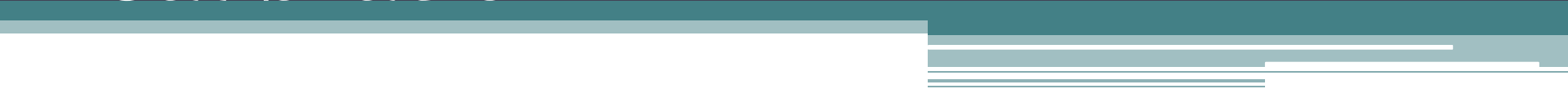


Calibration

A series of horizontal lines in teal, light blue, and white, extending from the left edge of the slide and ending on the right side.

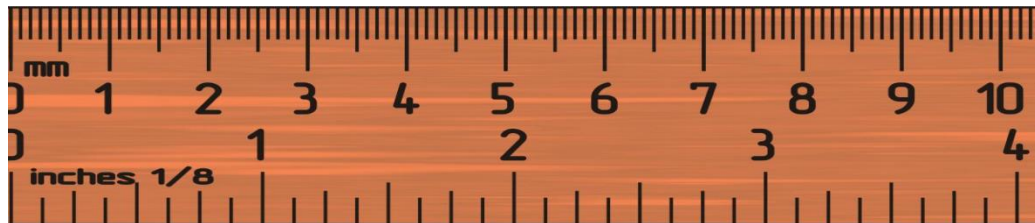
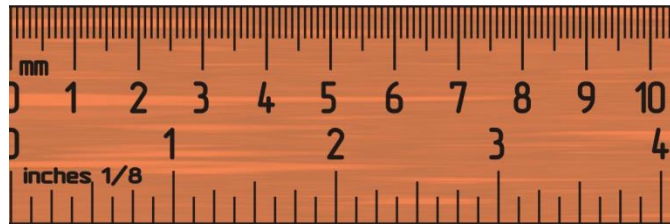
What is calibration?

- The process of converting the output of any transducing device into an engineering value that relates to the real world.

The case of the ruler

Given the following two rulers, which one represents a real inch in length?

How do you know?



Standards

- Calibrations are typically done based on some standard.
- Standards exist for ALL physical measurements
 - Length
 - Time
 - Mass
 - Pressure

Length



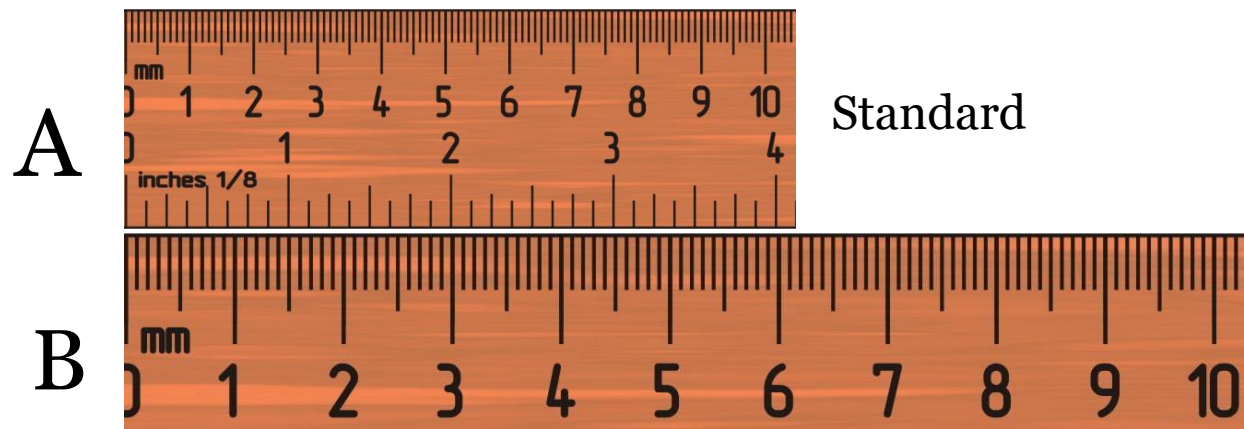
- The meter (m) is the Si unit of length and is defined as *the length of the path traveled by light in vacuum during the time interval of $1/299\,792\,458$ of a second*
- In 1886 it was defined as the length of a particular Platinum / Iridium bar.
- In 1960 it was based on Krypton86 radiation from an electrical discharge lamp

Traceability

- Traceability refers to the ability to certify the path of “copy” from the official standard to your instrument.
- Done with a certificate that shows how your official measure traces back to the “master”.
- Frequently required by government agencies as part of their test/standards compliance

Comparative Calibration

- Compare the device you are “calibrating” to a standard, or device that is related to the standard.



$$6 \text{ units} = 4 \text{ inches} \implies .66666 \text{ inches per unit}$$

Pressure

- Dead weight testers



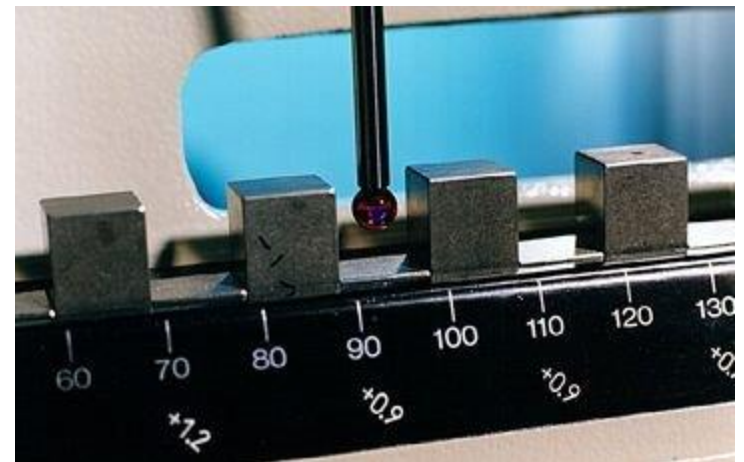
Mass

- Calibration Masses



Length

- Length bars and gage blocks

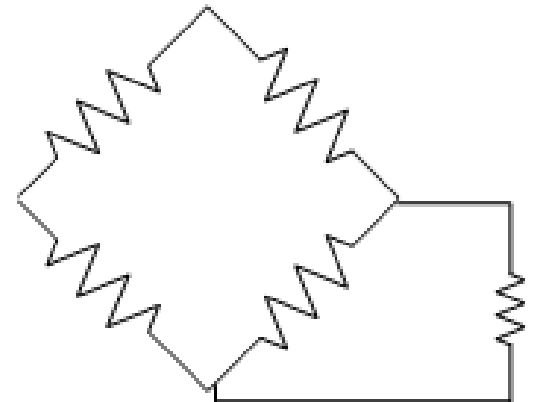


Many others

- Voltage
- Velocity
- Volume
- Current
- Resistance
- Frequency
- Light amplitude
- Sound pressure
- Etc etc etc

Special case for bridge transducers

- Bridge transducer can be “shunt calibrated”
- Simulates a known load by placing a shunt resistor across a portion of the bridge.



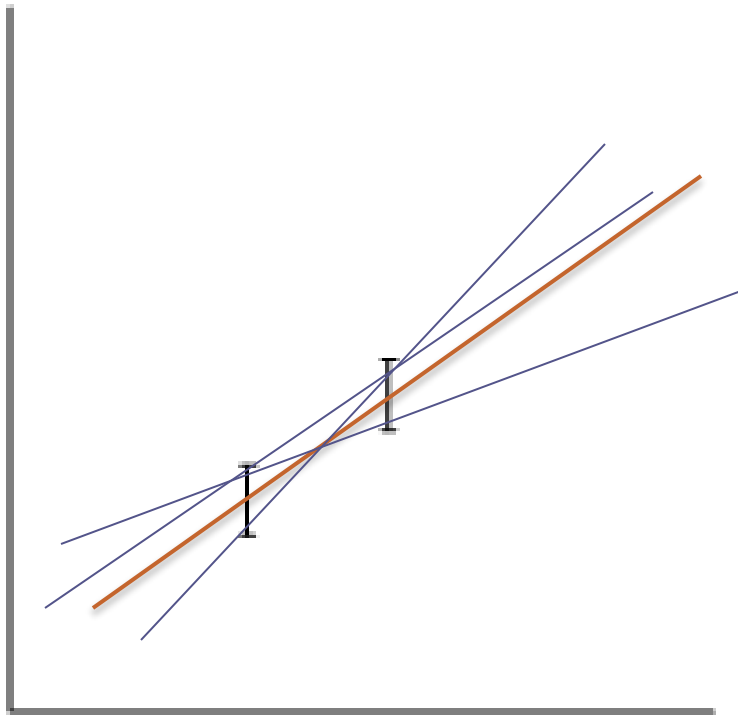
How do we calibrate

- 2 point method
 - Take two data points
 - Plot a straight line
 - Calculate $Y=mX+b$

