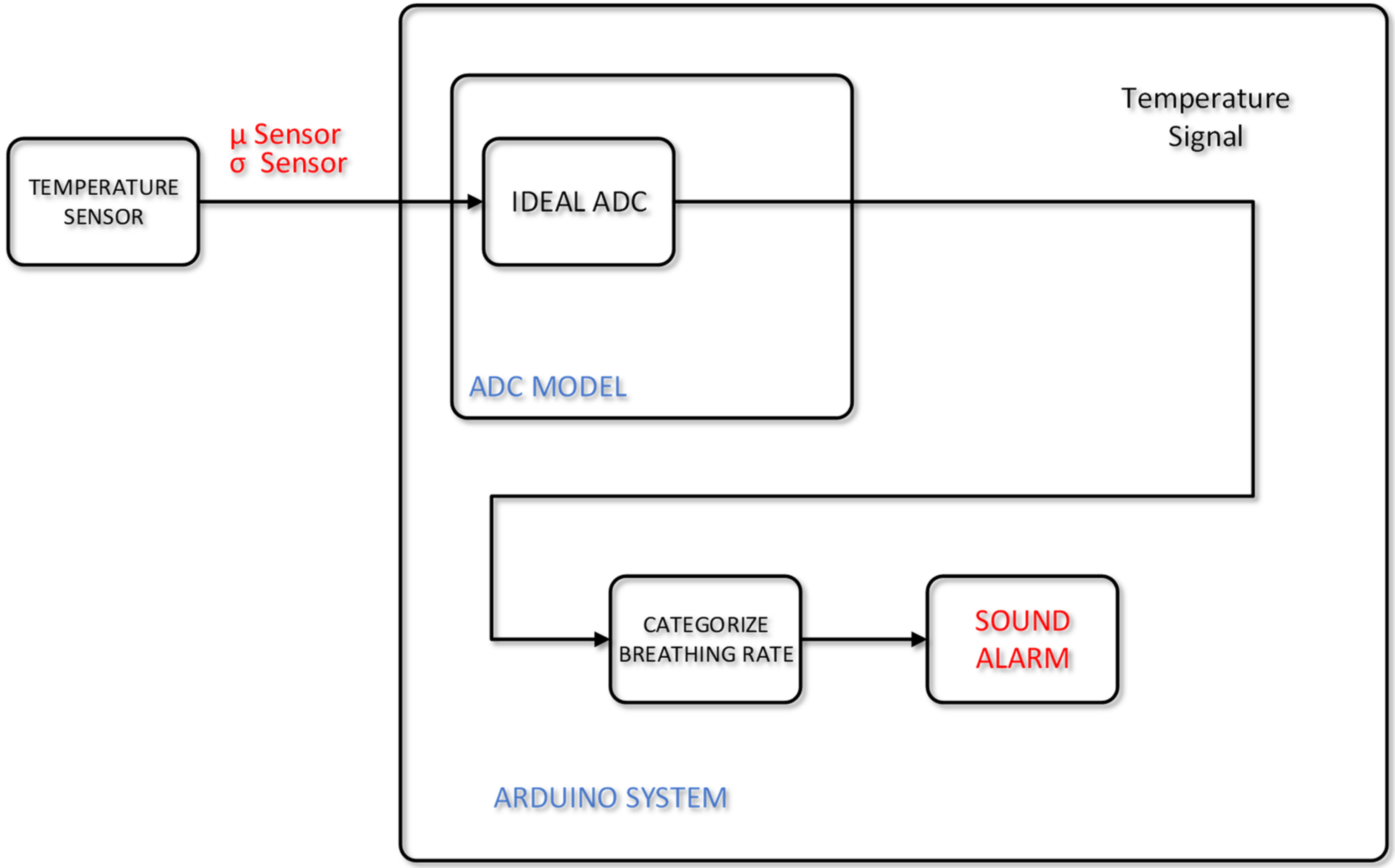
Digital Signal Processing

Lab 4 Introduction

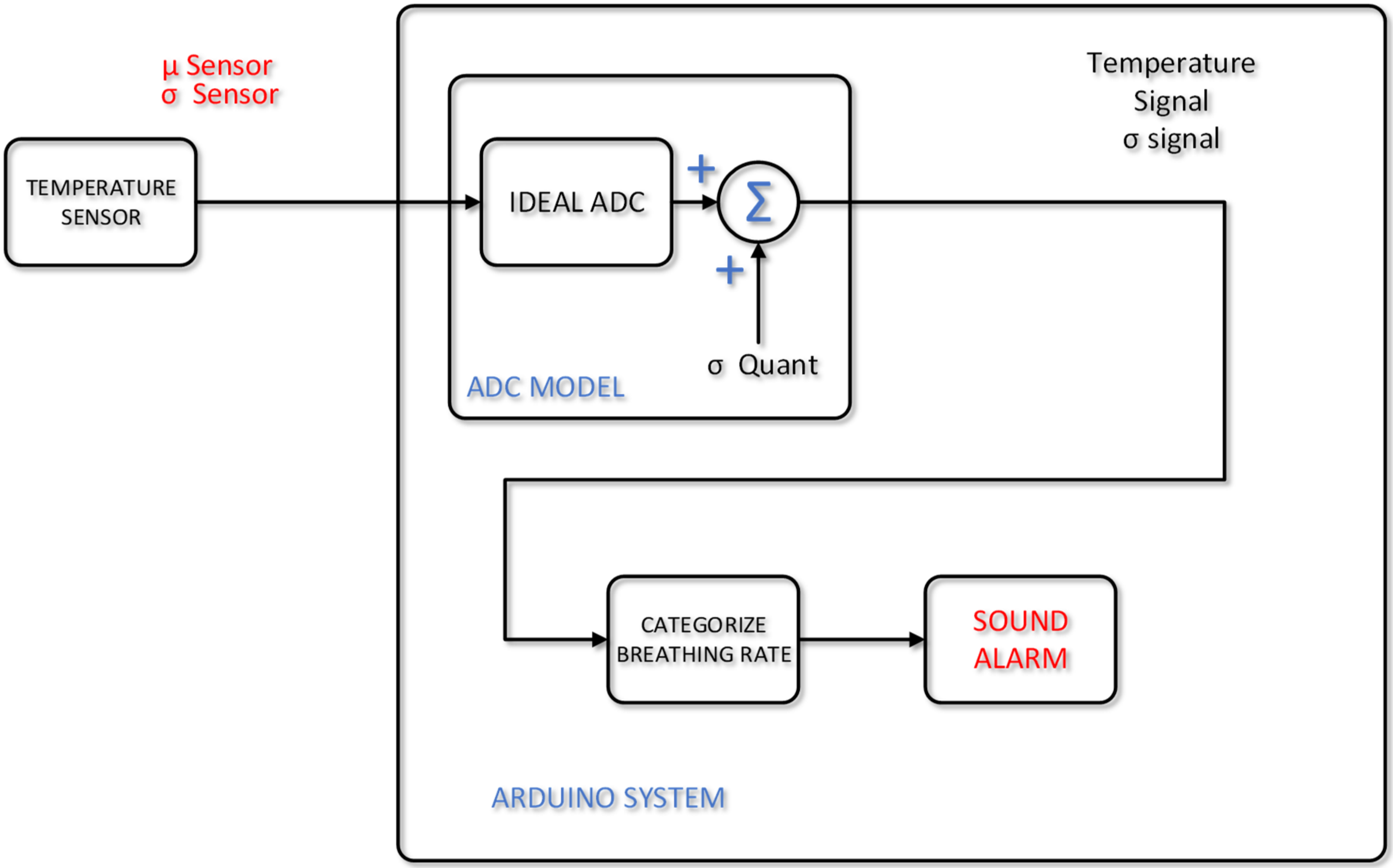
DSP Lab 4 -- Description

- Lab 4 will help you understand various noise contributions in the system
- Being able to make good temperature measurements is key in completing the final project
- There are a number of sections to this lab that need to be understood as you proceed
- Even though this is a two week lab, your team will need to work outside of your scheduled lab period to complete
    - Now is a good time to think about the division of labor in your team for Lab #4 and future labs
    - Plan for at least 2 prototype systems running for each team for this and future labs

