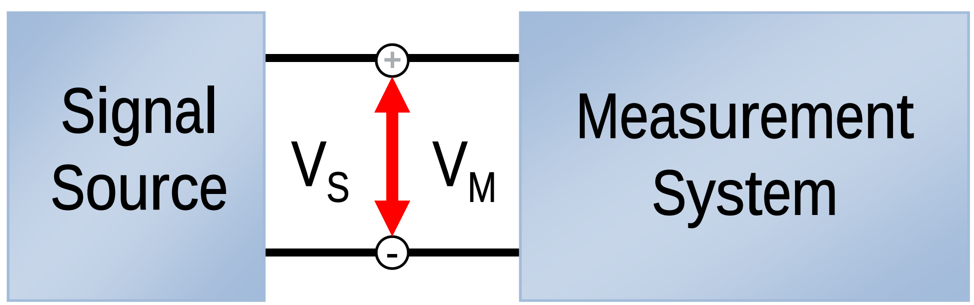
Lesson 3
Analog Input

TOPICS

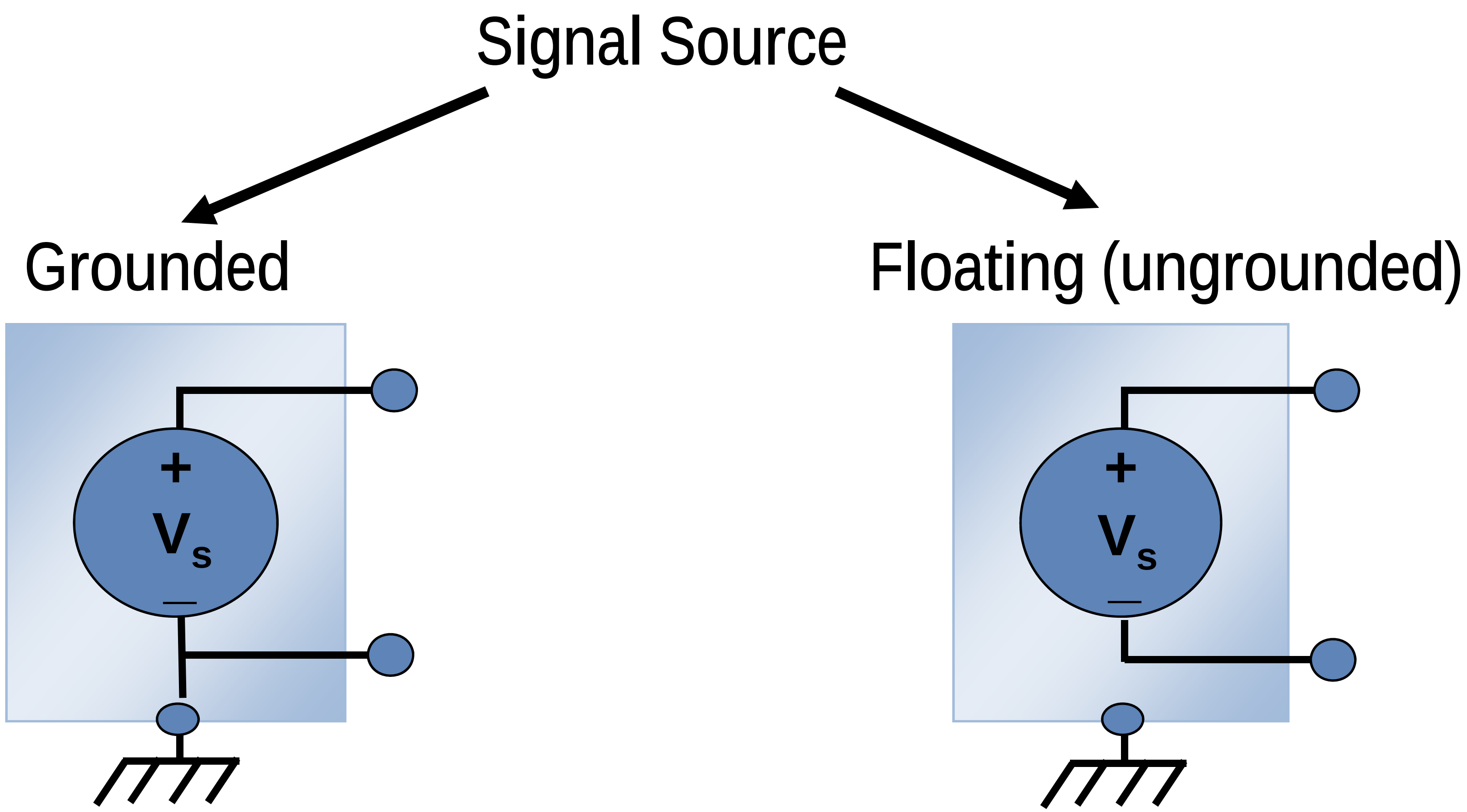
A. Grounding Issues
B. Sampling Considerations
C. Single Sample Acquisition
D. DAQ Device Architectures
E. Finite Buffered Acquisition
F. Continuous Buffered Acquisition
G. Triggering

A. Grounding Issues

- To get correct analog input measurements, you must properly ground your system
- How the signal is grounded affects how you should ground the instrumentation amplifier on the DAQ device
- Steps to proper grounding of your system:
  1. Determine how your signal is grounded
  2. Choose a grounding mode for your Measurement System



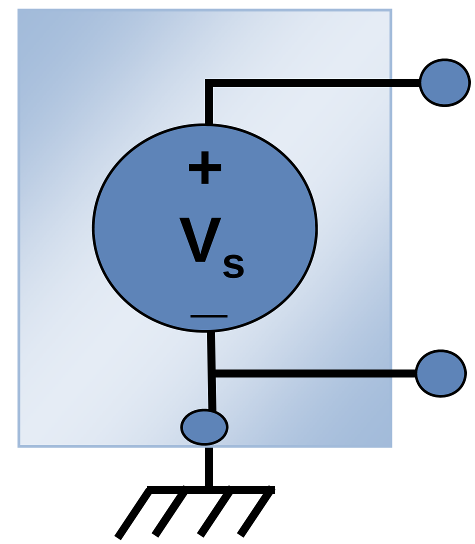
Signal Source Categories



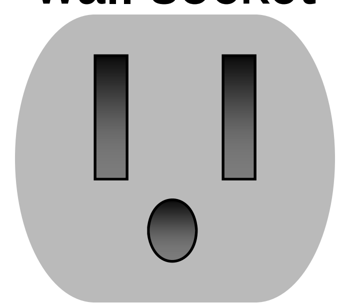
Grounded Signal Source

- Signal is referenced to a system ground
  - Earth ground
  - Building ground
- Examples:
  - Power supplies
  - Signal Generators
  - Anything that plugs into a grounded, electrical wall socket

Grounded



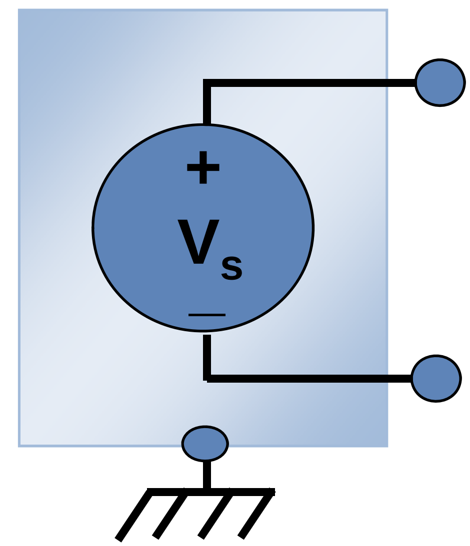
Grounded wall socket



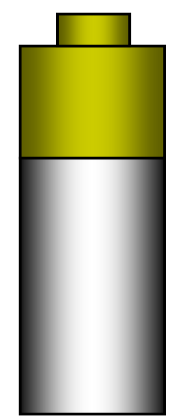
Floating Signal Source

- Signal is NOT referenced to a system ground
  - Earth ground
  - Building ground
- Examples:
  - Batteries
  - Thermocouples
  - Transformers
  - Isolation Amplifiers