Data point accuracy

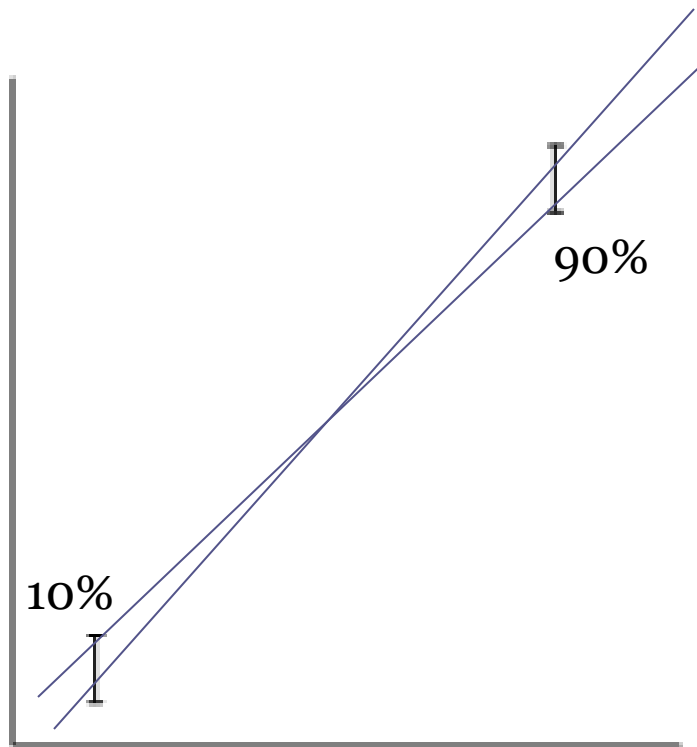
- Not all data points are created equal!
- Without going into a discussion of Error.....
- All data has error.... Therefore all data points have error!

Two randomly spaced points

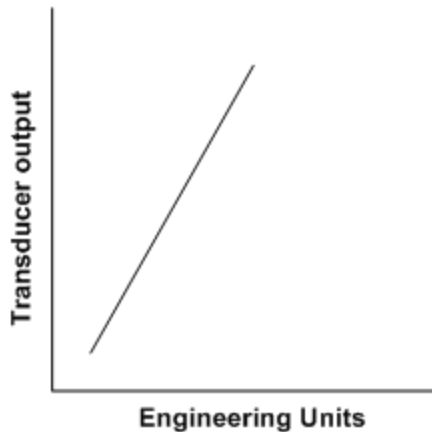


Desirable points

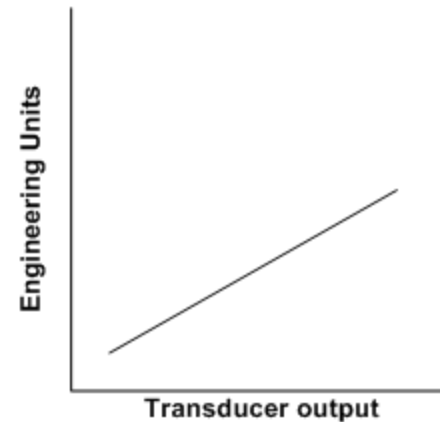
- 10 and 90%



Pay attention to Axis!!!!



What you think you need to do



What you really need to do!

Calculate $Y=mX+b$

- $m = (y_2 - y_1) / (x_2 - x_1)$
- $b = (y_1 - mx_1)$

How do we calibrate

- n point Linear Method
 - Take n data points
 - Plot a straight line
 - Calculate $Y=mX+b$ with a least squares fit

Data points

- Usually 8 to 10 points (or more)
- Option 1: Calculation method

$$\text{Slope (m)} = \frac{n \sum (X_i Y_i) - \sum(X_i) \sum(Y_i)}{n \sum (X_i^2) - [\sum(X_i)]^2}$$

$$\text{Y intercept (b)} = \bar{Y} - a_1 \bar{X}$$

Data points

- Option 2: Excel method
 - Plot the data points with transducer output (volts) on the X axis and Eng units on the Y axis
 - Add a “linear” trendline .
 - Display the equation on the graph.

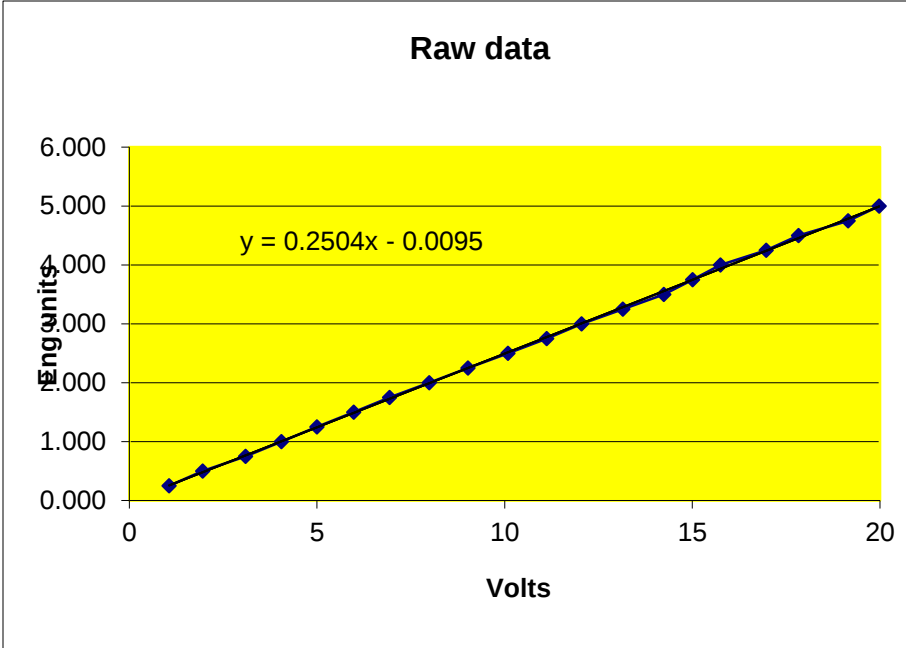
volts	Eng Units					
X	Y	sum XY	x^2	(Yi - Ye)^2	Ye	Error
1.06	0.250	0.265	1.124	3.54266E-05	0.256	2.32545
1.95	0.500	0.975	3.803	4.49046E-04	0.479	-4.42571
3.1	0.750	2.325	9.610	2.81265E-04	0.767	2.18722
4.05	1.000	4.050	16.403	2.16441E-05	1.005	0.46308
5	1.250	6.250	25.000	5.57459E-05	1.243	-0.60089
5.98	1.500	8.970	35.760	1.45755E-04	1.488	-0.81139
6.93	1.750	12.128	48.025	5.85231E-04	1.726	-1.40175
7.99	2.000	15.980	63.840	7.68433E-05	1.991	-0.44023
9.02	2.250	20.295	81.360	7.26847E-07	2.249	-0.03791
10.09	2.500	25.225	101.808	2.91623E-04	2.517	0.67844
11.12	2.750	30.580	123.654	6.24523E-04	2.775	0.90056
12.05	3.000	36.150	145.203	6.18392E-05	3.008	0.26144
13.15	3.250	42.738	172.923	1.10925E-03	3.283	1.01439
14.24	3.500	49.840	202.778	3.16327E-03	3.556	1.58153
15.01	3.750	56.288	225.300	8.98628E-07	3.749	-0.02529
15.75	4.000	63.000	248.063	4.31004E-03	3.934	-1.66866
16.97	4.250	72.123	287.981	1.03249E-04	4.240	-0.23966
17.83	4.500	80.235	317.909	2.00847E-03	4.455	-1.00593
19.15	4.750	90.963	366.723	1.27549E-03	4.786	0.74626
19.98	5.000	99.900	399.200	4.16390E-05	4.994	-0.12922
sum	210.42	52.500	718.278	2876.465	1.464197E-02	
	sum Xi	Sum Yi	sum (XiYi)	sum(Xi^2)	sum(Yi-a0 - a1*Xi)^2]	
mean	10.521	2.625	35.914	143.823		
n=	20					

$$a1 = \frac{n \sum (XiYi) - \sum(Xi)\sum(Yi)}{n \sum(Xi^2) - [\sum(Xi)]^2}$$

$$a0 = \bar{Y} - a1 \cdot \bar{X}$$

$$S_{xy} = 0.085563 \quad \text{Error} = \sqrt{\frac{\sum(Yi - a0 - a1 \cdot Xi)^2}{n-2}}$$

