Getting Data in the Lab

LabVIEW, Data Acquisition,

and Instrument Control

Dr. Jason D. Sommerville

President, UPVI, LLC.

jason.sommerville@upvi.net

www.upvi.net

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Getting Data in the Lab

Part 2: Data Acquisition

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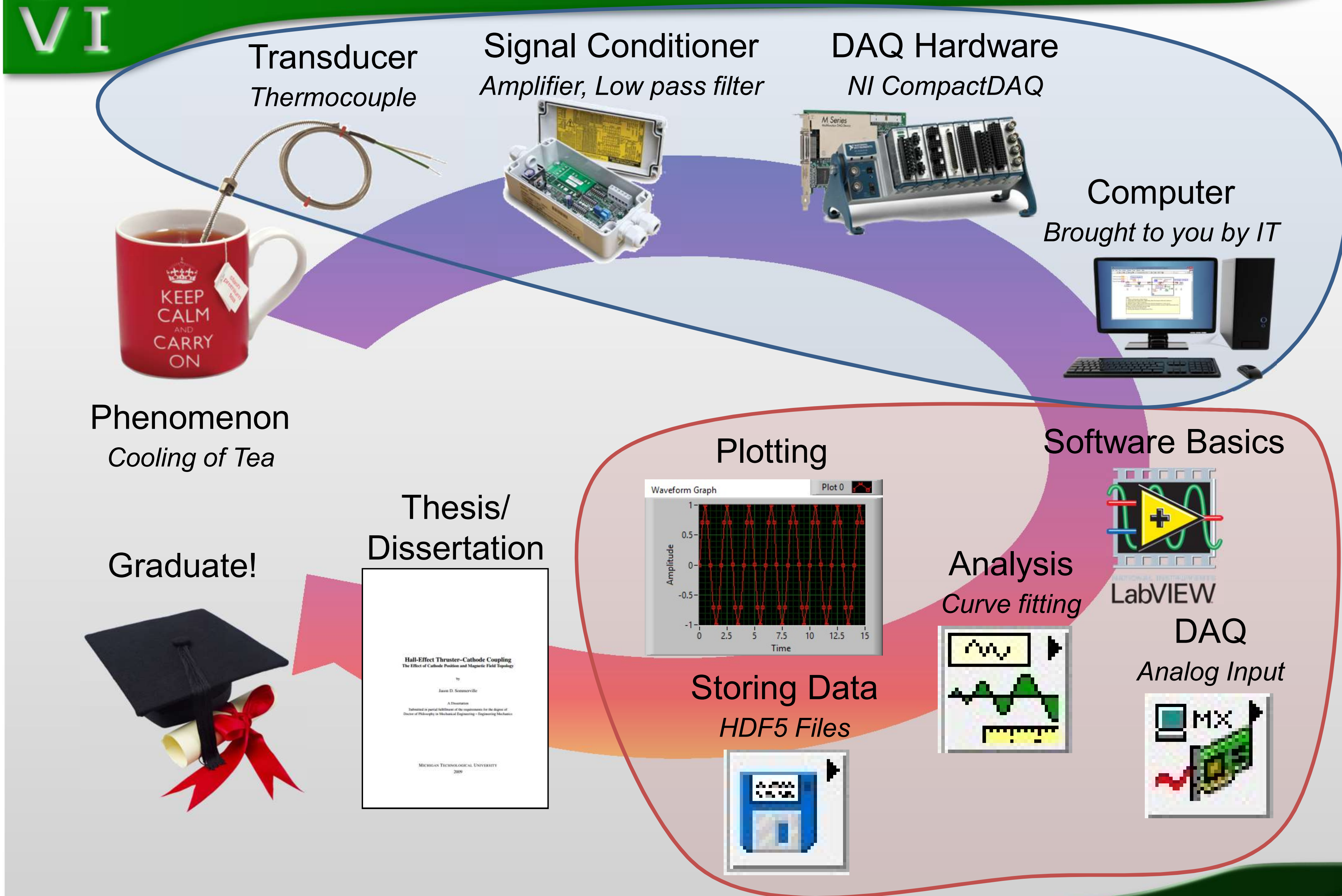

Transducer
Thermocouple
Signal Conditioner
Amplifier, Low pass filter
DAQ Hardware
NI CompactDAQ
Computer
Brought to you by IT
KEEP
CALM
AND
CARRY
ON
Phenomenon
Cooling of Tea
Plotting
Waveform Graph
Plot 0
Amplitude
Time
Software Basics
LabVIEW
Analysis
Curve fitting
DAQ
Analog Input
Storing Data
HDF5 Files
Thesis/
Dissertation
Hall-Effect Thruster–Cathode Coupling
Graduate!

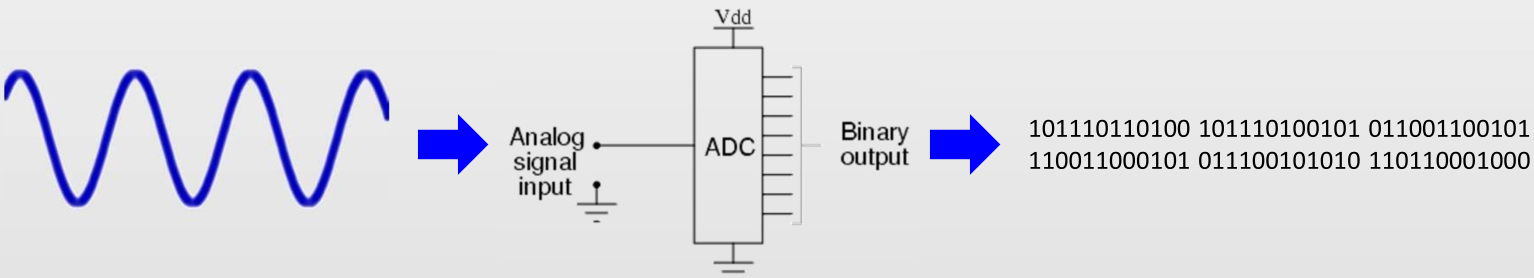
Data Acquisition

- **Data Acquisition or DAQ is the process of converting real-world measurements into digital computer data**
  - Signal measurement
  - Signal digitization
  - Moving the data to computer memory and/or disk
- **DAQ may also encompass signal generation**
  - Waveform generation
  - Triggering
  - Control systems
- **All the components must be compatible with each other!**
  - But we have to break it down in the lecture and handle one thing at a time
- **In 2016, if you’re writing data down by hand, you’re probably doing it wrong**

Types of DAQ: Signal Acquisition

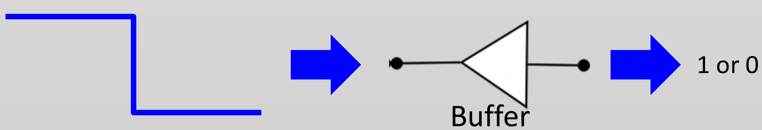
Analog Input

- Convert analog voltage signals into digital data
- Single-shot or timed measurements
- Use an analog-to-digital converter
- Examples: temperature, sounds, voltage



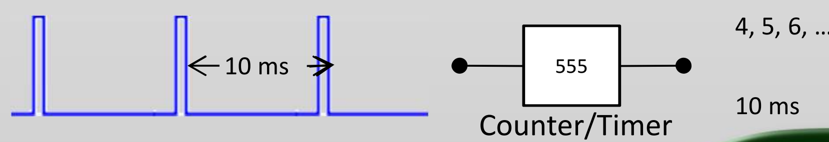
Digital Input

- Single-shot or timed
- Single bit or bus
- Example: proximity sensor, photointerrupter



Counter/Timers

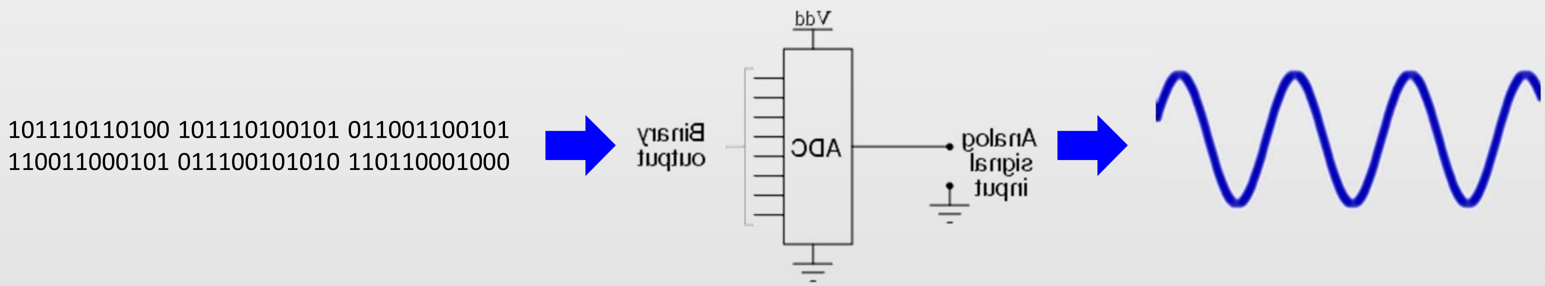
- Count events
- Time events
- Examples: encoders, pulse train timing, delay timing, delay generation



Types of DAQ: Generation

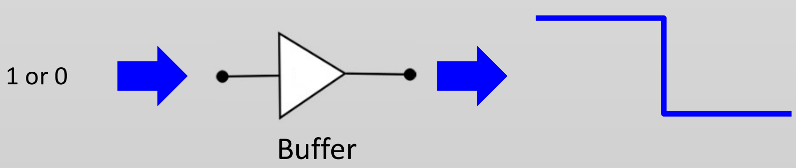
Analog Output

- Convert digital data into analog waveforms
- Single-shot or timed generation
- Use a digital-to-analog converter
- Examples: sound, system excitation, motor control



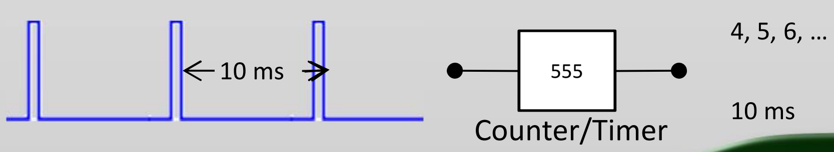
Digital Output

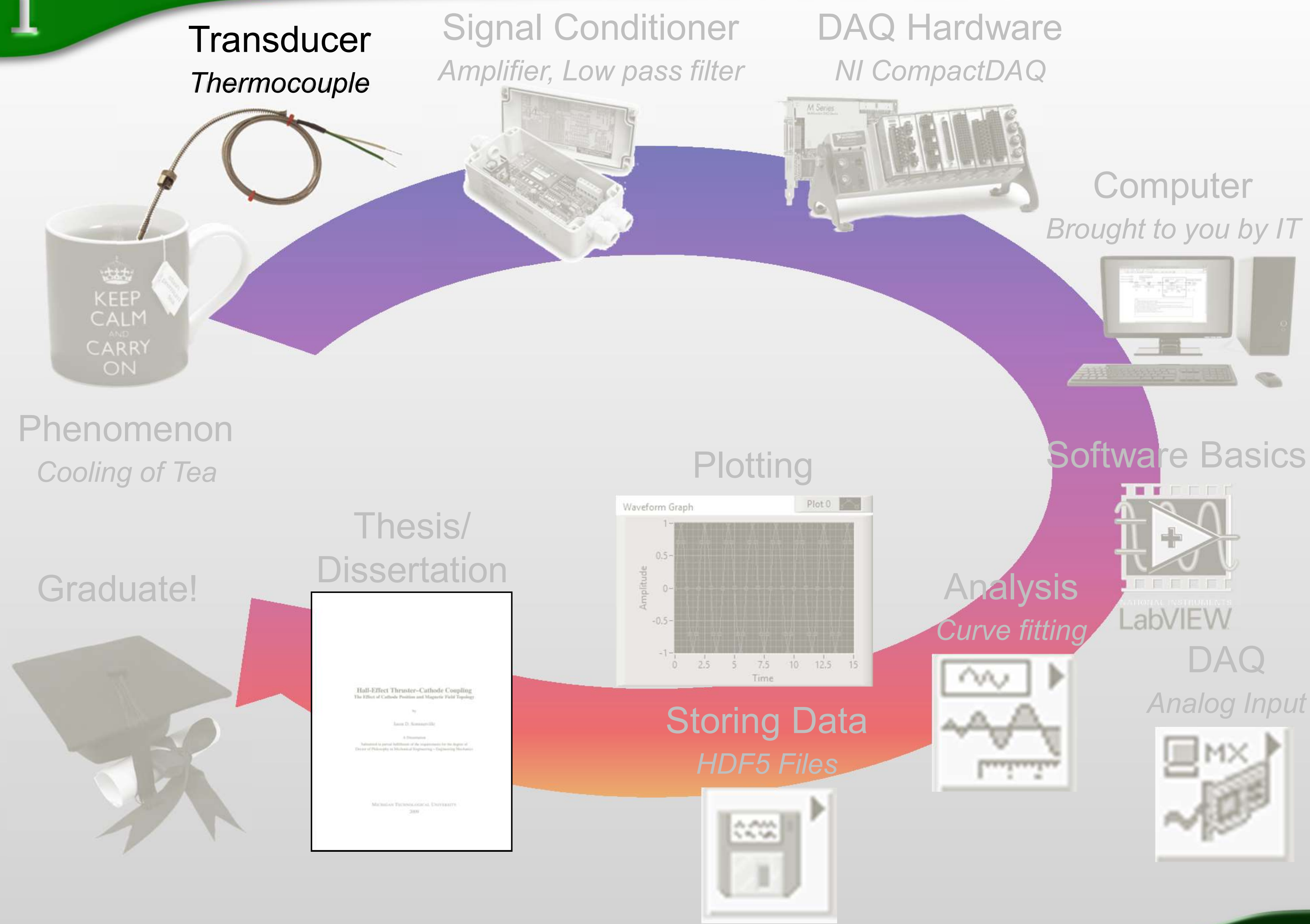
- Single-shot or timed
- Single bit or bus
- Generating a slow trigger, controlling an LED, controlling a bus



Counter/Timers

- Control timing
- Examples: Pulse train generation, delay generation

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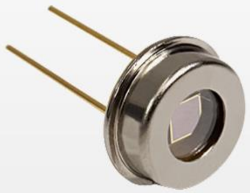
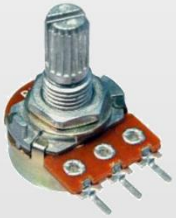
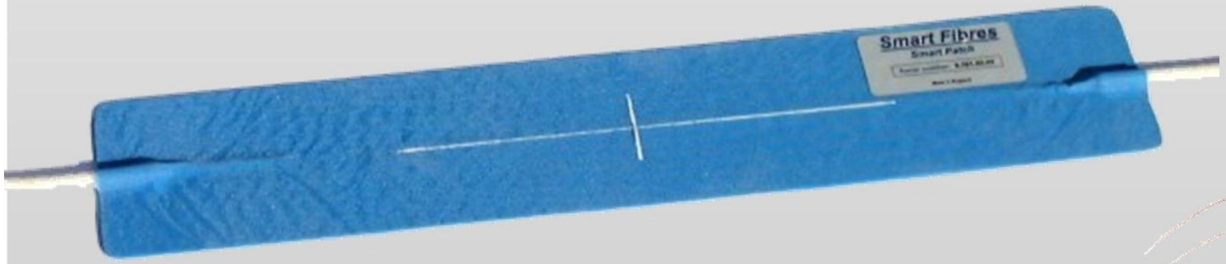
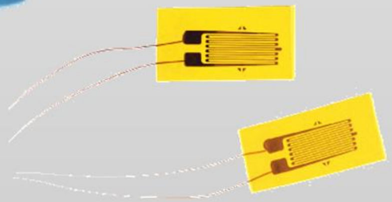
Transducers

- Convert real world data into something that can be measured by a data acquisition device
  - *Voltage*
  - Current
  - Resistance
- Also called sensors





Transducer Menagerie

Temperature	Pressure	Flow
• Thermocouple • Thermistor • RTD • IC Temp Sensor • IR Sensor • Fiber Bragg Grating (FBG)	• Piezo-resistive strain gauge • Capacitive • Electromagnetic • Piezoelectric • Microphone • FBG • Ion gauge	• Differential Pressure • Pitot tube • Calorimetric • Turbine • Electromagnetic • Ultrasonic

Light	Position/Velocity	Strain, weight, etc
• Photodiode • Phototransistor • Photomultiplier • Single-photon avalanche diode • CCD/CMOS array	• Optical Encoders (A,L) • LVDT (L) • Resolver (A) • Potentiometer (A) • String Pot (L) • Radar (L) • Laser interferometry (L)	• Strain gauge • Load cell • Piezoelectrics

How to chose a transducer

- What type of measurement do you need to make?
- Calibration Curve
  - Range
    - Input range (25 – 300 ºC, 1 – 100 mN, etc.)
    - Output range (0 to 10V, -5 to 5 V, 4 to 20 mA, etc.)
  - Sensitivity—How well can change be detected?
- How good is the measurement?
  - Accuracy (±1 ºC, ±0.1 mN, etc.)
  - Precision (repeatability)
  - Linearity—can be handled in software
  - Drift—Change in calibration over time
  - Hysteresis—is it the same going up as coming back down?
- Timing
  - Response time
  - Bandwidth (1 Hz, 100 kHz – 1 MHz, etc.)
- Other considerations
  - Analog or digital
    - Analog: voltage, current, impedance, etc.
  - What signal conditioning or excitation/power does it require?
  - How will I connect it to my DAQ system?
  - Environmental isolation
    - *Voltage*, temperature, noise, vacuum, water, etc.
  - Ruggedness
  - Cost

Q: Where do I find this stuff?

A: All this info *should* be on the transducer's datasheet or specification sheet

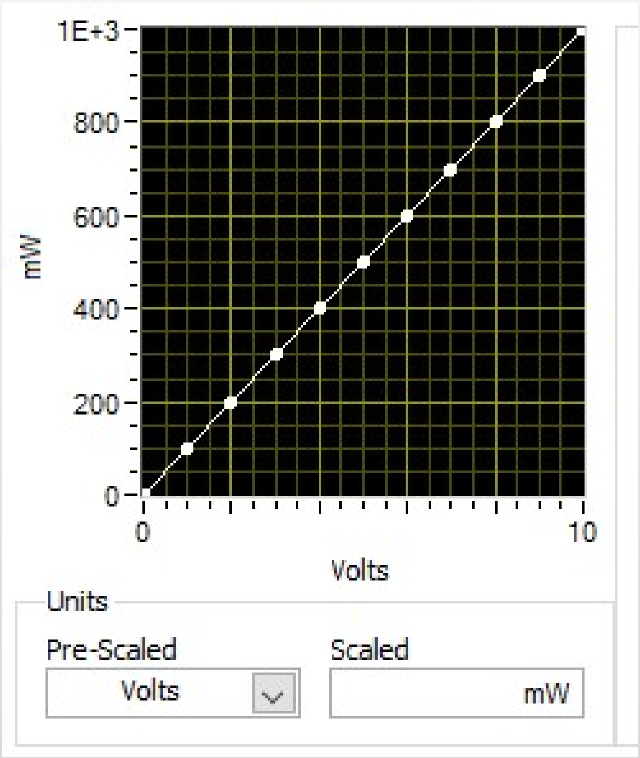
(which *should* be available from the manufacturer's website)

Range

- Range specifies the maximum and minimum values a transducer can accurately handle
- Input range (or just “range”) is the values of the real world signals that can be accurately measured
  - 0 – 100 degrees C
  - 0 – 10 mN
  - -500 – 500 mm
  - **Should cover the expected range of your physical system!**
- Output range is the corresponding range of output:
  - 0 – 10 V
  - -2 – 5 V
  - 4 – 20 mA
  - 0 – 100 kΩ
  - **Must work with your DAQ system!**

Sensitivity

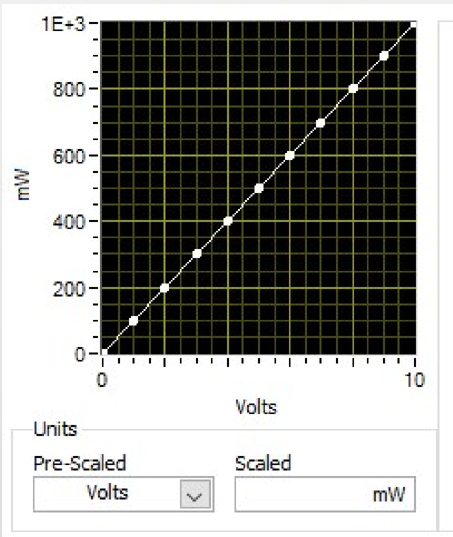
- **How much does the output change for a given change in input?**
  - That is, the slope of the calibration curve
- **Units of output unit/physical unit**
  - V / deg C
  - V / N
  - mV / mrad
  - mA / (L/s)
- **Tradeoff between sensitivity and range**
- **Sensor may not be equally sensitive across its full range**
  - I.e., calibration curve may not be linear



Calibration Curve

Relates the physical input signal to the electrical output signal

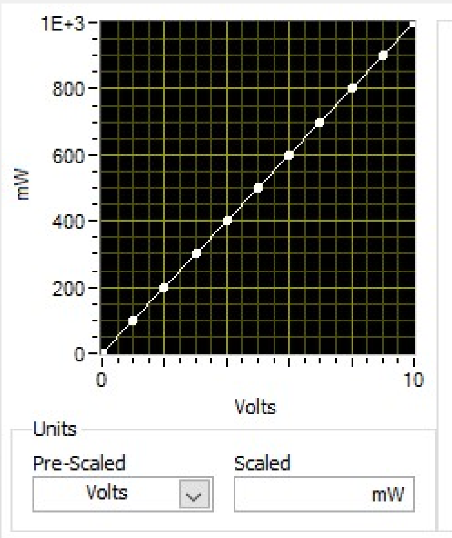
Linear



A linear function is used to relate input (x) to output (y).

$$y = mx + b$$

Mapped ranges



Different way of specifying a linear calibration curve

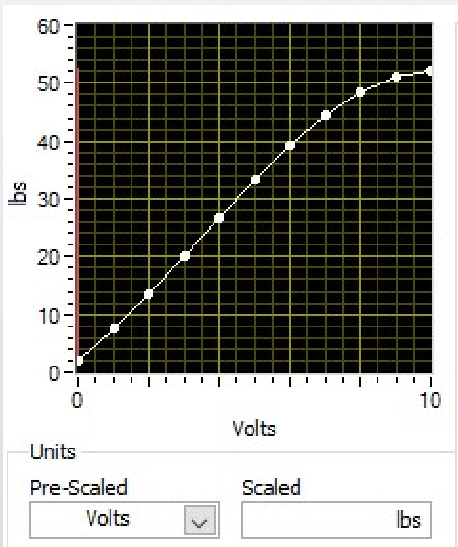
$$x_1 \longrightarrow y_1$$

$$x_2 \longrightarrow y_2$$

Calibration Curve

Relates the physical input signal to the electrical output signal

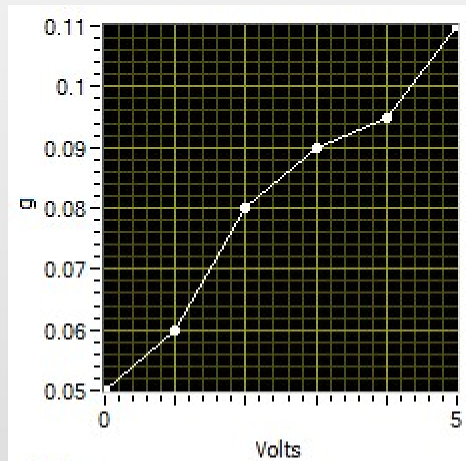
Functional, e.g polynomial



A general function is used to relate input (x) to output (y), e.g.

$$y = \sum_i a_i x^i$$

Table, i.e. piecewise linear



Pre-Scaled Values	Scaled Values
0	0.05
1	0.06
2	0.08
3	0.09
4	0.095
5	0.11

- Linearly interpolate between measured points.
- Useful for measured calibration curves