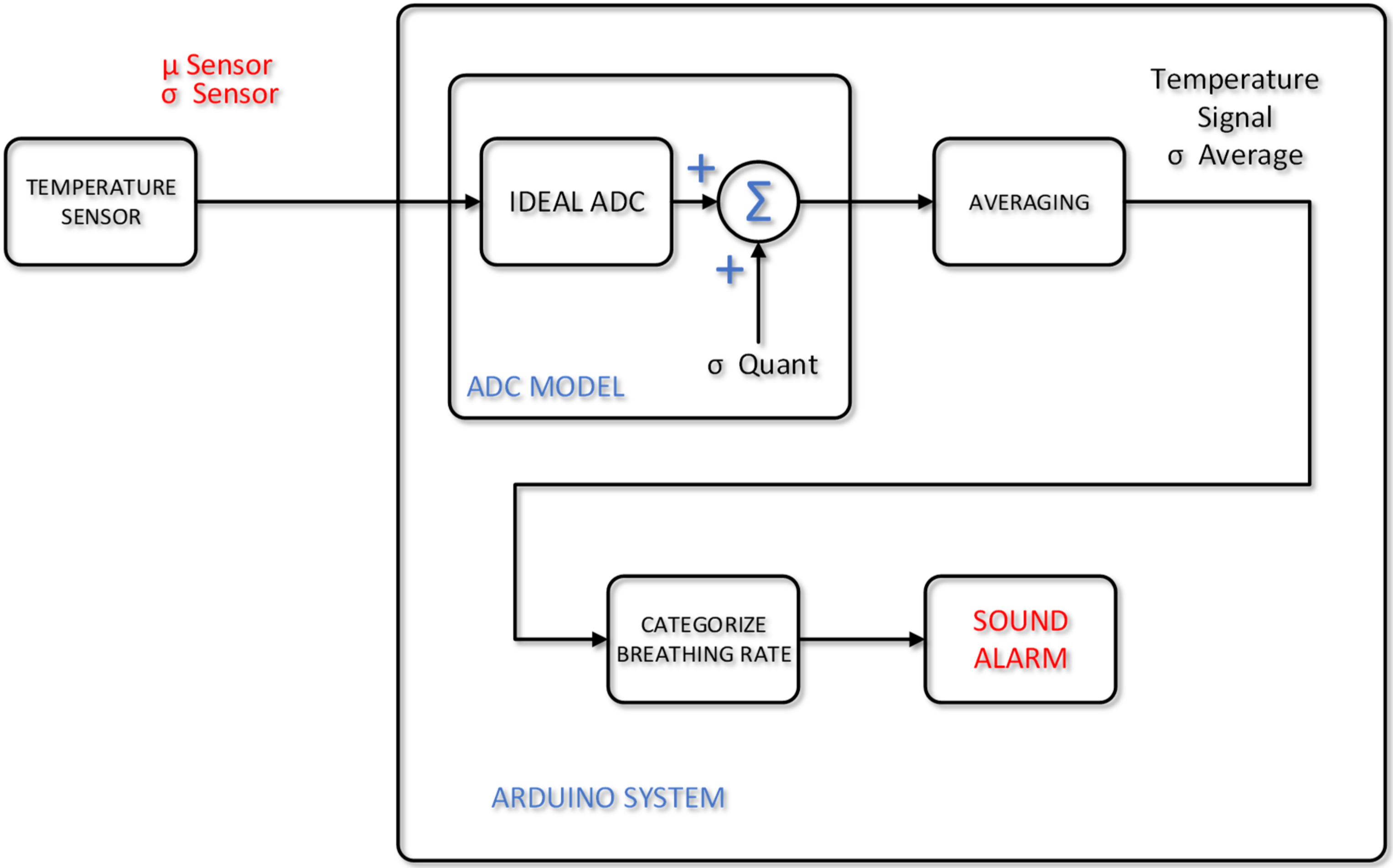
Pneumonia Detection System



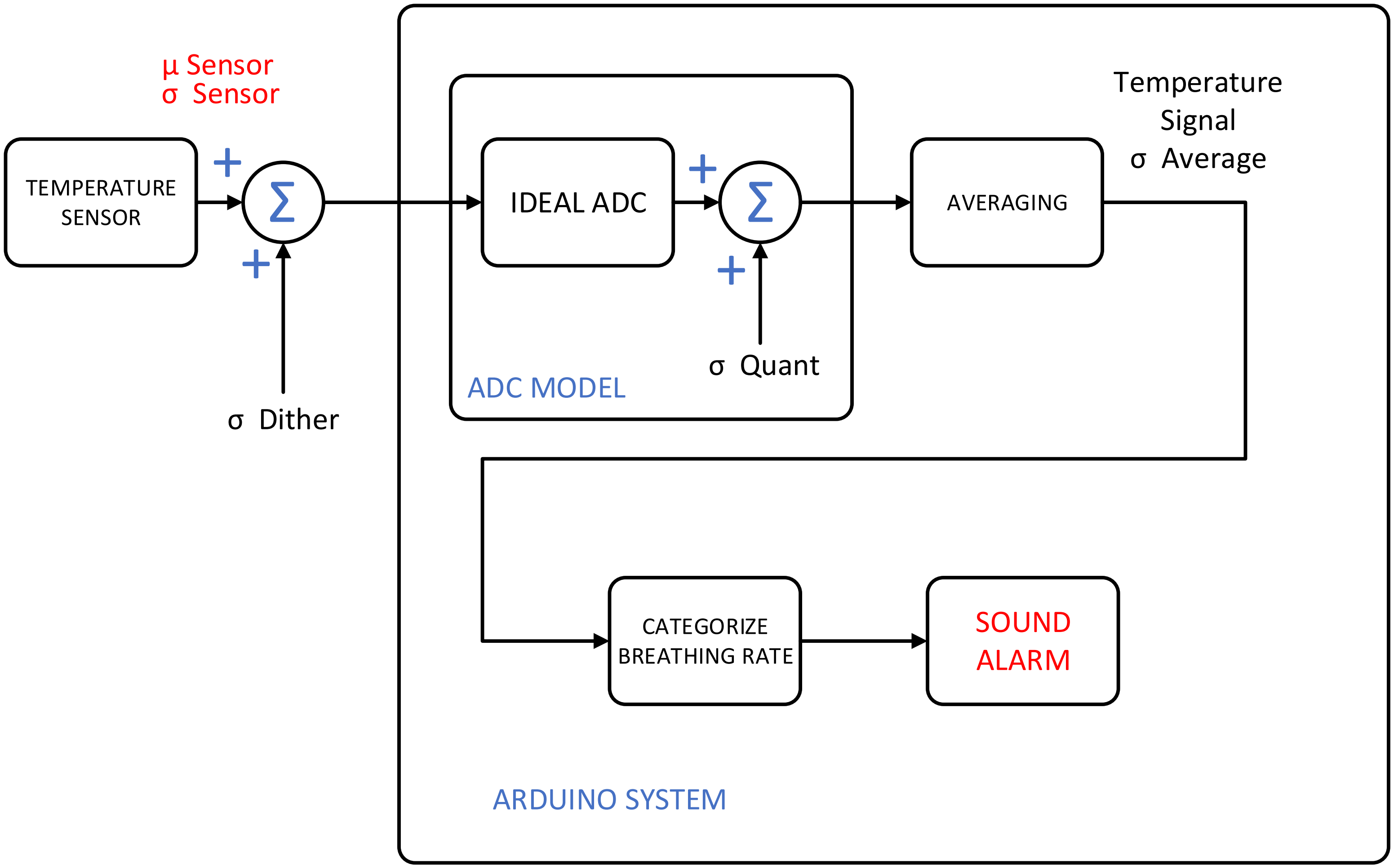
Quantization Noise and Sensor Noise



Oversample Averaging

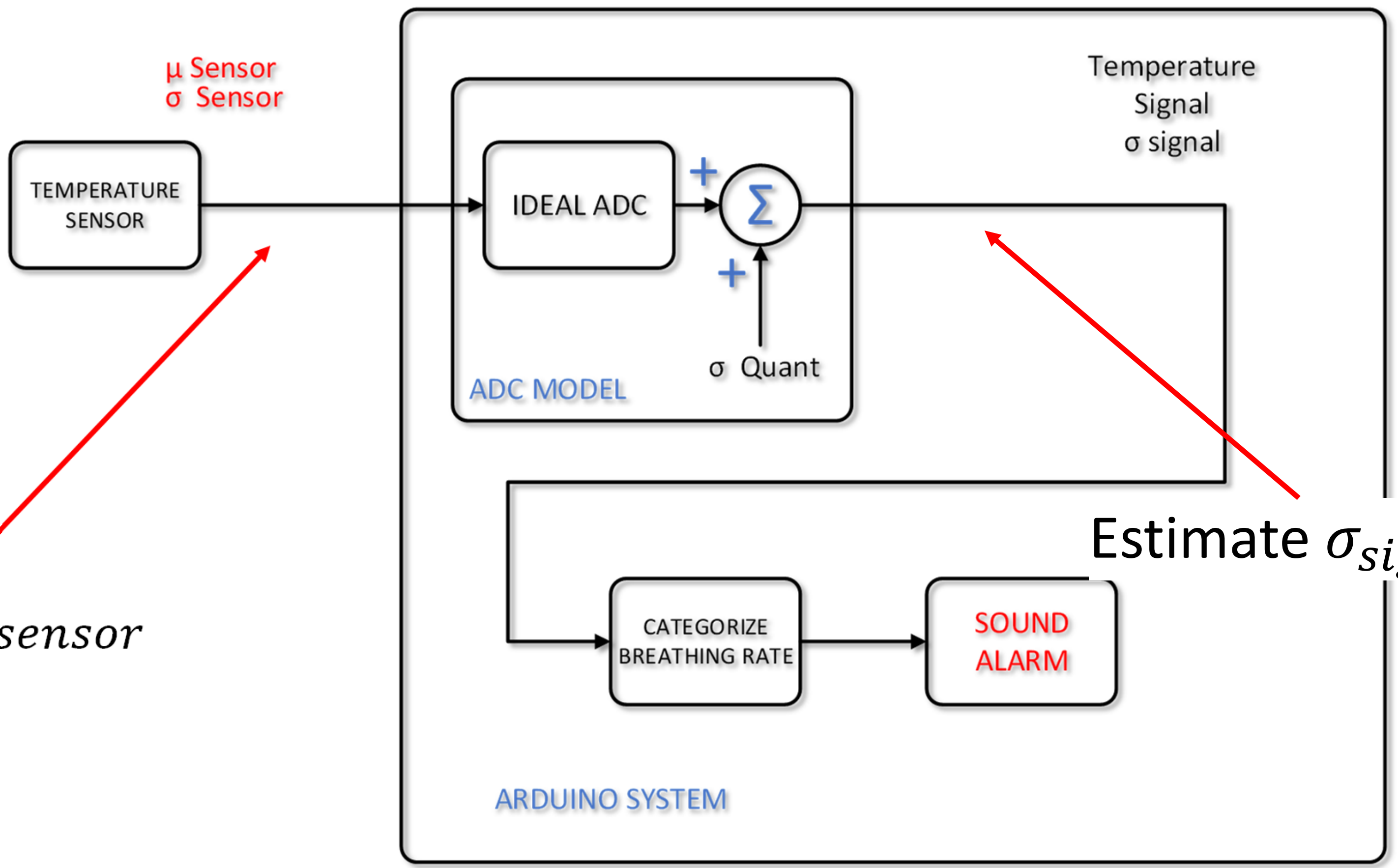


Adding Dithering



DSP Lab 4 -- Description

Part 1a -- Estimate of the temperature sensor noise

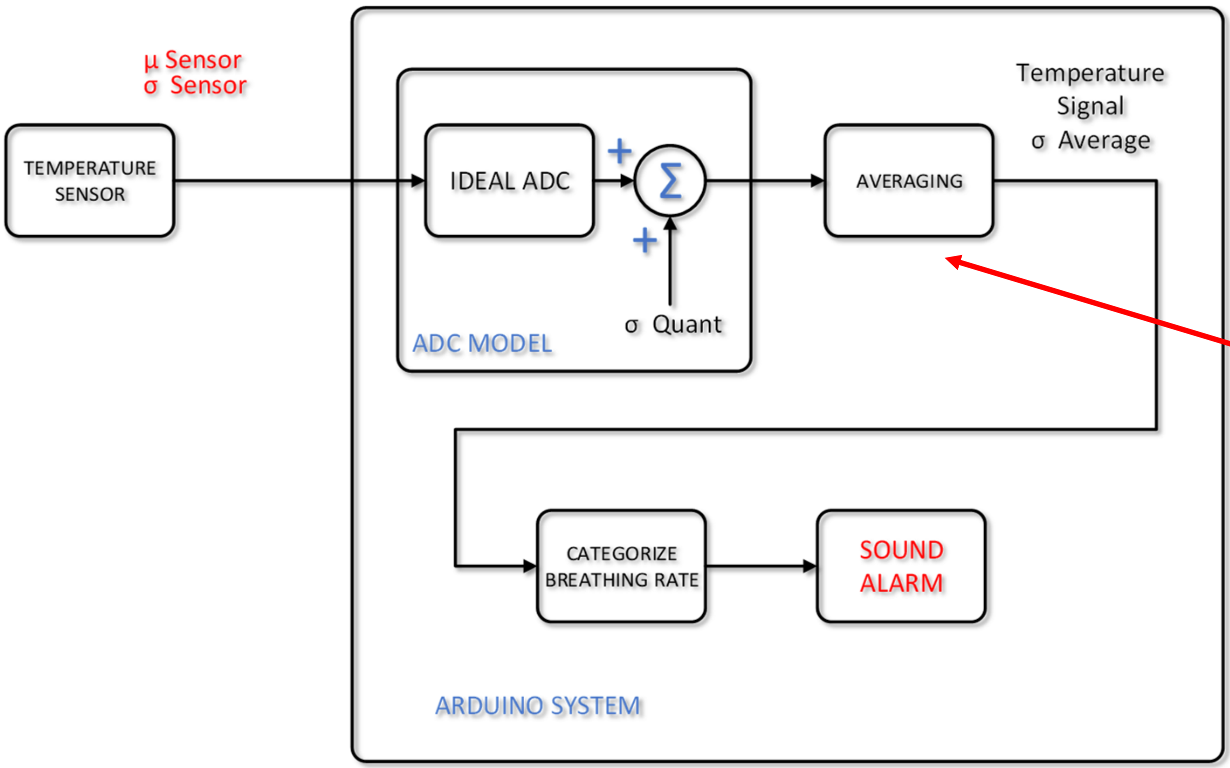


Estimate σ_{sensor}

Estimate σ_{signal}

DSP Lab 4 -- Description

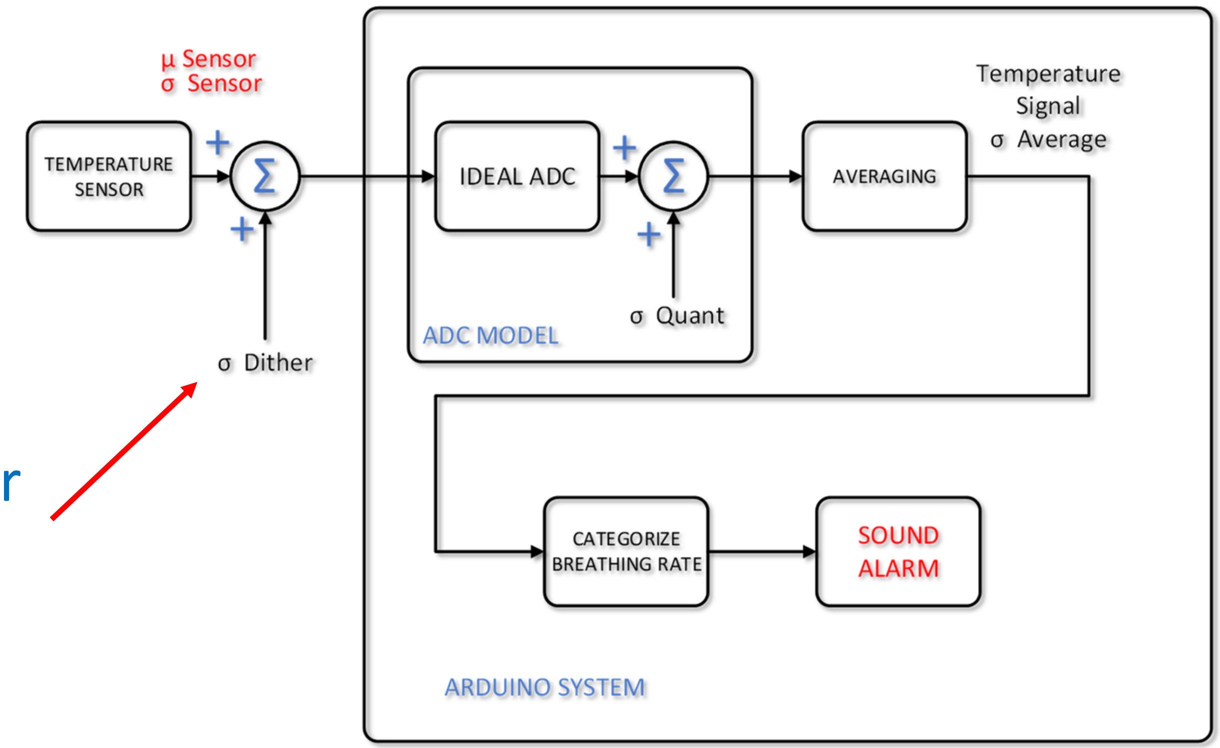
Part 1b – Try using oversampling to try and reduce quantization noise