$$Y = -0.00947 + 0.250401X$$

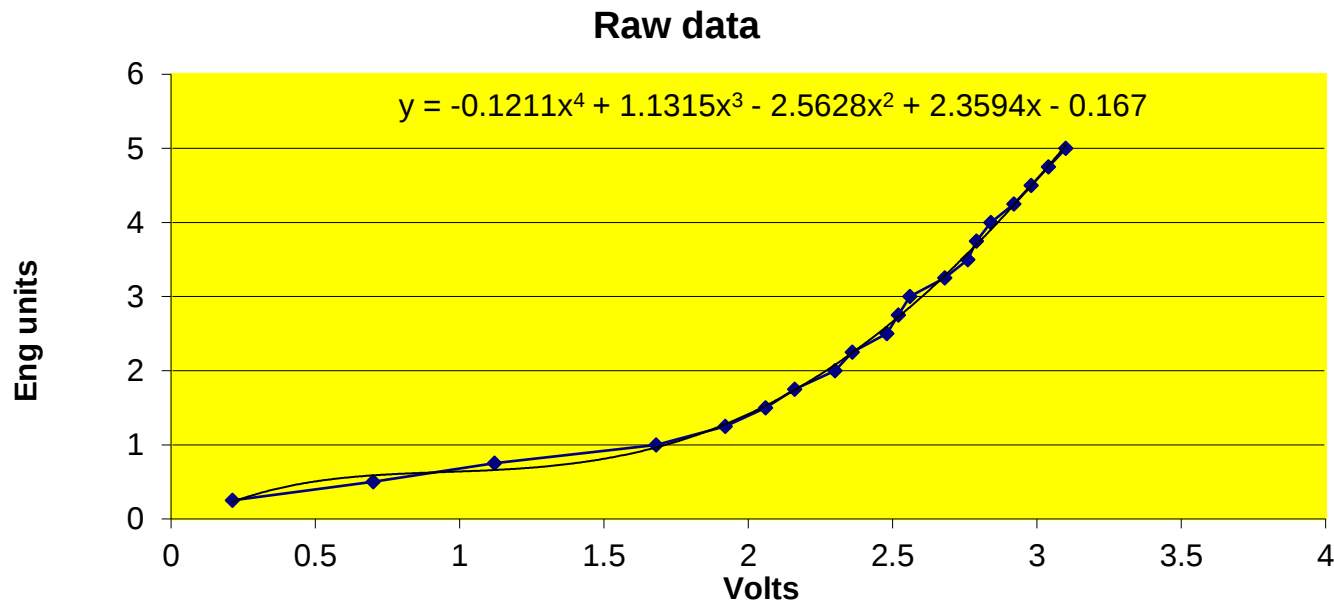


Non-linear

- Not all transducer outputs are linear
- Non-linear calibration methods:
 - Hard: Numerical solution
 - Long hand
 - Labview
 - Matlab
 - C++
 - etc

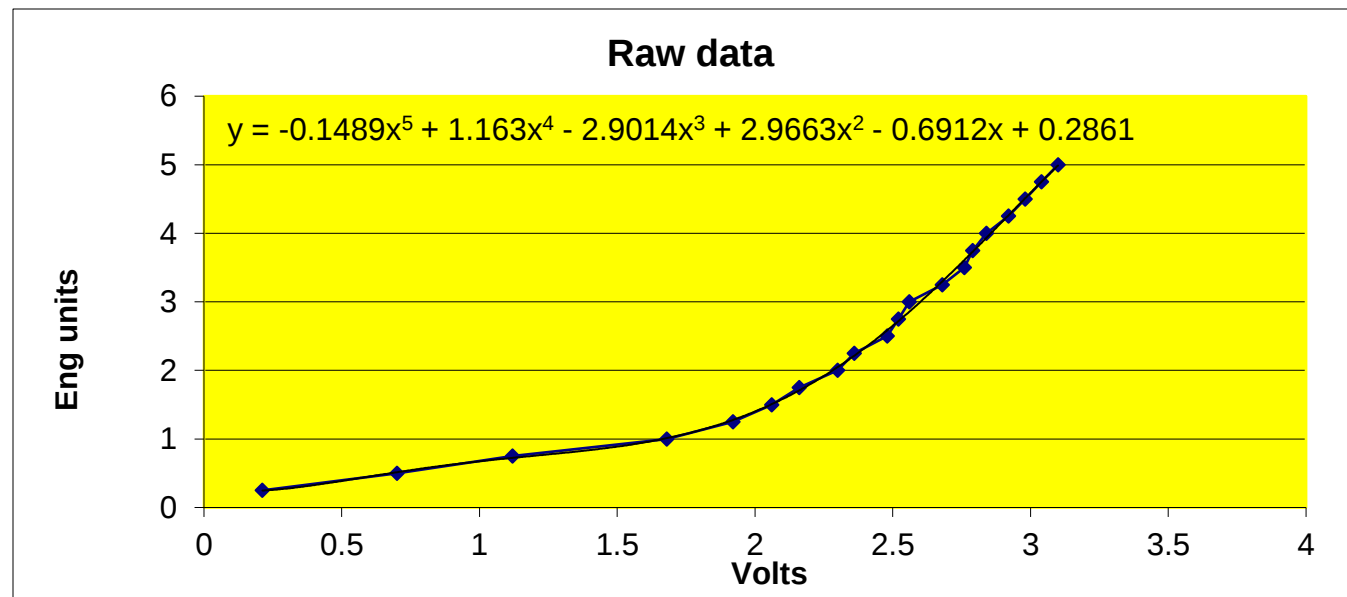
Non-linear

- Non-linear calibration methods:
 - Easy:
 - Plot the points in Excel and add a trendline
 - Allows you to visual the quality of the fit



4th order.
Poor fit!

5th order
Better fit!



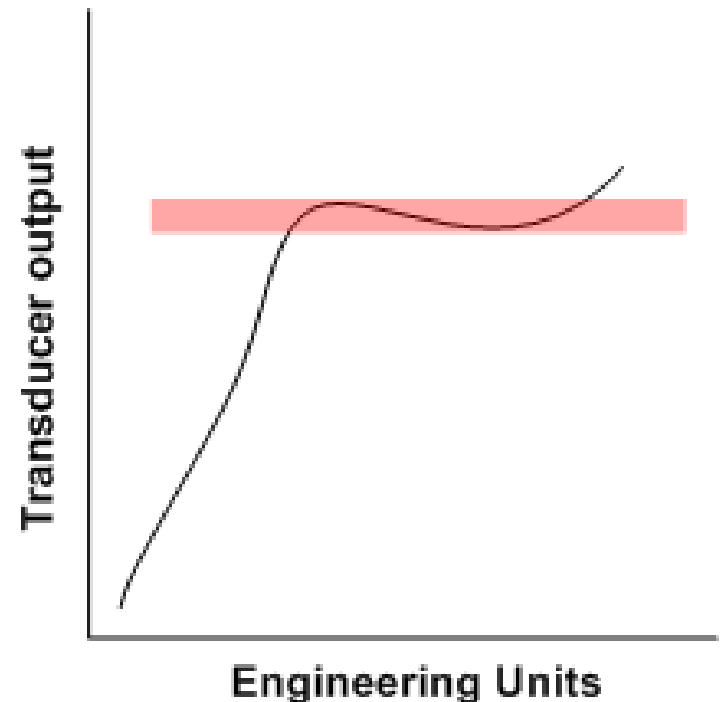
Compound curves

- Some curves can not be fit with a simple polynomial
 - Break up the curve into “ranges” and fit each range
 - Add code to your program to manage the ranges

Foldback

- Some curves have an area where multiple values correspond to a single voltage

Which engineering unit does the voltage the transducer is putting out represent?

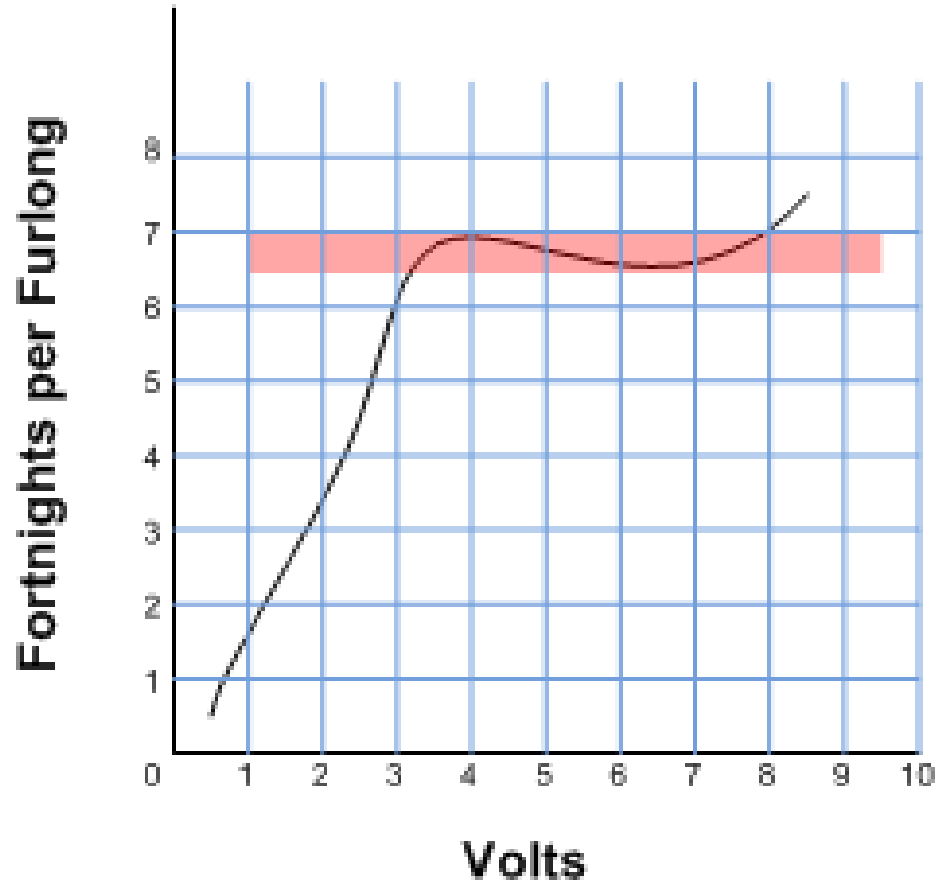


Foldback

- Solutions:
 - Limit the transducer “travel” or range so that it can never get to the foldback area.
 - Program the system to generate error messages with those values