Example

- Thermocouples measure the *difference* in temperature between the hot junction and the cold junction
- There are different types of thermocouples for different temperature ranges
- More reading: http://www.ni.com/white-paper/4218/en/

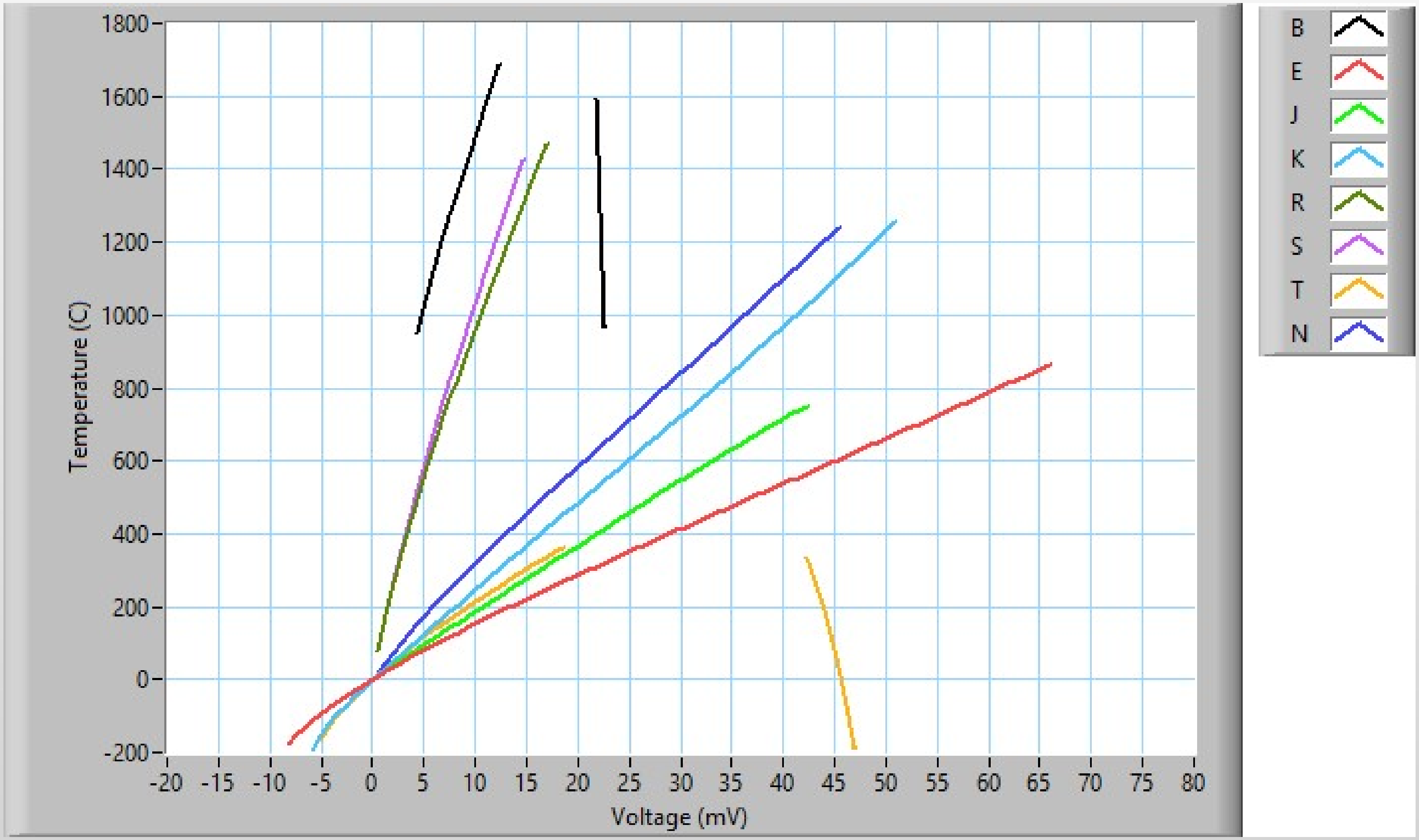
Range: Choosing a thermocouple

THERMOCOUPLE TYPE: (ASTM Standard Color Coded)	OPERATING TEMPERATURE:	SPECIAL LIMITS OF ERROR: (WHICH EVER IS GREATER)	EACH CONDUCTOR:	ANSI COLOR CODING EXTENSION WIRE:	T/C WIRE:
E	0 - 900° C (32 - 1650° F) -200 - 0° C (-200 - 32° F)	± 1.0 C or ± .4% of reading ± 1.7° C or ± 1% of reading	Positive / Chromel™ = Purple Negitive /Constantan =Red	Purple	Brown
J	0 - 750° C (32 -1380° F)	± 1.1° C or ± .4% of reading	Positive / Iron = White Negitive / Contantan = Red	Black	Brown
K	0 - 1250° C (32 - 2280° F) -200 - 0° C (-325 - 32° F)	± 1.1° C or ± .4% of reading ± 2.2° C or ± 2 % of reading	Positive / Chromel™ = Yellow Negitive / Alumel™ = Red	Yellow	Brown
T	0-350° C (32-660° F) -200-0° C (-325 - 32° F)	± .5° C or ± .4% of reading ± 1.0° C or ± 1.5 % of reading	Positive /Copper = Blue Negitive / Constantan = Red	Blue	Brown

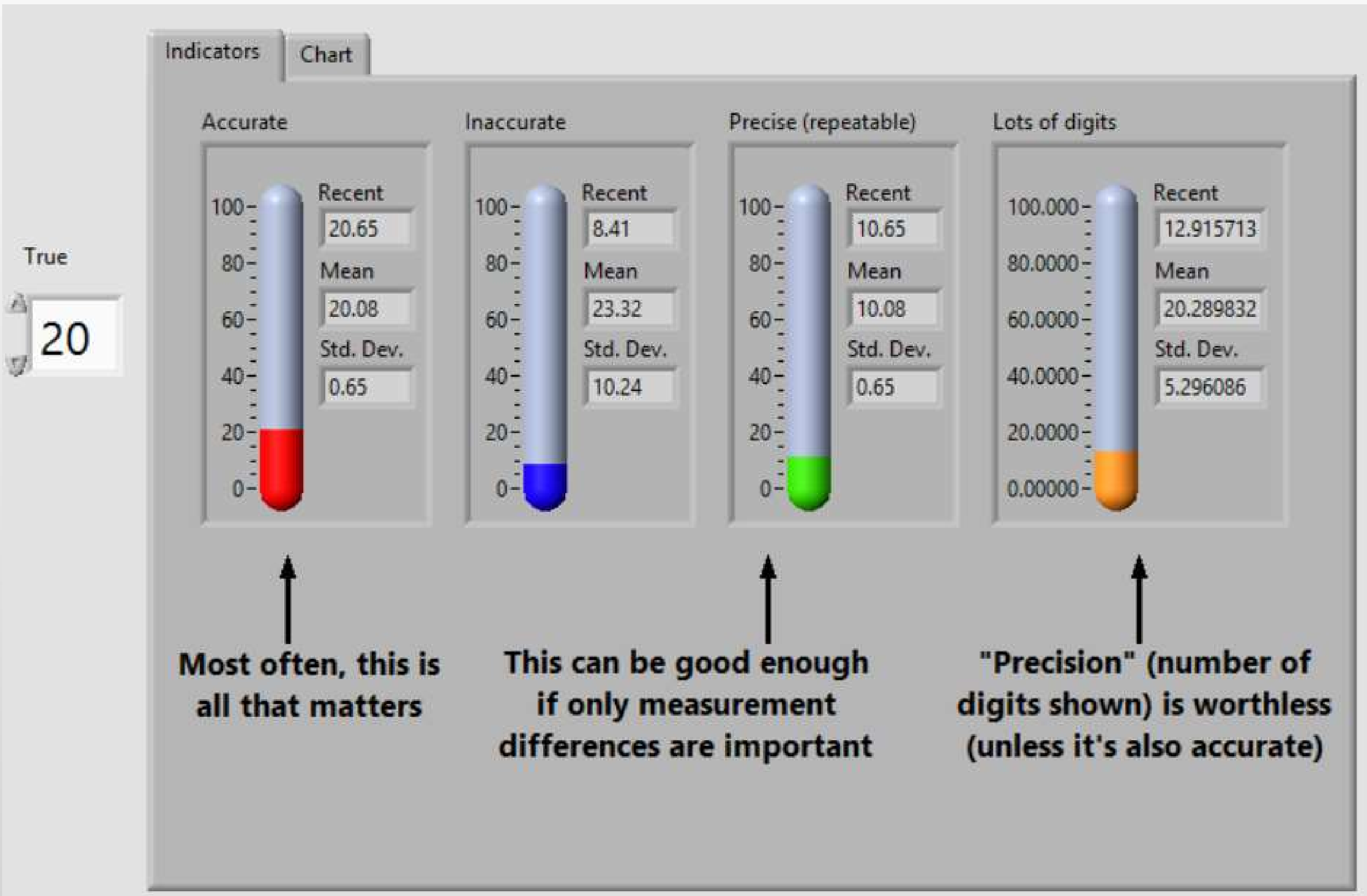
http://www.temprel.com/support/how-to-choose-thermocouple.aspx

Linearity and Sensitivity:

Ex: Choosing a thermocouple

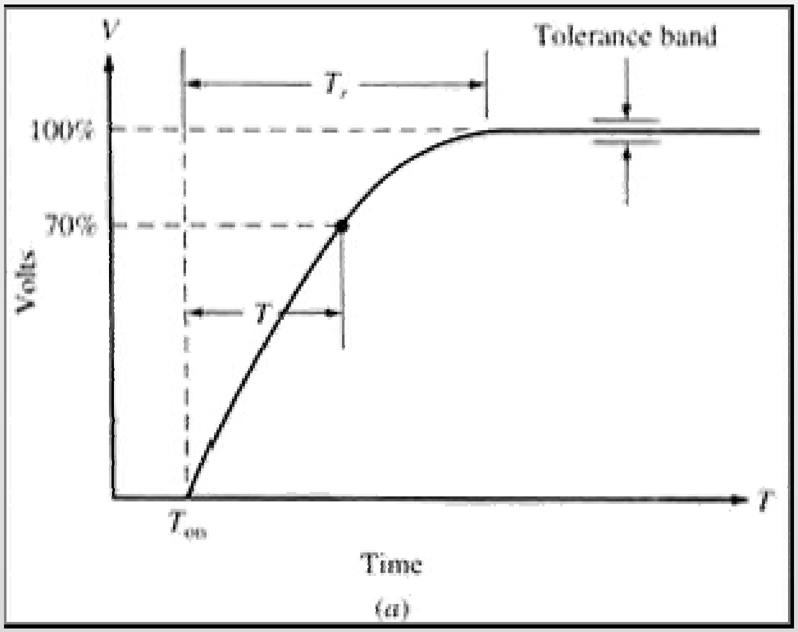


How well does it measure?

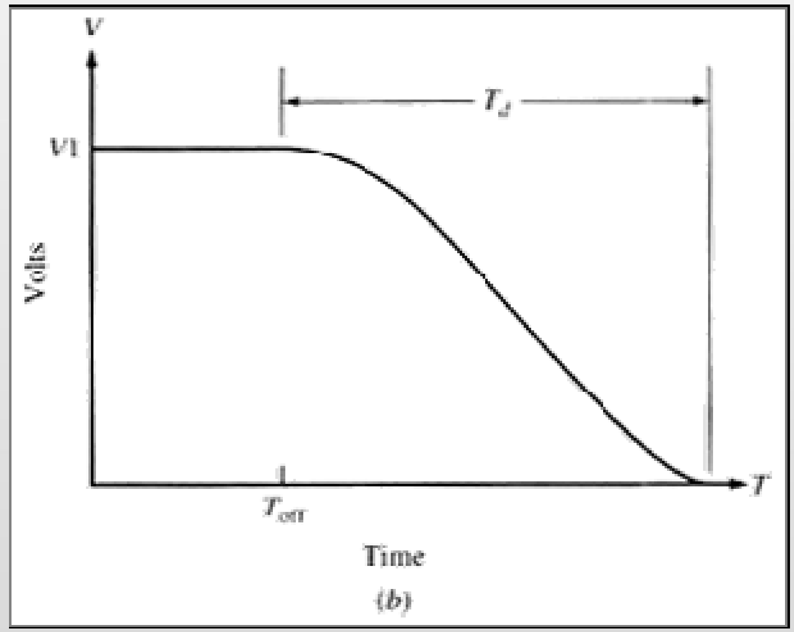


Response/Rise/Fall Time

How fast can the sensor respond to changes in the measured property?



Rise Time



Fall Time

[Hall sensor]

Bandwidth

Usually another way of specifying the response time

$$\text{Bandwidth} \approx \frac{1}{2 \times \text{Response Time}}$$

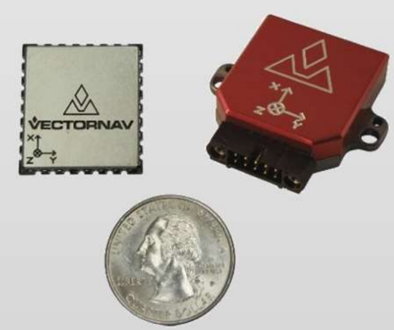
Note: For response time given as 10% to 90% rise/fall

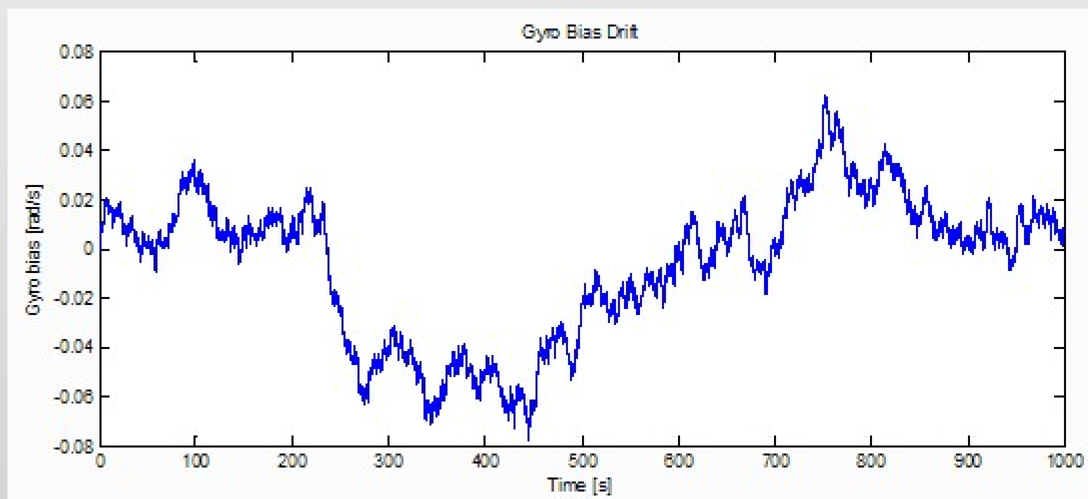
$$\text{Bandwidth} = \frac{1}{2\pi\tau}$$

$$\text{Response Time} \approx 2.197\tau$$

Drift

- The calibration of a sensor may change over “long” periods of time
  - Temperature effects
  - Humidity effects
  - Aging effects
- What is long? Depends on your measurement.





Source: http://www.vectornav.com/support/library/calibration

Hysteresis

Is it the same going up as coming down?

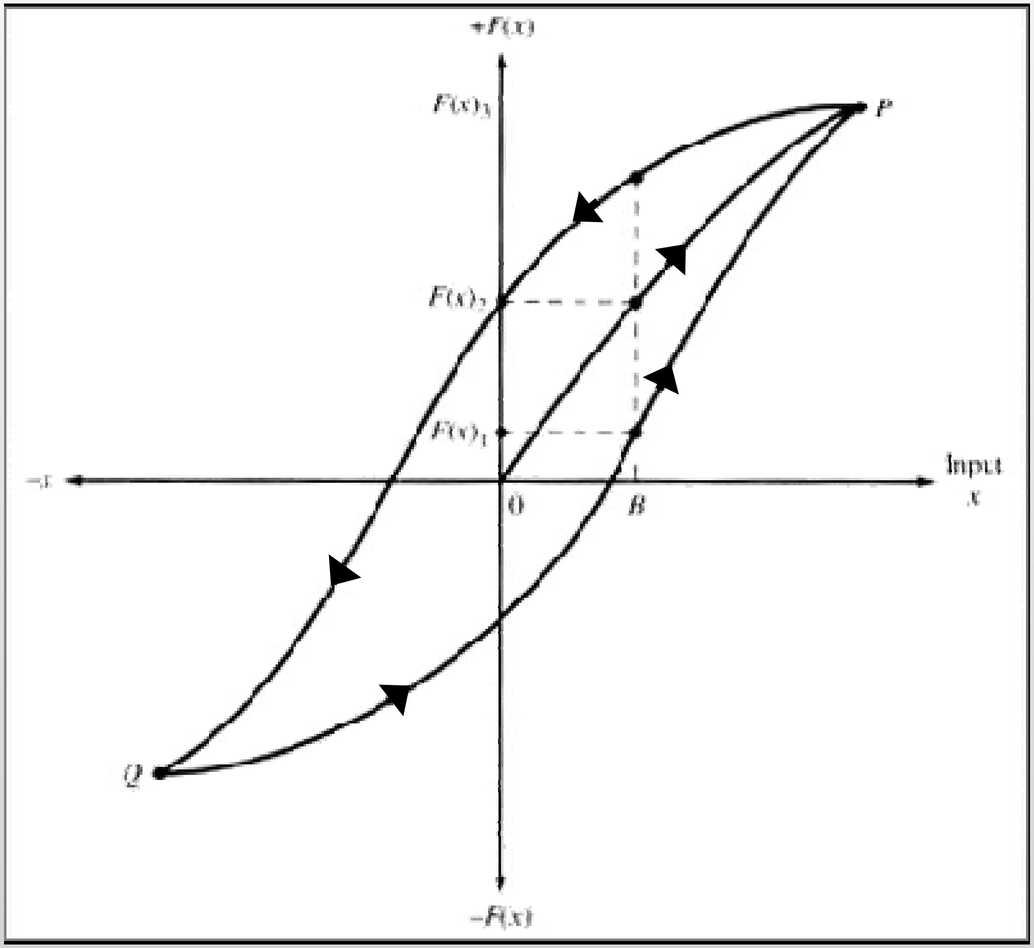


Image: http://www.ni.com/white-paper/14860/en/#toc8

Analog vs. Digital

- Nearly all transducers are analog *internally*
- However, some are packaged with dedicated ADCs, signal conditioners and may provide digital communication outputs

Analog

- Voltage, current, impedance, etc.
- Requires DAQ device
- Typically faster
  - Sensor response time limits update speed
- Typically cheaper
- Transmission lines susceptible to noise
- More difficult/expensive to isolate

Digital

- Communicates via GPIB, RS-232, USB, Ethernet, etc.
- May require interface card, or may be built into system
- Typically slower and more expensive
  - Comm limits update speed
- Typically more expensive
- Less susceptible to noise
- Easier to isolate

Example: Gas Flow Meter

Analog: Omega FMA-3103

- No internal calibration curve
- Analog output only
  - Output is linearized
  - => internal signal conditioning
- Update rate of 0.5 Hz
- Cost: $375

http://www.omega.com/pptst/FMA3100_3200_3300.html

Digital: Omega FMA-4102

- Internal, programmable gas calibration curves
- Interface: RS-232 or RS-485
- Unspecified, probably about 2 Hz
- Cost: $730

http://www.omega.com/pptst/FMA4100_4300.html

Transducers: Other Considerations

- **What signal conditioning or excitation/power does it require?**
- **How will I connect it to my DAQ system?**
  - Cabling
  - Isolation (see next bullet)
- **Environmental isolation**
  - *Voltage*, temperature, noise, vacuum, water, etc.
- **Ruggedness**
- **Cost**

How to chose a transducer

- What type of measurement do you need to make?
- Calibration Curve
  - Range
    - Input range (25 – 300 ºC, 1 – 100 mN, etc.)
    - Output range (0 to 10V, -5 to 5 V, 4 to 20 mA, etc.)
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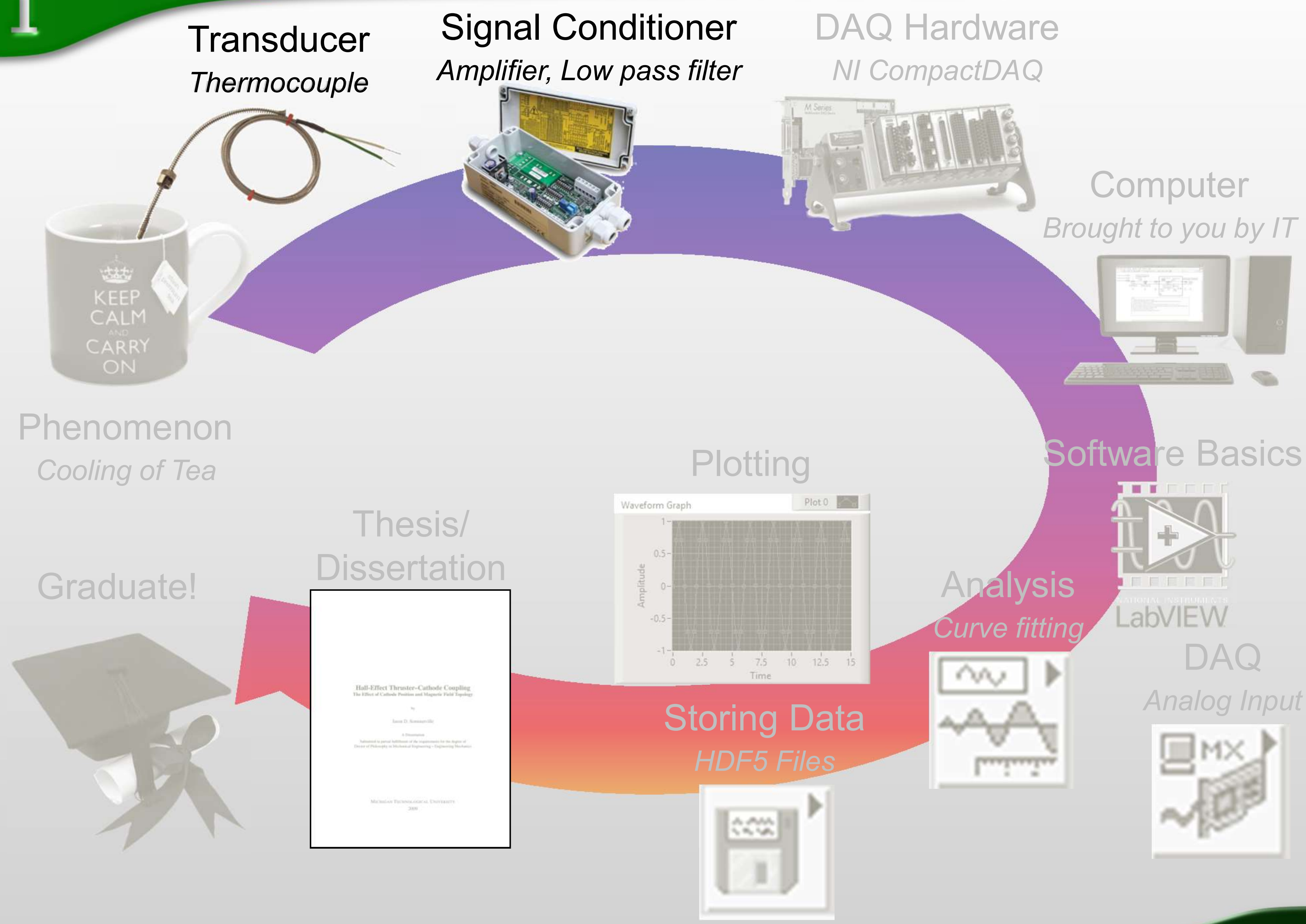
  - Linearity—can be handled in software
  - Drift—Change in calibration over time
  - Hysteresis—is it the same going up as coming back down?
- Timing
  - Response time
  - Bandwidth (1 Hz, 100 kHz – 1 MHz, etc.)
- Other considerations
  - Analog or digital
    - Analog: voltage, current, impedance, etc.
  - What signal conditioning or excitation/power does it require?
  - How will I connect it to my DAQ system?
  - Environmental isolation
    - *Voltage*, temperature, noise, vacuum, water, etc.
  - Ruggedness
  - Cost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Signal Conditioning

- Modify the transducer output so that it can be accurately measured by the DAQ system
- Some basic signal conditioning is often included with some transducers and some DAQ systems
  - X -> Voltage conversion
  - Amplification
  - Anti-aliasing filters
- Amplification/Attenuation
  - Small signals (typ. <100 mV) should be amplified to a range readable by the ADC
  - Large signals (>5 – 10 V) voltage signals need to be attenuated
- Filtering
  - Noise: use low-pass or notch filters to remove known noise sources
  - Anti-aliasing filter: a low-pass filter designed to prevent high-frequency components from being digitized and aliased by the DAQ system

Signal Conditioning (cont.)