Floating

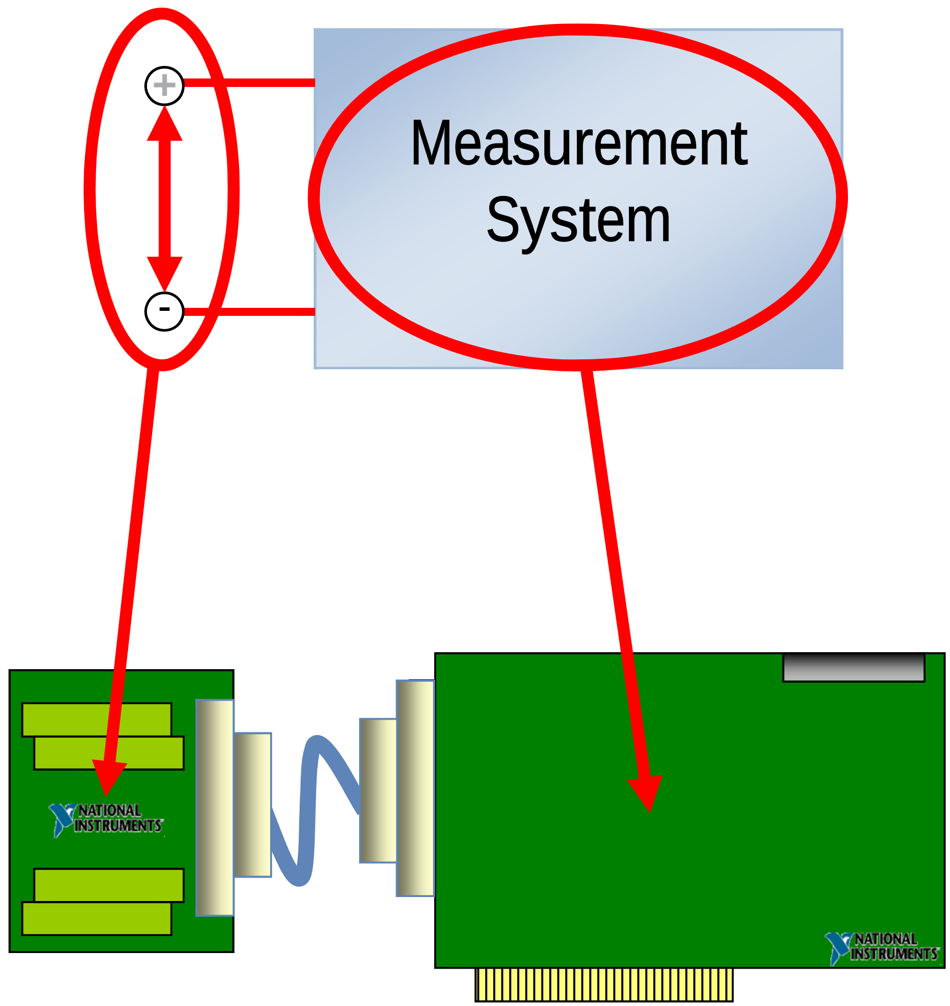


Battery



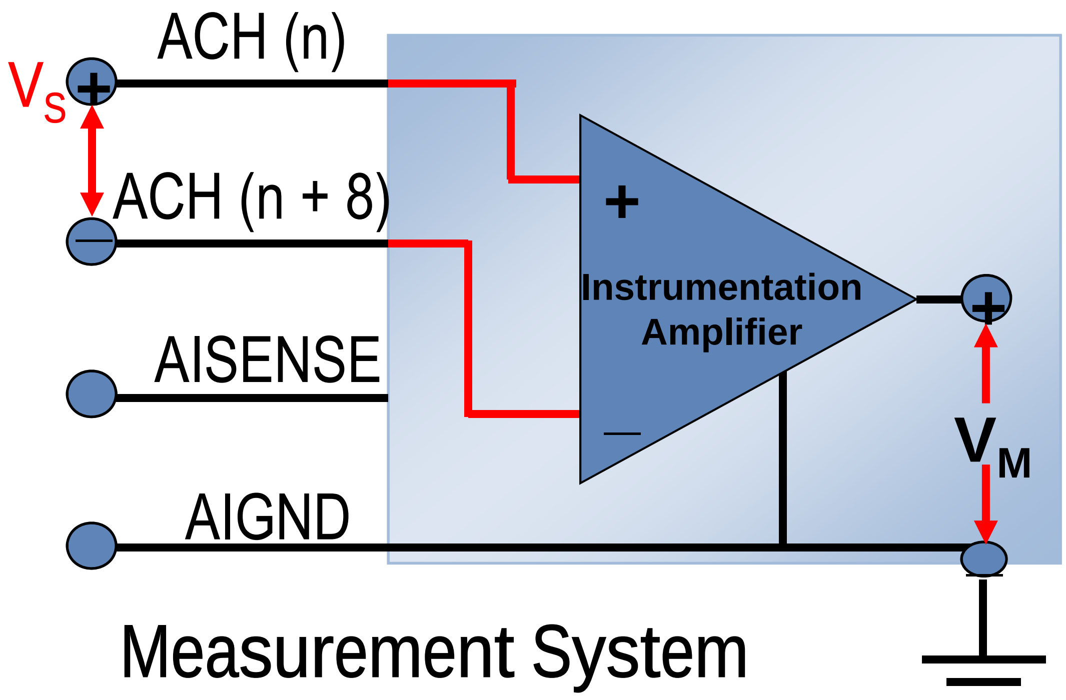
Measurement System

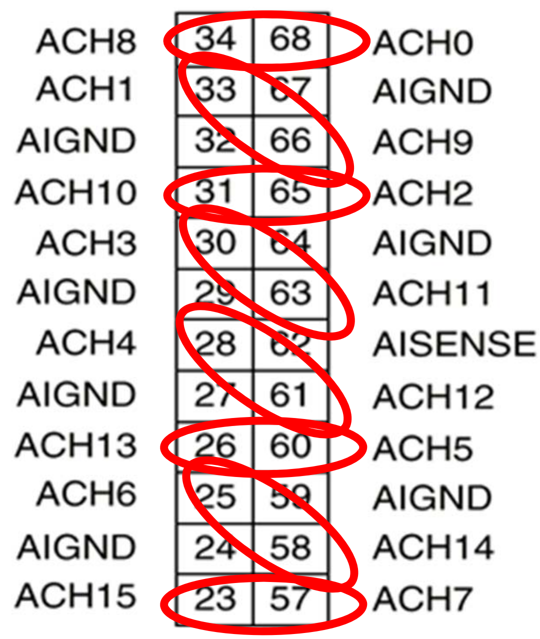
- Three modes of grounding for your Measurement System
  - Differential
  - Referenced Single-Ended (RSE)
  - Non-Referenced Single-Ended (NRSE)
- Mode you choose will depend on how your signal is grounded



Differential Mode

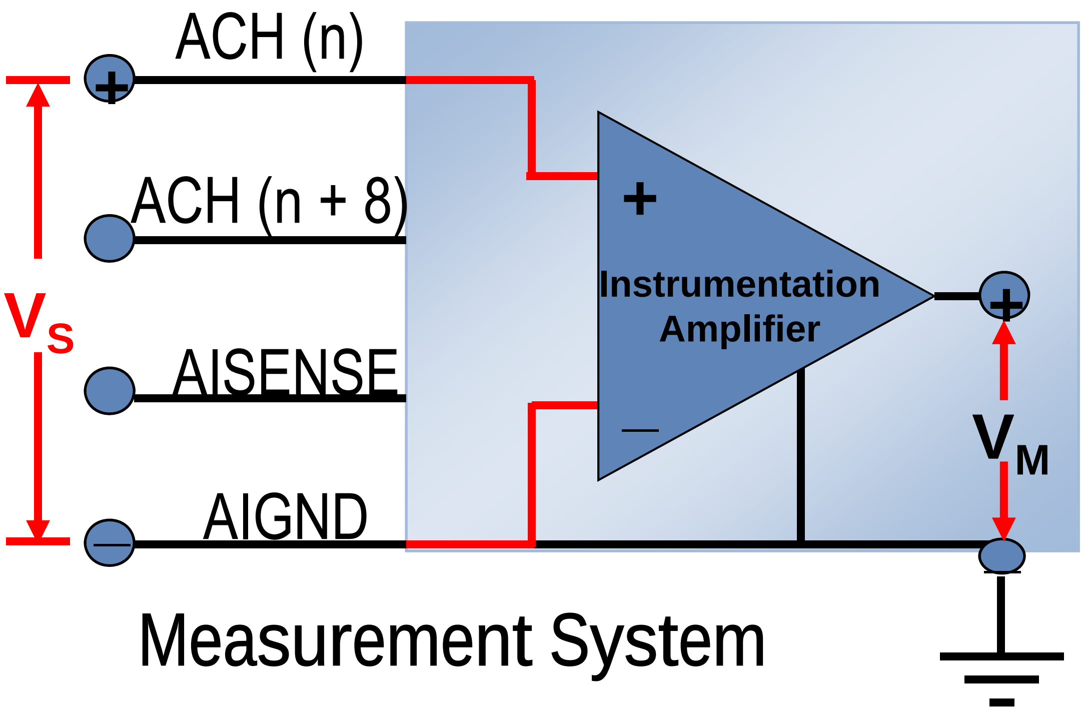
- Two channels used for each signal
  - ACH 0 is paired with ACH 8, ACH 1 is paired with ACH 9, and so on.
- Rejects common-mode voltage and common-mode noise