Example

Limit the rate transducer
to 7 and generate an error
for any transducer voltage
Larger than 4 volts



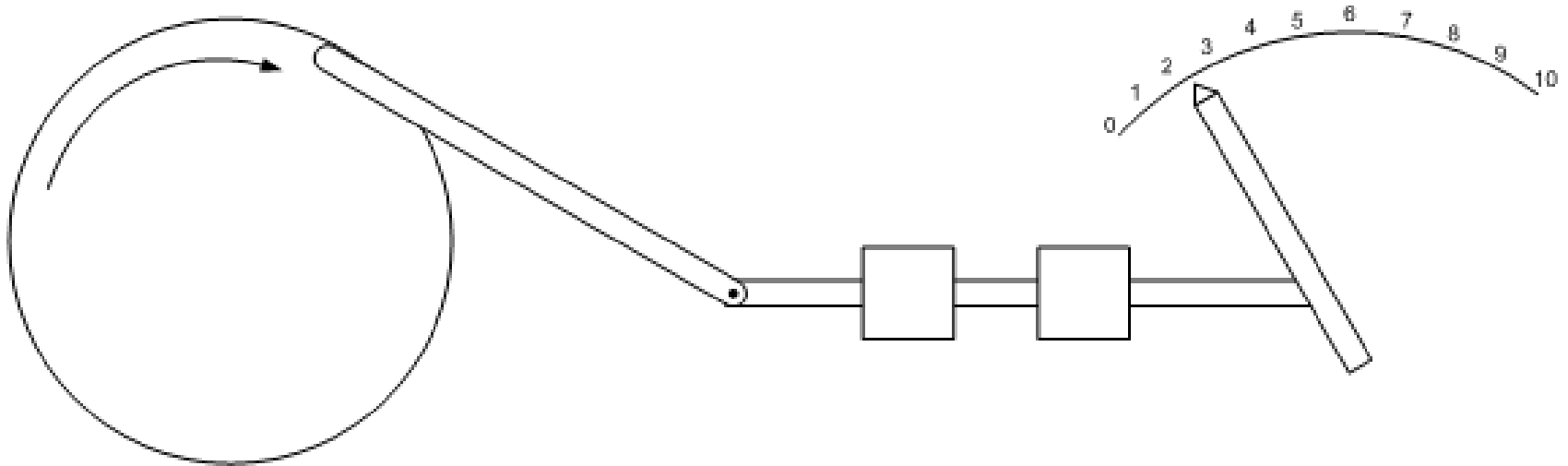
Error in transducer systems

A series of horizontal lines in teal, light blue, and white, extending across the width of the slide below the title.

Transducer error

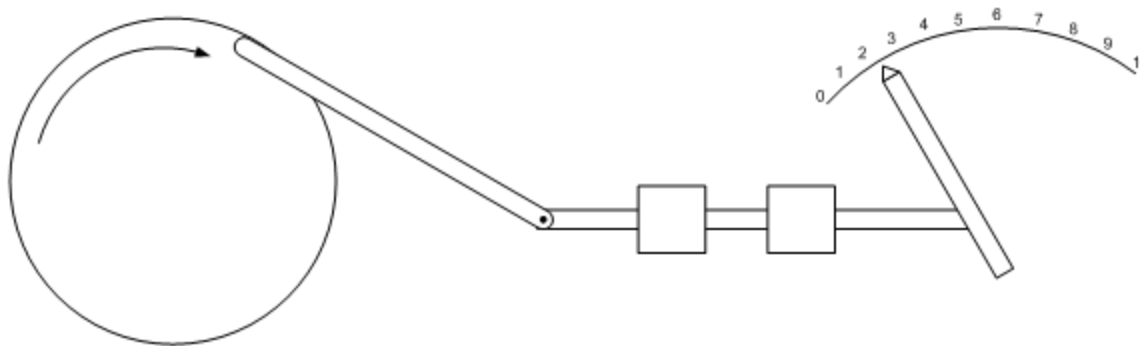
- At a later time we will discuss system errors
- For now we are interested only in errors that affect the calibrated output of a transducer.
- May be measured for a single transducer or for a group of transducers to characterize “expected” or nominal error values.

Example system

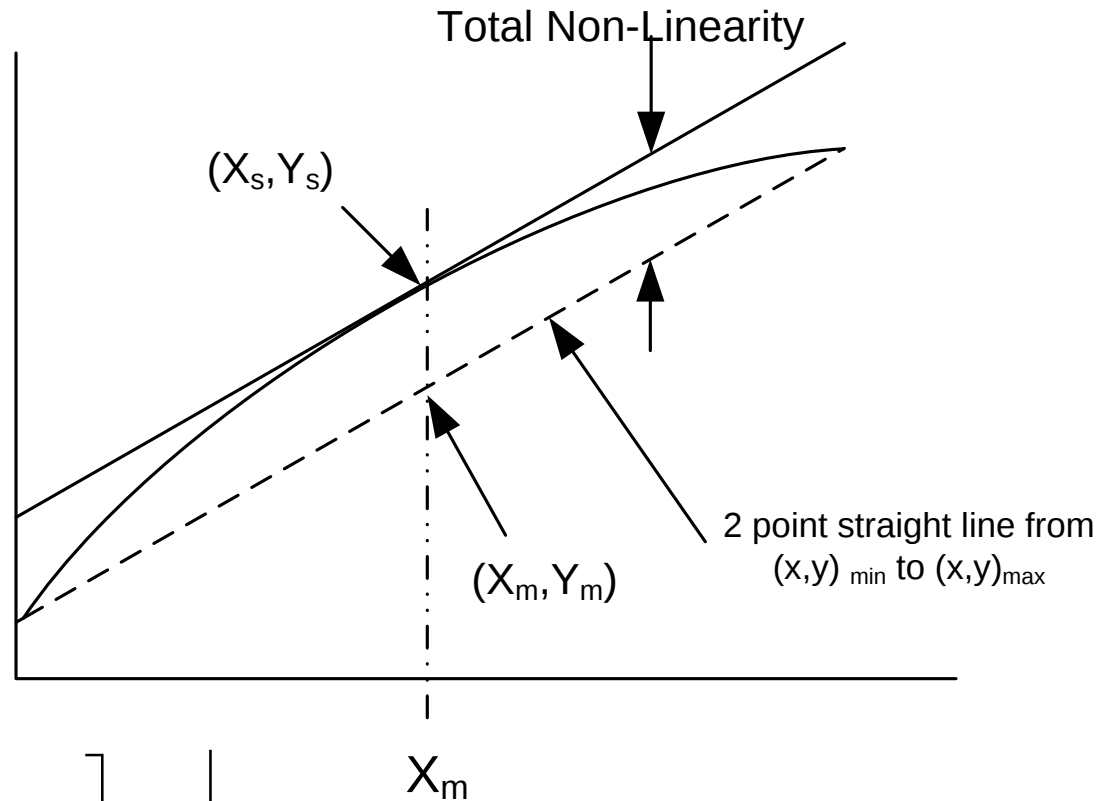


Linearity:

- The output of the display is not always linear with respect to the input.
 - Input is in degrees
 - Output is in “numbers 0 to 10”
 - Is the output linear with respect to position?