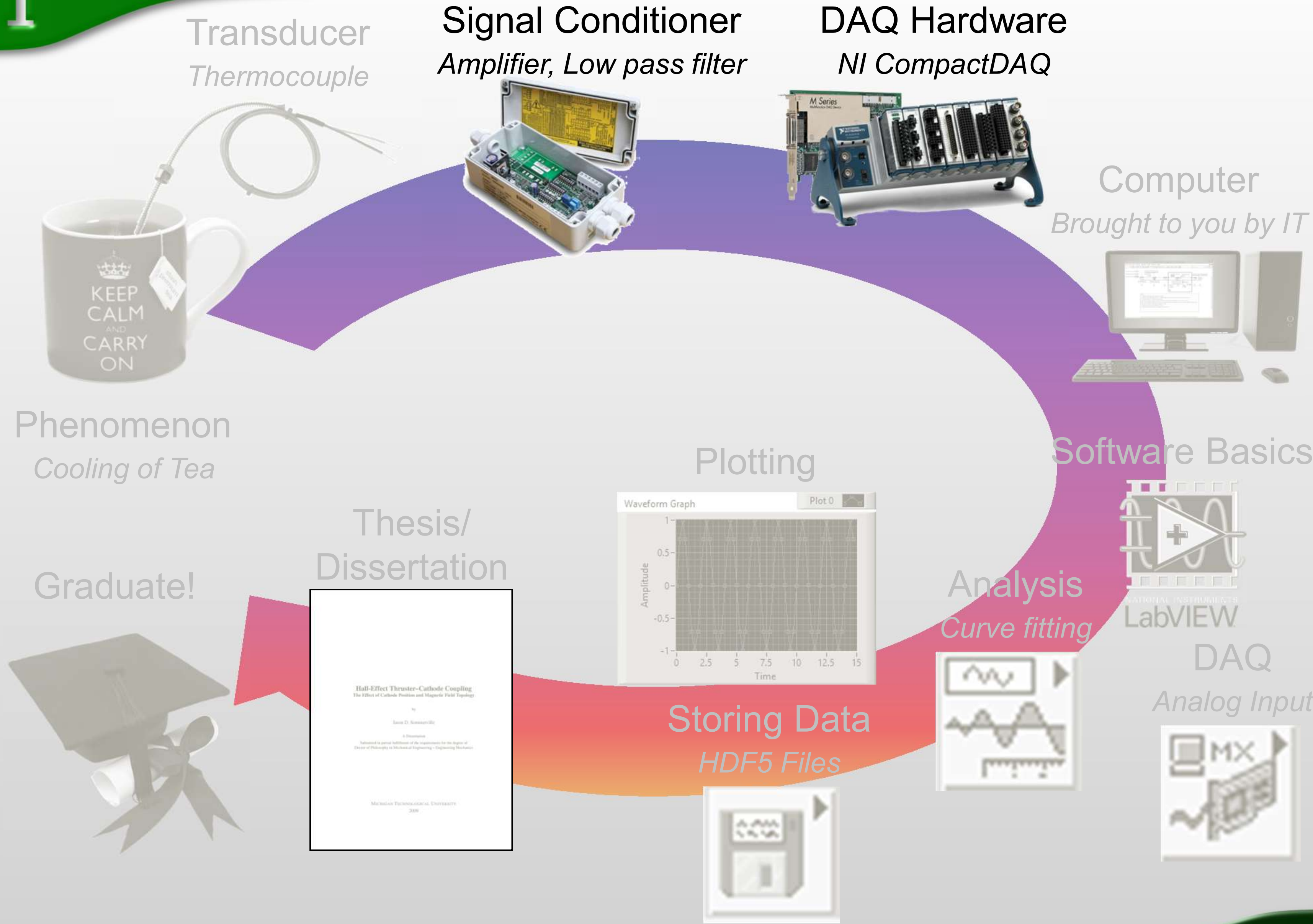
- **Voltage Isolation**
  - Allows signals at high potential differences to be safely connected to a DAQ system
- **Linearization**
  - Corrects for non-linearities in the transducer
  - In modern systems this is usually done in software
- **Transconductance, etc.**
  - Convert current signals to voltage signals
  - Other conversions possible as well (i.e. resistance to voltage, pulse-train to voltage, etc.)
- **Excitation**
  - Some sensors, e.g. RTDs and strain gauges, require a power source to excite them
  - Not strictly *signal conditioning*

Signal Conditioning—Hardware

- Amplifiers and filters often build into DAQ hardware
- Rack and rail systems
  - NI SCXI
  - Omega DRG or OM7
- Custom solutions
  - Build it yourself

NI SCXI

Omega DRG Module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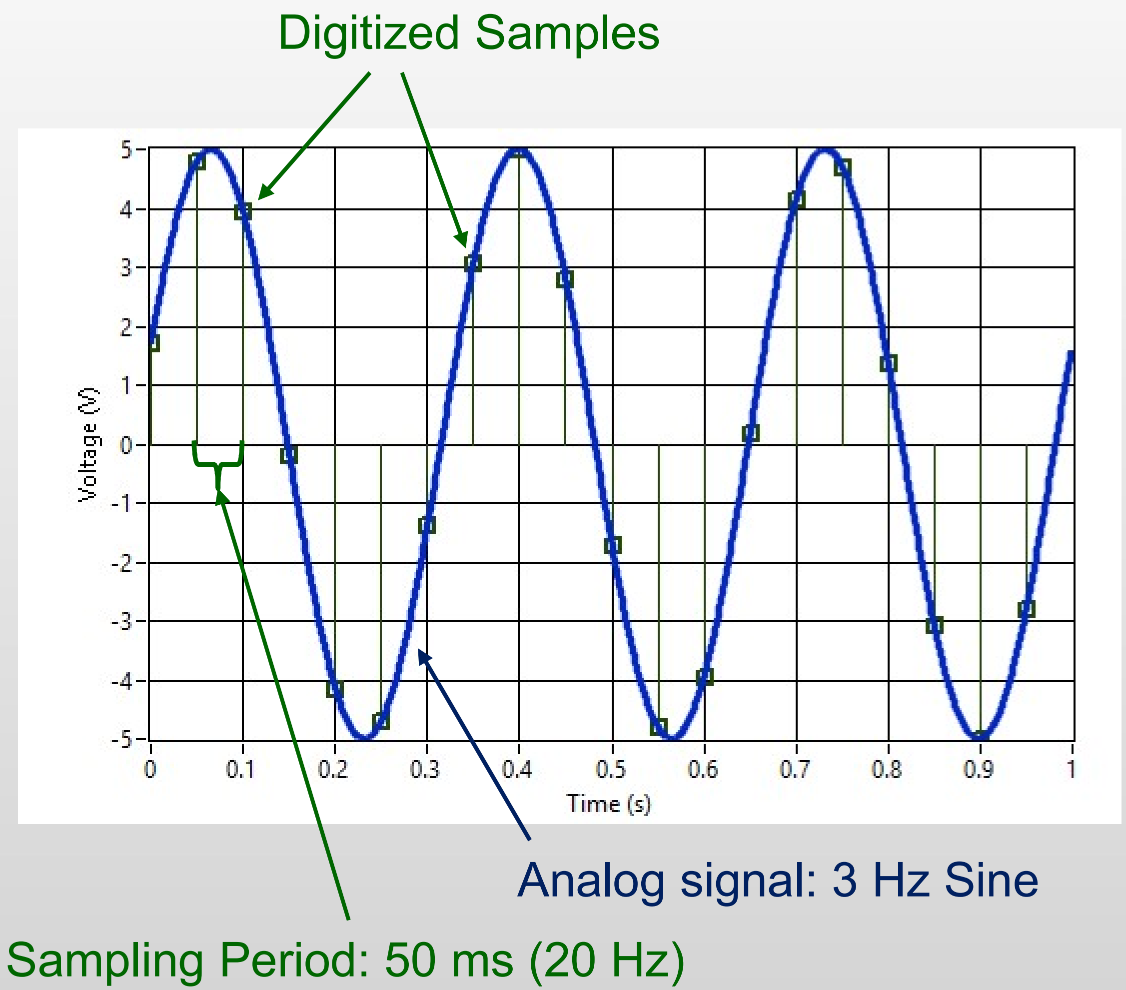
How to choose DAQ hardware

- What type of signals do you need to acquire/generate?
- How many channels of each type?
- After external conditioning, what will the polarity and range of your signal be?
- DI/SE?
- What resolution do you need across that range?
- What bandwidth do you need?
- At what rate do you need to acquire/generate the data?
    - Note that bandwidth ≠ sampling frequency, but related
    - How precise are you timing requirements? Can you use software timing?
    - How much time-skew is acceptable?
- Memory depth if signals cannot be transferred to system memory
- Connectors
- Form factor
- Computer interface (e.g. PCIe, PXI, USB, etc.)
- Software interface
- Front panel controls
- Cost

Analog Input Digitization

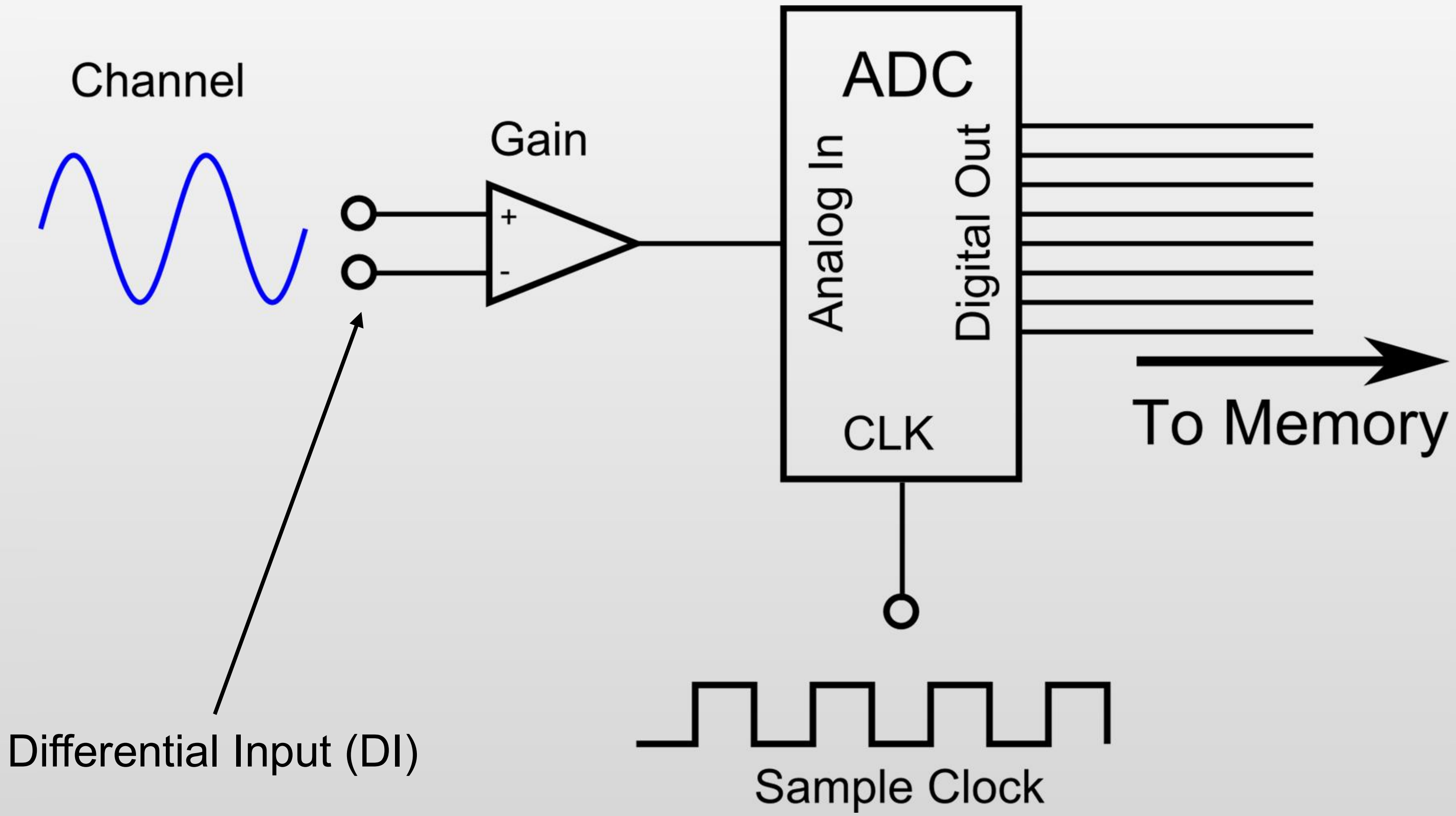


Sample Index	Time (s)	Voltage (V)
0	0.00	1.7101
1	0.05	4.80631
2	0.10	3.94005
3	0.15	-0.174497
4	0.20	-4.14519
5	0.25	-4.69846
6	0.30	-1.37819
7	0.35	3.07831
8	0.40	4.99695
9	0.45	2.79596
10	0.50	-1.7101
11	0.55	-4.80631
12	0.60	-3.94005
13	0.65	0.174497
14	0.70	4.14519
15	0.75	4.69846
16	0.80	1.37819
17	0.85	-3.07831
18	0.90	-4.99695
19	0.95	-2.79596

DAQ: Analog Input

- Central component is the Analog-to-Digital (ADC) converter
  - Digitizes the analog signal and making a digital measurement available for storage in memory
  - ADC must be supported by amplifiers, clocks, multiplexers, and other items
- Typical DAQ-AI system has the following parameters:
  - Differential vs. Single-ended inputs
  - Voltage range and polarity (bipolar or unipolar)
  - Gain settings
  - ADC resolution
  - Sampling speed and bandwidth
  - Multi-channel multiplexing

Analog Input



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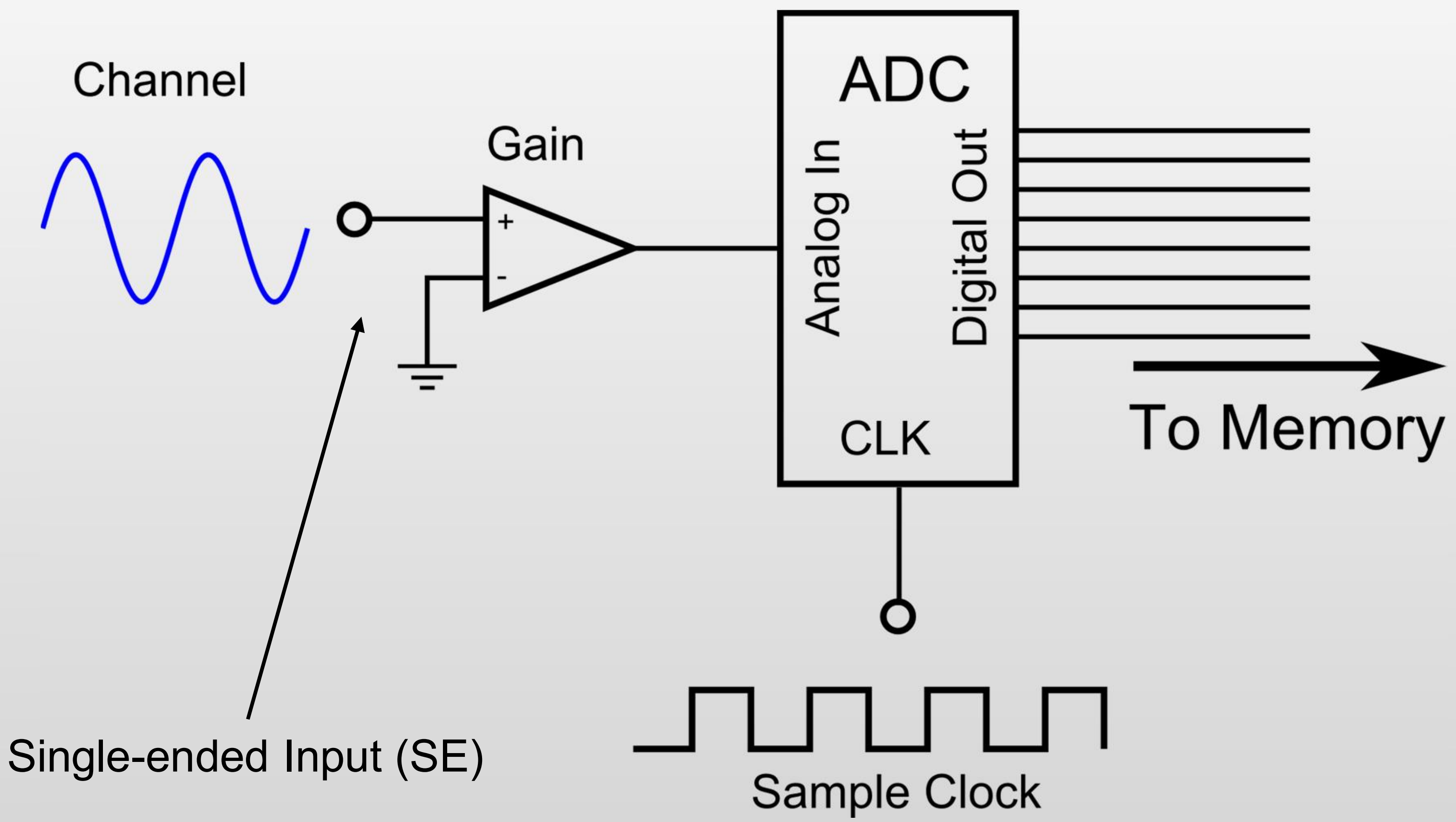
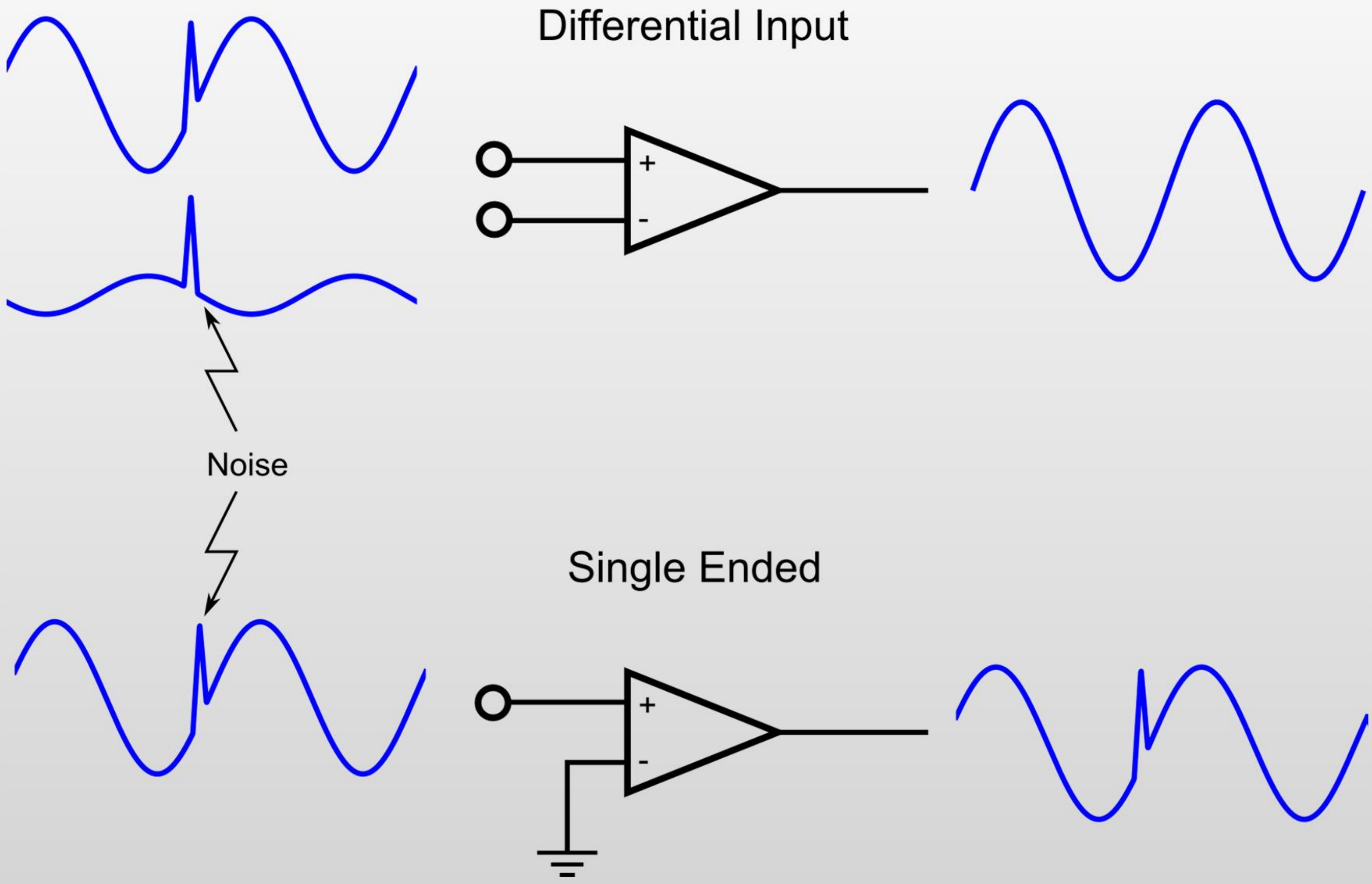


Analog Input: DI vs. SE



Analog Input: DI vs. SE

Differential Input

- Used with balanced signal lines
- Less susceptible to noise
- Less likelihood of ground loops
- Lower channel count