Add oversample averaging to see if that improves things

DSP Lab 4 -- Description

Part 1c – Build and test a DAC to generate a dithering signal. Using dither to reduce the effects of quantization noise



Add “dither” noise to better distribute Q-Noise

DSP Lab 4 -- Description

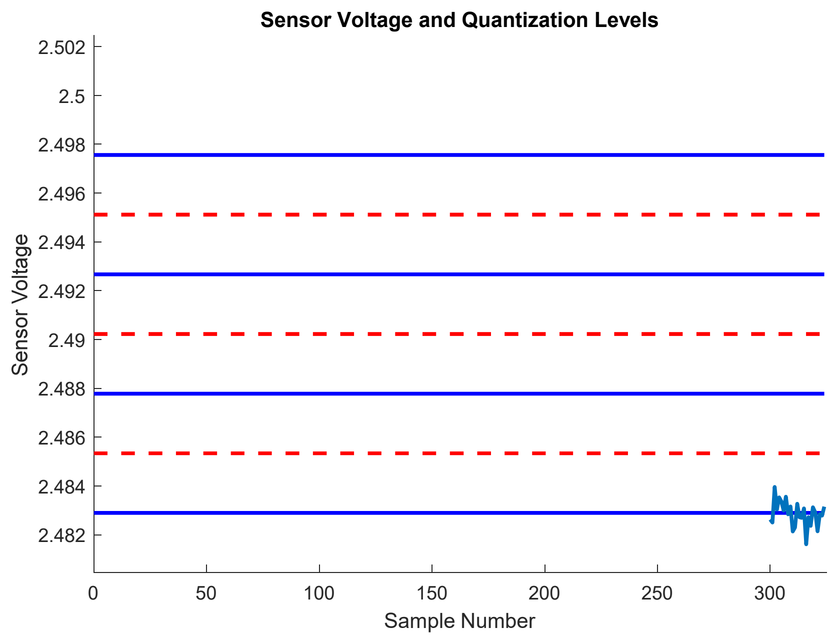
Part 1d – Estimate the improved resolution and effective number of bits

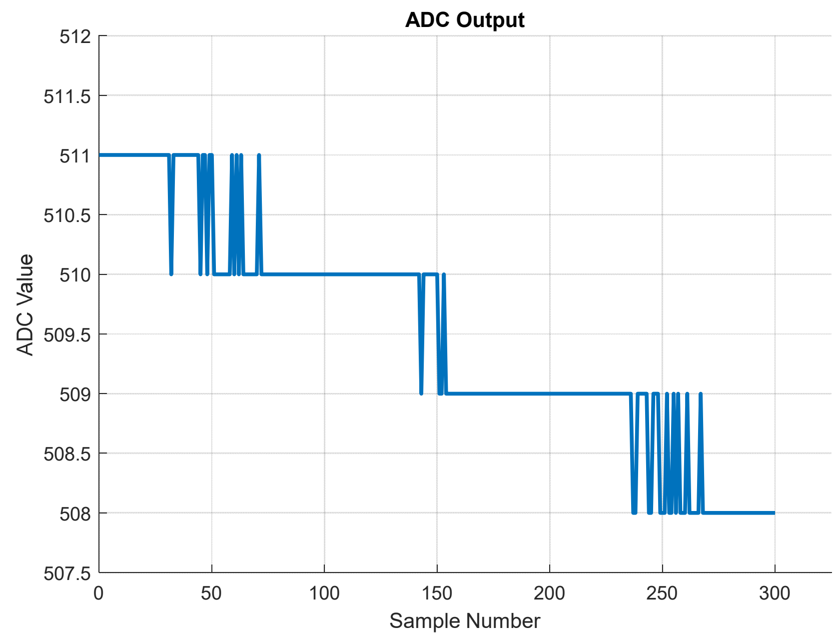
Part 2 – Calculating signal to noise ratio estimate of the temperature sensor noise