Linearity



$$\%Linearity = \left| \frac{\left[\left(\frac{y_{max} - y_{min}}{2} \right) + y_{min} \right] - y_s}{\left[\left(\frac{y_{max} - y_{min}}{2} \right) + y_{min} \right]} \right| \times 100\%$$

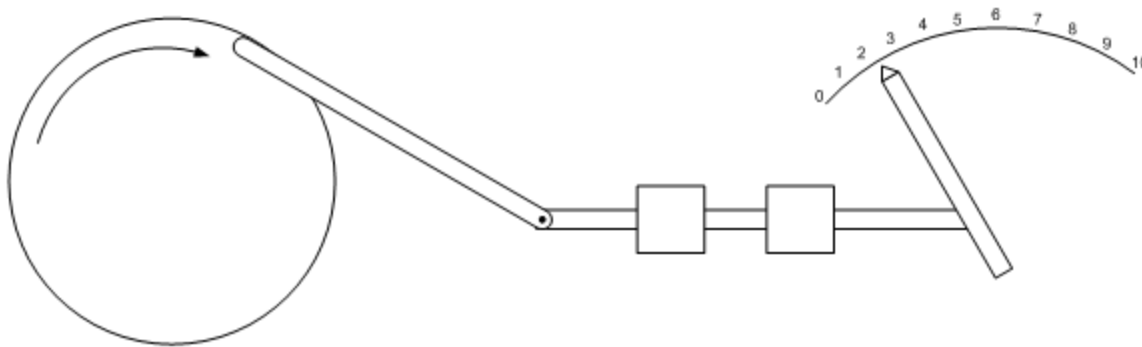
Linearity

- If the line passes through 0 then you can simplify

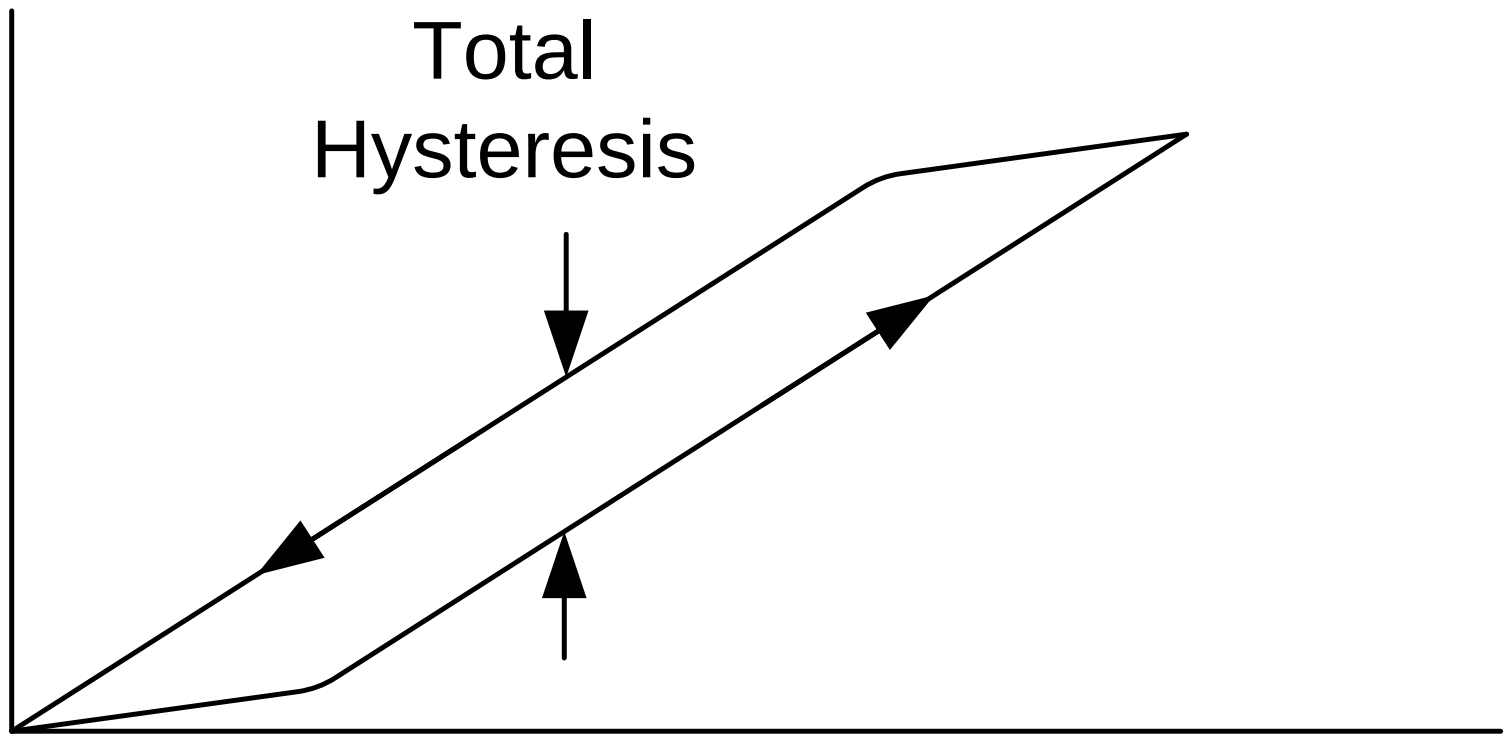
$$\%Linearity = \left| \frac{\left(\frac{y_{max}}{2} \right) - y_s}{\left(\frac{y_{max}}{2} \right)} \right| \times 100\%$$

Hysteresis

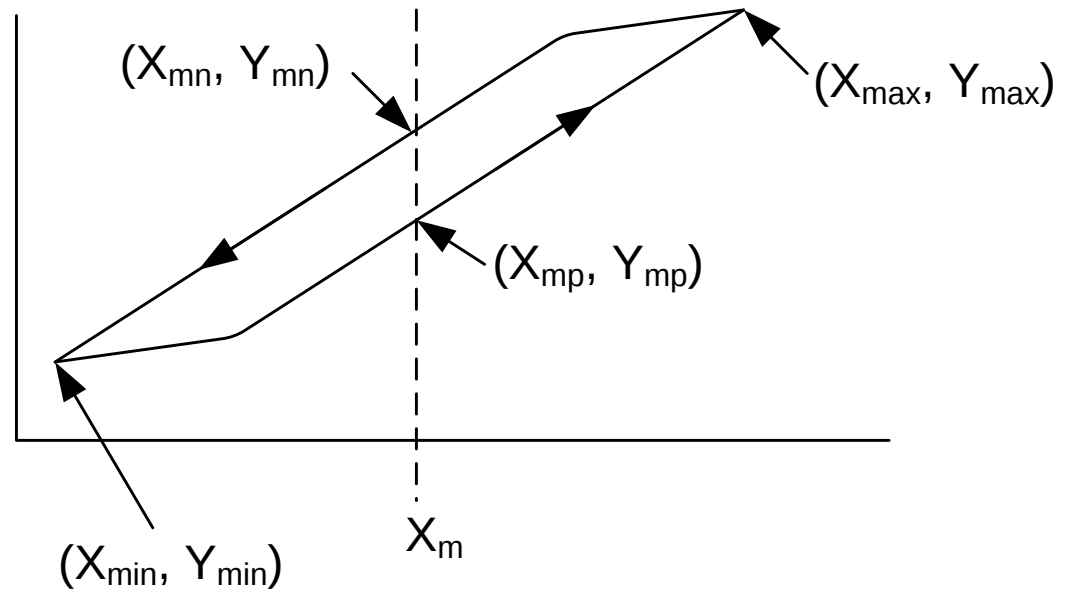
- The general description of this is “slop”
- How much the positive going path does NOT follow the negative going path.



Hysteresis



Hysteresis



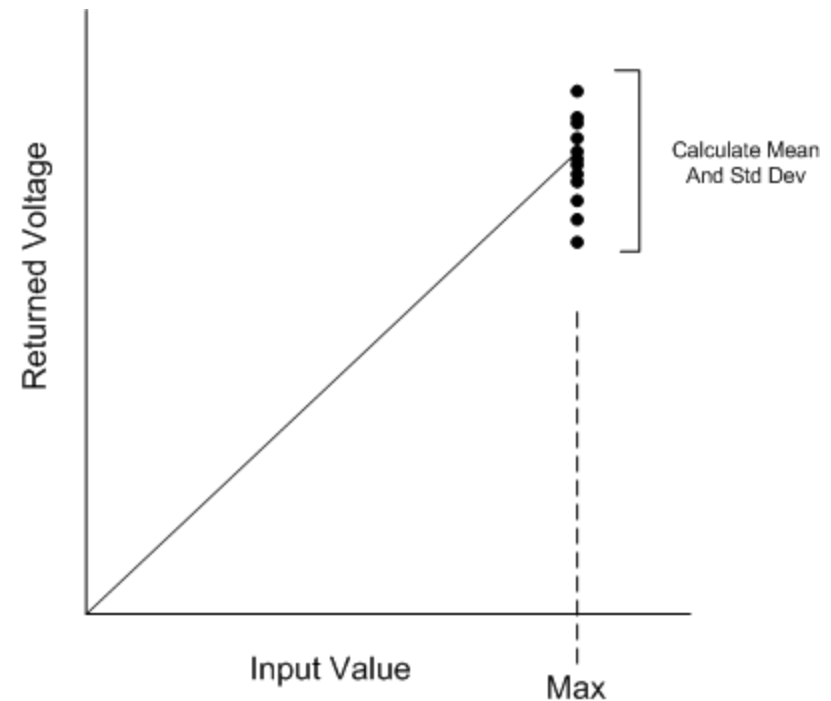
$$X_m = \left(\frac{X_{\max} - X_{\min}}{2} \right) + X_{\min}$$

$$\text{Hysteresis}\% = \left| \frac{(Y_{mn} - Y_{mp})}{(Y_{\max} - Y_{\min})} \right| \times 100\%$$

Repeatability

- How well a transducer (or group of transducers) hits the same maximum range point.
- A statistical measure
- Run the transducer multiple times from 0 to max
- Measure the output at max input

Repeatability



$$\text{Repeatability \%} = \frac{2\sigma}{Y} \times 100\%$$

Calibration in LabVIEW

A series of horizontal lines in teal and light blue colors, with varying lengths and offsets, creating a modern, layered effect across the width of the slide.