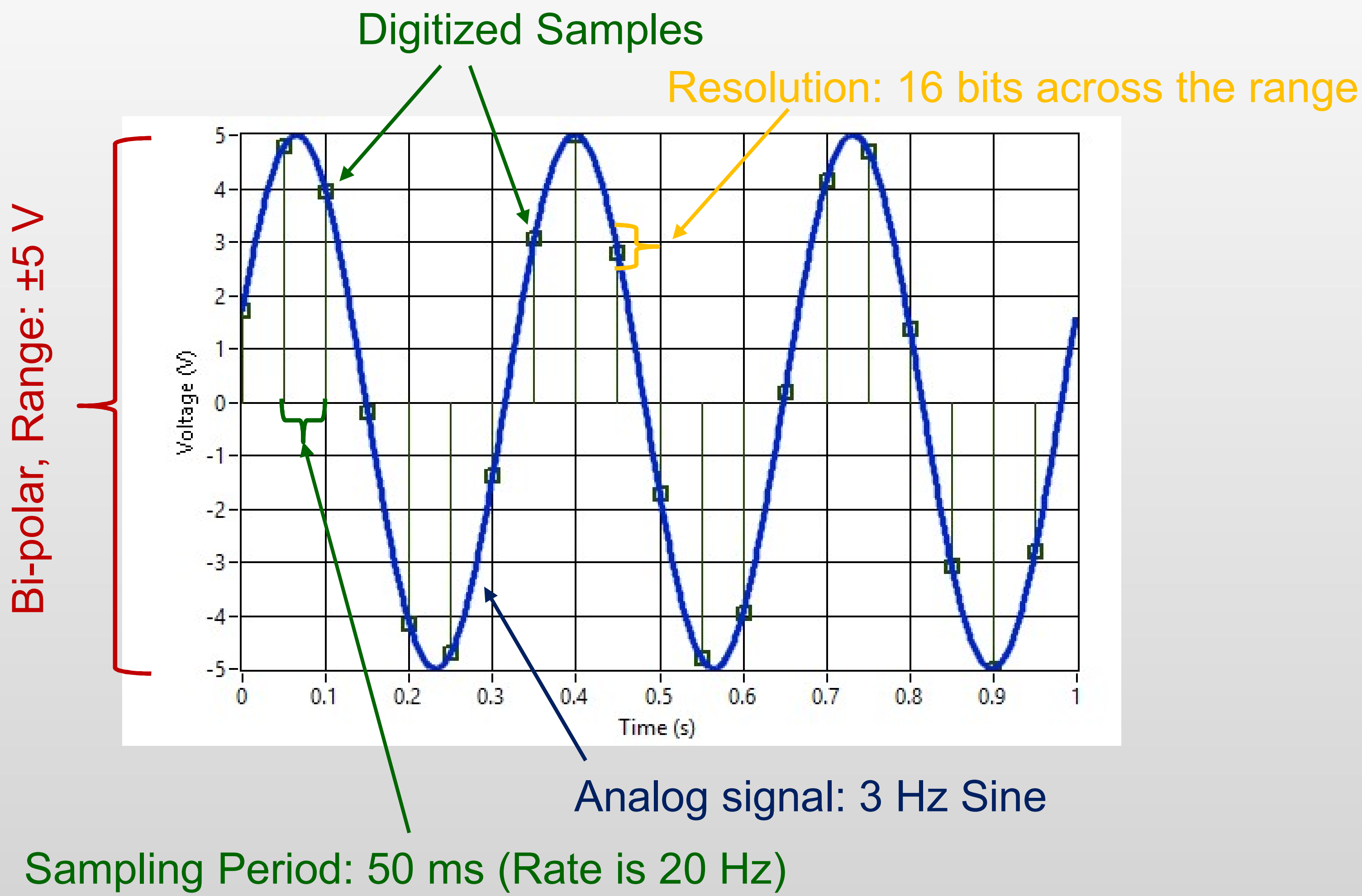
Single-Ended

- Used with unbalanced signals
- Increased susceptibility to noise
- Increased likelihood of ground loops
- Higher channel count

Differential Input Caveats

- Voltage difference must be within DAQ range
- Neither side must float too far from DAQ ground

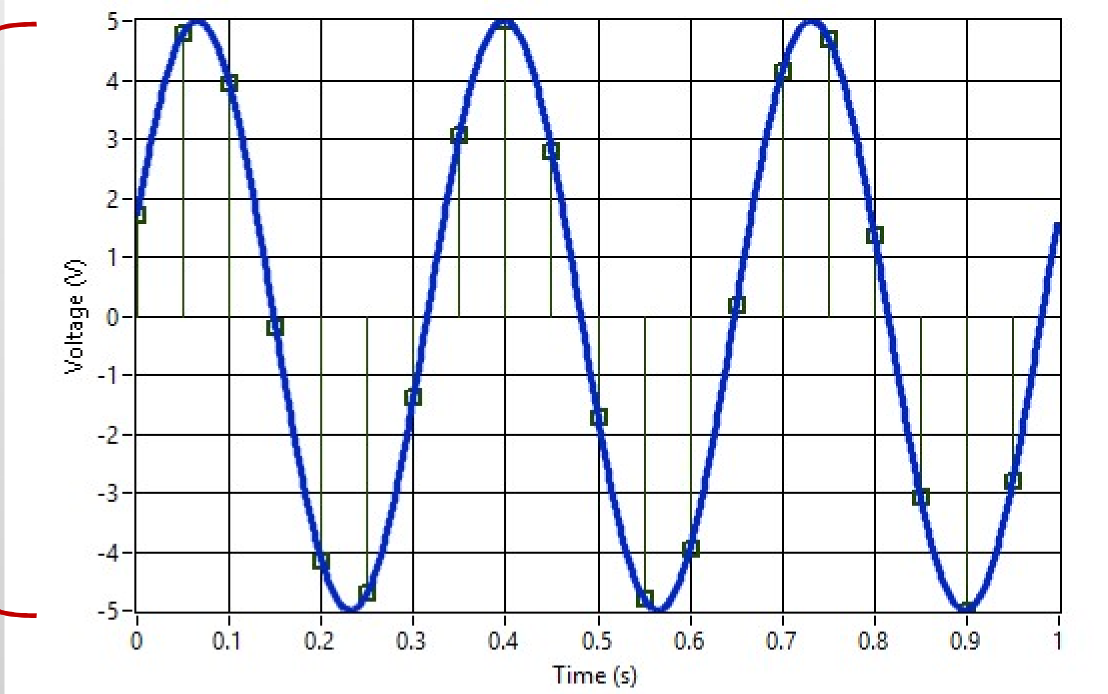
Analog Input



ADC Range and Polarity

- Range: the maximum and minimum voltage that may be read
- Unipolar: only read signals >= 0 V (or only <= 0, sometimes)
- Bipolar: may read positive and negative signals

Bi-polar, Range: ±5 V

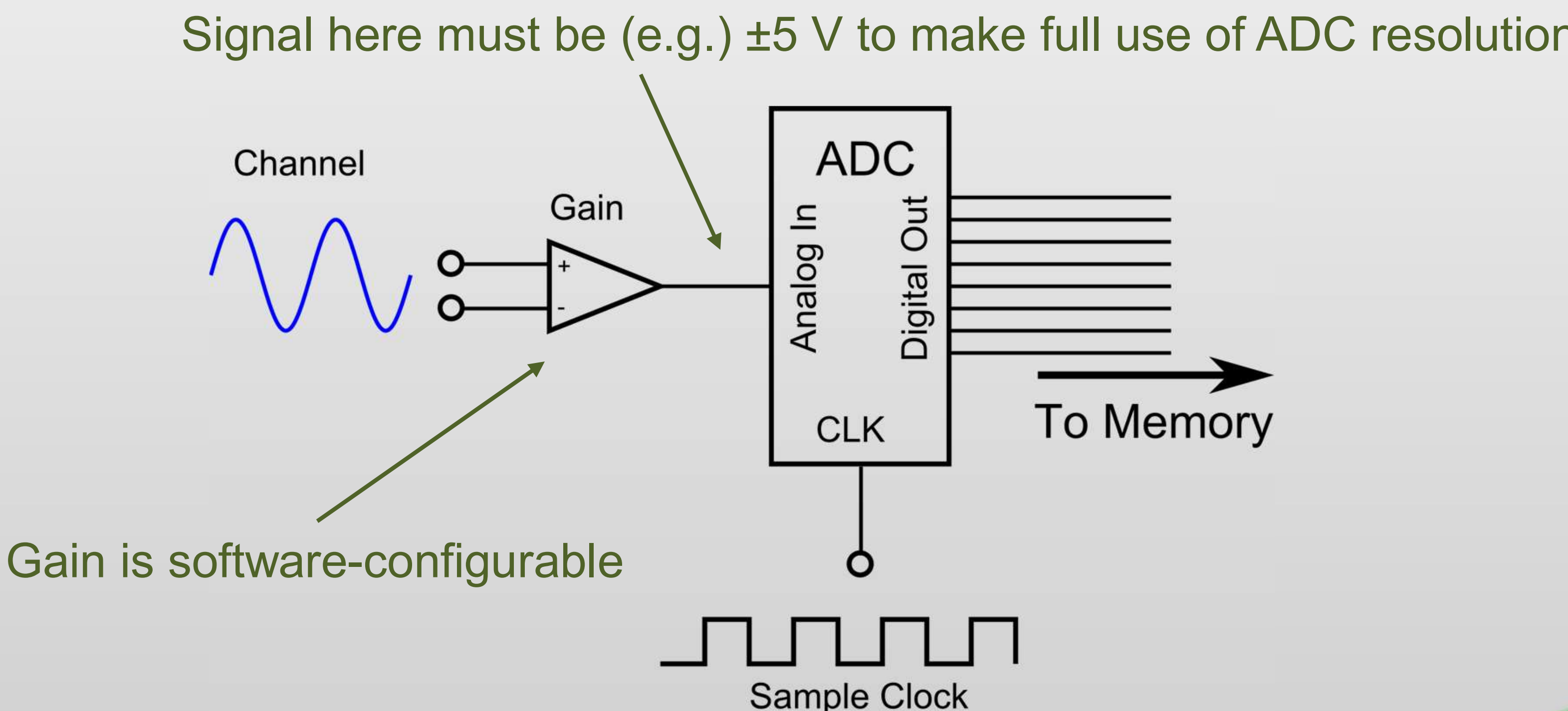


Most Common Ranges:

±5 V, ±10 V

Gain Settings

- Configurable gain settings allow ADC to make more use of available ADC resolution
- Note that noise is also amplified—better to amplify at source, if possible

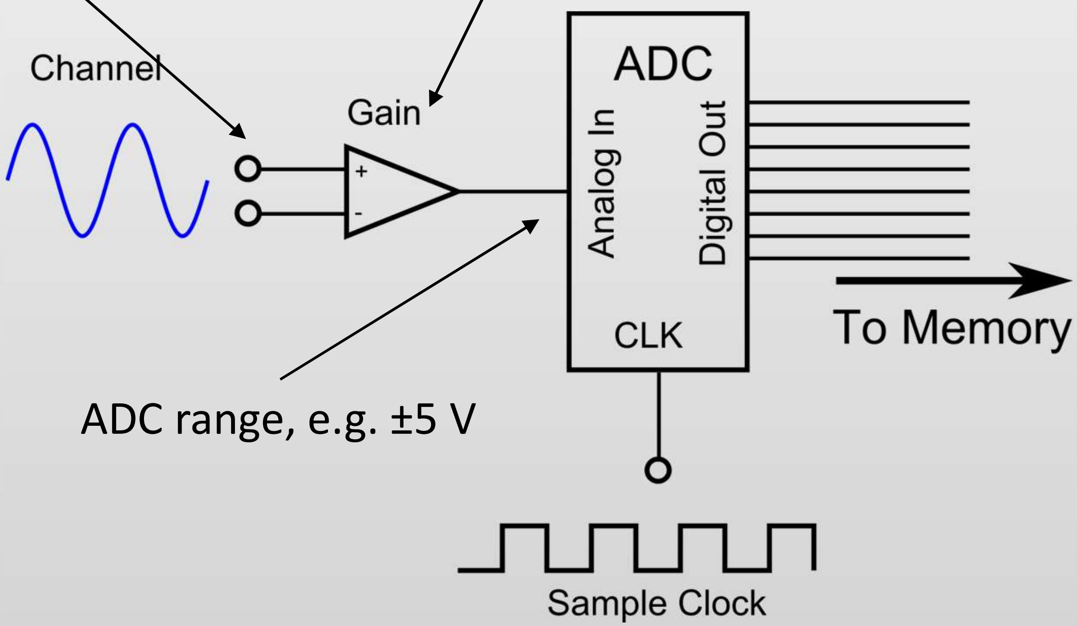


Gain Settings

$$\text{Working Range} = \frac{\text{ADC Range}}{\text{Gain}}$$

Working range <= signal range
e.g.: ±250 mV

Gain, e.g. 20



ADC range, e.g. ±5 V

Gain Settings: Specifications

Spec. Ranges

- Multiple ranges specified
- Gain unspecified
- Actual ADC range unspecified
- Example: NI PCI-6251
  - http://www.ni.com/pdf/manuals/375213b.pdf

Spec. Gains

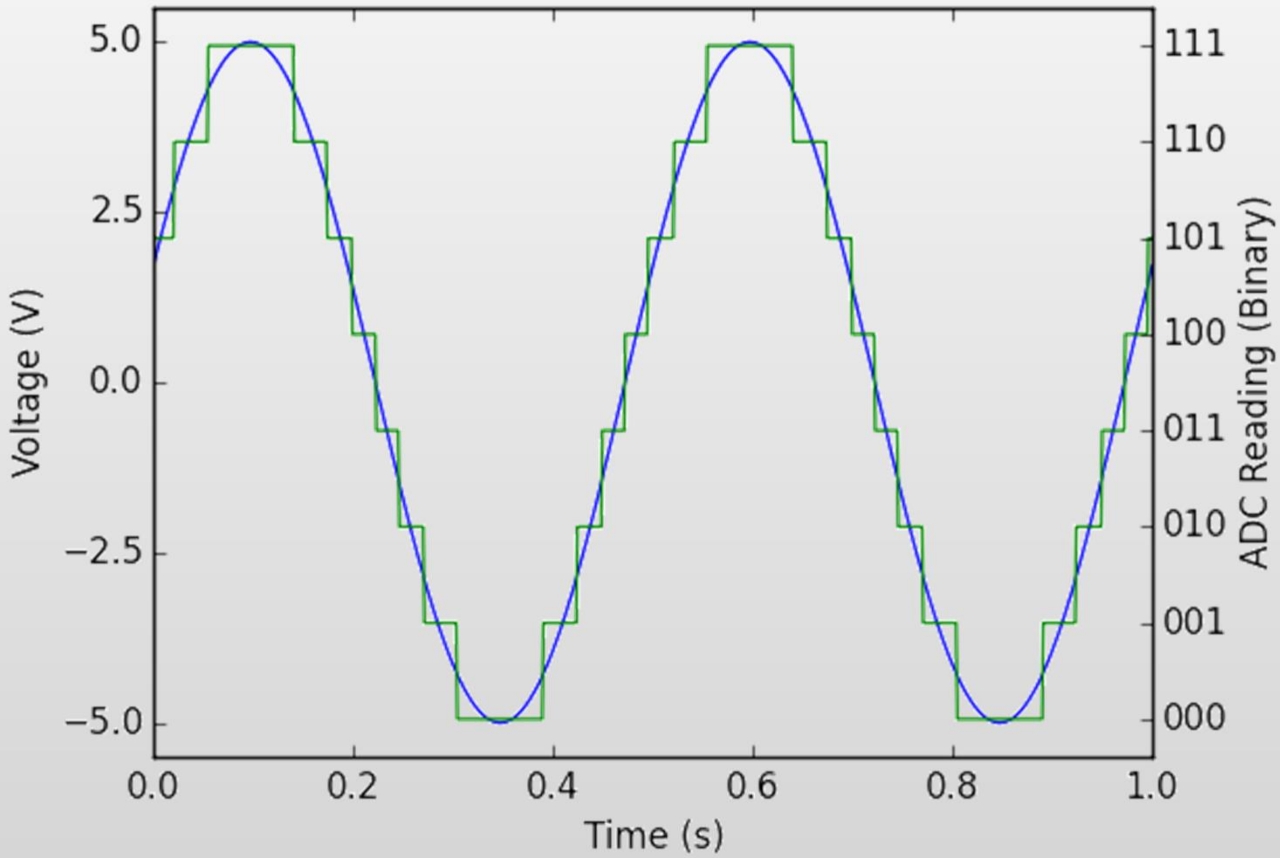
- Multiple gains specified
- Only maximum range specified
- ADC range must be specified
- Example: Keithley KUSB-3101
  - (Actually specifies both)
  - http://www.keithley.nl/data?asset=50072

$$\text{Working Range} = \frac{\text{ADC Range}}{\text{Gain}}$$

ADC Resolution: 3 bits

Number of bins = $2^3 = 8$

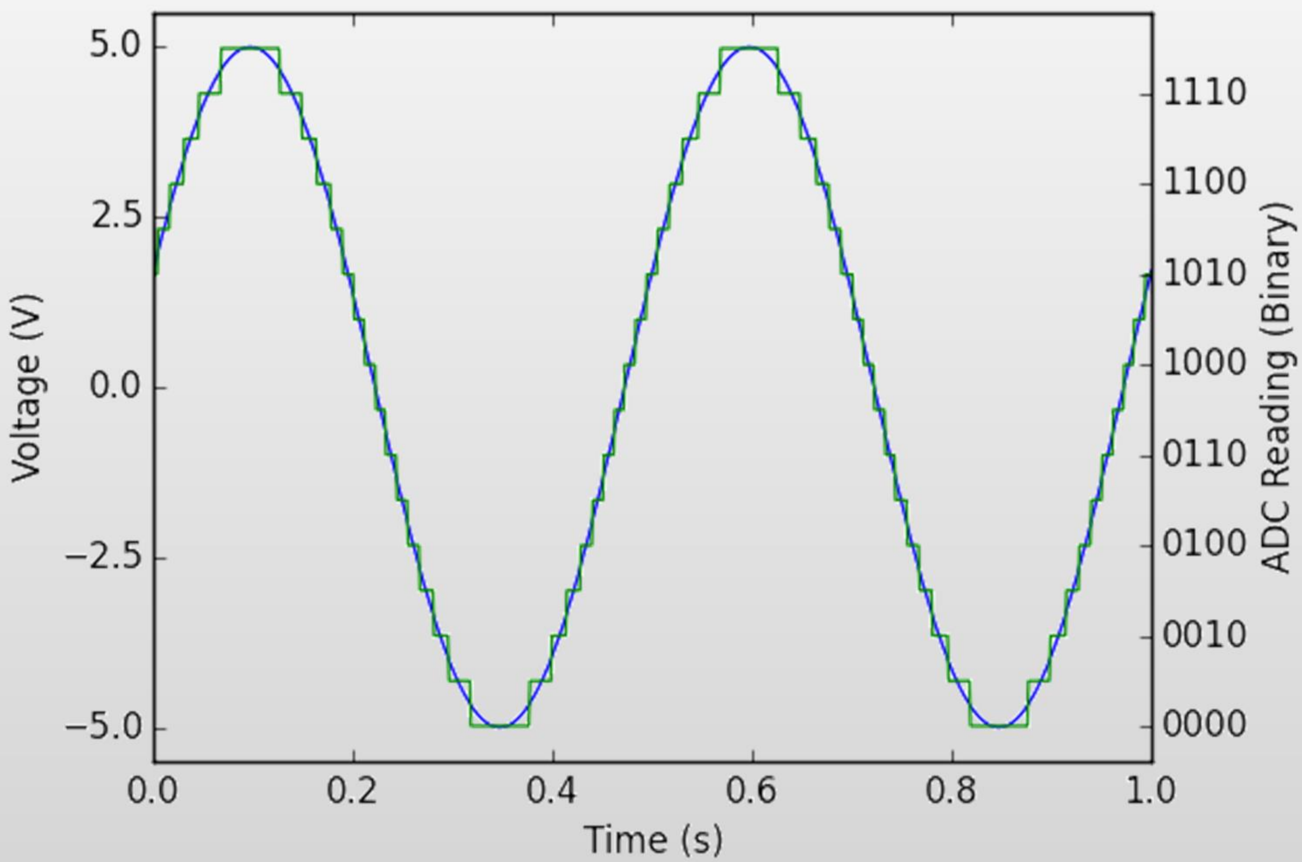
Range = 5V – (-5V) = 10 V



ADC Resolution: 4 bits

Number of bins = $2^4 = 16$

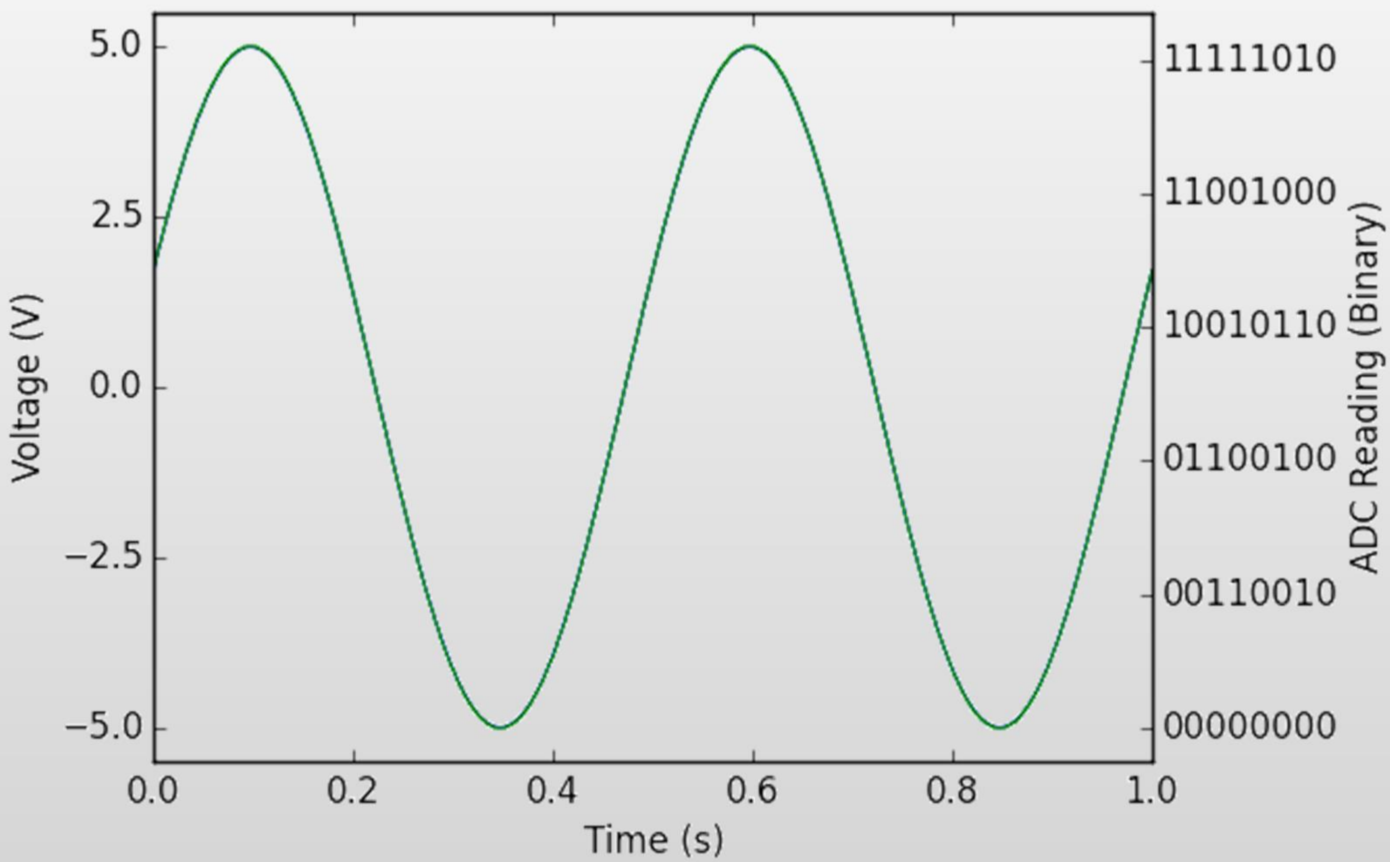
Range = 5V – (-5V) = 10 V



ADC Resolution: 8 bits

Number of bins = $2^8 = 256$

Range = 5V – (-5V) = 10 V



ADC Resolution

- The resolution with which a signal can be measured, specified in bits
- Resolution in volts is given by ADC Range, Gain setting, and ADC resolution

$$\text{Res} = \frac{\text{Working Range}}{2^{\text{bits}}} = \frac{\text{ADC Range}}{\text{Gain} \times 2^{\text{bits}}}$$

Example: $\frac{10\ \text{V}}{20\times 2^{16}} = 7.6\ \mu\text{V}$

Most Common Resolutions:

8, 12, 16, 24

- Note that sometimes the specified “range” will be the product of the smallest gain and range, or all range-gain products will be specified.