DSP Lab 4

Estimating Sensor Noise

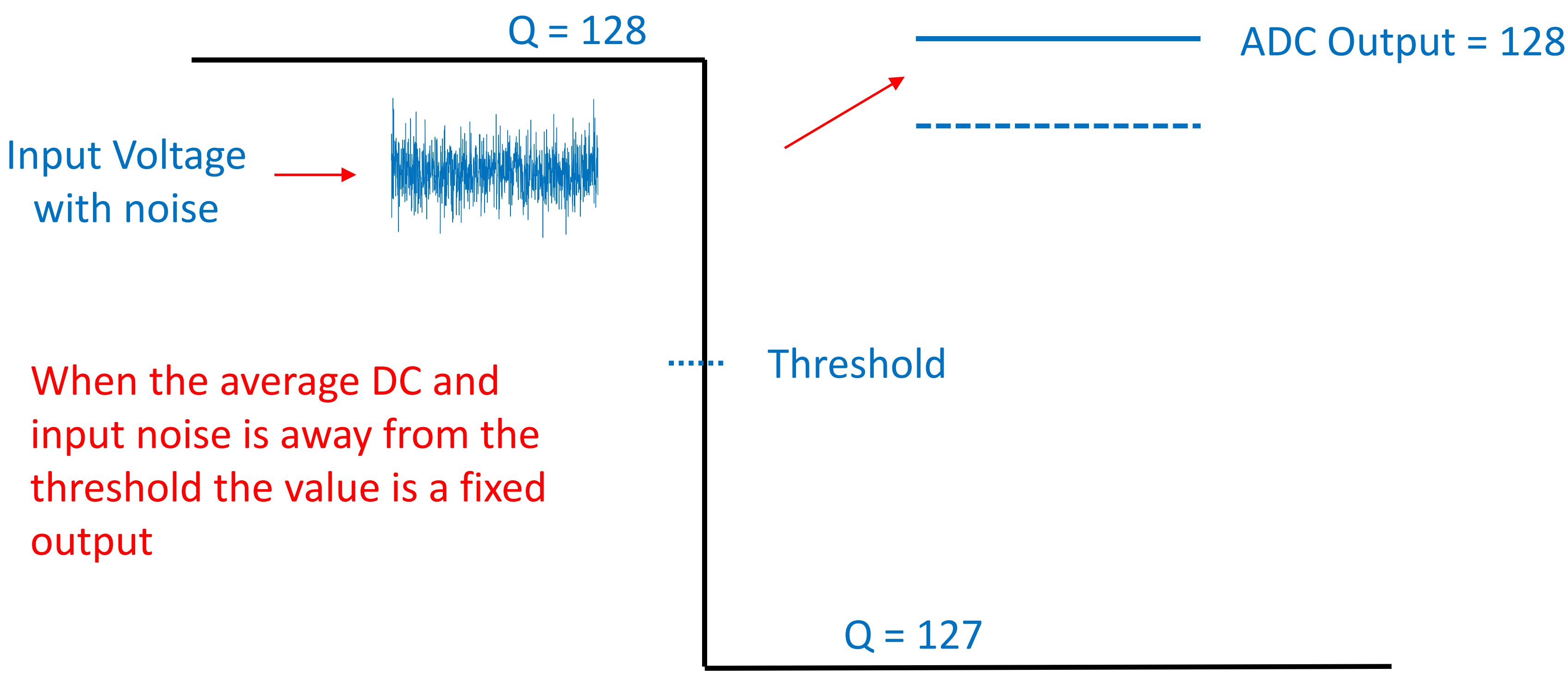
Chatter Noise Demo





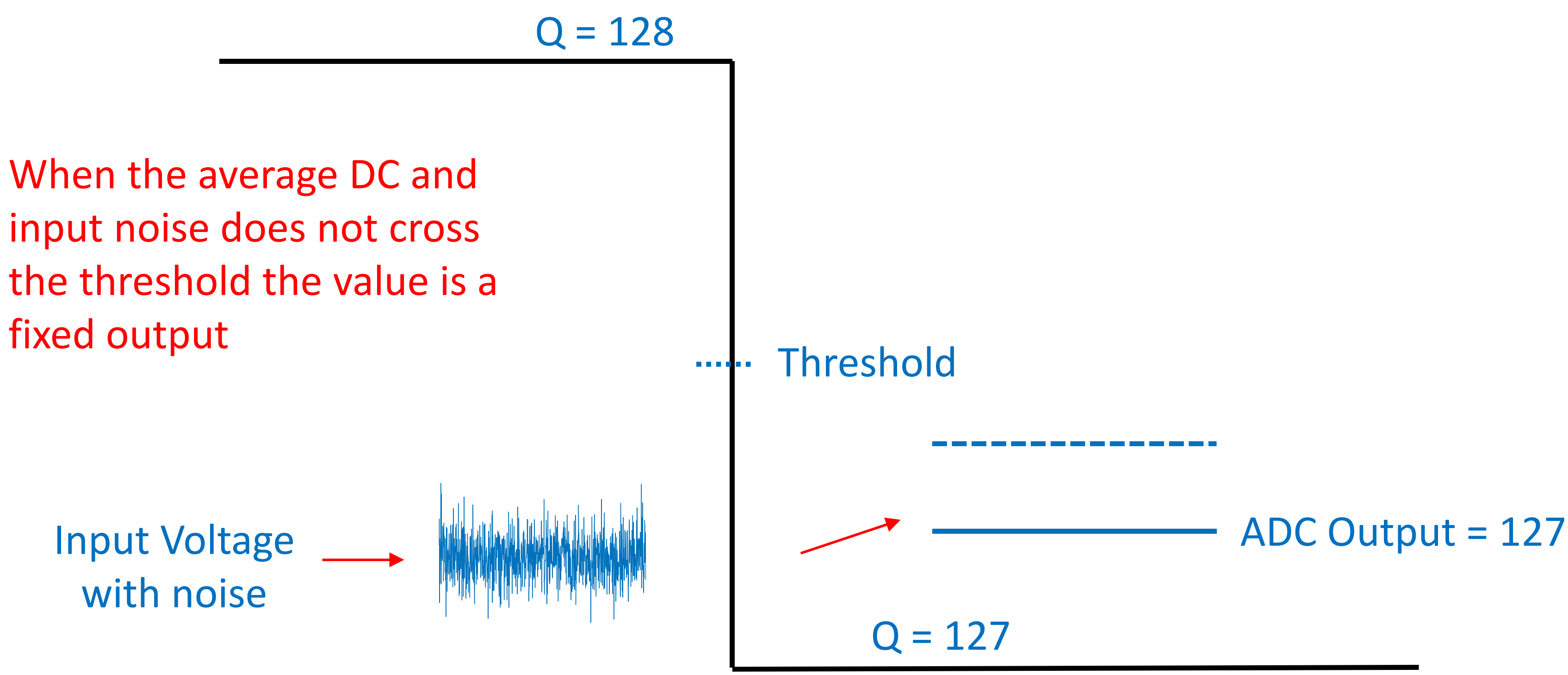
Estimating the Sensor Noise

- The sensor has an average DC value with some noise impressed on it



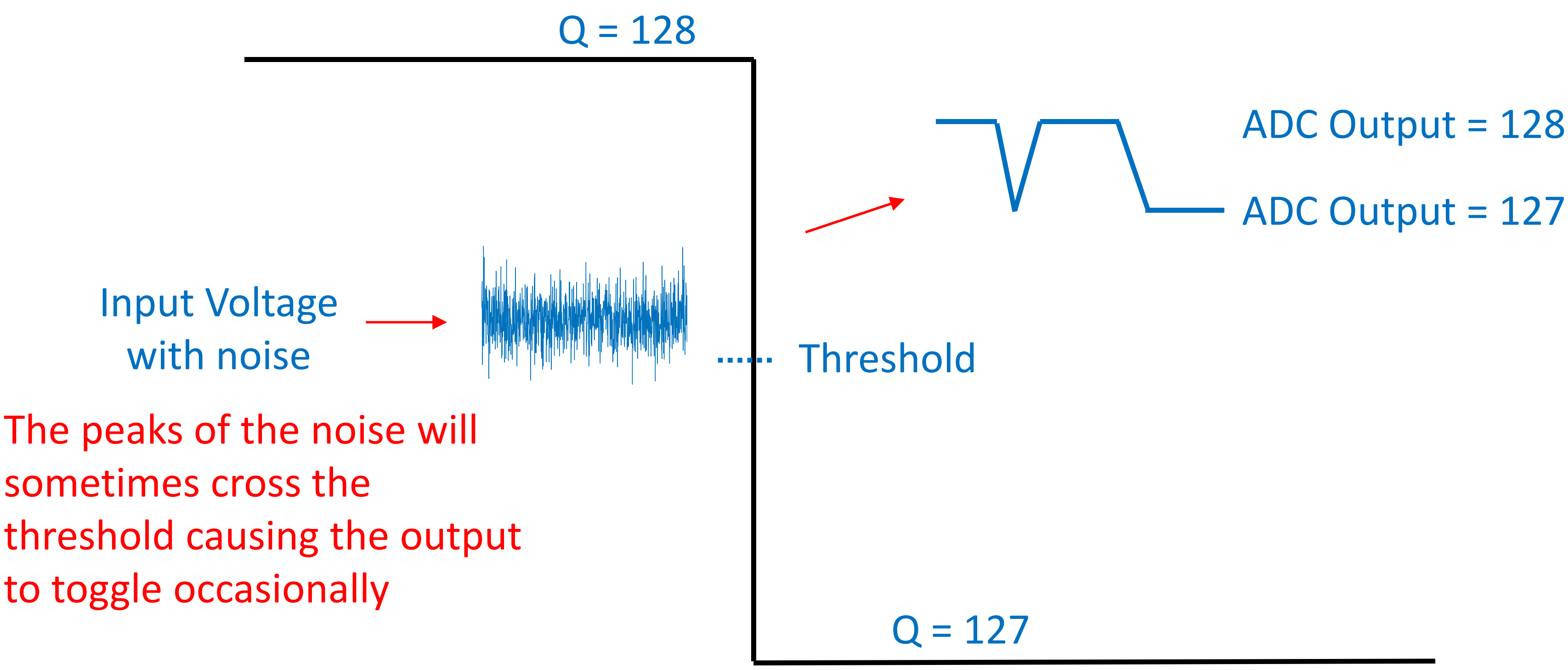
Estimating the Sensor Noise

- The sensor has an average DC value with some noise impressed on it



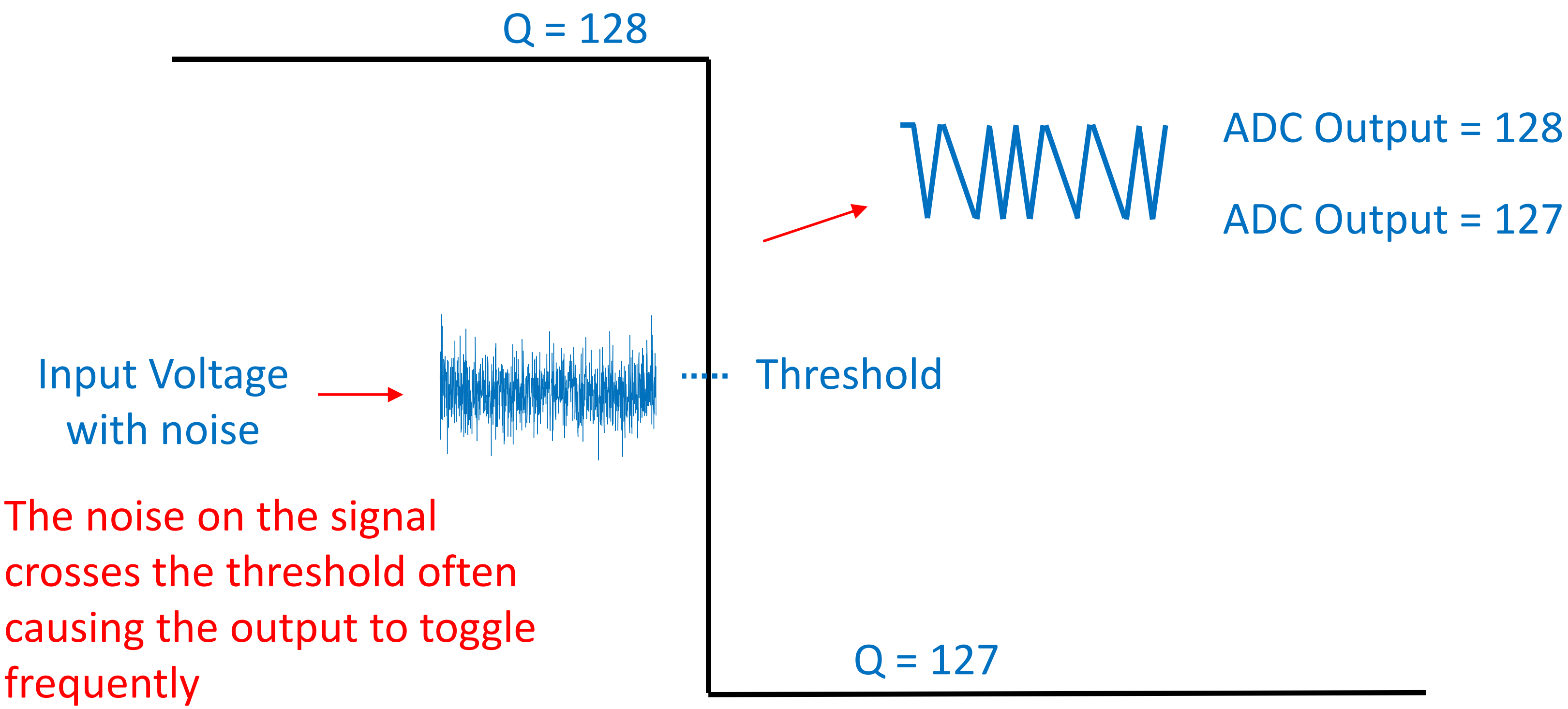
Estimating the Sensor Noise

- As the peaks of the noise cross the threshold some toggling of the output value occurs



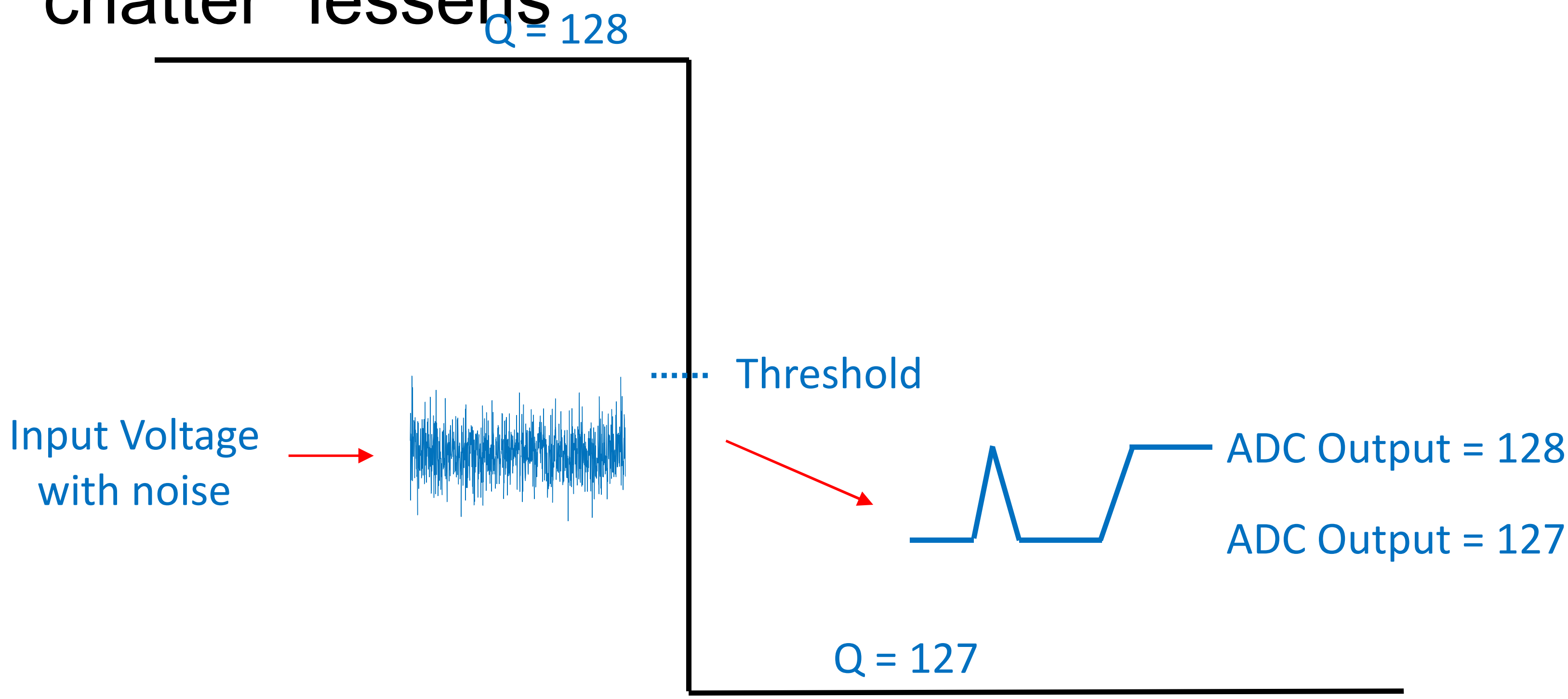
Estimating the Sensor Noise

- As the mean is centered at the threshold the output “chatters”