Embedded

- Inside the program, place a calculation to convert the raw input voltage to engineering units
 - Advantages:
 - Portable (everything is inside the program)
 - Flexible (all you need is the formula for your curve)
 - Disadvantages
 - Not entirely intuitive
 - Can be difficult to update if you don't document

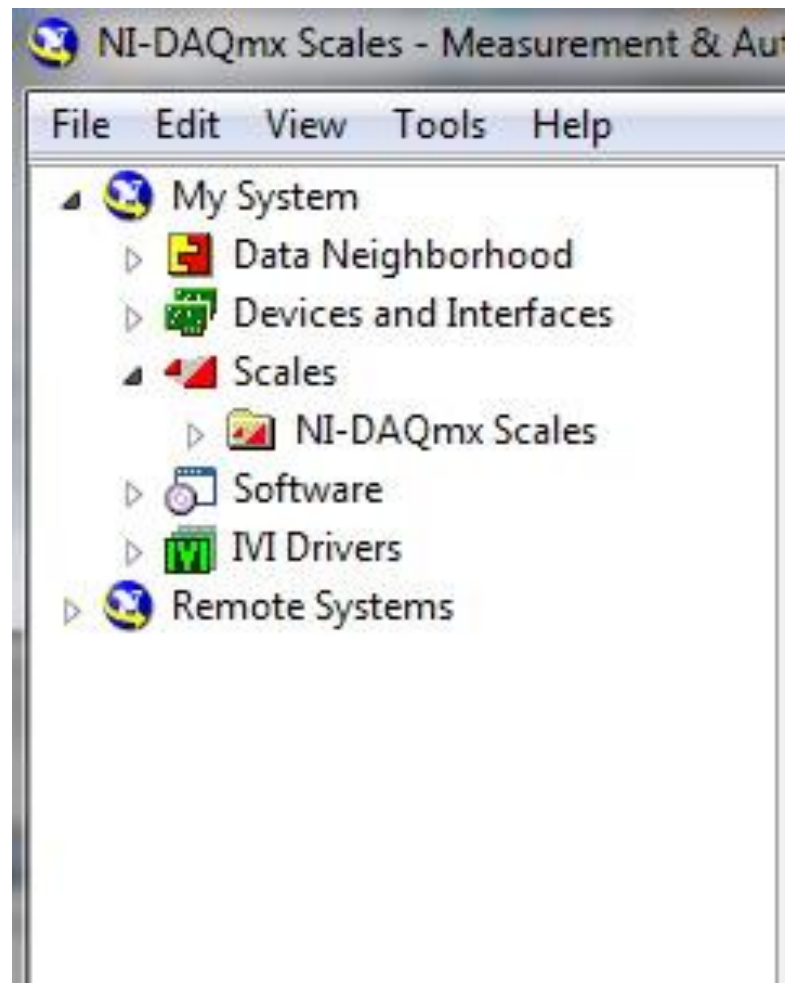
Custom Scale

- Build the scale into Measurement and Automation Explorer.
 - Advantages:
 - Transparent (easy to find and update)
 - Only done in one place and every program that uses it is automatically updated
 - Disadvantages:
 - NOT portable
 - If you mess up the cal...its messed up EVERYWHERE!



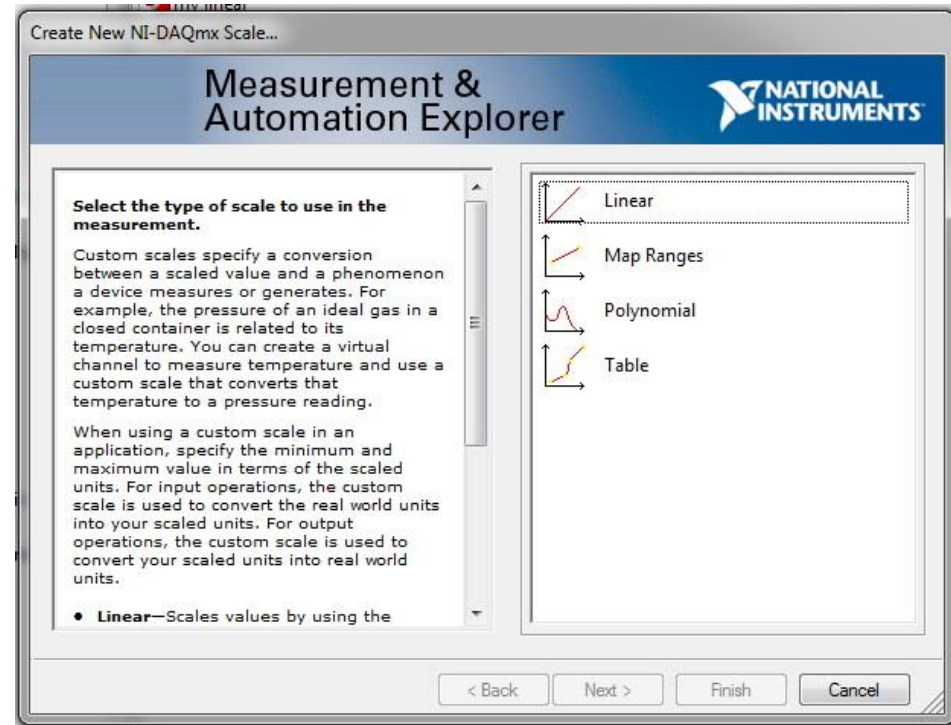
Example of embedded:

Custom Scale

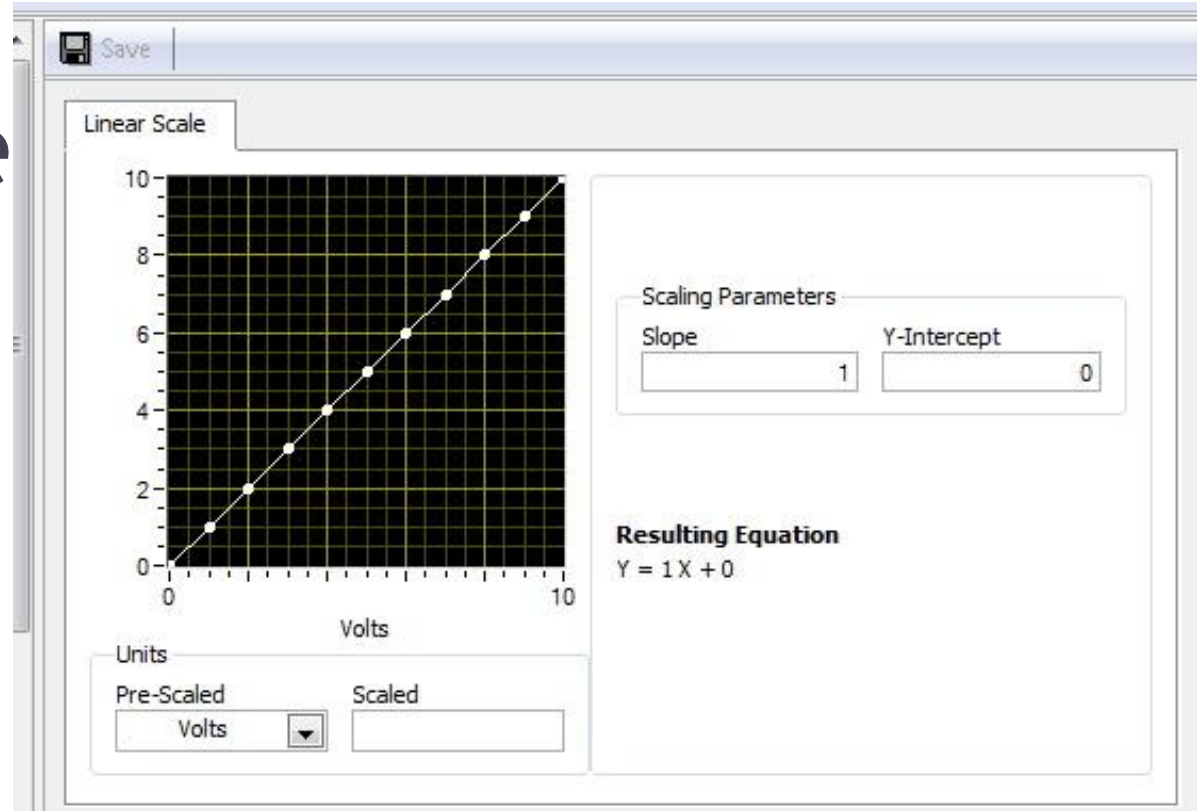


Custom Scale

- **Linear:** $Y=mX+b$ input linear
- **Map ranges:** two point input linear
- **Polynomial:** Polynomial equation
- **Table:** Lookup table of values. Allocates proportionally between table values