Referenced Single-Ended (RSE) Mode

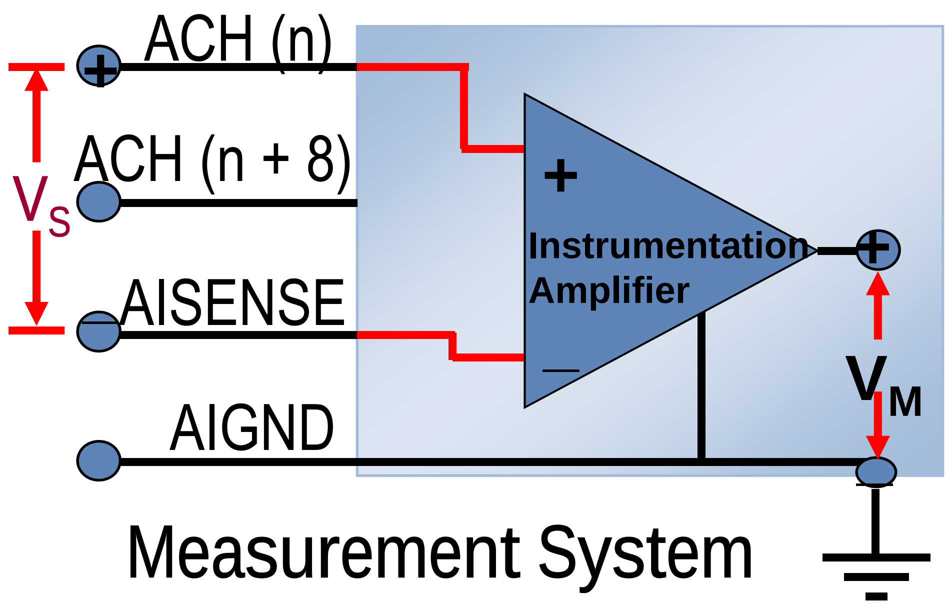
- Measurement made with respect to system ground
- One channel used for each signal
- Does not reject common mode voltage



ACH8	34	68	ACH0
ACH1	33	67	AIGND
AIGND	32	66	ACH9
ACH10	31	65	ACH2
ACH3	30	64	AIGND
AIGND	29	63	ACH11
ACH4	28	62	AISENSE
AIGND	27	61	ACH12
ACH13	26	60	ACH5
ACH6	25	59	AIGND
AIGND	24	58	ACH14
ACH15	23	57	ACH7

Non-Referenced Single-Ended (NRSE) Mode

- Variation on RSE
- One channel used for each signal
- Measurement made with respect to AISENSE not system ground
- AISENSE is floating
- Does not reject common mode voltage



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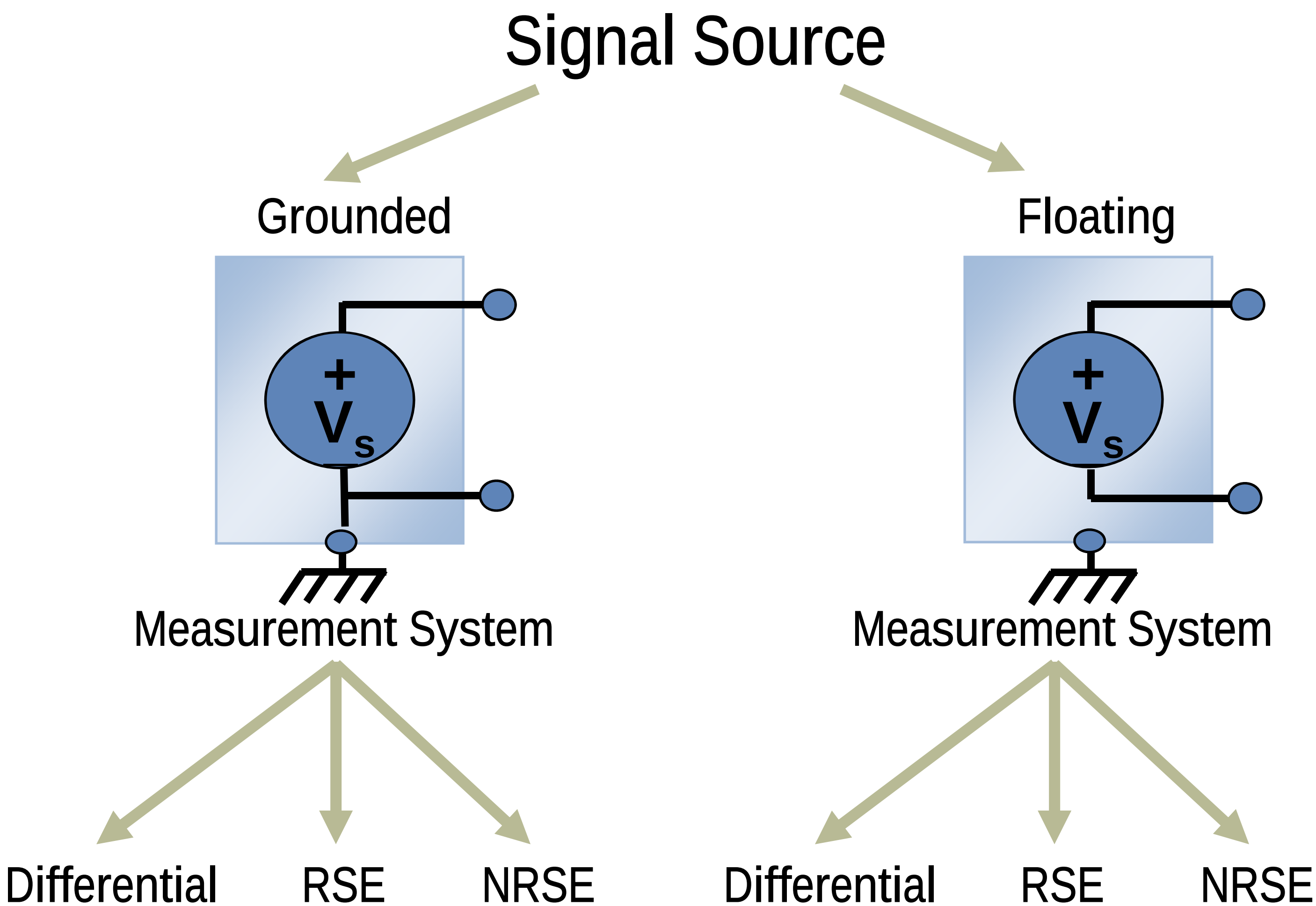
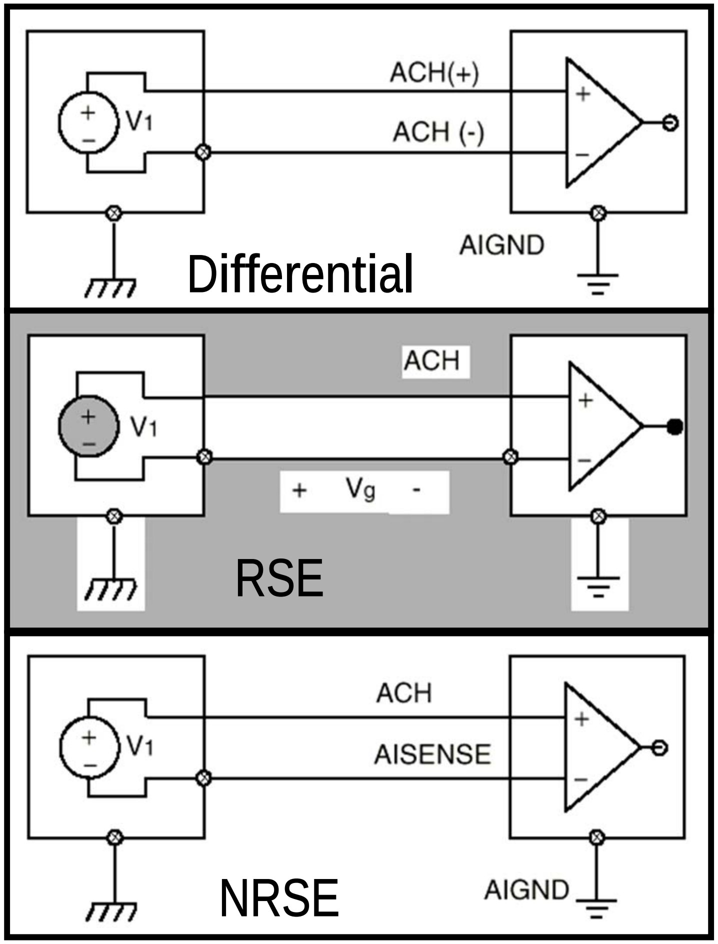
ACH15	23	57	ACH7