Voltage <-> ADC Reading

$$\text{Volts} = \text{Res} \times \text{ADC Reading} + \text{Min Range}$$

Example:, 5 – (-5) V range, 16 bit resolution, reading = 8745

$$-3.66 \text{ V} = 152\ \mu\text{V} \times 8745 + (-5 \text{ V})$$

Other direction:

$$\text{ADC Reading} = \frac{\text{Volts} - \text{Min Range}}{\text{Res}}$$

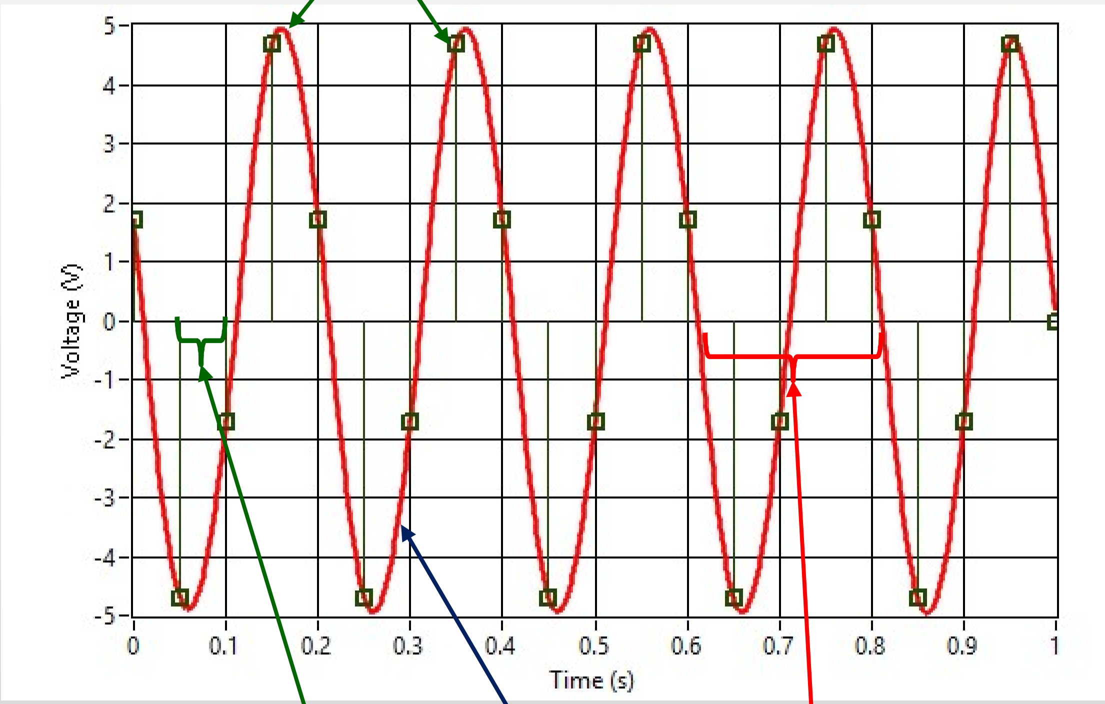
$$8745 = \frac{-3.66 \text{ V} - (-5 \text{ V})}{152\ \mu\text{V}}$$

Sampling Speed

- The maximum rate that the hardware can make ADC conversions
- In samples per second
  - E.g. 250 S/s, 350 kS/S, 10 MS/s
- Hardware or software controlled?
  - Low-end hardware must be clocked by software—very unreliable timing on modern Oses, no better than 100 ms
  - Lab-quality software will use hardware timing
- What about bandwidth?
  - A system may be able to sample above its bandwidth
  - Imagine putting a 10 Hz low-pass filter ahead of your 10 MS/s ADC
  - Bandwidth is set by the analog characteristics of the electronics
  - Bandwidth may be affected by your setup, esp. cabling.
  - *Usually* not a concern until you get to 10s – 100s of MHz

Undersampling

Digitized Samples



Analog signal: 35 Hz Sine

Sampling Period: 50 ms (20 Hz)

Alias Period: 200 ms (5 Hz)

- Undersampled data causes *aliasing*
- The alias looks like a lower frequency signal

$$f_a = |nf_s - f_0|$$

f_a : alias frequency

n : integer that minimizes f_a

f_s : sampling frequency

f_0 : original signal frequency

Nyquist-Shannon Sampling Theory

$$f_s \geq 2BW$$

"The sampling frequency must be greater than or equal to twice the bandwidth of the signal sampled to determine the frequency content of the sample."

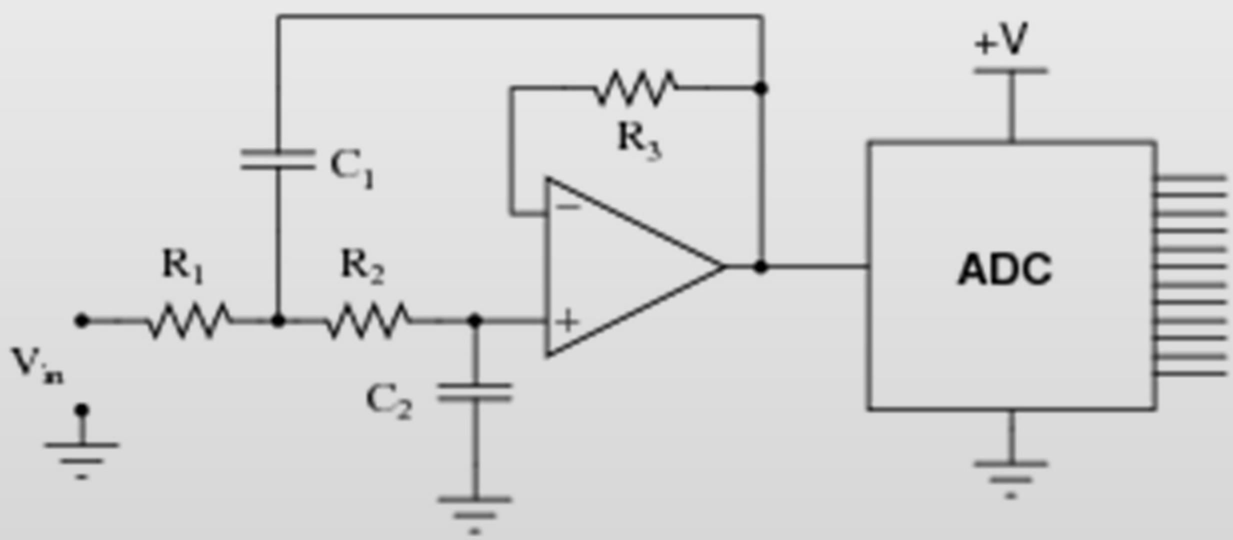
If bandwidth starts at 0 Hz (usual), BW is simply the maximum frequency component in our sample.

If you need to determine the non-sinusoidal shape of a signal repeating at X Hz

$$f_s \sim 10X$$

Anti-alias Filters

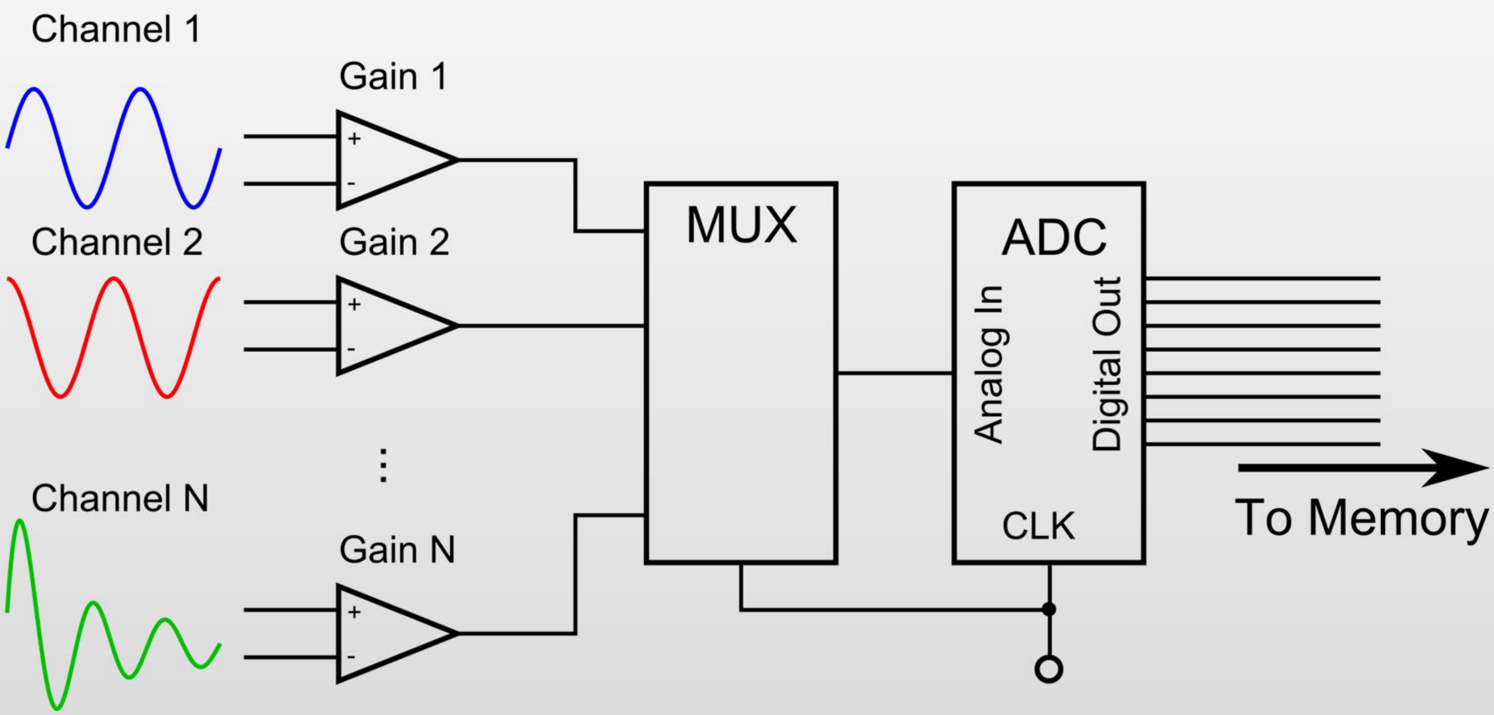
- If you know you have frequency components which are not interesting, use an anti-alias filter.
- Prevents aliasing by preventing the signal!

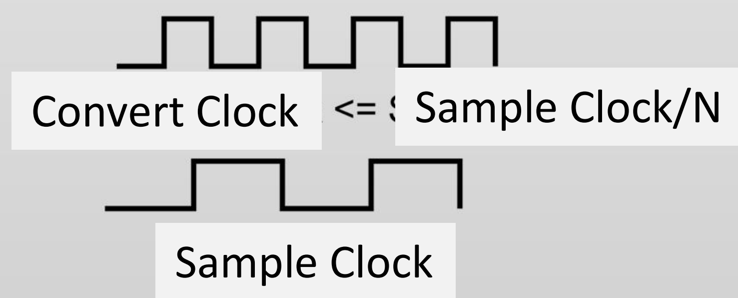


Trade off: Resolution or Speed

- For the same priced-system, there is a tradeoff between resolution and sample speed.

Analog Input: Multiplexing

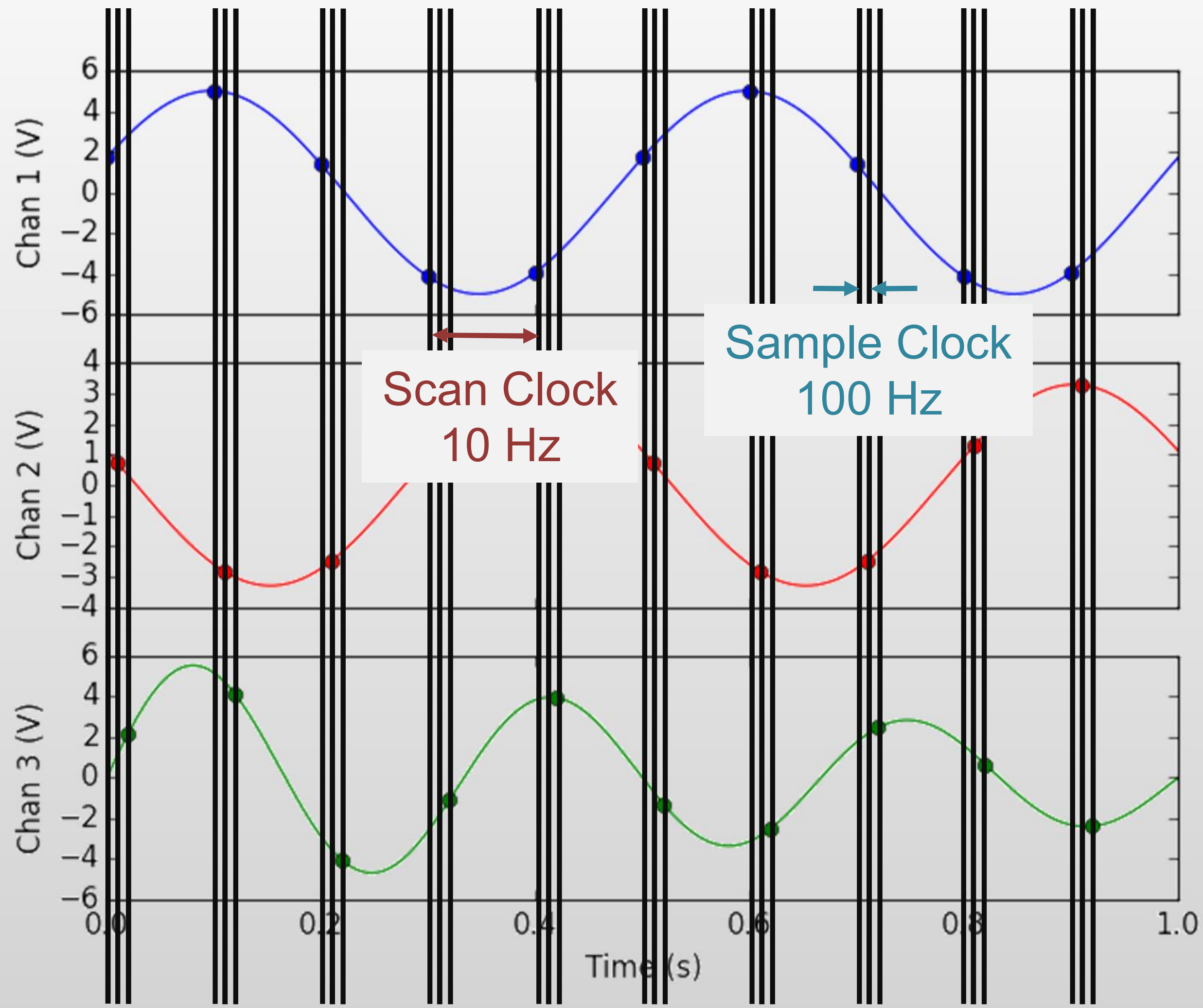




Sample Clock: Acquire one data point from every channel

Convert Clock: Acquire one data point from any channel

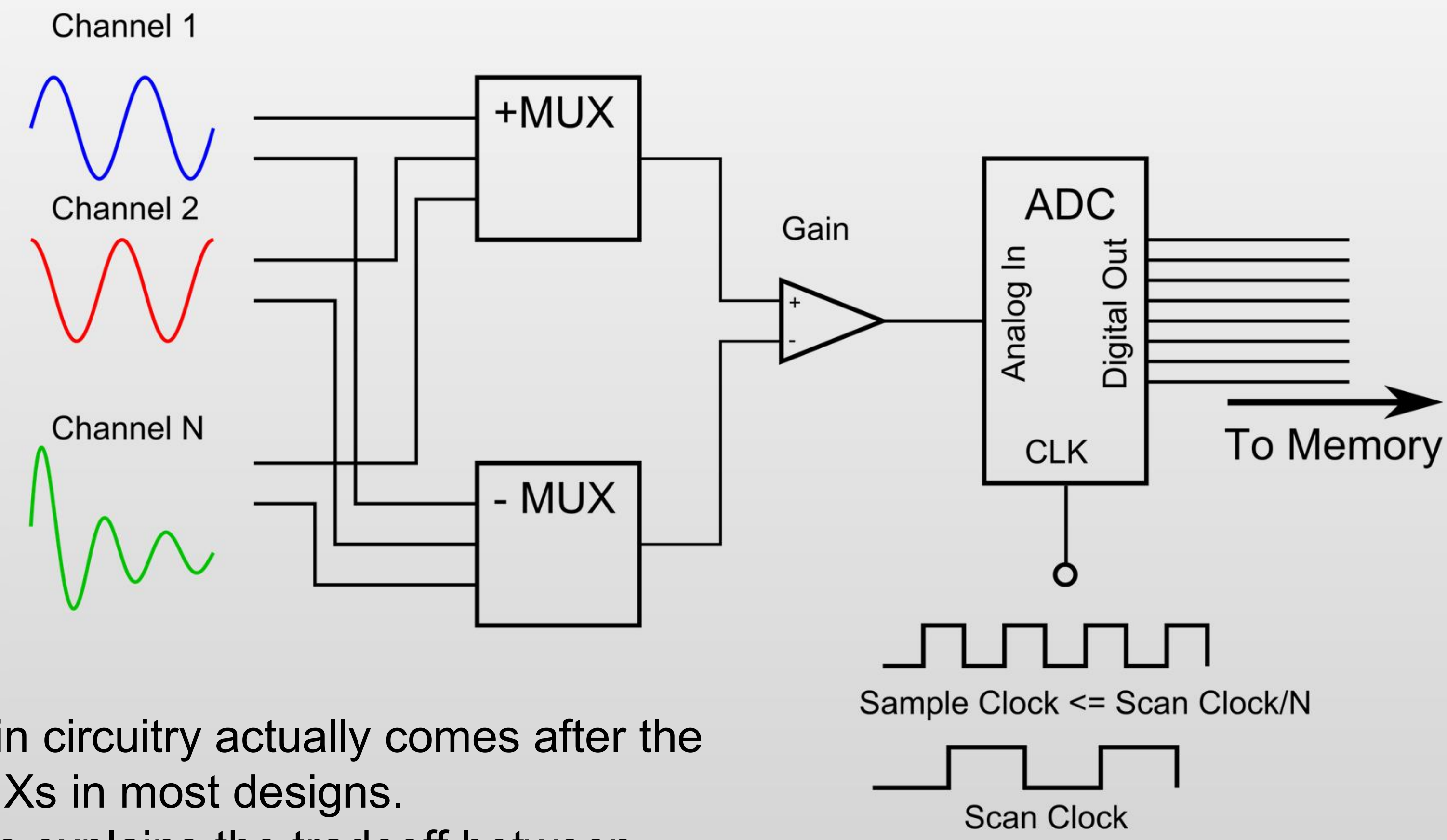
Analog Input: Time Skew



Dealing with Time Skew

1. Live with it
   - Does it really matter for your data?
   - Make sure you understand the effect it will have on your data
   - By far the most common solution
2. Sample-and-hold circuitry
   - An analog circuit which captures all channels' voltages simultaneously
   - Allows ADC and MUX to cycle through sampled voltages at scan clock rate
3. Multiple ADCs

Analog Input: Full Disclosure



- Gain circuitry actually comes after the MUXs in most designs.
- This explains the tradeoff between DI/SE and channel count

Some Examples

NI CompactDAQ Platform
- USB connectivity or embedded controller
- Modules support AI, AO, DIO Counter/timers, some signal conditioning
- $800+

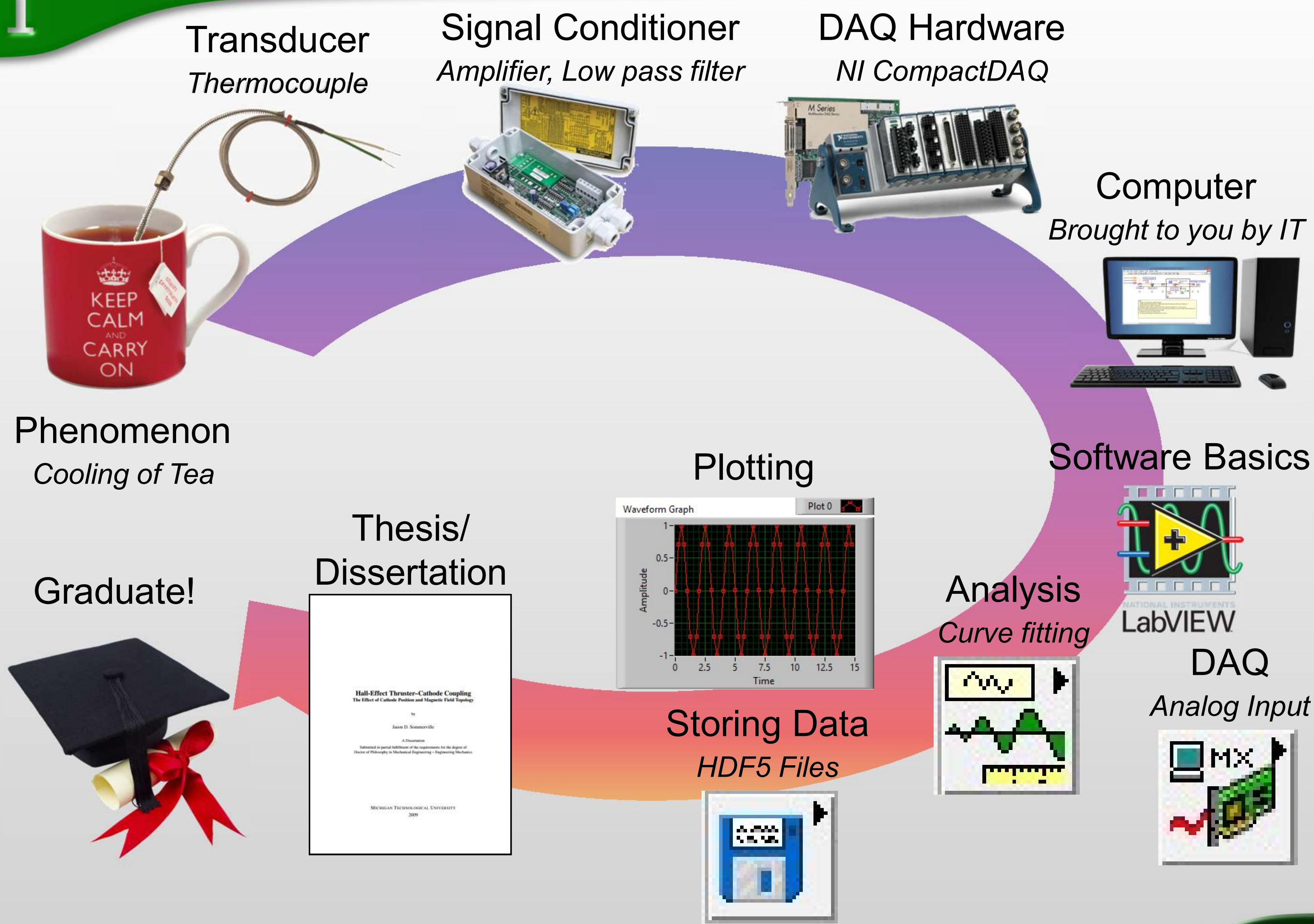
NI USB-6008
- USB connectivity
- 12-bit AI 8 SE/4 DI
- 10 kS/s
- 2 AO
- $189

Meas. Computing PCI-2513
- PCI card
- 16-bit AI 16 SE/8 DI
- 1 MS/s
- DIO, counter/timers
- $909

NI PXIe Platform
- Embedded controller or PCIe bridge
- Modules support everything
- $2000+

How to choose DAQ hardware

- What type of signals do you need to acquire/generate?
- How many channels of each type?
- After external conditioning, what will the polarity and range of your signal be?
- DI/SE?
- What resolution do you need across that range?
- At what rate do you need to acquire/generate the data?
  - Note that bandwidth ≠ sampling frequency, but related
  - How precise are you timing requirements? Can you use software timing?
  - How much time-skew is acceptable?
- What bandwidth do you need?
- Memory depth if signals cannot be transferred to system memory
- Connectors
- Form factor
- Computer interface (e.g. PCIe, PXI, USB, etc.)
- Software interface
- Front panel controls
- Cost


Transducer
Thermocouple
Signal Conditioner
Amplifier, Low pass filter
DAQ Hardware
NI CompactDAQ
Computer
Brought to you by IT
Phenomenon
Cooling of Tea
KEEP CALM AND CARRY ON
Software Basics
LabVIEW
Plotting
Waveform Graph
Plot 0
Amplitude
Time
Analysis
Curve fitting
DAQ
Analog Input
Storing Data
HDF5 Files
Thesis/
Dissertation
Graduate!