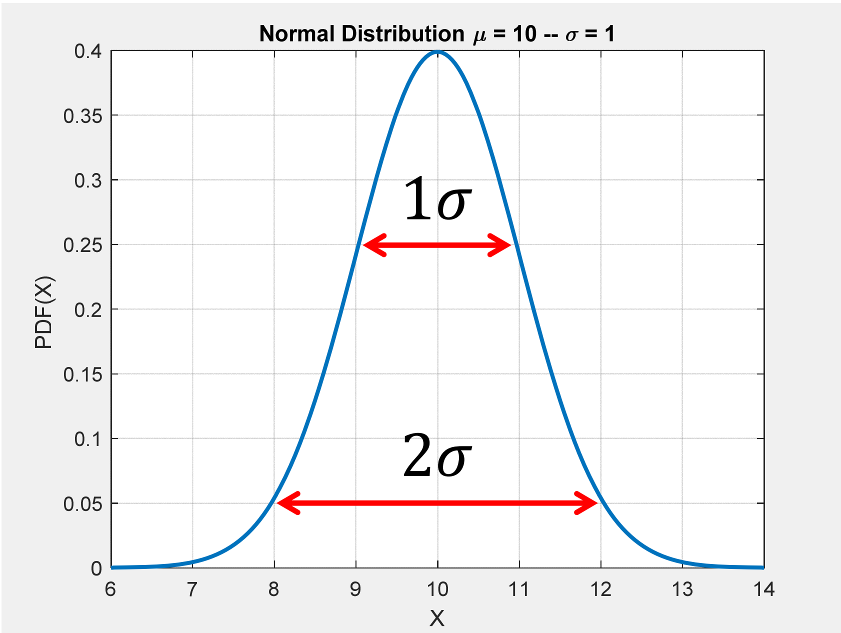
Estimating the Sensor Noise

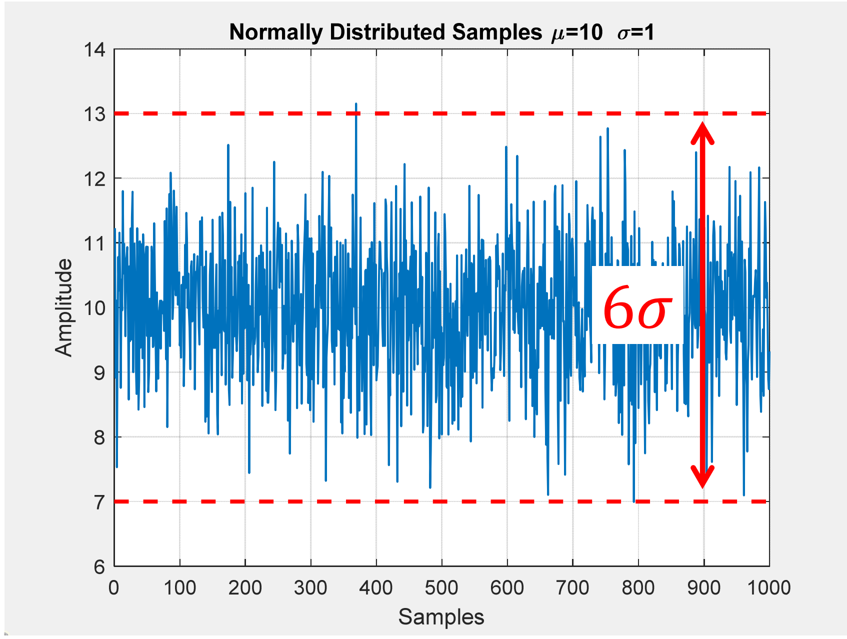
- As the signal drifts further downward the “chatter” lessens



Peak to Peak Value of Normally Distributed Noise

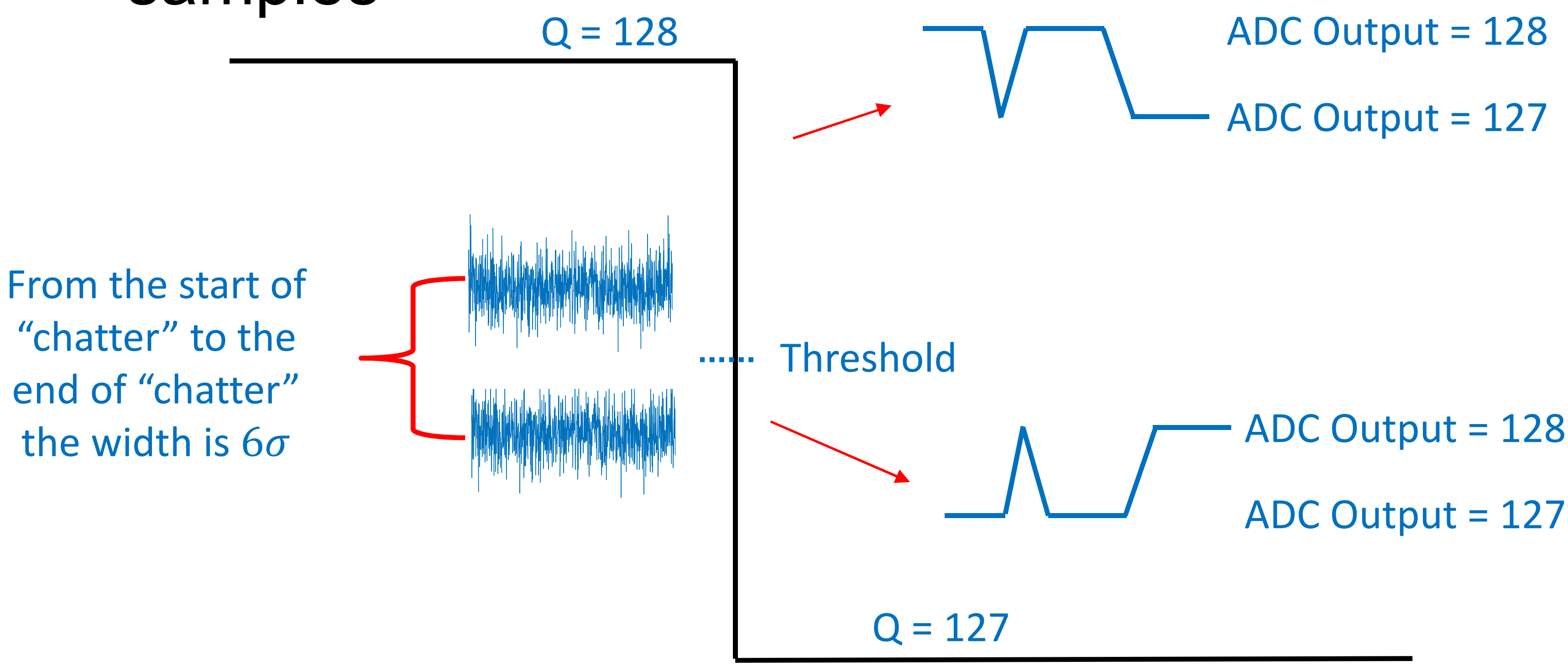
- The likelihood of values far from the mean, e.g. 4 sigma away from the mean, is very low.
- This is why the signal appears to have a bounded peak to peak value of ~6-8 times sigma $(\pm 3\sigma\ to\ \pm 4\sigma)$





Estimating the Sensor Noise

- The width of the chatter is 6σ in units of "samples"



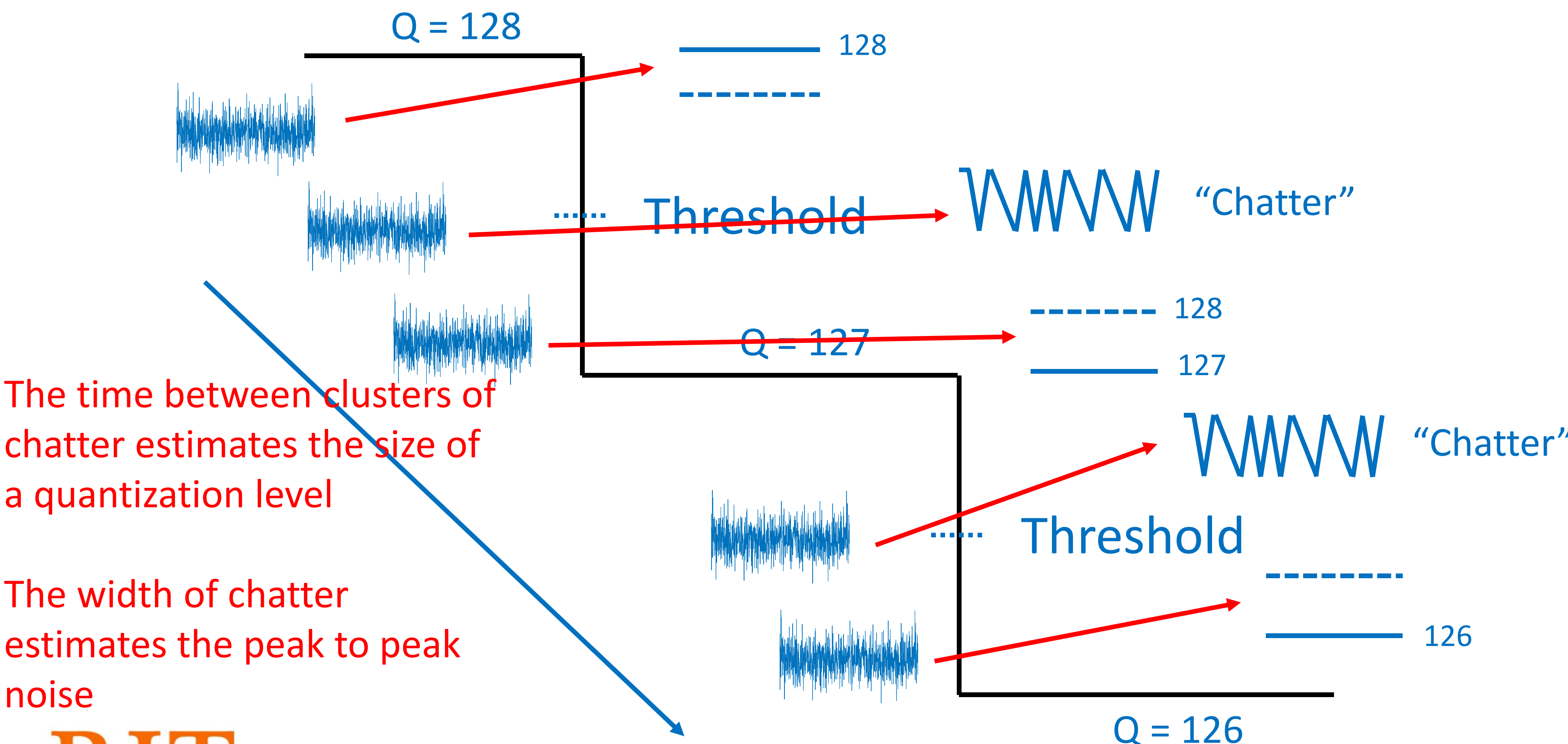
Measuring Sensor Noise Using the "Pinch" Test