Choosing Your Measurement System



Options for Grounded Signal Sources



Better

+ Rejects common-mode voltage
– Cuts channel count in half

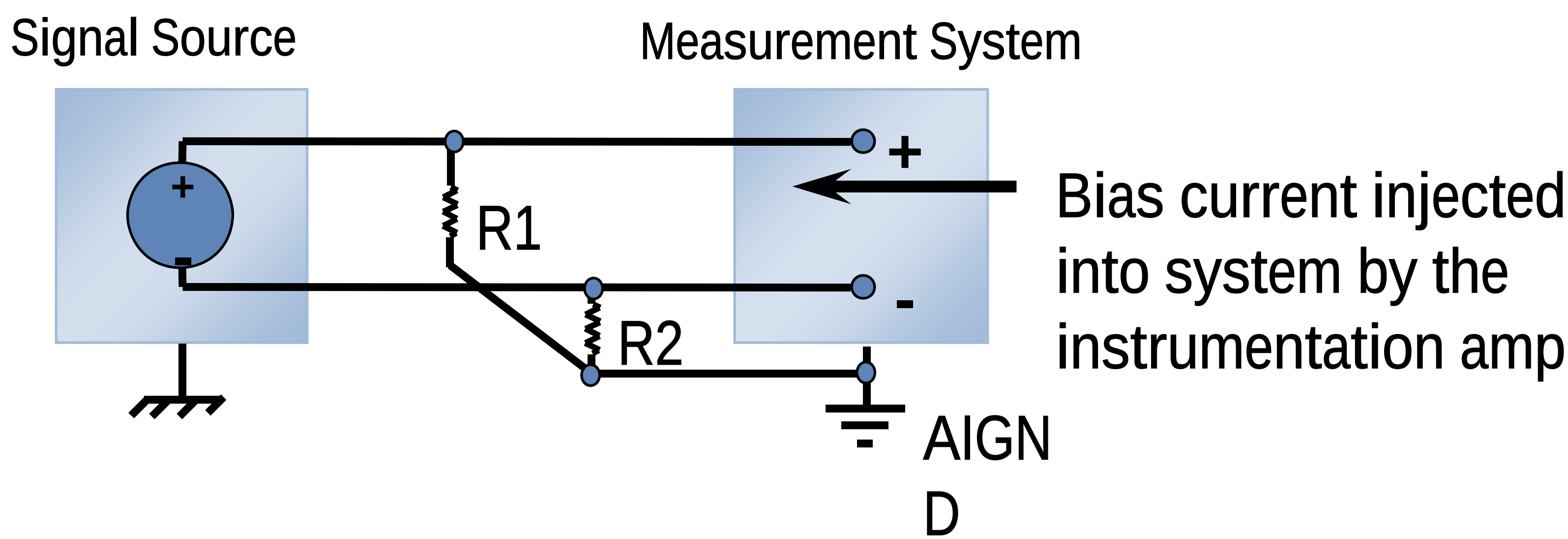
Not Recommended

– Voltage difference (Vg) between the two grounds makes a ground loop that could damage the device

Good

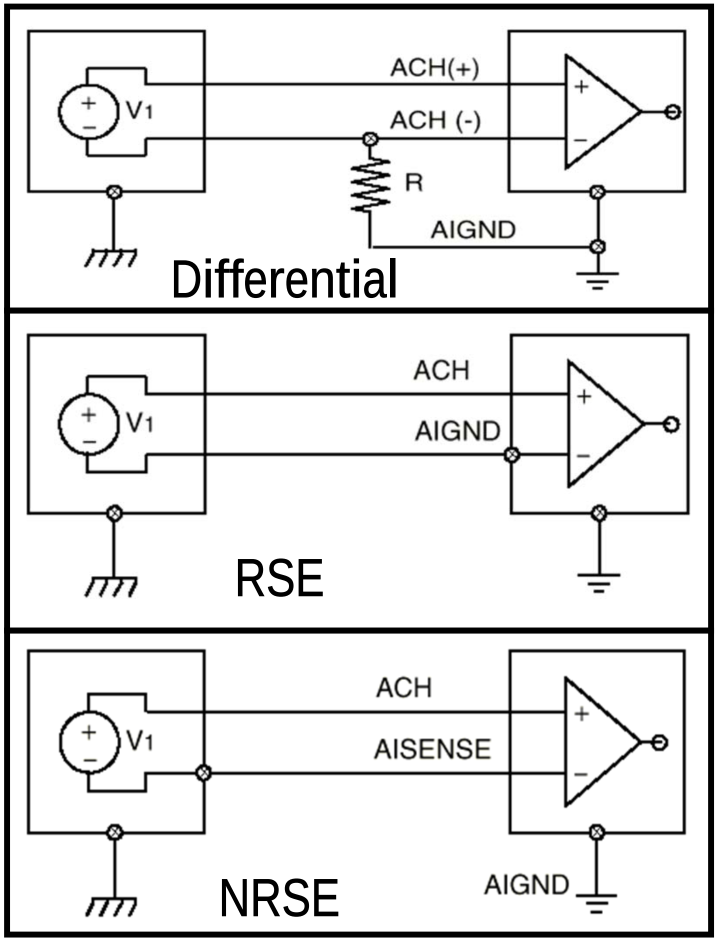
+ Allows use of entire channel count
– Does not reject common-mode voltage

Bias Resistors



- Needed with floating signal source and floating measurement system (Differential or NRSE)
- Bias resistors provide a return path to ground for instrumentation amplifier bias currents
- Recommended value is between 10 kΩ and 100 kΩ

Options for Floating Signal Sources



Best

+ Rejects common-mode voltage
– Cuts channel count in half
– Needs bias resistors

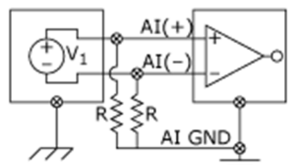
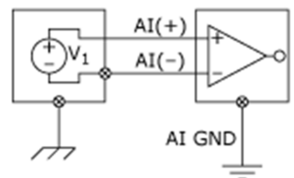
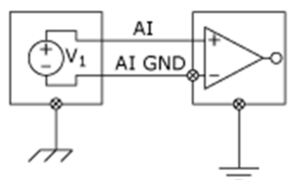
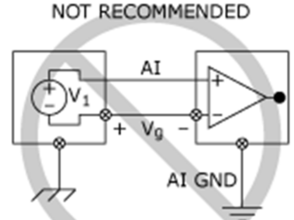
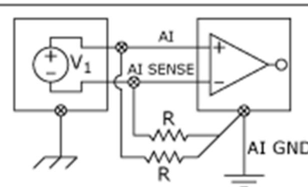
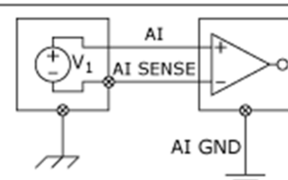
Better

+ Allows use of entire channel count
+ Do not need bias resistors
– Does not reject common-mode voltage

Good

+ Allows use of entire channel count
– Needs bias resistors
– Does not reject common-mode voltage

Signal Source Connections Overview

Input Configuration	Signal Source Type: Floating Signal Source (Not Connected to Building Ground)	Signal Source Type: Grounded Signal Source
	Examples • Thermocouples • Signal Conditioning with Isolated Outputs • Battery Devices	Examples • Plug-in Instruments with Nonisolated Inputs
Differential (DIFF)	 Two resistors (10 kΩ<R<100 kΩ) provide return paths to ground for bias currents	
Single-Ended – Ground Referenced (RSE)		NOT RECOMMENDED  Ground-loop losses, V_g, are added to measured signal.
Single-Ended – Nonreferenced (NRSE)		

Exercise 3-1: Differential, RSE, and NRSE

To learn how to choose a grounding mode for a measurement system and how to connect signals properly to that measurement system.