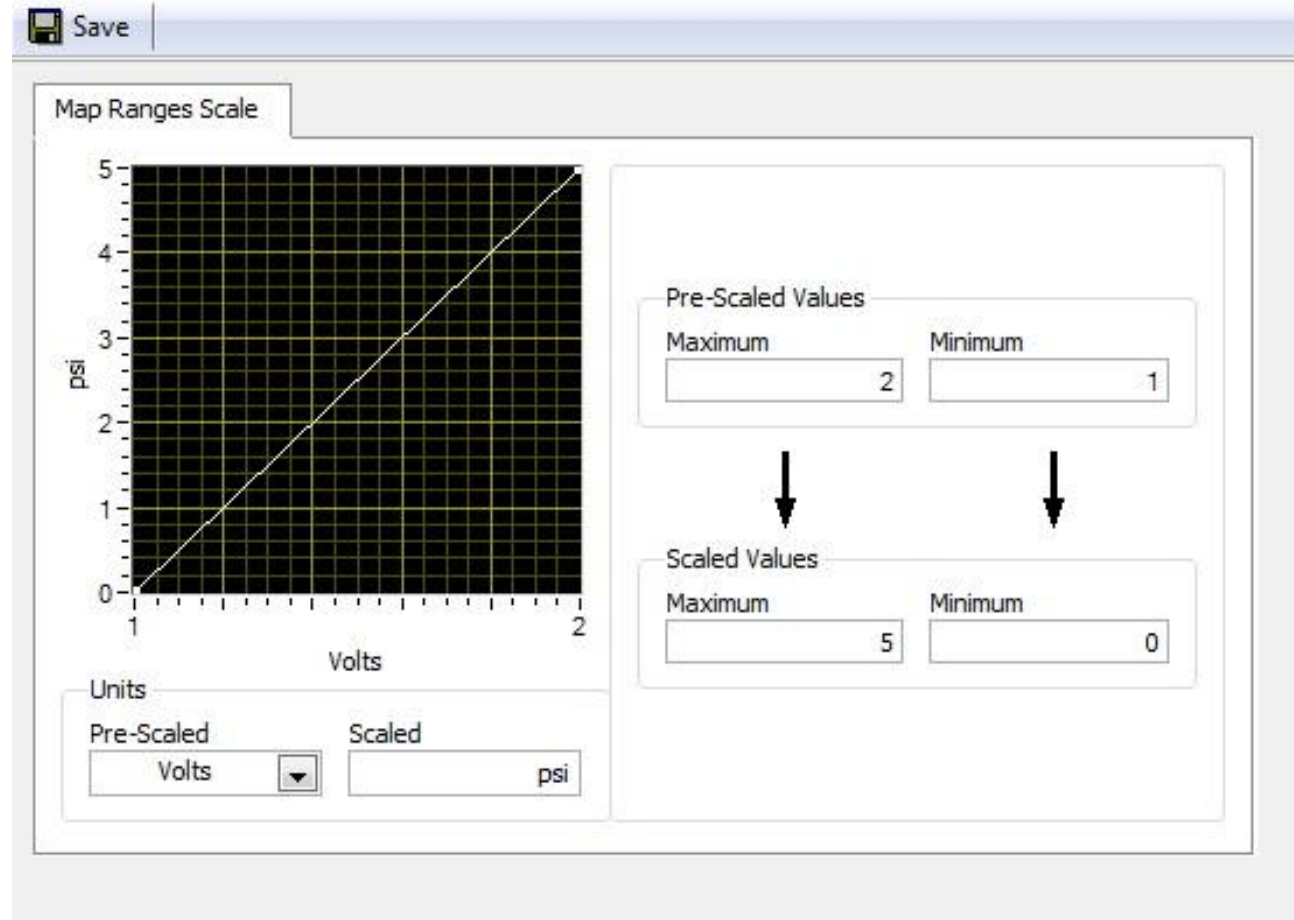


Linear scale



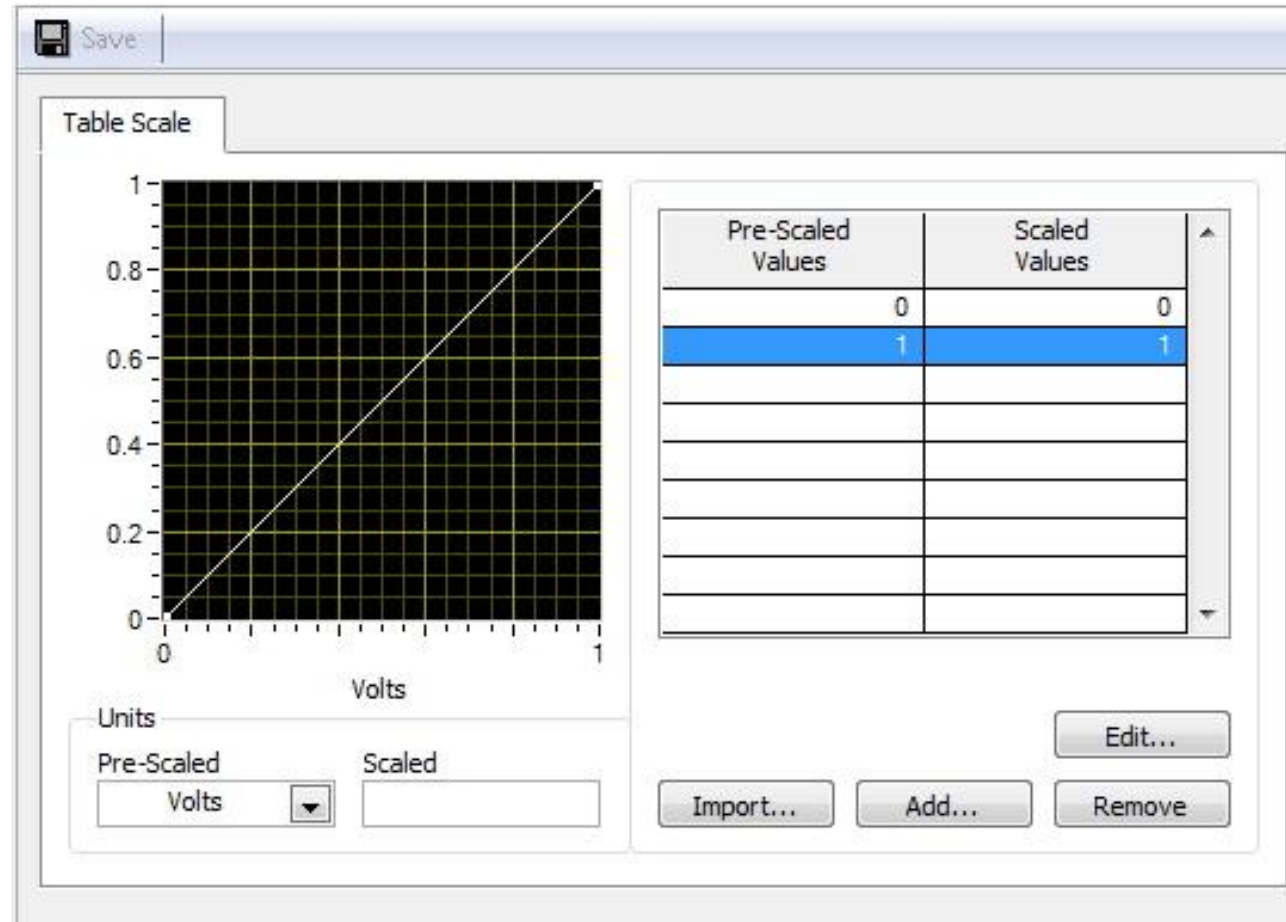
- Requires $Y=mX+b$ format for a line

Map Scale



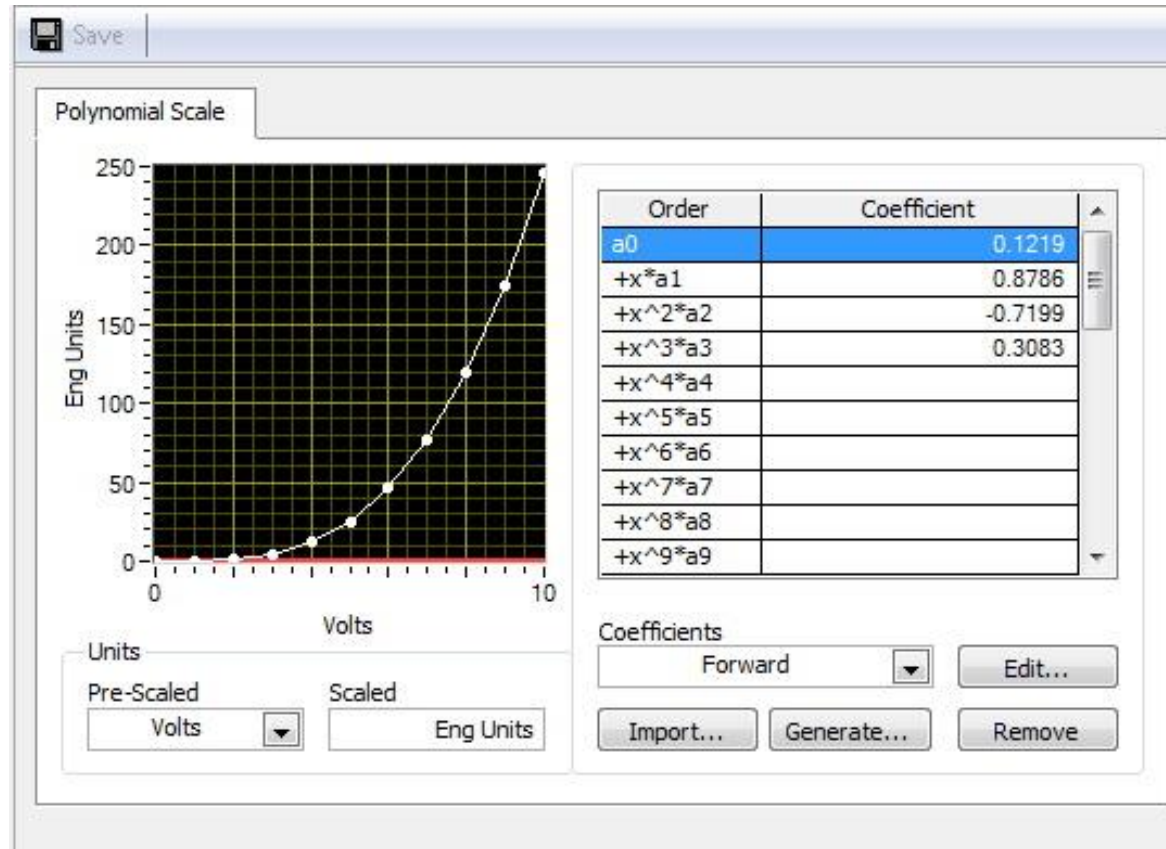
- Uses two point format for a line
- Two points **MUST** be end points of the line because the range is limited by the map

Table



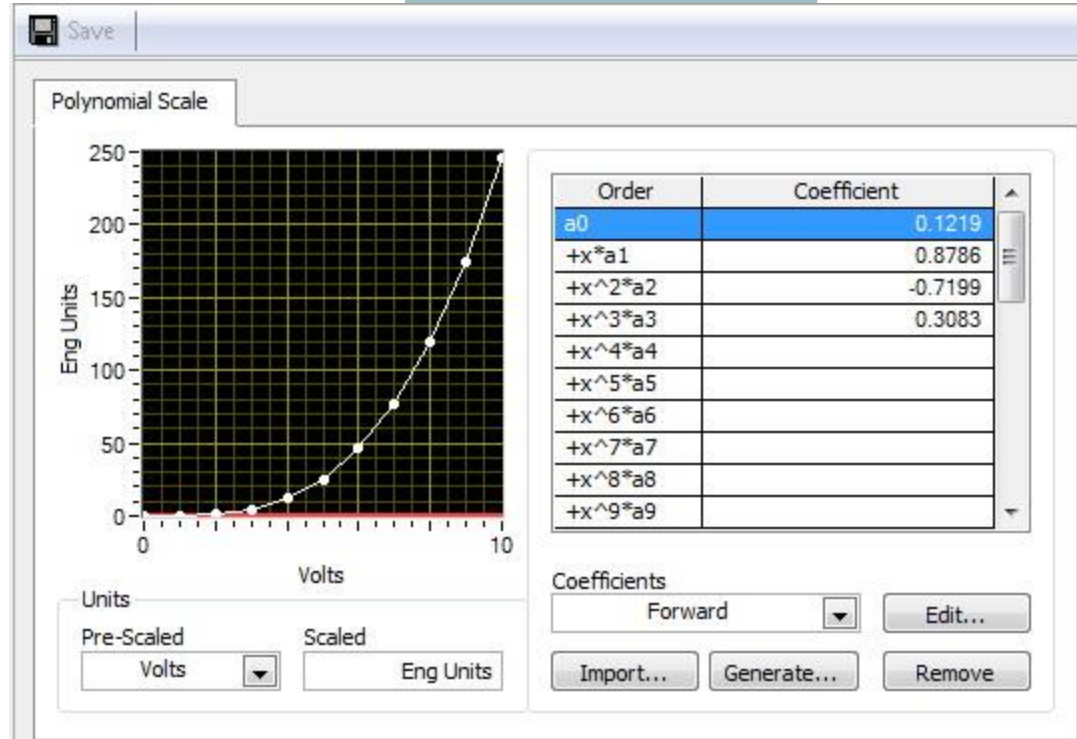
- Enter map values
- System interpolates linearly between values
- Must have end points for the scale

Polynomial



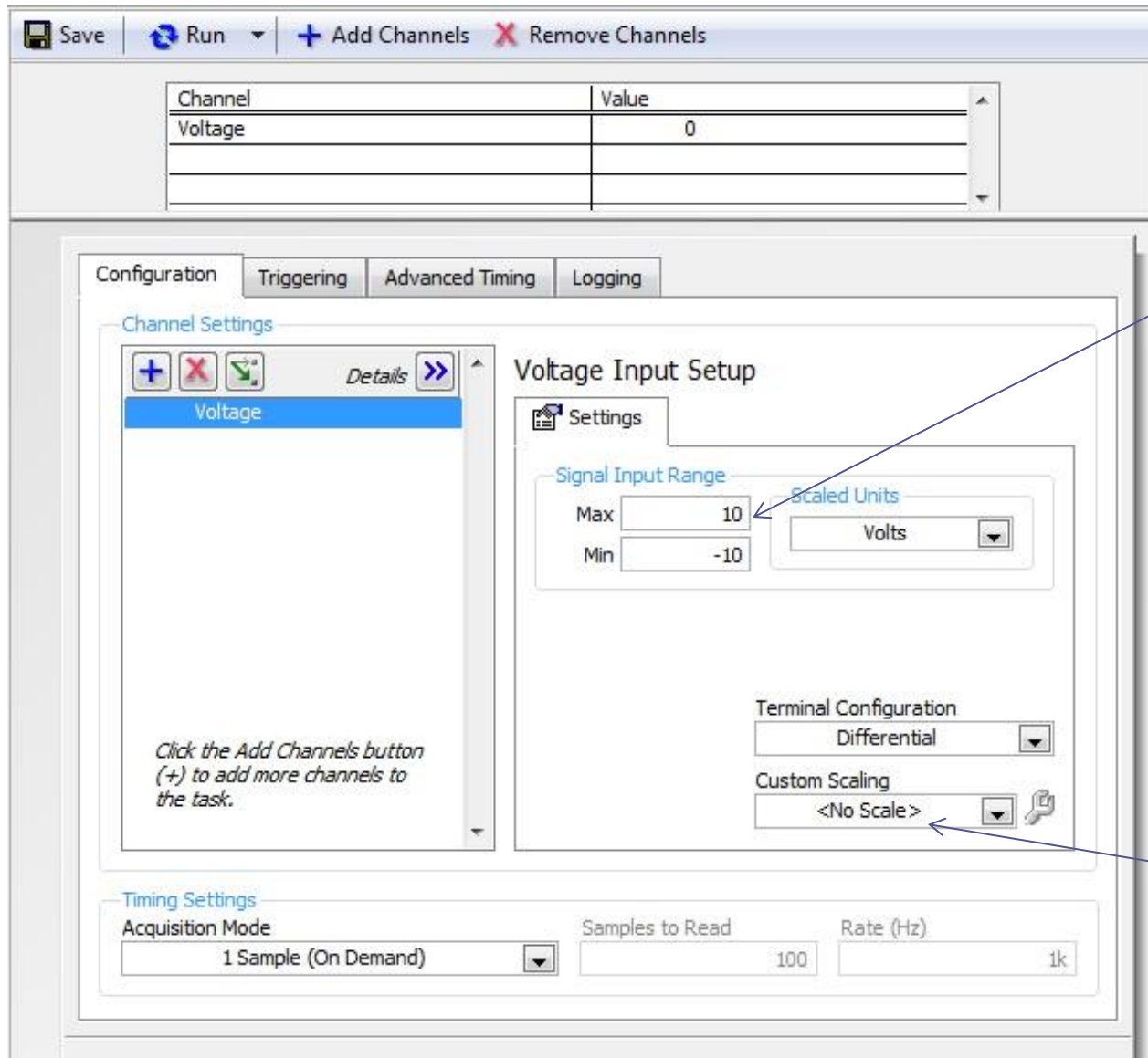
- Most difficult
- Must enter coefficients forward (or rev) and then calculate the opposing one

Polynomial



- On graph you MUST adjust the voltage limits.
- If you leave them at 10 volts and you entered cal information for 0 to 3, data beyond 3 will be junk and will distort your curve.

Using your scale



Channel	Value
Voltage	0

Configuration Triggering Advanced Timing Logging

Channel Settings

+ -

Details >>

Voltage

Click the Add Channels button (+) to add more channels to the task.

Voltage Input Setup

Settings

Signal Input Range

Max 10
Min -10

Scaled Units

Volts

Terminal Configuration

Differential

Custom Scaling

<No Scale>

Timing Settings

Acquisition Mode

1 Sample (On Demand)

Samples to Read

100

Rate (Hz)

1k

Adjust the engineering Units scale values here

Select your scale here