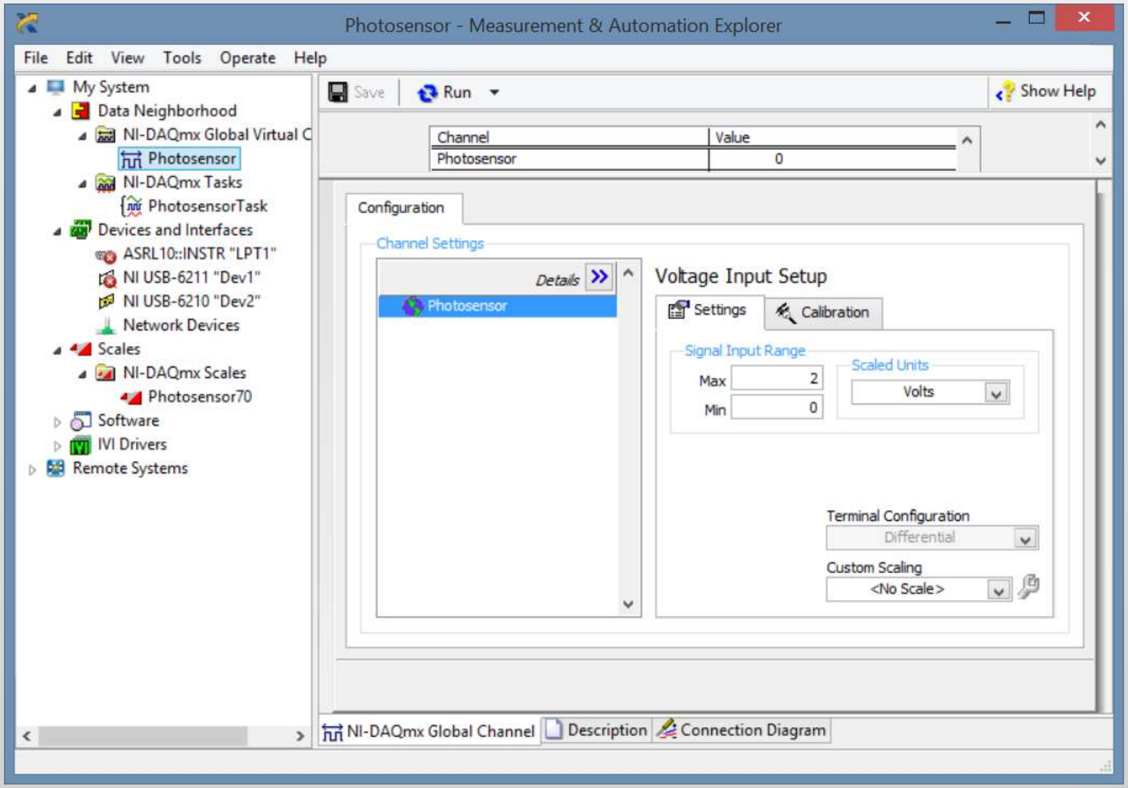
Analog Input Software

Making your hardware work for you

- Hardware Driver
  - Provides the a software interface to the hardware
  - For NI it's *NI-DAQmx*
- NI-DAQmx terminology:
  - Channel: a single interface, e.g. one AI channel, one counter-timer, etc.
  - Task: A acquisition or generation of one or more data points on one or more channels of the same type.

A Word about MAX

- NI Measurement and Automation Explorer (MAX)
  - Central location for investigating NI Hardware and Software
- Allows for *global* (i.e. system-wide) channel and task creation
  - Useful for fixed or infrequently-changed installations



The Mantra

Open, Configure, Start, Read/Write, Stop, Close

1. **Open**: Open a device for further access
2. **Configure**: setup the task, including channel(s), range(s), timing, triggering, etc. for the task
3. **Start**: Begin the acquisition (or generation) process
4. **Read/Write**: read acquired data (or write data to be generated), typically repeatedly, until the task is complete
5. **Stop**: stop the acquisition but do not close the device and free the resources associated with it
6. **Close**: okay, now close the device and free the resources

The Mantra

A note about NI-DAQmx

NI-DAQmx is “smart” and will attempt to do steps in the mantra that you “forget.”

- If you don’t configure the task, defaults are chosen
- If you don’t start the task before reading, it starts it when you attempt to perform the read
- If you don’t stop the task before closing it, it stops it for you

For learners, especially, don’t “forget” to do any of the steps.

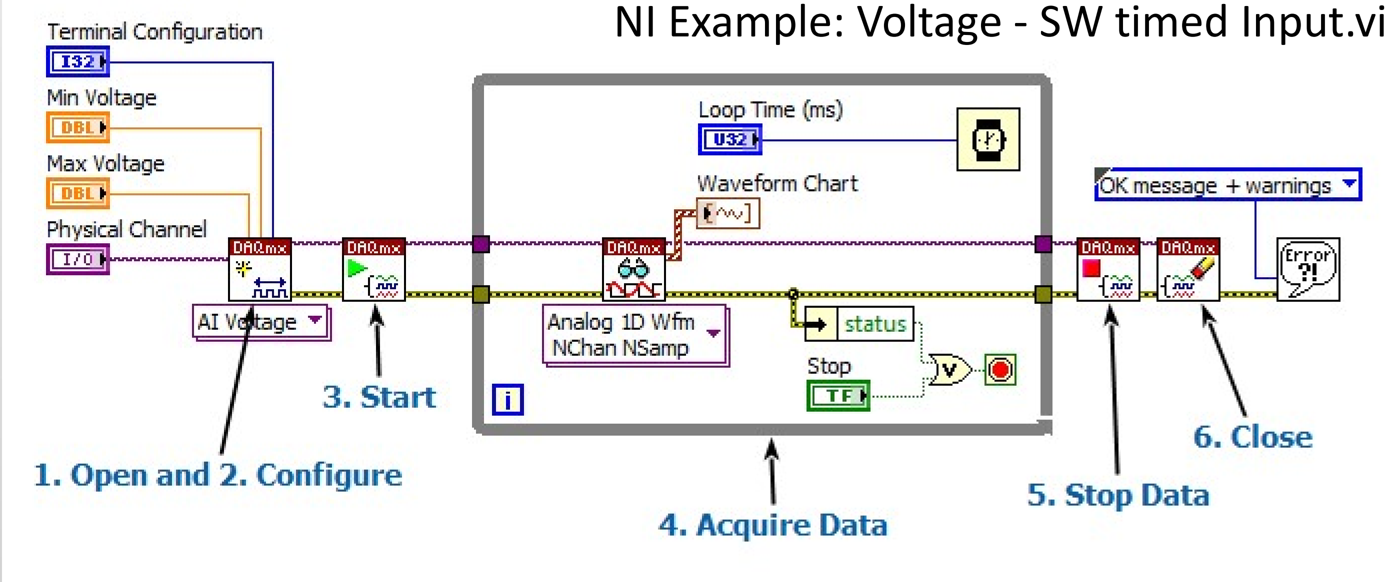
- Leads to muddled thinking
- May have unexpected results because the coder doesn’t understand what NI-DAQmx is doing under the hood.

Open, Configure, Start, Read/Write, Stop, Close

Software Timed Analog Input

- Uses system clock
  - Best timing ~ 1 ms period on modern, non-RT OSes
- Subject to jitter due to processor multitasking
- Must be used for process control systems
  - Maybe you should consider an RT system?

NI Example: Voltage - SW timed Input.vi



Software Timing: Jitter

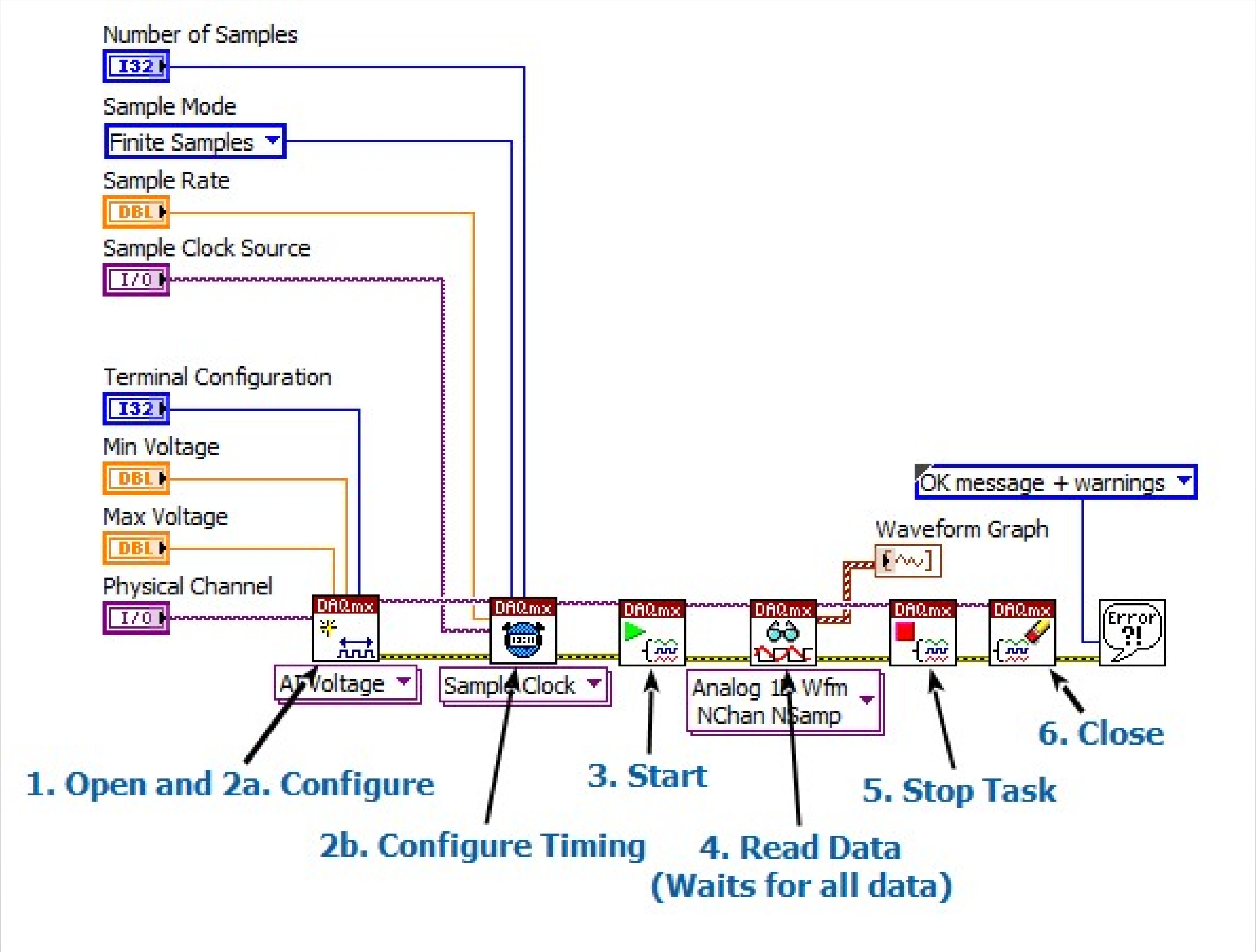
- Show jitter example

Finite Samples, Hardware Timed

- To relieve jitter and free up the process, let the DAQ card handle the timing
- We must now configure the channel timing
  - Use DAQmx Timing.vi
  - Specify:
    - Timing type (Finite samples in this case)
    - Frequency
    - Number of samples
    - Timing source*

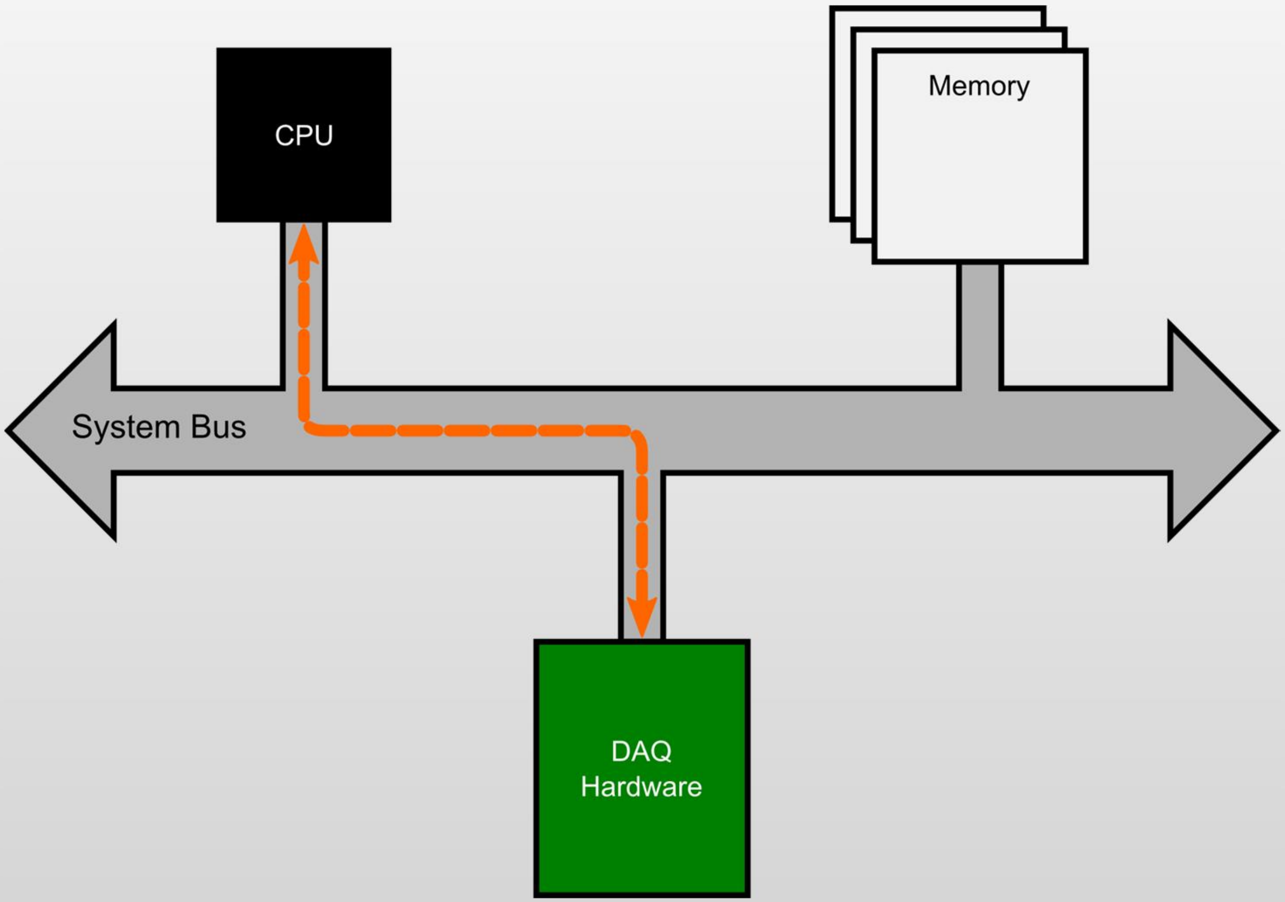
*Timing source allows one to use an external clock rather than an internal clock. This is useful for clocking in data based on external events signals, e.g. an encoder pulse, a clock from another DAQ task (e.g. analog output) or an external instrument.

Finite Samples, Hardware Timed



What's really happening?*

1 Configuration Step

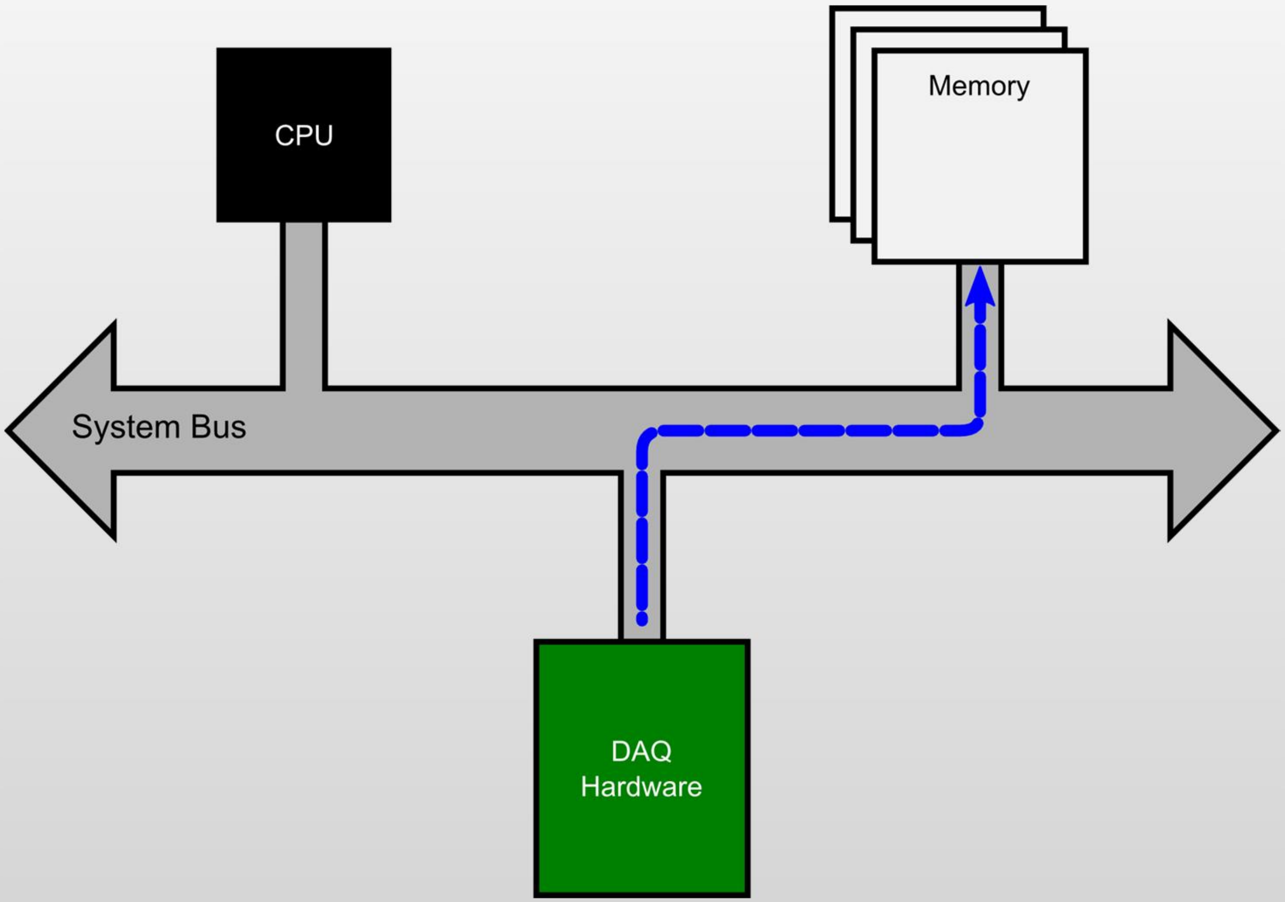


*This is still a simplification of the real architecture. Sorry.

What's really happening?*

1 Configuration Step

N Reads w/o CPU

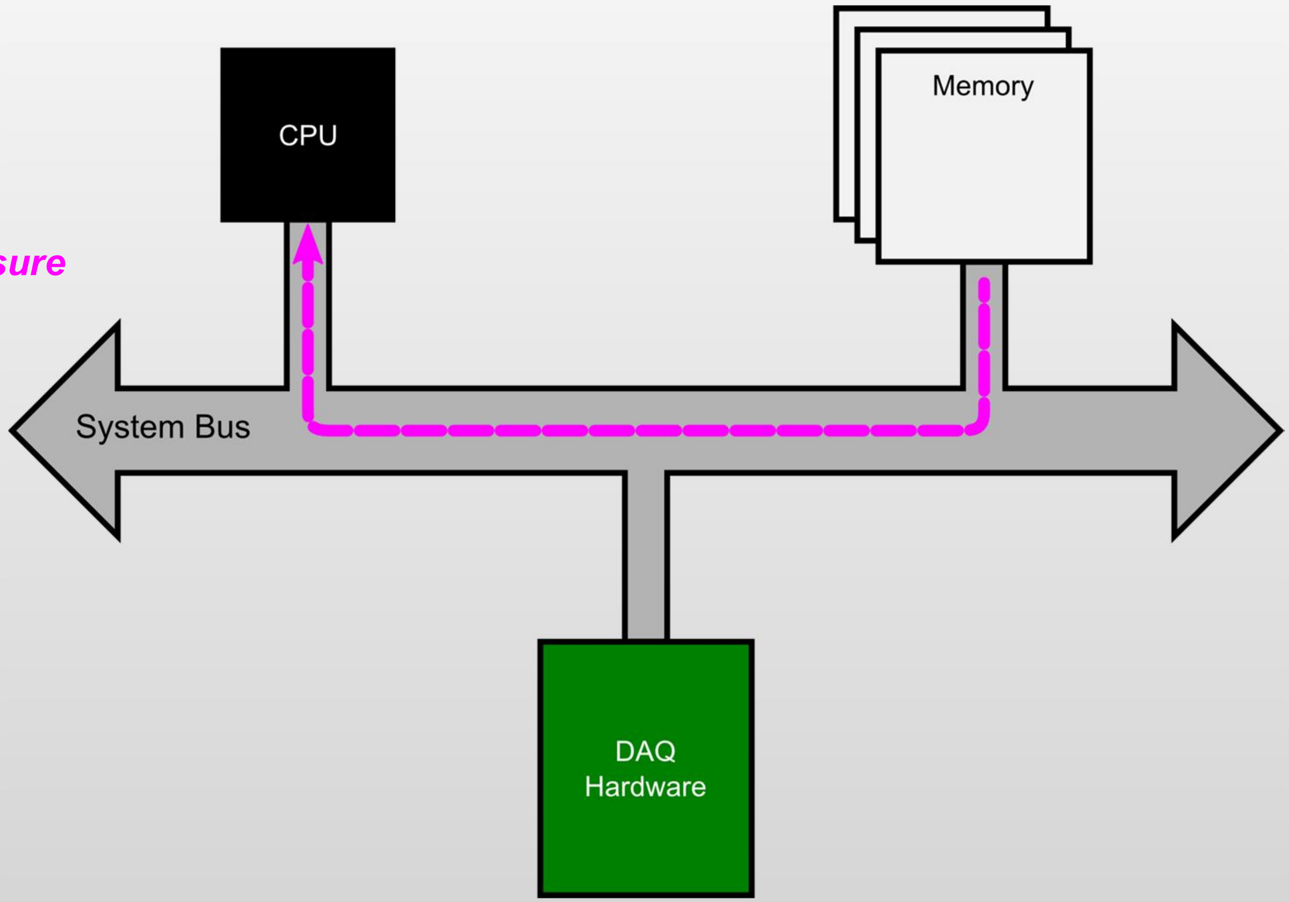


What’s really happening?*

1 Configuration Step

N Reads w/o CPU

N Reads w/ CPU *at our leisure*



Why is DMA better than PIO?