GOAL

Exercise 3-1: Differential, RSE, and NRSE

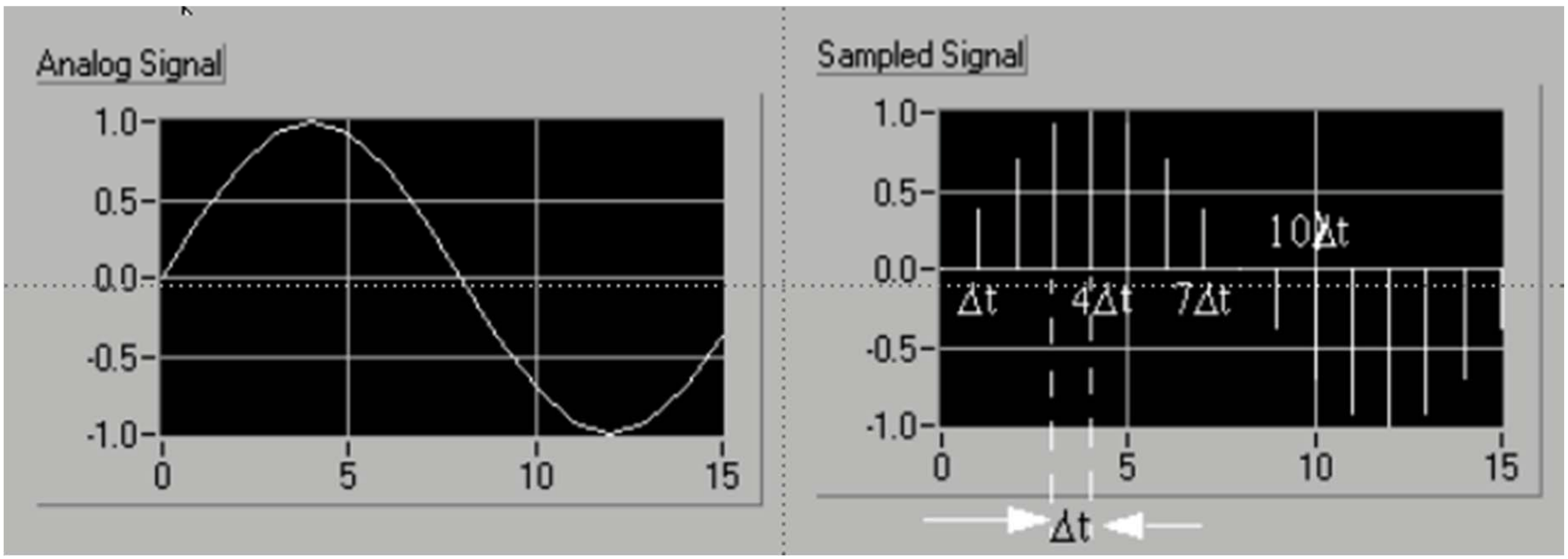
- What are the pros and cons of choosing RSE for the floating signal source?
- What are the pros and cons of choosing differential for the floating signal source?

DISCUSSION

Sampling Signals

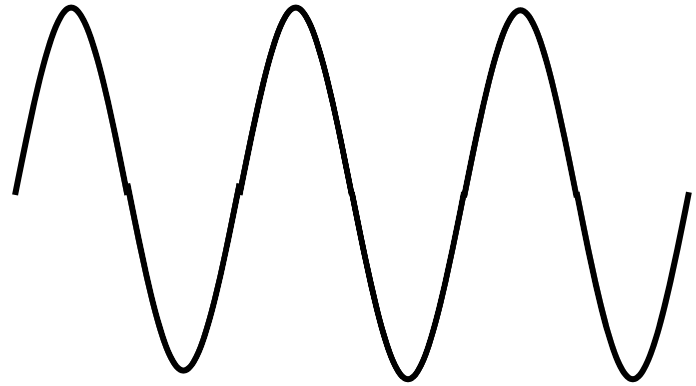
- Individual samples are represented by: $x[i] = x(i\Delta t)$, for $i = 0, 1, 2, \ldots$
- If N samples are obtained from signal $x(t)$:

  $X = \{x[0], x[1], x[2], \ldots x[N-1]\}$
- The sequence $X = \{x[i]\}$ is indexed on i and does not contain sampling rate information

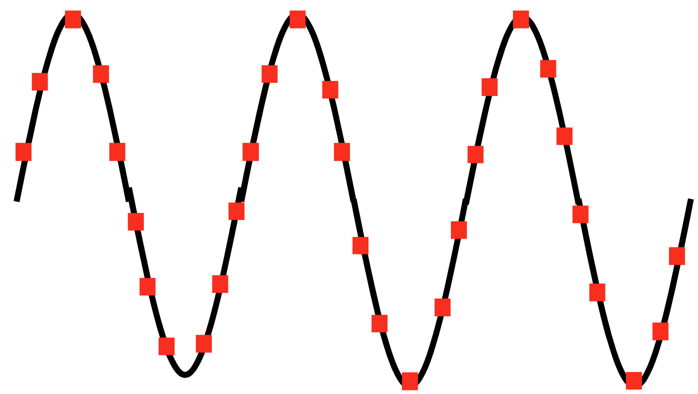


B. Sampling Considerations

- Actual analog input signal is continuous with respect to time
- Sampled signal is series of discrete samples acquired at a specified sampling rate
- The faster we sample, the more our sampled signal will look like our actual signal
- If not sampled fast enough, a problem known as aliasing will occur



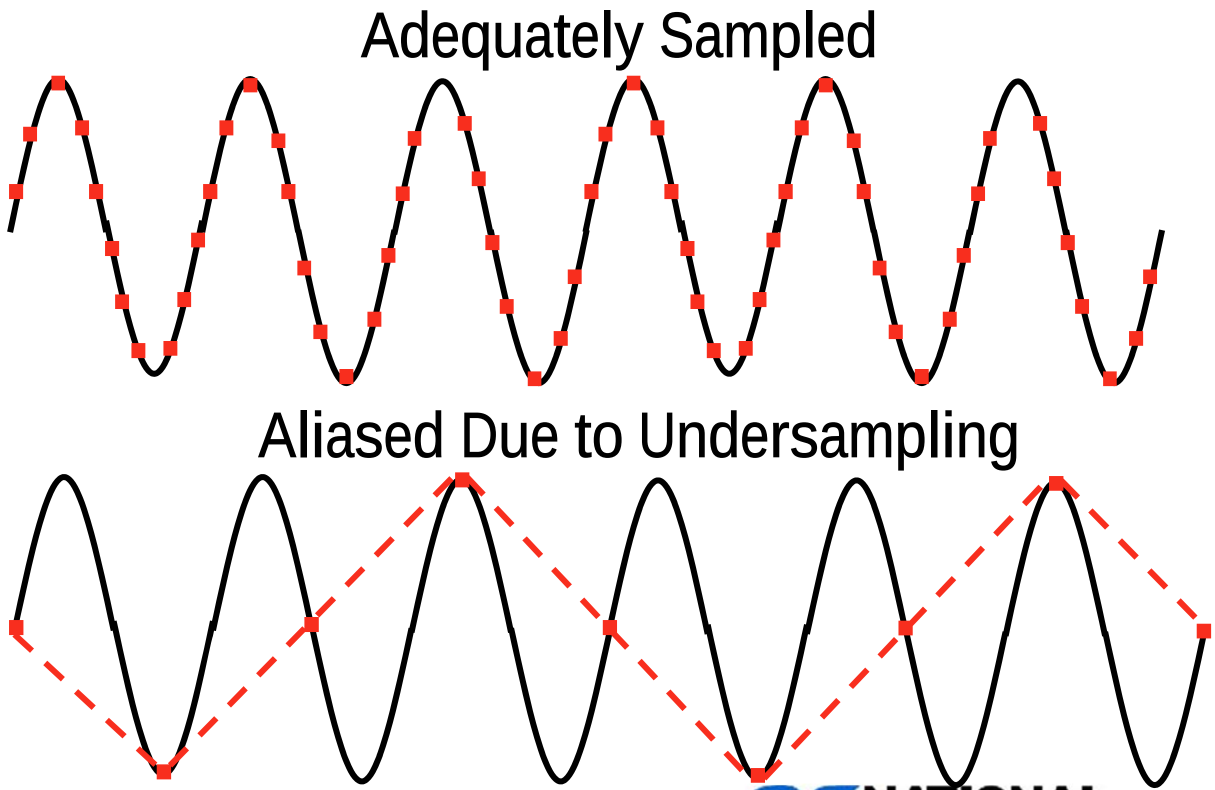
Actual Signal



Sampled Signal

Aliasing

- Sample rate – how often an A/D conversion takes place
- Alias – misrepresentation of a signal



Nyquist Theorem

You must sample at **greater** than 2 **times** the **maximum** frequency component of your signal to accurately represent the FREQUENCY of your signal.