- The sensor temperature is elevated (by pinching the sensor) and then allowed to decay

- As the temperature cools, the voltage will slowly decrease and move between quantization levels

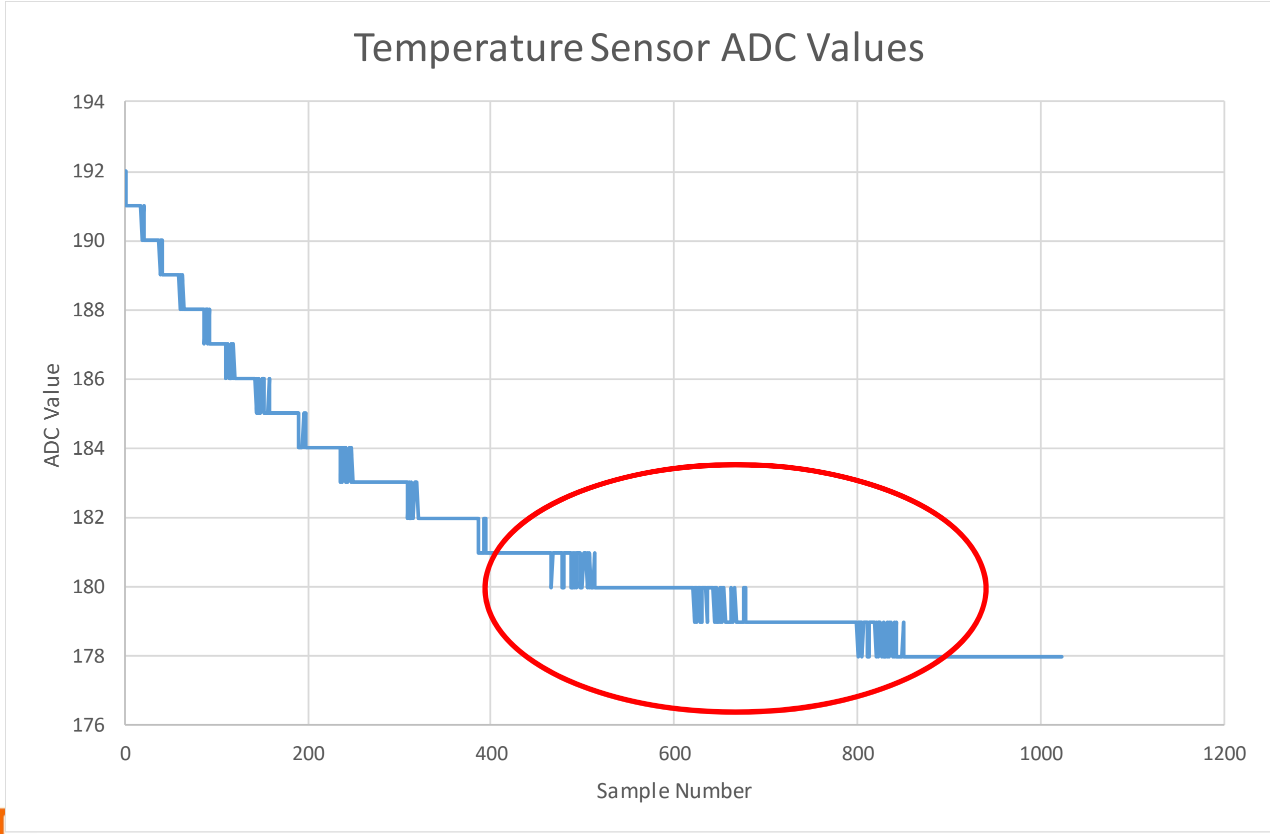
Measuring Sensor Noise Using the “Pinch” Test

- The time (samples) between clusters estimates the magnitude of the bit in “samples”



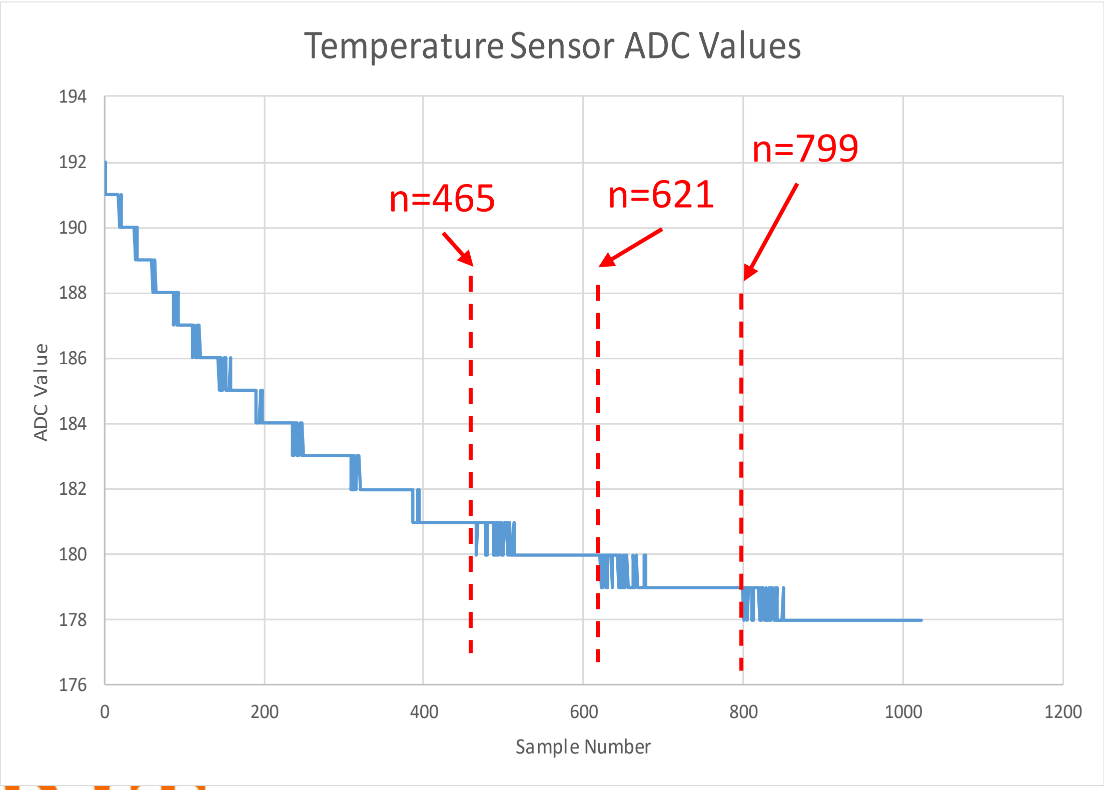
Measuring Sensor Noise Using the "Pinch" Test

- Adjust your procedure to get several clusters that have a significant width of "chatter"



Measuring Sensor Noise Using the "Pinch" Test

- Measure the distance between clusters. This is representative of the quantization magnitude



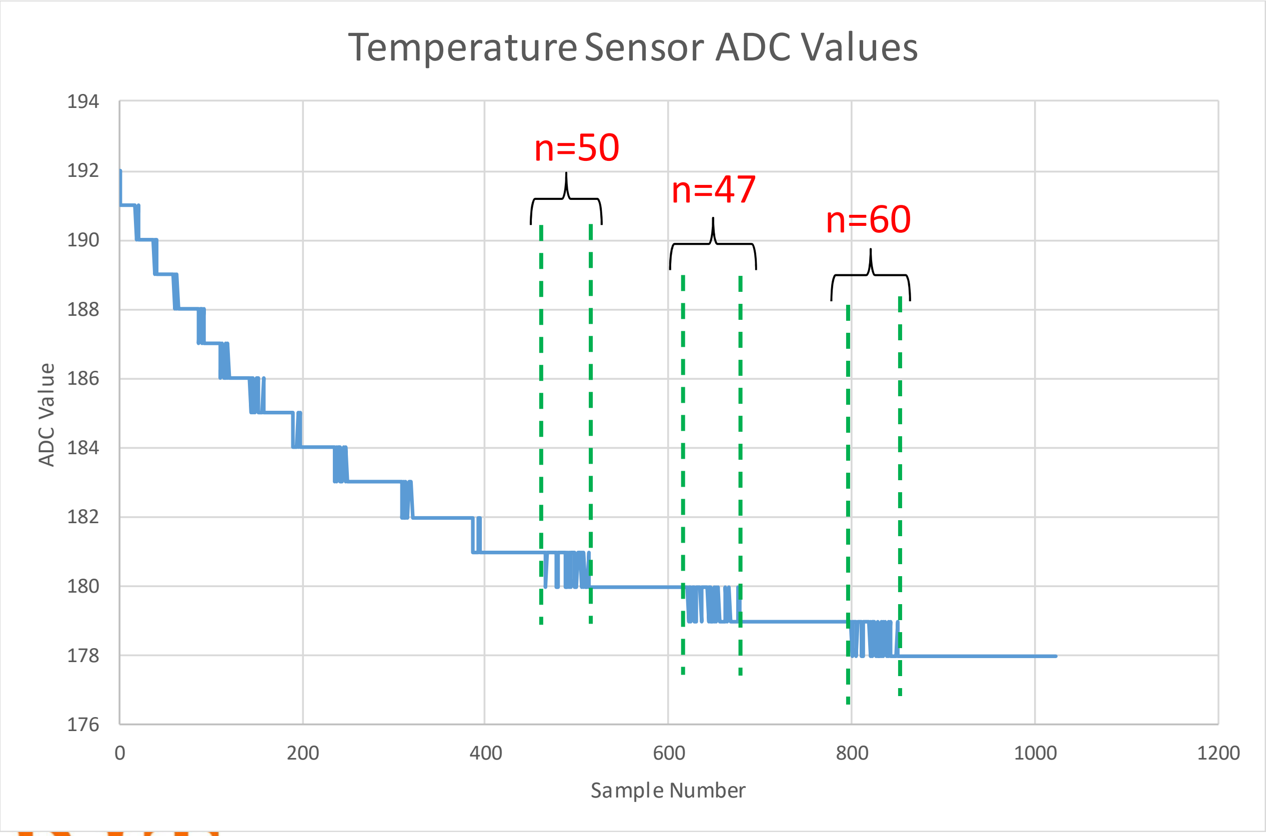
$$d_1 = 621 - 465 = 156$$

$$d_2 = 799 - 621 = 178$$

$$d_{average} = 167$$

Measuring Sensor Noise Using the "Pinch" Test

- Measure the width of the clusters. This is representative of the standard deviation of the noise



Use the average width

Average = 52.33

Estimating Sensor Noise

- The width of the "chatter" (in samples) is an estimate of the peak to peak value of the noise
- The σ of the noise can be estimated by taking the peak-peak values and dividing by 6

$$\sigma_{sensor} \approx \frac{chatter\ width}{6}$$

Units are samples

$$\sigma_{sensor} \approx \frac{52.33}{6} = 8.72\ samples$$

Estimating Sensor Noise

- The distance between each bit can be represented by the number of samples between “clusters” of “chatter”
- We can use this to estimate how large a bit is in samples

$$distance\ between\ chatter \rightarrow d\,\frac{samples}{bit}$$

$$d = \frac{samples}{bit} = 167\,\frac{samples}{bit}$$

Estimating the σ of the Sensor Noise

- Then we can estimate the sensor noise in bits or code values

$$\sigma_{sensor} \approx \frac{chatter\ width}{6}$$

$$distance\ between\ chatter \rightarrow d\,\frac{samples}{bit}$$

$$\sigma_{bits} = \frac{\sigma_{sensor}}{d\left(\frac{samples}{bit}\right)} = \frac{8.72\ samples}{167\left(\frac{samples}{bit}\right)} = 0.052\ bits$$