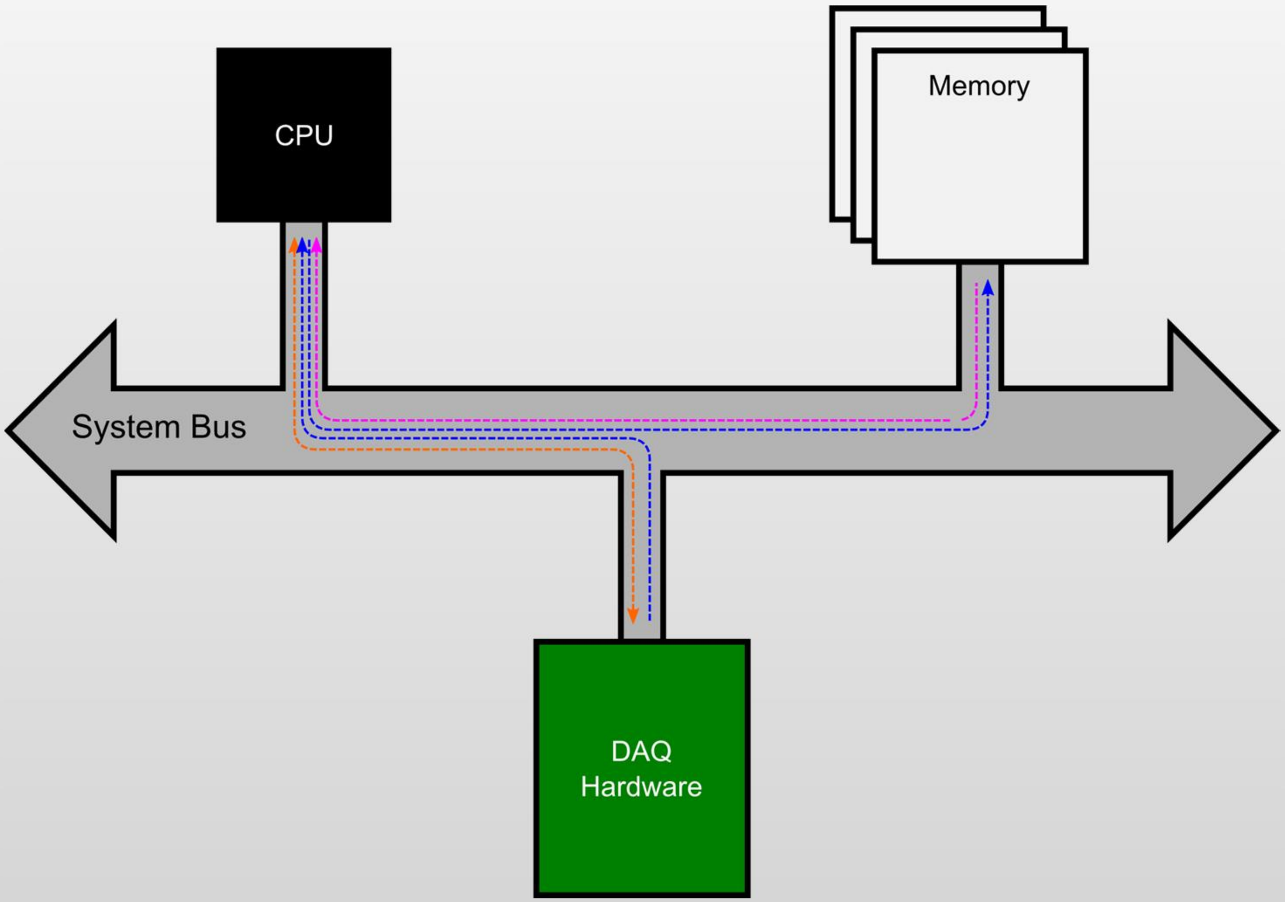
1 Configuration Step

N Reads w/ CPU

N Writes w/ CPU

N Reads w/ CPU

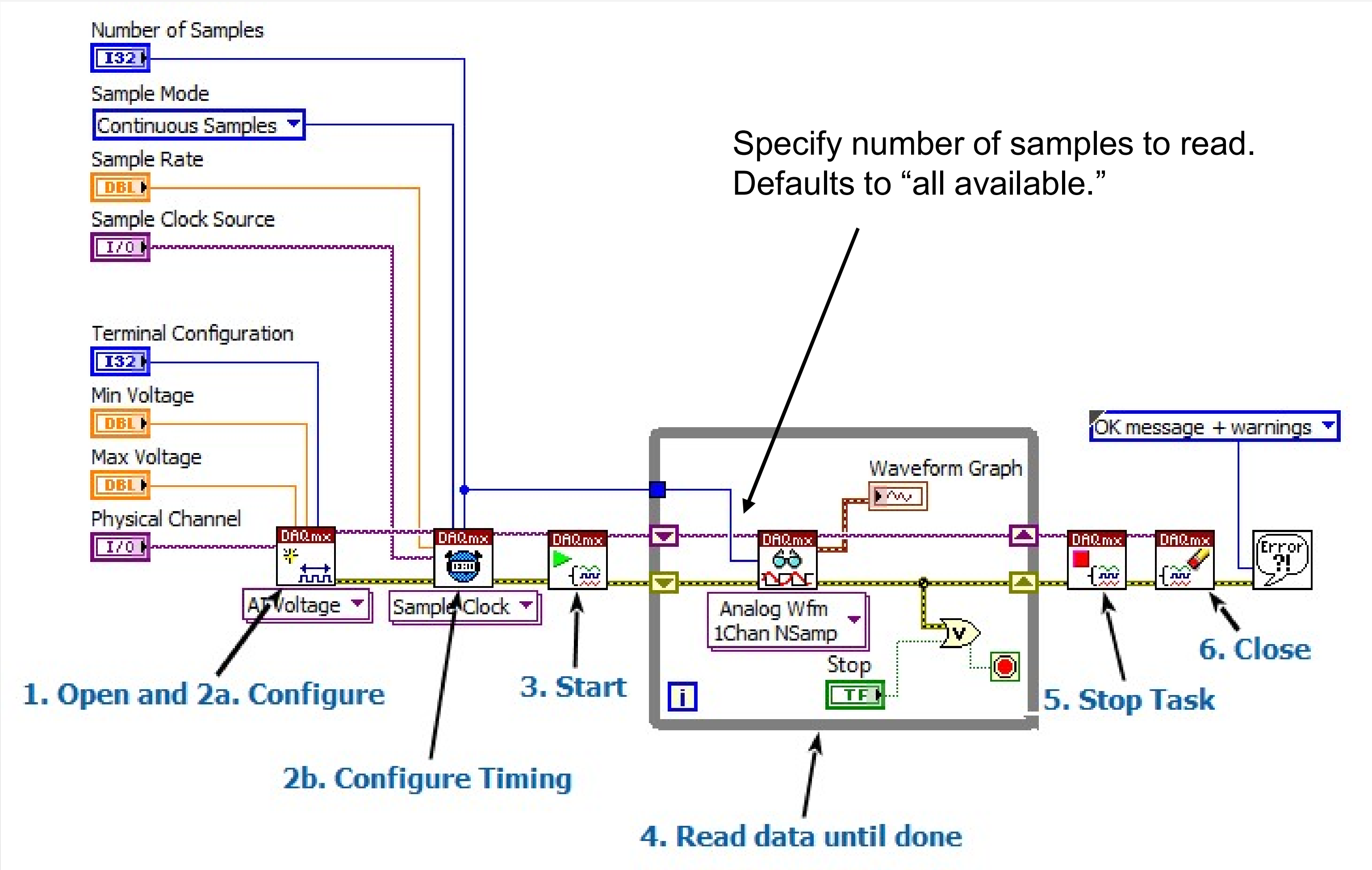
All must be on time!



Continuous Sampling

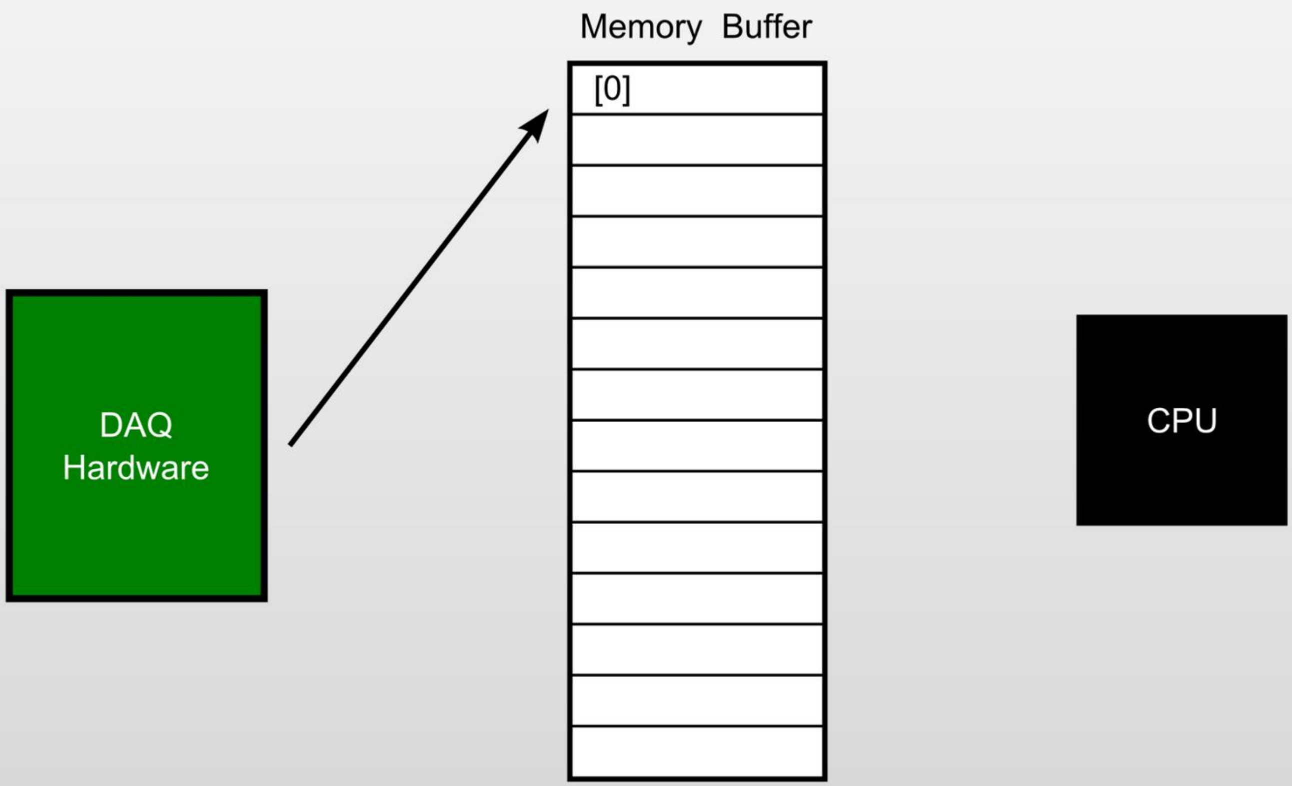
Acquiring data *forever*

But how will I graduate?



What’s really happening?

Circular Buffering

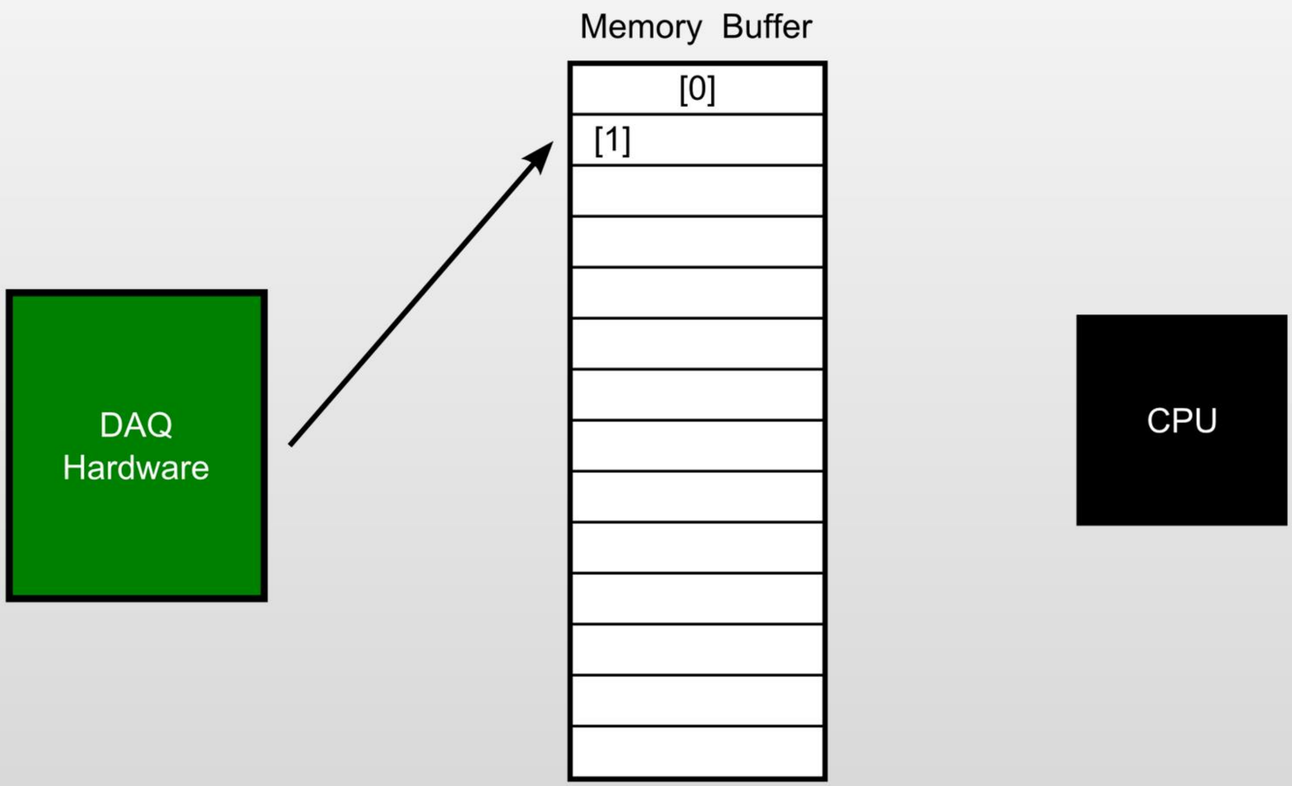


DAQ begins DMA write

CPU waiting for N (=7) samples

What's really happening?

Circular Buffering

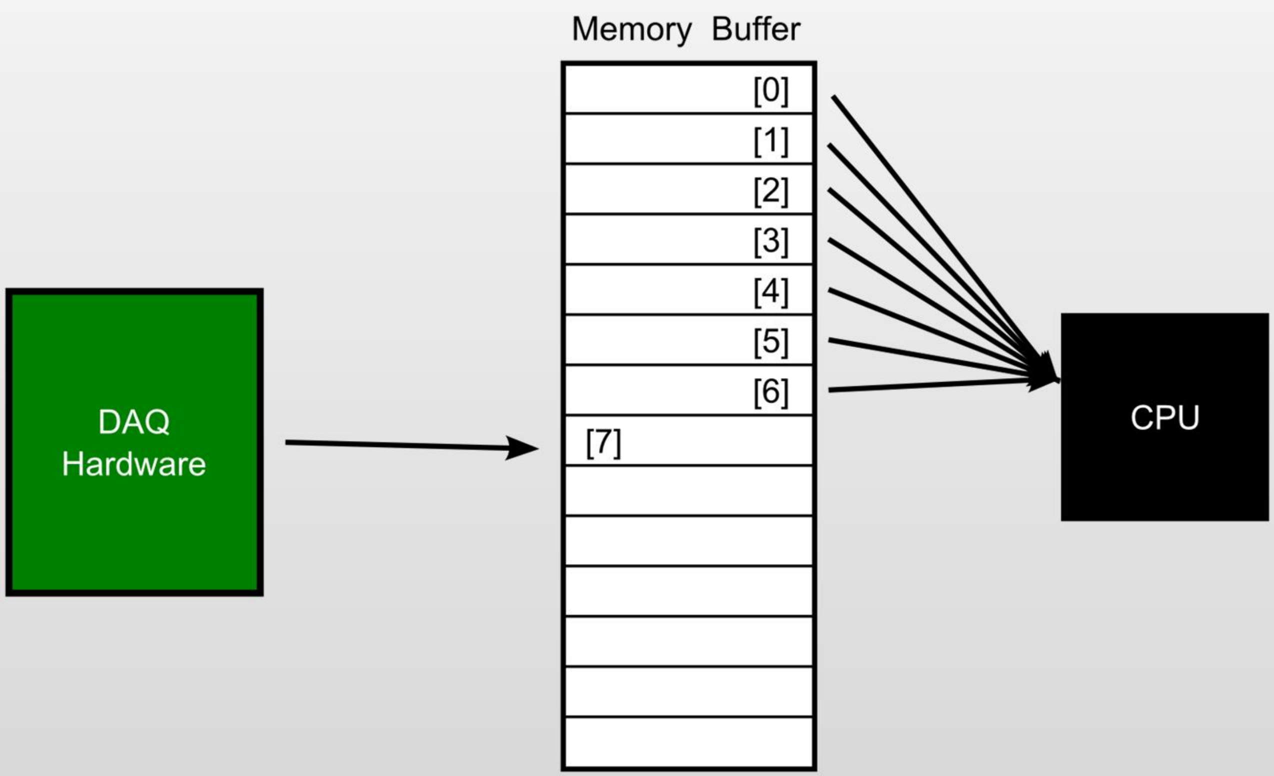


DAQ writes next point

CPU waiting for N (=7) samples

What’s really happening?

Circular Buffering

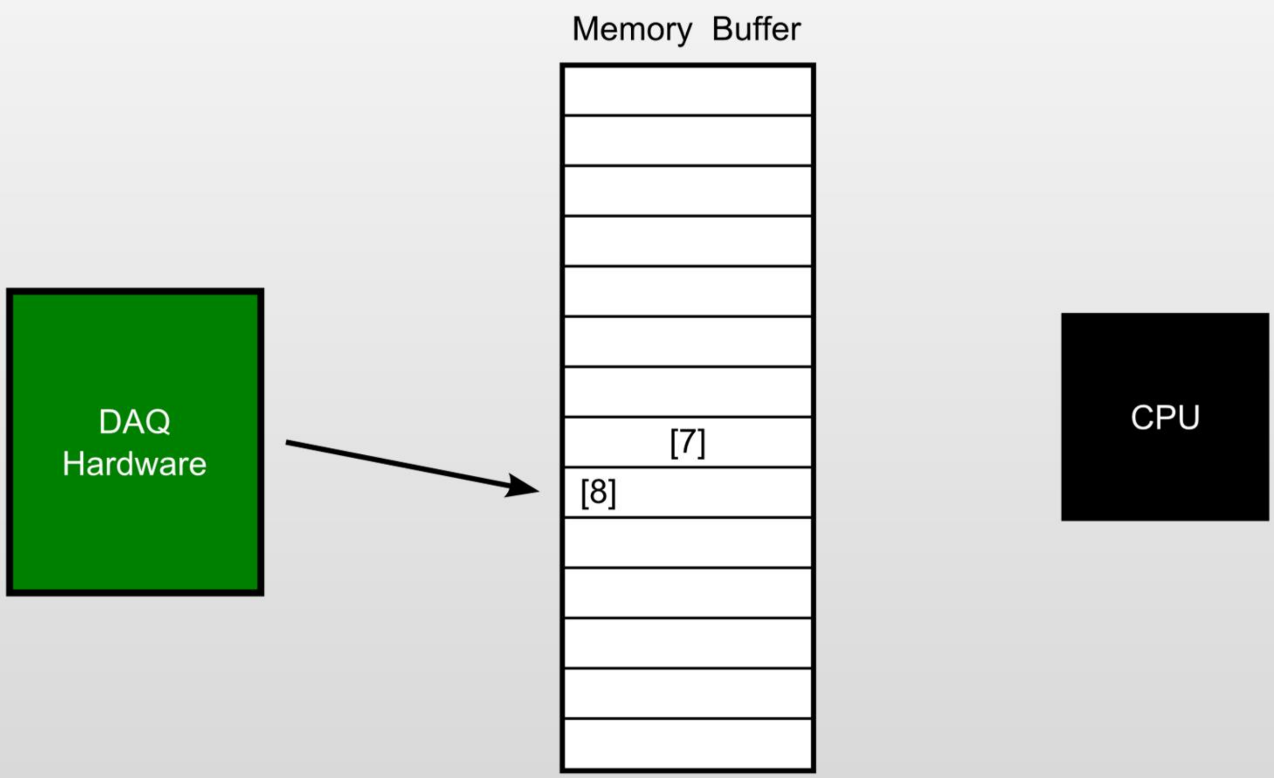


DAQ writes next point

N samples available. CPU reads.

What's really happening?

Circular Buffering

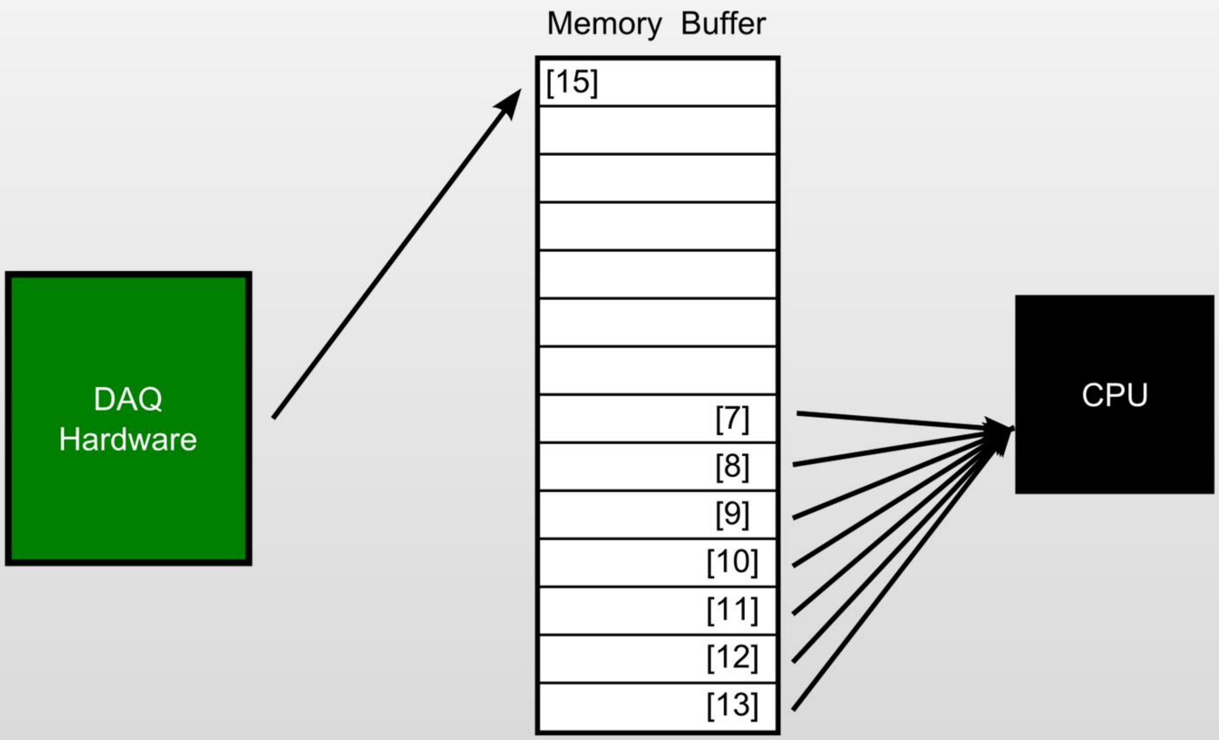


DAQ writes next point

CPU waiting for N (=7) samples

What's really happening?

Circular Buffering

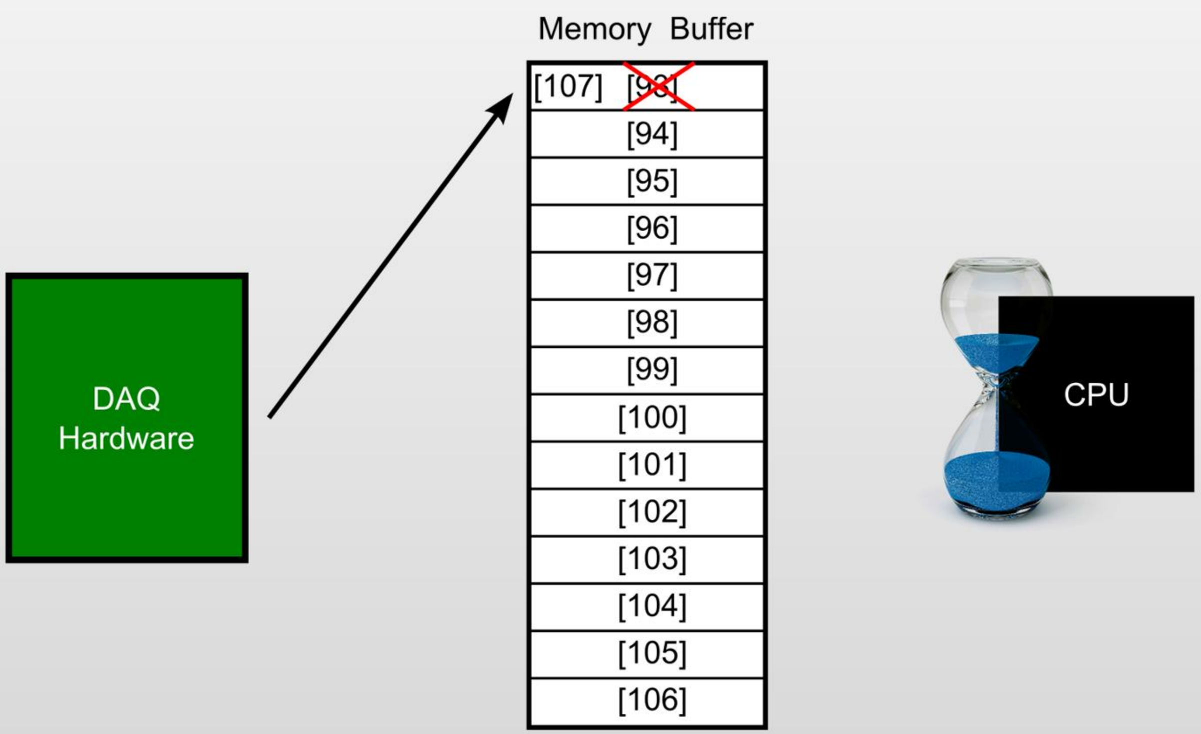


When DAQ reaches end of buffer
it *circles* back to the beginning

CPU has N more samples

What’s really happening?