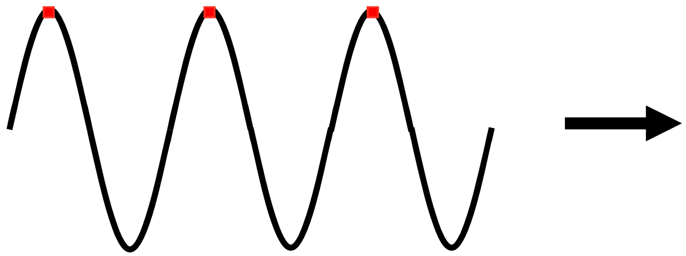
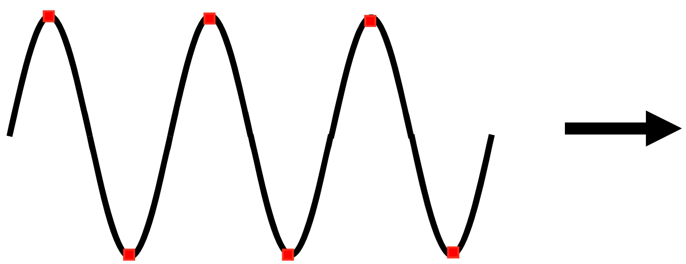
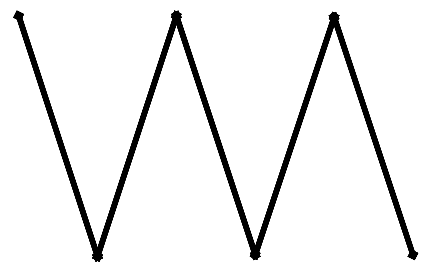
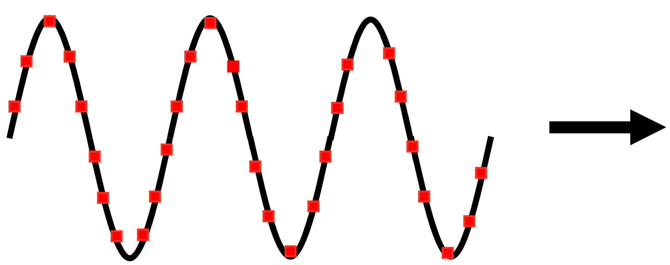
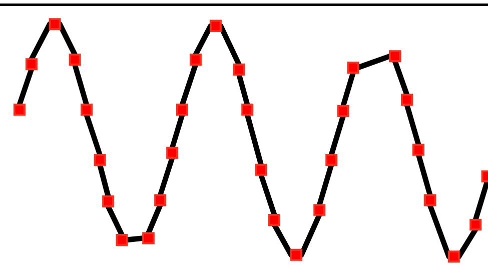
NOTE: You must sample between 5–10 times greater than the maximum frequency component of your signal to accurately represent the SHAPE of your signal.

Nyquist Frequency

- Half the sampling frequency
- You will only get a proper representation of signals that are equal to or less than your Nyquist Frequency
- Signals above Nyquist Frequency will alias according to the following formula:

Alias frequency =
|(closest integer multiple of sampling frequency - signal frequency)|

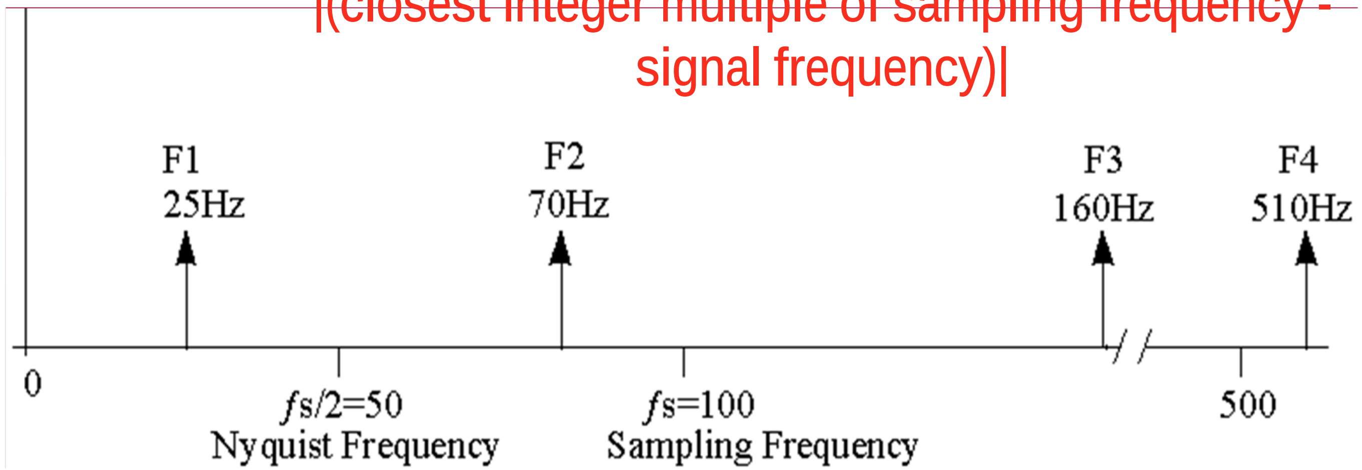
Nyquist Example

 100Hz Sine Wave	Sampled at 100Hz	Aliased Signal
 100Hz Sine Wave	 Sampled at 200Hz	Adequately Sampled for Frequency Only (Same # of cycles)
 100Hz Sine Wave	 Sampled at 1kHz	Adequately Sampled for Frequency and Shape

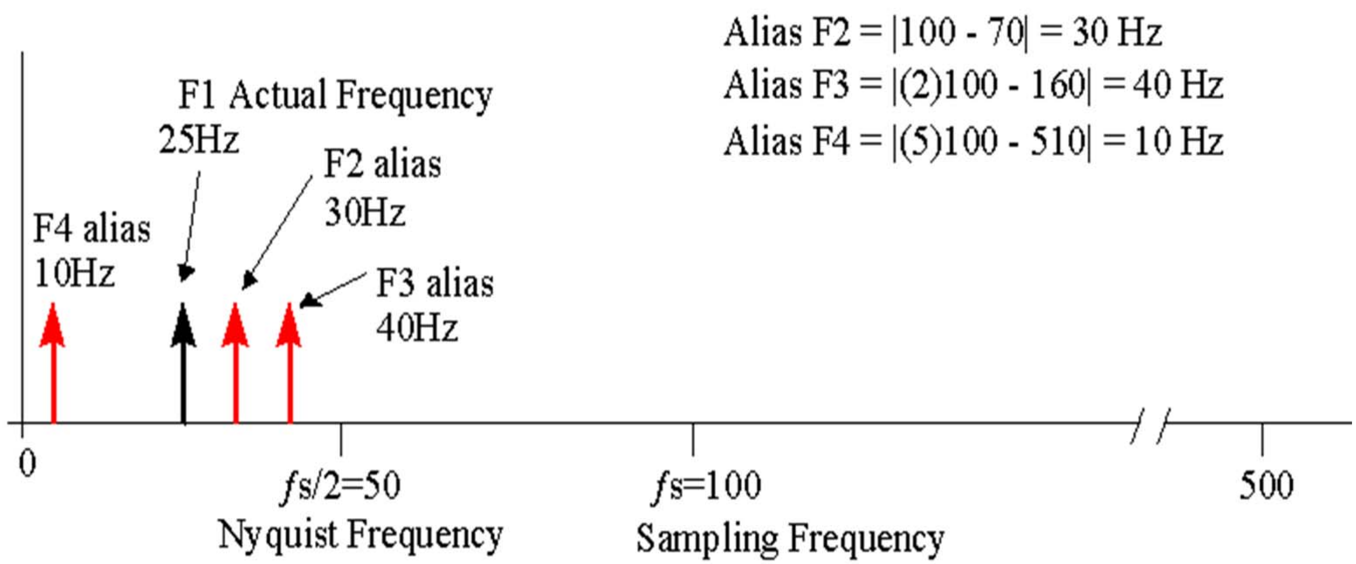
Aliasing Example

Alias frequency =
|(closest integer multiple of sampling frequency - signal frequency)|