Estimate the ADC output Noise

- Recall that σ of multiple noise sources add in quadrature

$$\sigma_{total} = \sqrt{\sigma_1^2 + \sigma_2^2}$$

- The total output noise of the ADC is the combination of the sensor noise and quantization noise

$$\sigma_{ADC} = \sqrt{\sigma_{sensor}^2 + \sigma_{quant}^2}$$

DSP Lab 4

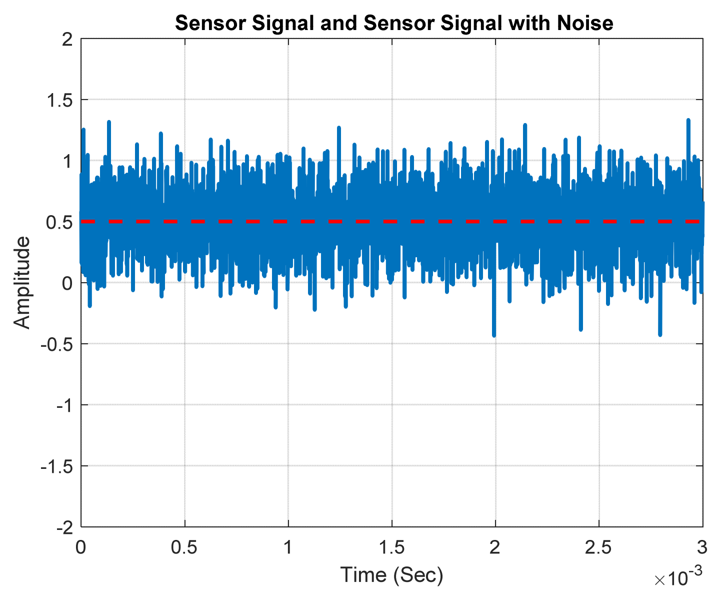
What is our signal?

How Compute SNR?

What is Our Signal?

- Simply -- The signal is the information that we are interested in.

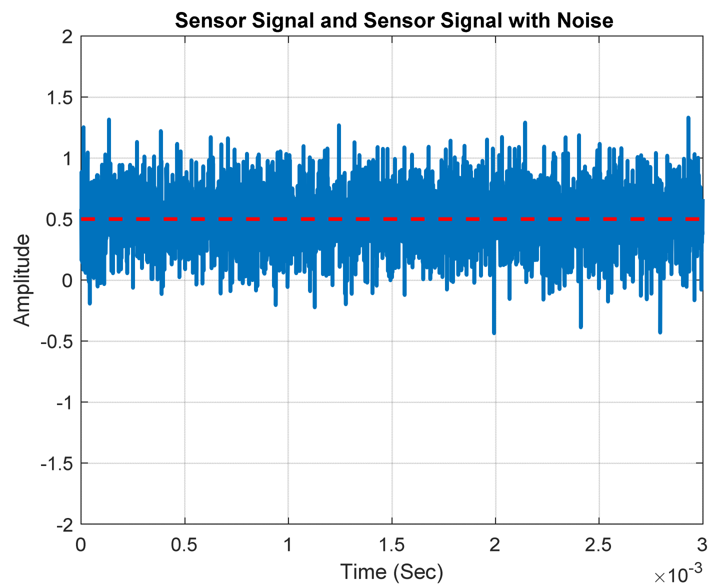
- It could be a DC voltage



What is Our Signal?

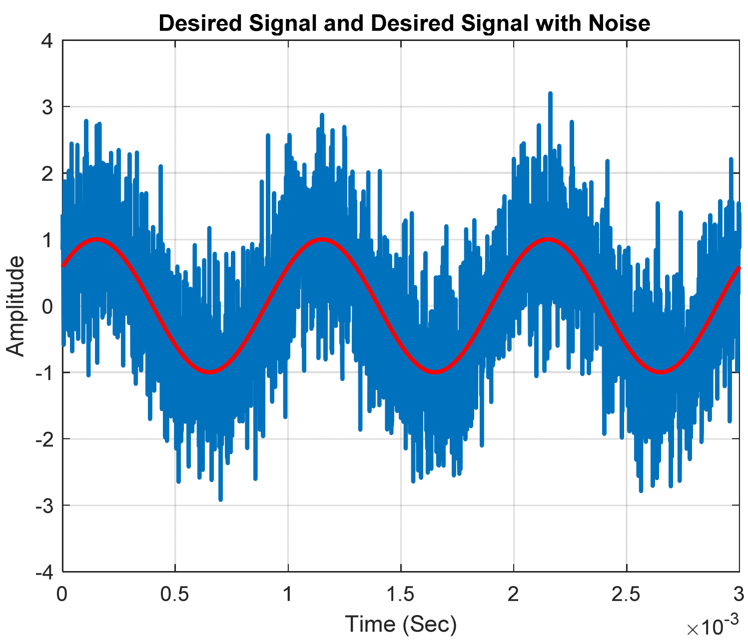
- In this case a good estimate of the signal is $\hat{\mu}$. The SNR is then

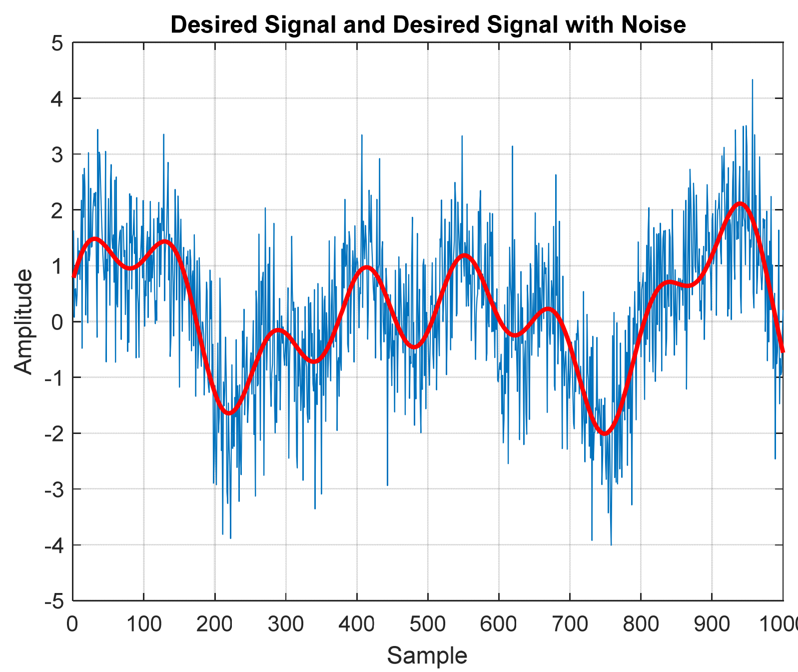
$$SNR = \frac{\hat{\mu}\hat{}2}{\hat{\sigma}_{noise}\hat{}2}$$



What is Our Signal?

- It could be the variation in the signal around a DC level
  - A sine wave or other time varying signal

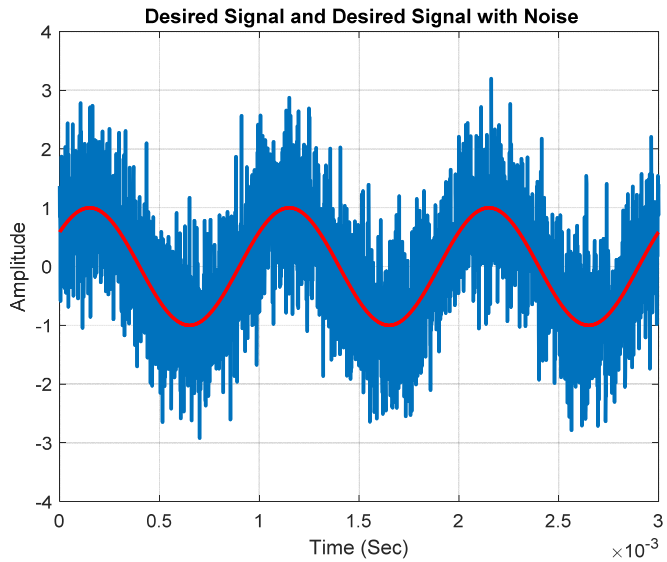


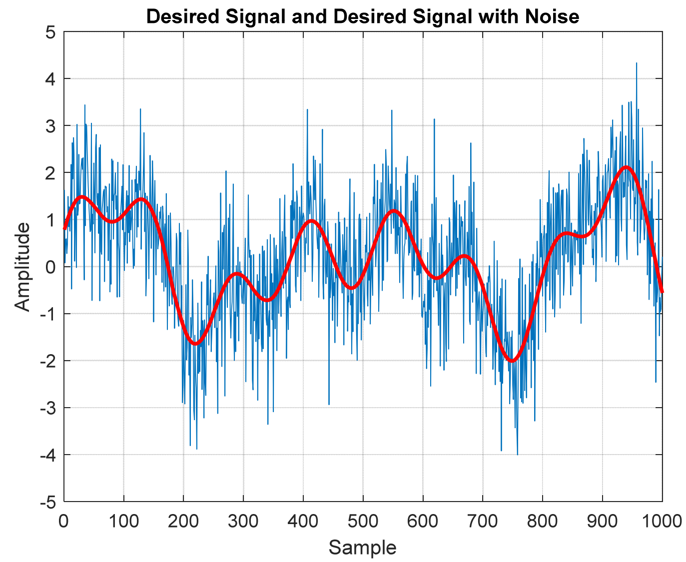


What is Our Signal?

- In this case a good estimate of our signal level is the <u>standard deviation</u> of the signal and the SNR is:

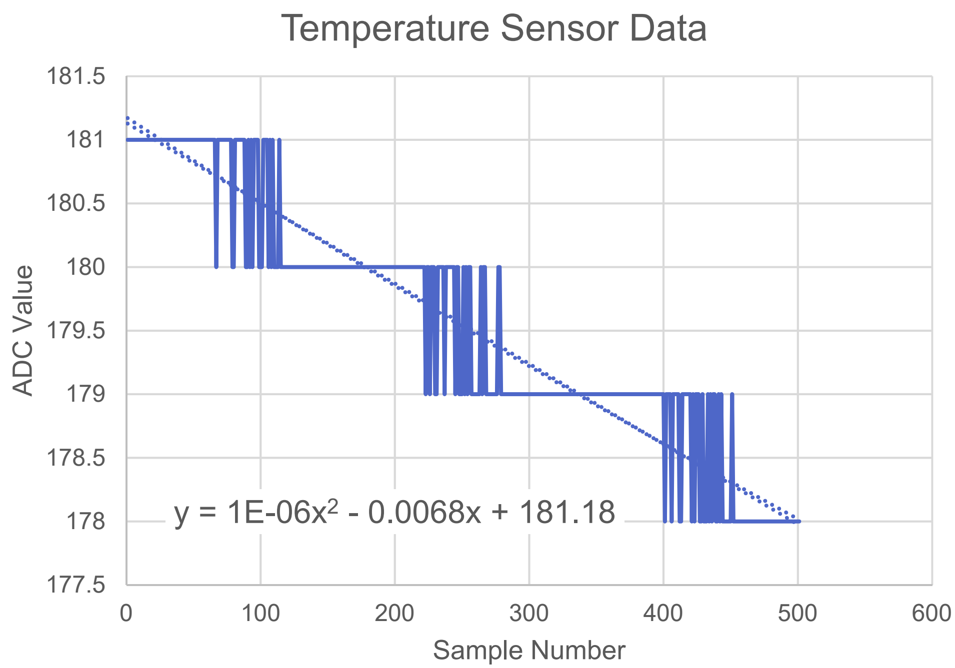
$$SNR = \frac{\sigma_{signal}\hat{}2}{\sigma_{noise}\hat{}2}$$





What is our Signal?