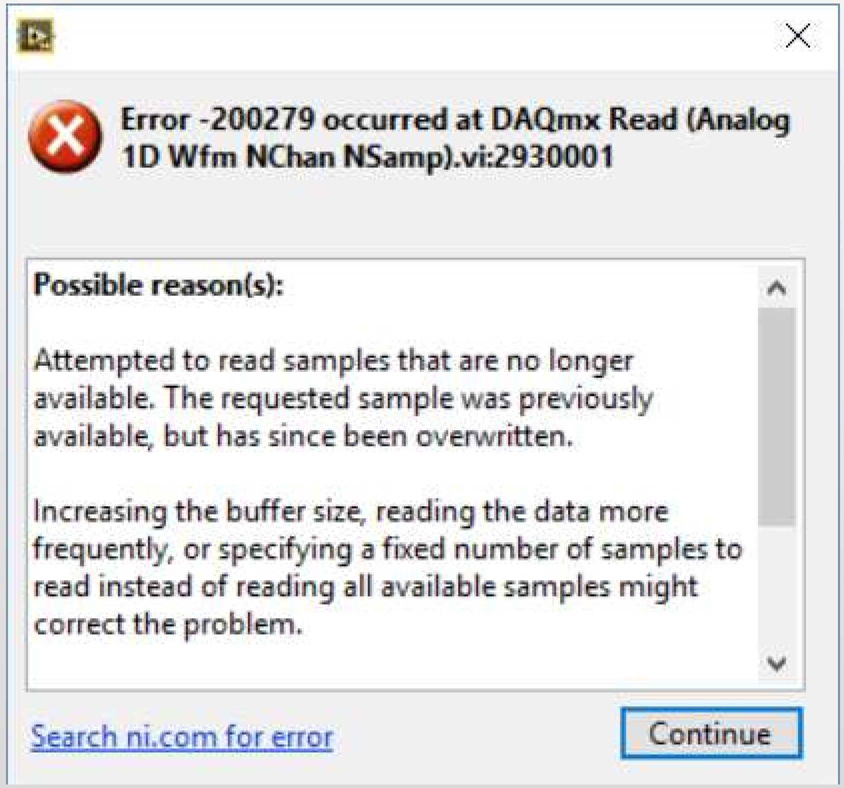
Circular buffer overflows



DAQ circles back to the beginning.
Oh no! Buffer overflow!

CPU busy and can't service the buffer

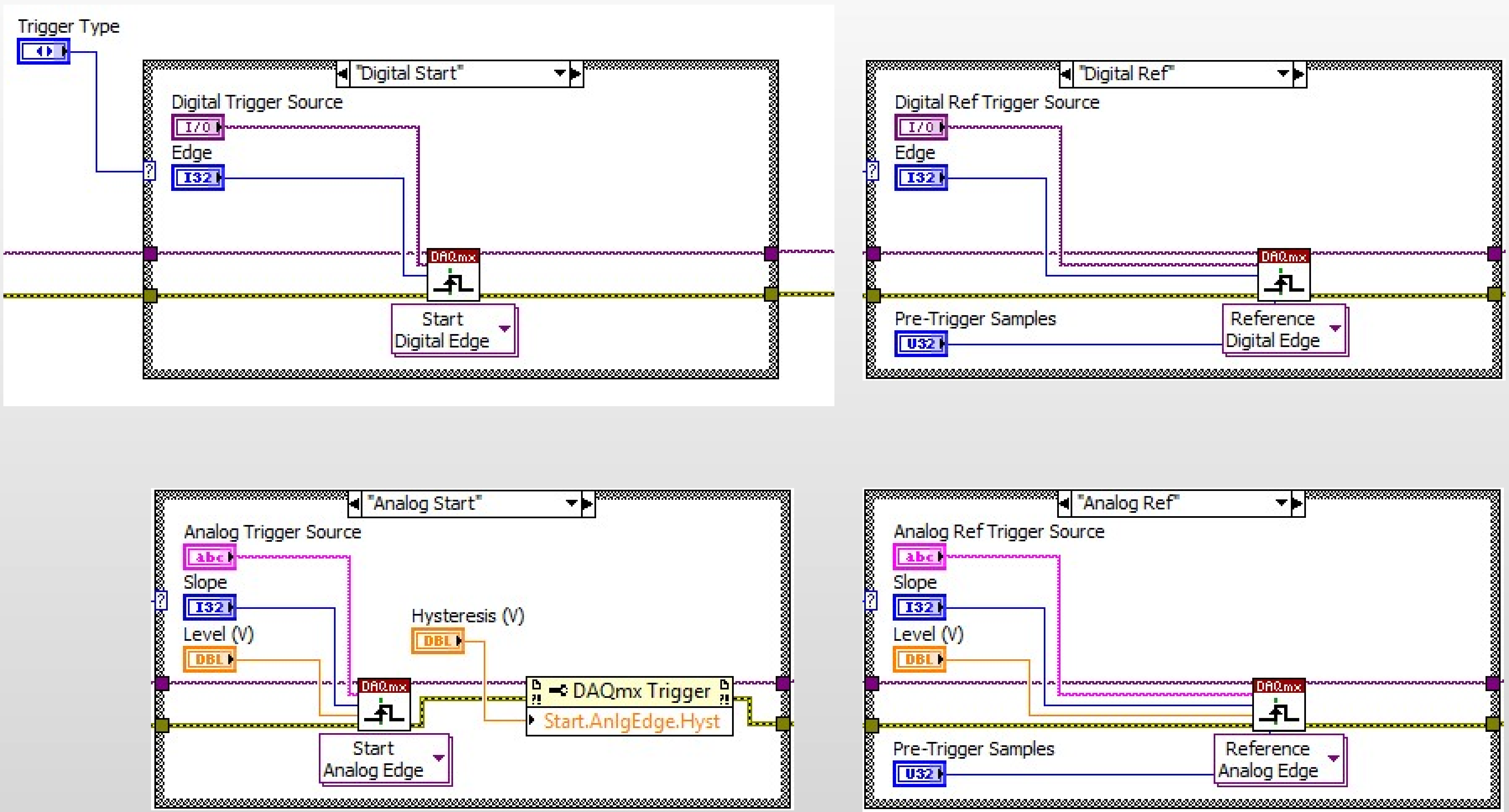
Buffer Overflows



Triggering

- Use *triggering* to delay the start of acquisition until a certain event occurs
- Common Types:
  - **Digital start trigger:** start when a rising or falling edge of a TTL (0-5 V) signal is detected
  - **Analog start trigger:** start when a signal’s voltage rises above or falls below a certain level
  - **Digital reference trigger:** similar to digital start, but may acquire pre-trigger samples
  - **Analog reference trigger:** similar to analog start, but with pre-trigger samples

Triggering


Trigger Type
"Digital Start"
Digital Trigger Source
I/O
Edge
I32
Start Digital Edge
"Digital Ref"
Digital Ref Trigger Source
I/O
Edge
I32
Pre-Trigger Samples
U32
Reference Digital Edge
"Analog Start"
Analog Trigger Source
abc
Slope
I32
Level (V)
DBL
Hysteresis (V)
DBL
DAQmx Trigger
Start.AnlgEdge.Hyst
Start Analog Edge
"Analog Ref"
Analog Ref Trigger Source
abc
Slope
I32
Level (V)
DBL
Pre-Trigger Samples
U32
Reference Analog Edge

Digital Start Triggering

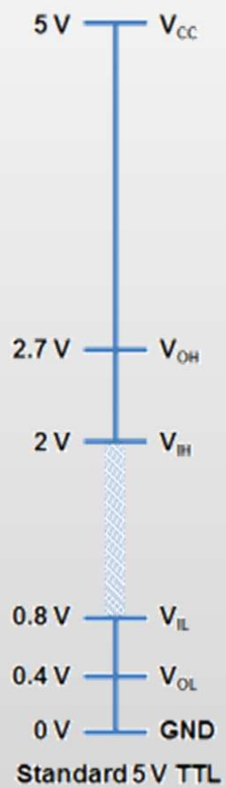
- Show Digital – Finite Input Example

Problems with Digital Triggers

- Wrong polarity
  - Triggers look for rising or falling edges (or sometimes either)
- Wrong voltage
  - Digital logic operates on specific voltage levels
- Glitches

Problems with Digital Triggers

TTL Logic Levels



Voltage	Description	TTL	LVTTL
V_{CC}	Supply voltage	5.0	3.3
V_{OH}	Logic-high output voltage minimum	2.7	2.4
V_{IH}	Logic-high input voltage minimum	2.0	2.0
V_{IL}	Logic-low input voltage maximum	0.8	0.8
V_{OL}	Logic-low output voltage maximum	0.4	0.4

Figure from https://learn.sparkfun.com/tutorials/logic-levels/ttl-logic-levels

Problems with Digital Triggers

More logic levels

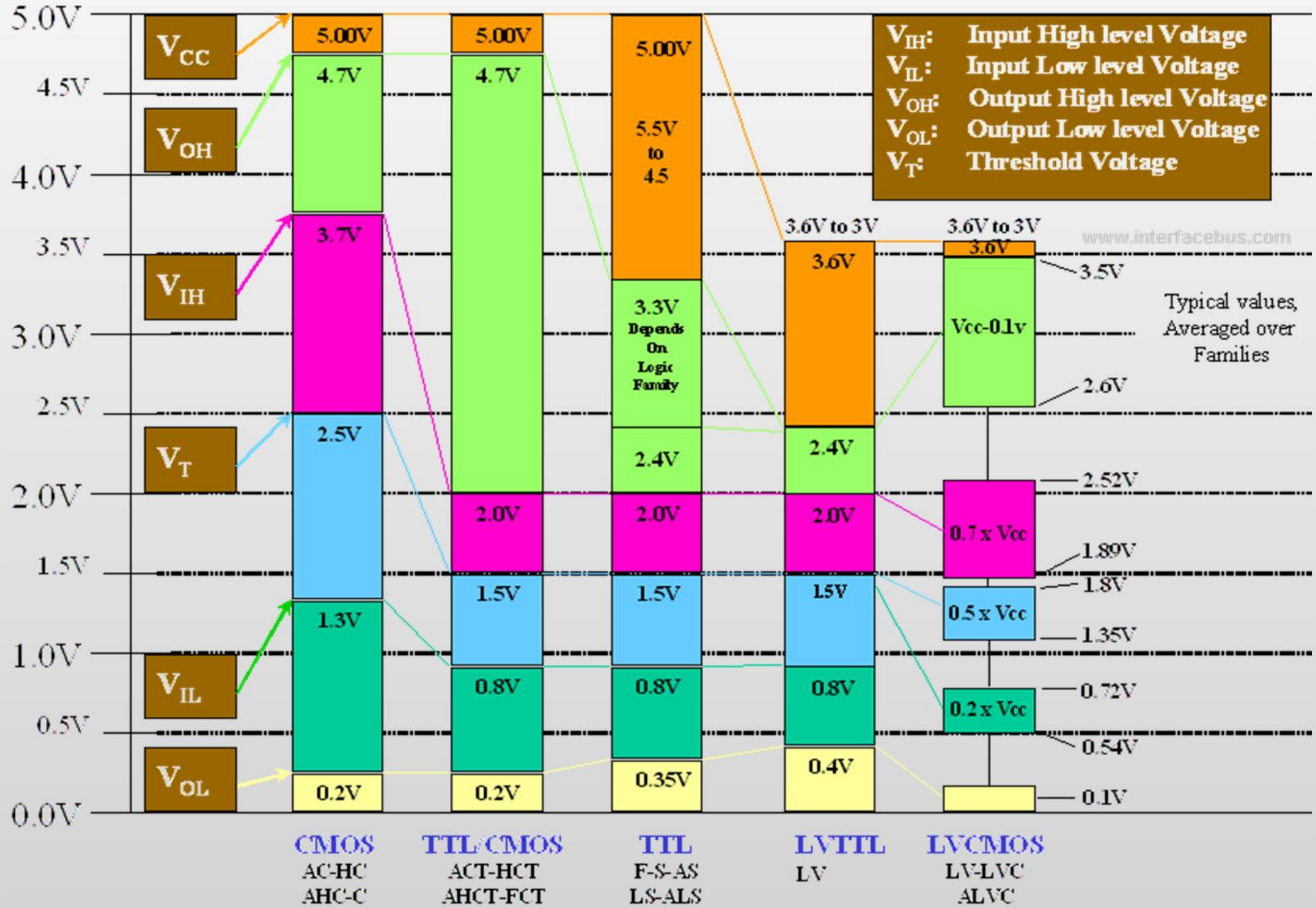
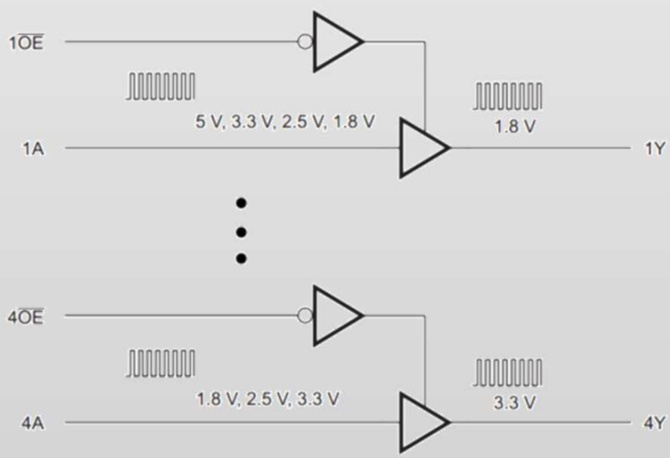


Figure from http://www.interfacebus.com/voltage_LV_threshold.html

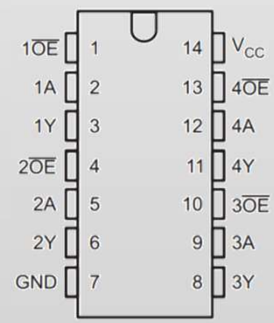
Problems with Digital Triggers

How to solve level problems

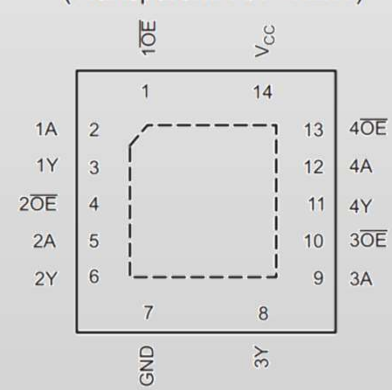
- Ignore it
  - Some voltage levels are cross-compatible, e.g. most TTL and LVTTL
  - ***However—if at all possible, check all output levels before connecting to the input***
- Use level-shifter circuit (voltage level translation)
  - e.g. SN74LV4T125



PW Package
(TOP VIEW)



RGY Package
(Transparent TOP VIEW)



Figures from Texas Instruments SN74LV4T125 Datasheet

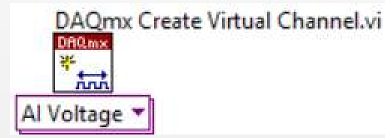
Problems with Digital Triggers

Glitches

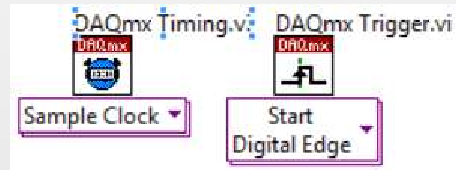
Figure from http://www.interfacebus.com/voltage_LV_threshold.html

Review

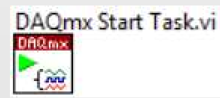
Open



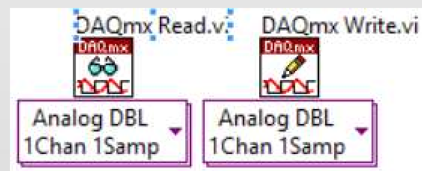
Configure



Start

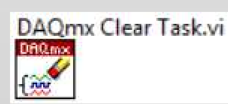


Read/Write



Stop

Close



About Floating Sources

- Unreferenced sources may float at potentials different from the DAQ potential
  - Unpowered devices
  - Devices power by batteries
  - Devices powered by isolated power supplies—Just because it's plugged in doesn't mean it's grounded

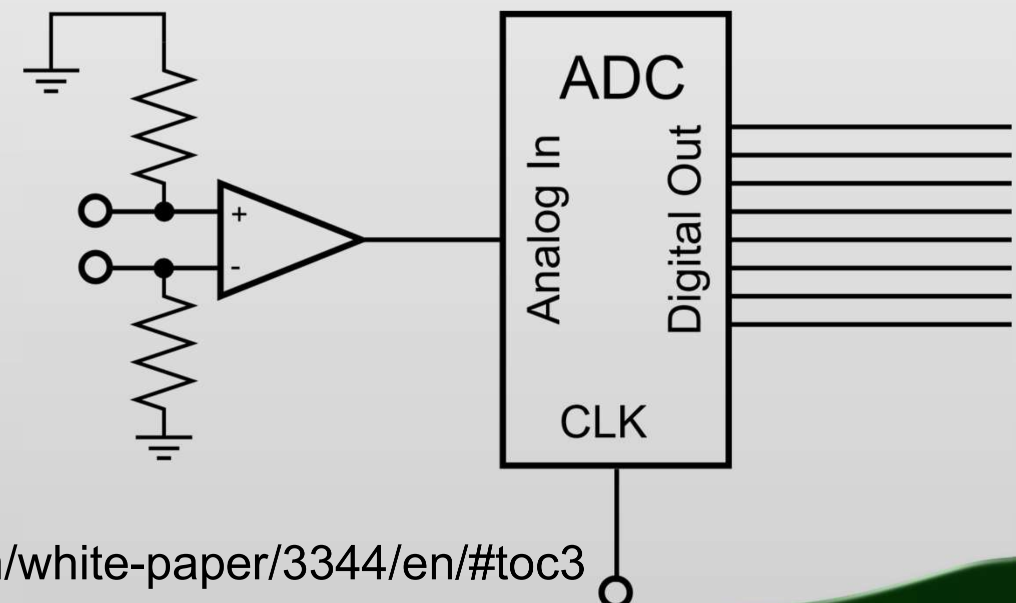
Bias resistors

- Differential signals may float outside of the operating range of the ADC
  - Floating source: powered by batteries or isolated supply
- Bias resistors can hold the voltages in range by preventing the source from floating
  - Make sure source is actually floating!

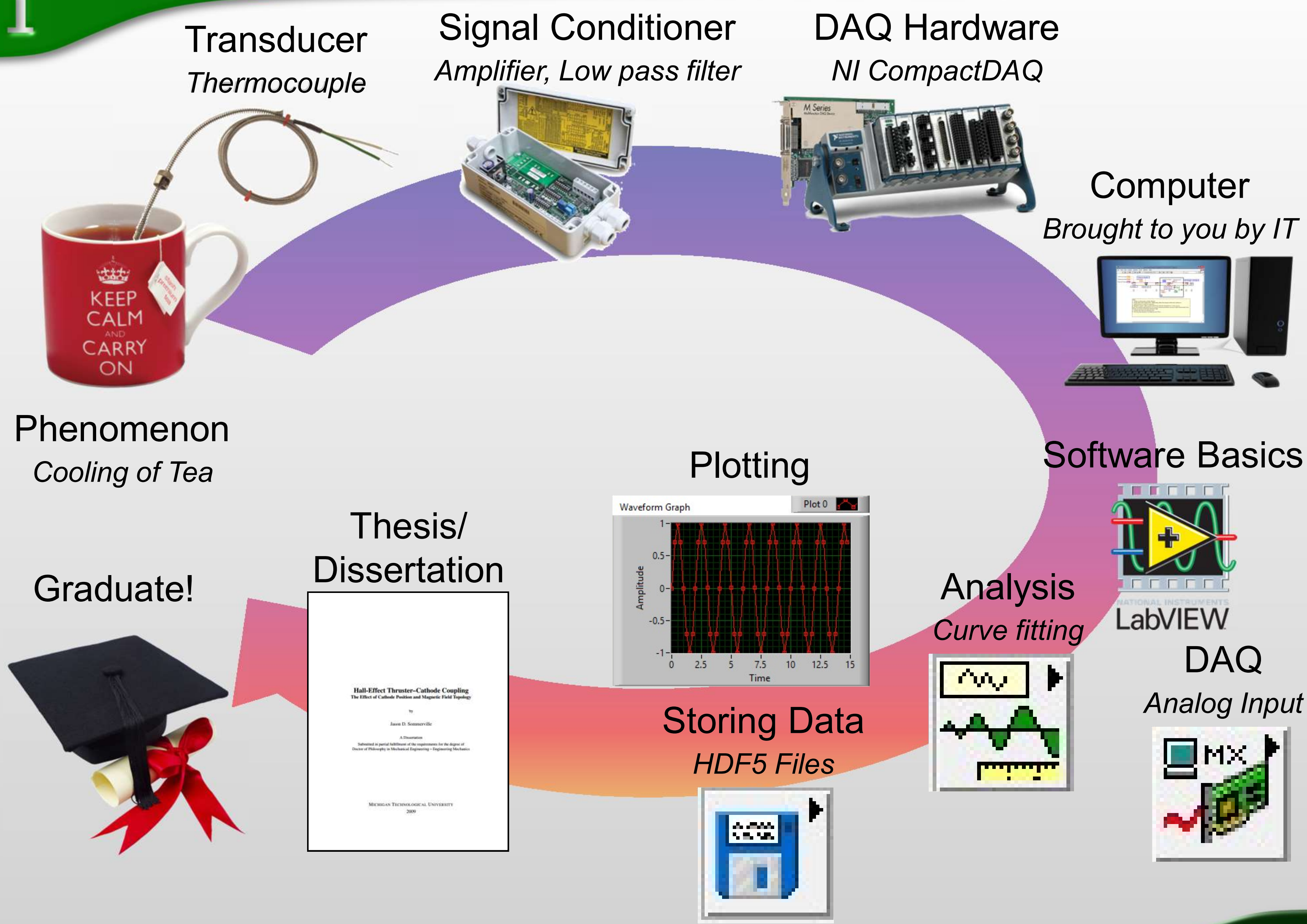
- Value R should be such that:

  Output impedance < R < Input impedance

- Typically 10 kΩ – 100 kΩ



Further reading: http://www.ni.com/white-paper/3344/en/#toc3


Transducer
Thermocouple
Signal Conditioner
Amplifier, Low pass filter
DAQ Hardware
NI CompactDAQ
Computer
Brought to you by IT
Phenomenon
Cooling of Tea
KEEP CALM AND CARRY ON
Software Basics
LabVIEW
Plotting
Waveform Graph
Plot 0
Amplitude
Time
Thesis/ Dissertation
Graduate!
Analysis
Curve fitting
DAQ
Analog Input
Storing Data
HDF5 Files