Signals before acquisition



Signals after acquisition



Preventing Aliasing

Oversampling

+ Increases your Nyquist Frequency

– ADC may not go that fast

Low Pass Filtering

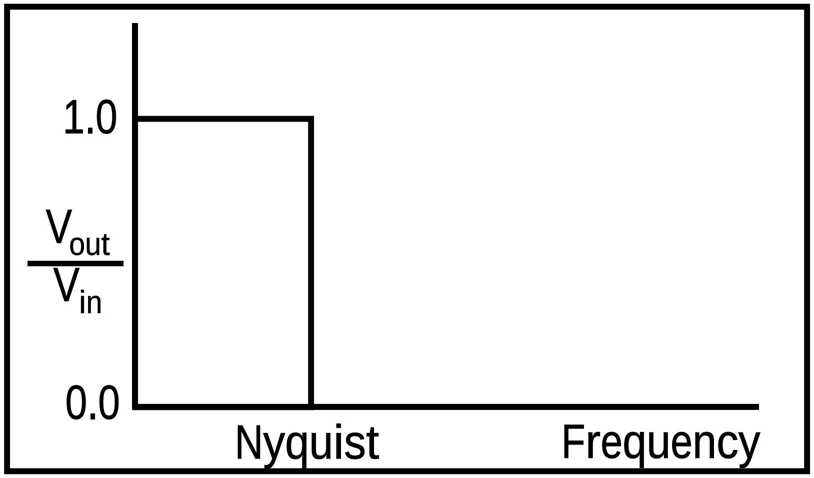
+ Eliminates most frequencies above cutoff of filter

– Transition region still allows some frequencies to alias

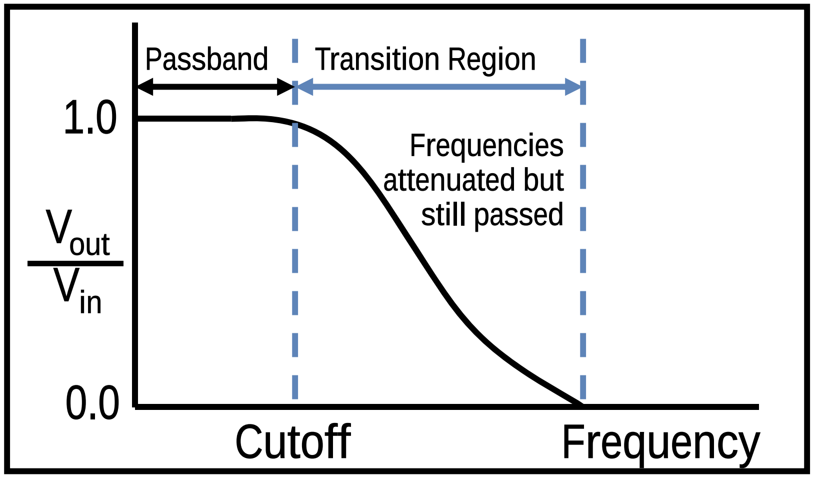
Best Solution

- Both oversampling and low pass filtering

Ideal Filter



Real-World Filter



Exercise 3-2: Sampling Rate and Aliasing

To demonstrate aliasing and the effects of sampling rate on an input signal.

GOAL

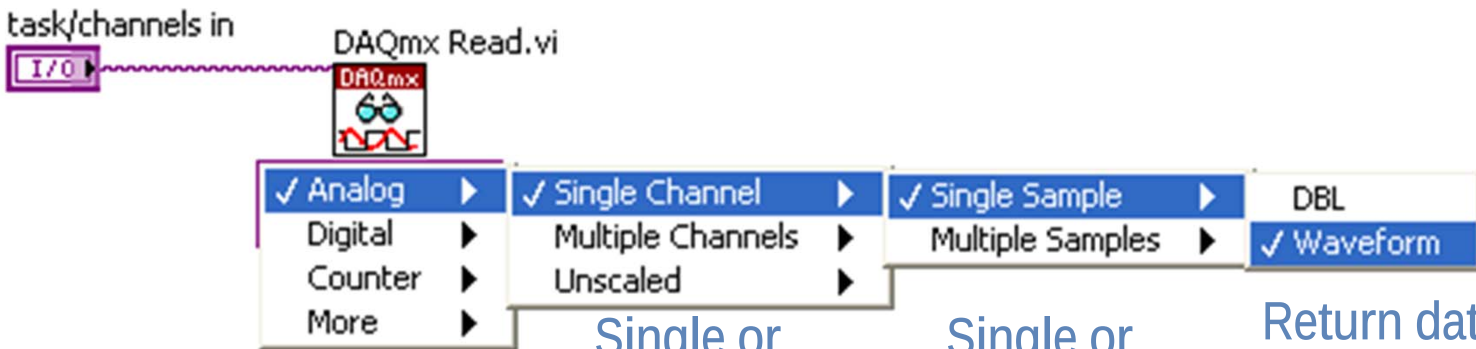
Exercise 3-2: Sampling Rate and Aliasing

- If the analog output signal is set to 5000 Hz, what should the analog input sampling rate be in order to correctly detect the analog output frequency?

DISCUSSION

DAQmx Read Function

1. Select Settings



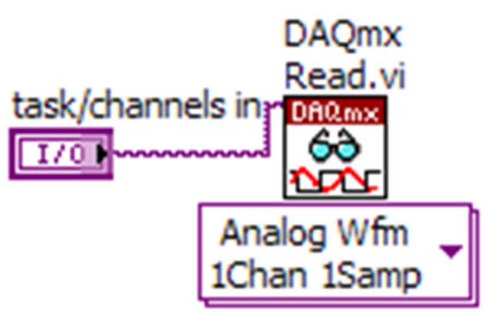
Signal Type

Single or Multiple Channels?

Single or Multiple Samples?

Return data as waveform or double (array) type?

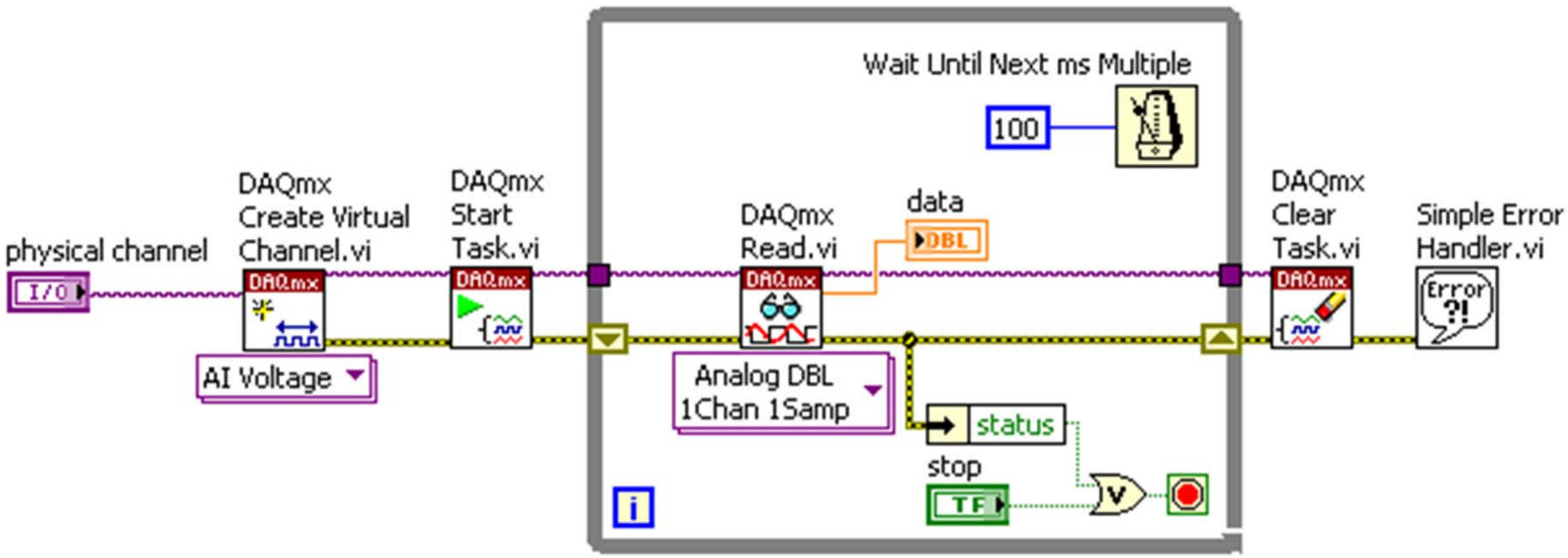
2. Verify Settings



- ✔ Analog
- ✔ 1 Channel
- ✔ 1 Sample
- ✔ Waveform

C. Single Sample Software-Timed Acquisition

- DAQmx Read VI
  - Acquires one sample each iteration
- Wait Until Next ms Multiple function
  - Determines rate of acquisition using software timing



Exercise 3-3: Voltmeter VI

To acquire an analog signal using a DAQ device.