- In this lab, in some cases we have used a linear regression fit to estimate our signal



The signal level would then be the standard deviation of the fitted values

DSP Lab 4

Oversample Averaging

Using Oversample Averaging to Decrease Noise

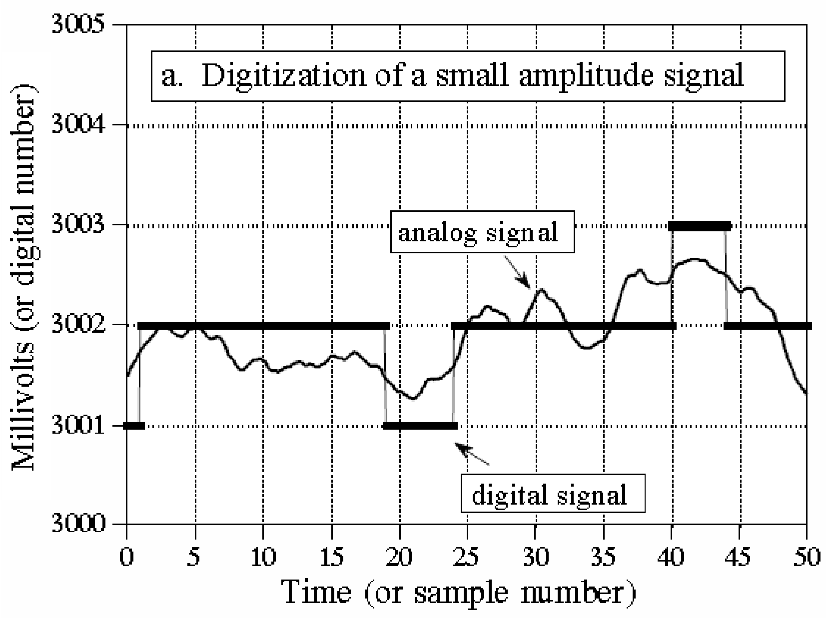
- We know that the "typical" error of the estimate of the mean decreases as one increases the number of samples

$$\sigma_{est} = \frac{\sigma}{\sqrt{N}}$$

- If we take multiple samples of a signal then average them the standard deviation of our estimates should decrease

Using Oversample Averaging to Decrease Noise

- However if the noise is "hidden" by quantization levels this may not be effective



Taking multiple samples of the same value doesn't help improve the noise

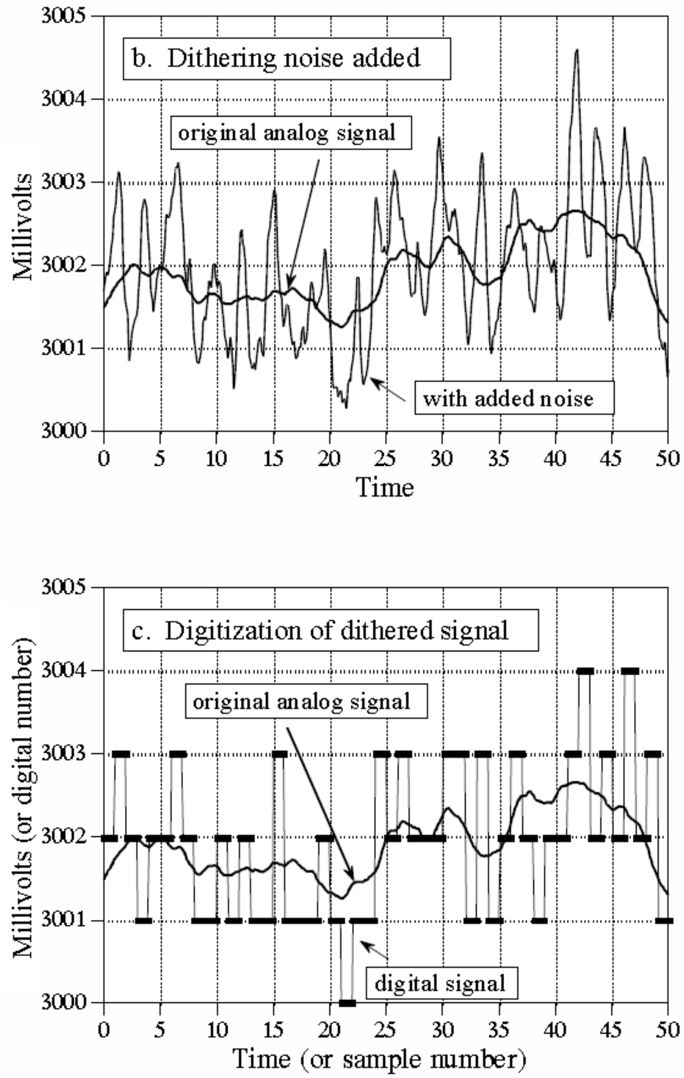
- We'll try this to see what happens

DSP Lab 4

Dithering

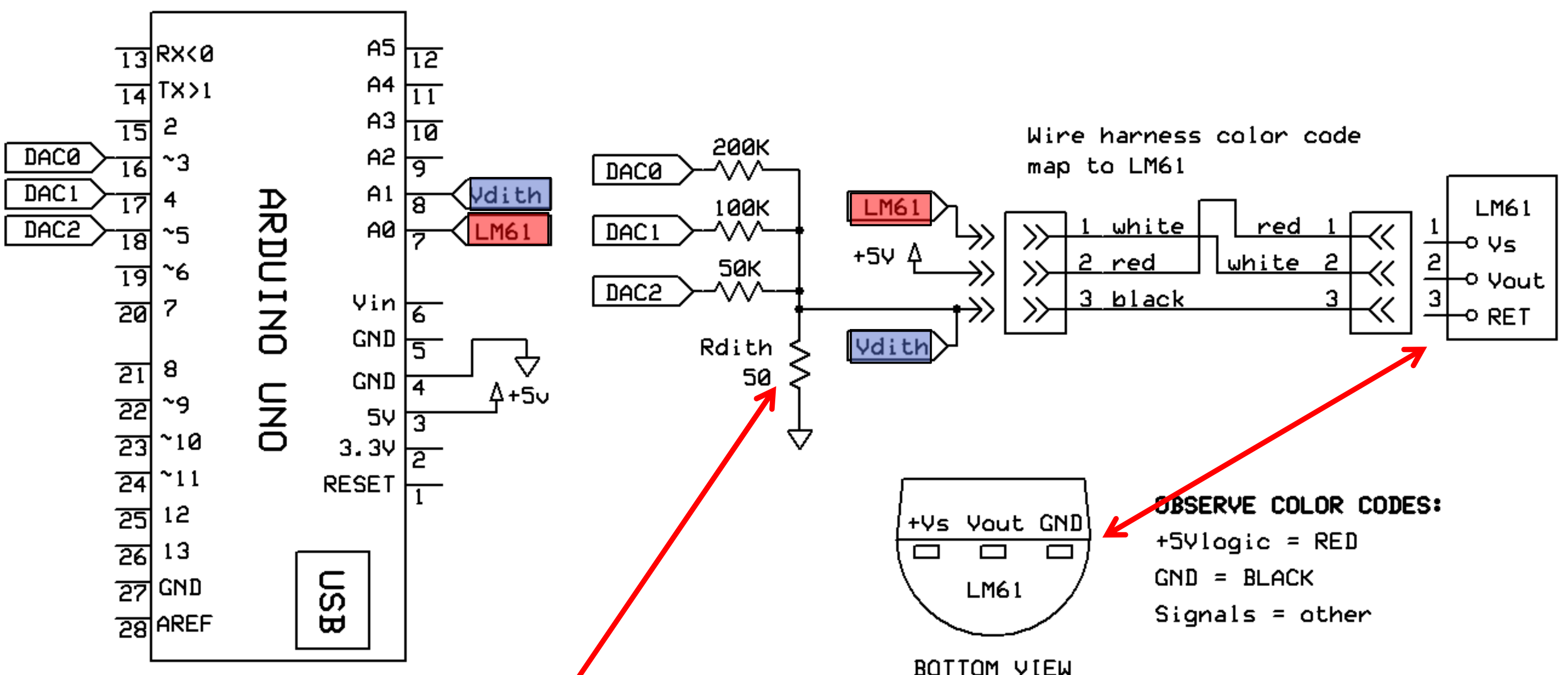
Decreasing Noise by Adding Noise?

- We'll see if adding noise, then oversampling and averaging will improve the situation
- Called "Dithering"



Creating a 3-Bit DAC to Generate Dither Noise

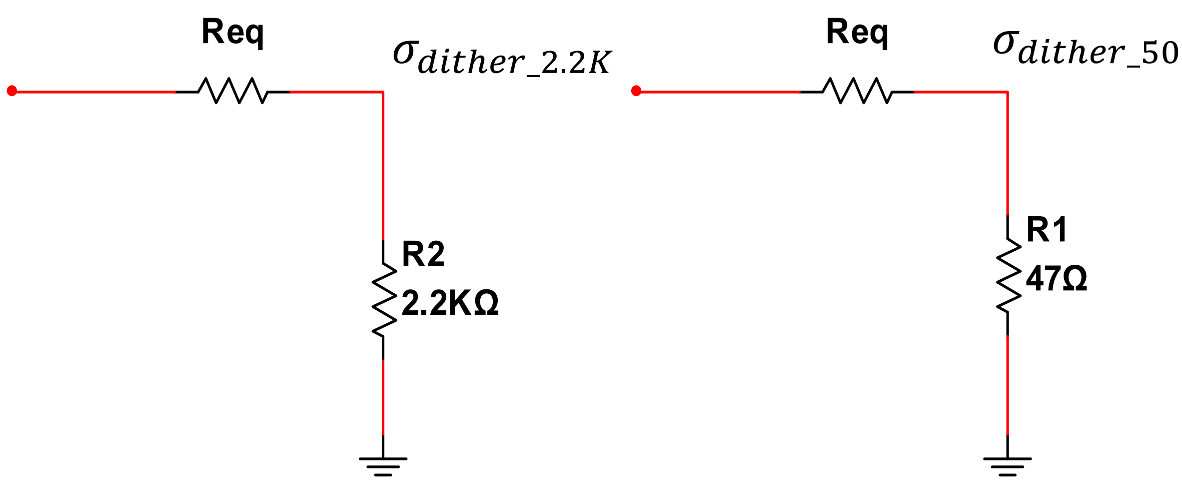
- Be sure to follow the schematic below
- Connect LM61 to A0, V_{dith} to A1



Measure σ_{dith} using $2.2K\Omega$

Creating a 3-Bit DAC to Generate Dither Noise

- Once you estimate the σ_{dith} with the larger resistor $(2.2K\Omega)$ you will need to scale it when using the $\approx 50\Omega$ resistor.



- How should σ_{dither} be scaled?

Lab Pointers

- The key result of this lab is Table 1
  - Make sure you understand what it tells you
  - Handout Tables are included in myCourses so you don't have to create them (2 tables)

Quantity	Raw Values (No Averaging)	Values after 160x Oversampling and Averaging (No Dithering)	Values after 160x Oversampling and Averaging (with Dithering)
1 Code Value Signal	1.00	1.00	1.00
Sensor Noise SD			
Quant Noise SD	0.29	0.29	0.29
Dither Noise SD	0.00	0.00	
Total Input Noise			
Noise after averaging (theoretical)			
Noise after averaging (measured)			

Lab Pointers

- Locations of signals and noise referenced in the table