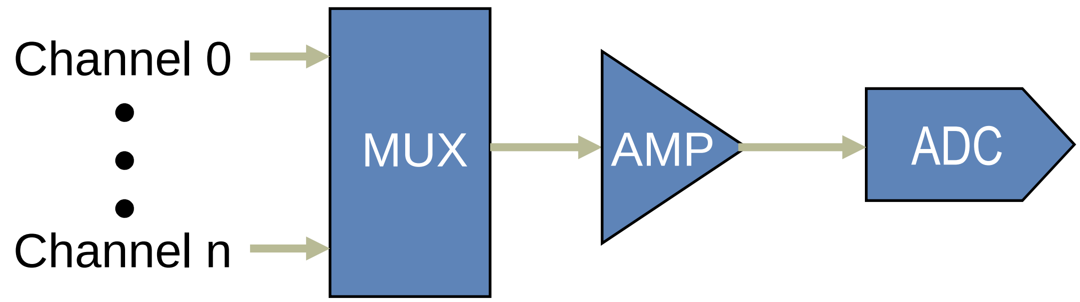
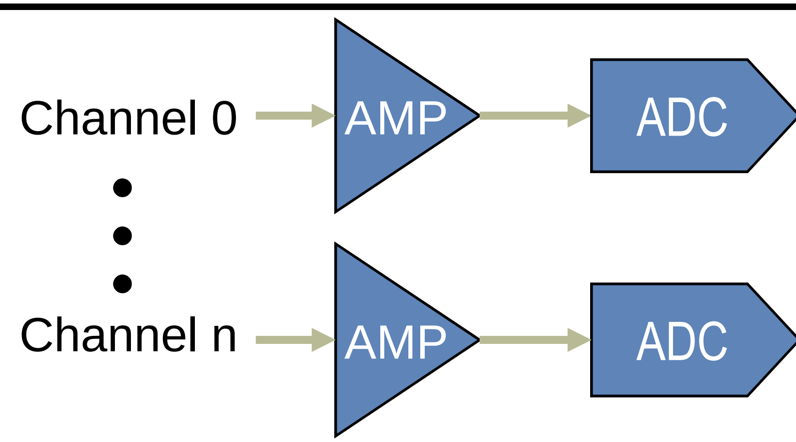
GOAL

Exercise 3-3: Voltmeter VI

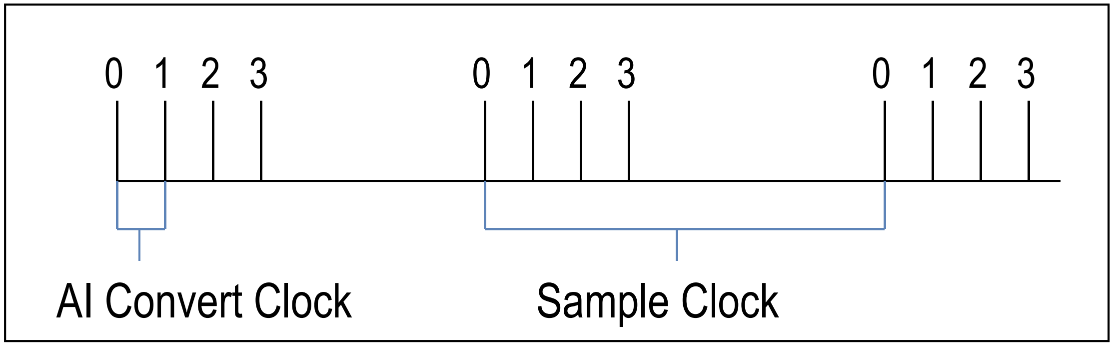
- What determines the rate at which this VI acquires samples?

DISCUSSION

D. DAQ Device Architectures

One amplifier and ADC for ALL channels – Cost effective – Used on M Series and some X Series devices	 Multiplexed Sampling Architecture
One amplifier and A/D Converter for EACH channel – More expensive – Used on most S Series and cDAQ devices and some X Series devices	 Simultaneous Sampling Architecture

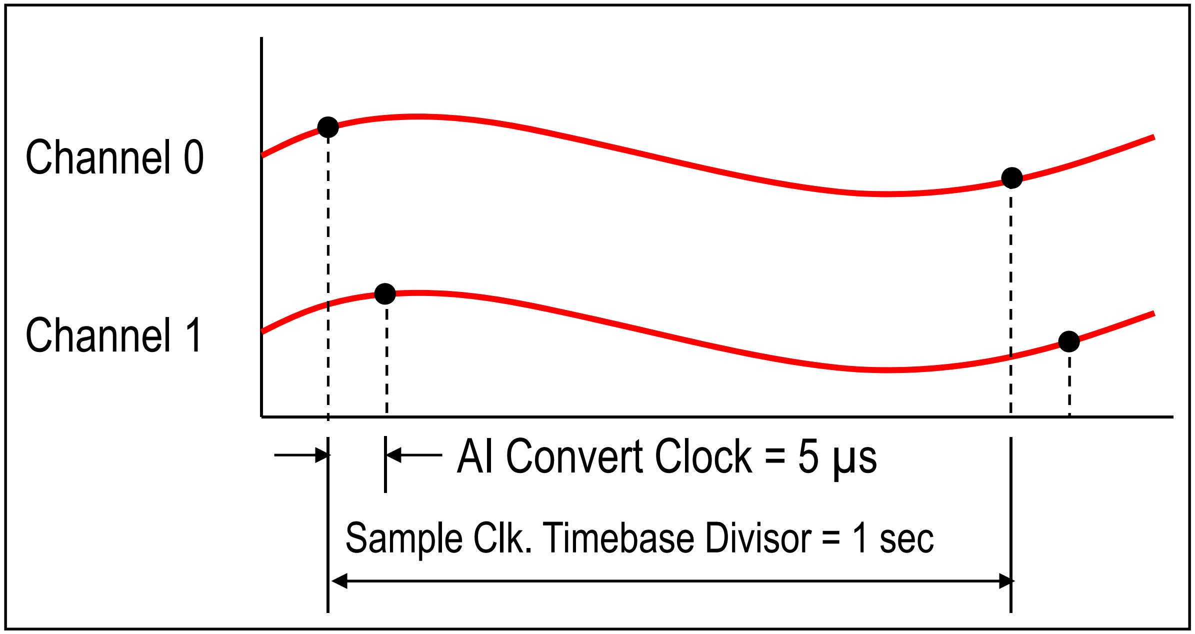
Sampling Terminology



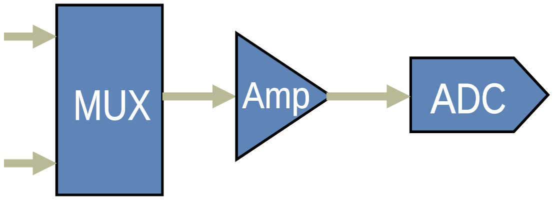
- Sample
  - A single measurement from a single channel
- Sample Rate
  - Samples per Channel per Second
- Sample Clock
  - Clock that controls time interval between samples
  - During each cycle of the sample clock, one sample for each channel is acquired
- AI Convert Clock
  - Clock that directly causes analog-to-digital conversions
  - Interchannel delay

Multiplexed Sampling

- Uses both Sample Clock and AI Convert Clock
  - Gives the effect of simultaneous sampling for less money
- By default, NI-DAQmx chooses the fastest AI Convert Clock rate possible that allows for adequate settling time
  - Can manually set AI Convert Clock rate using property node



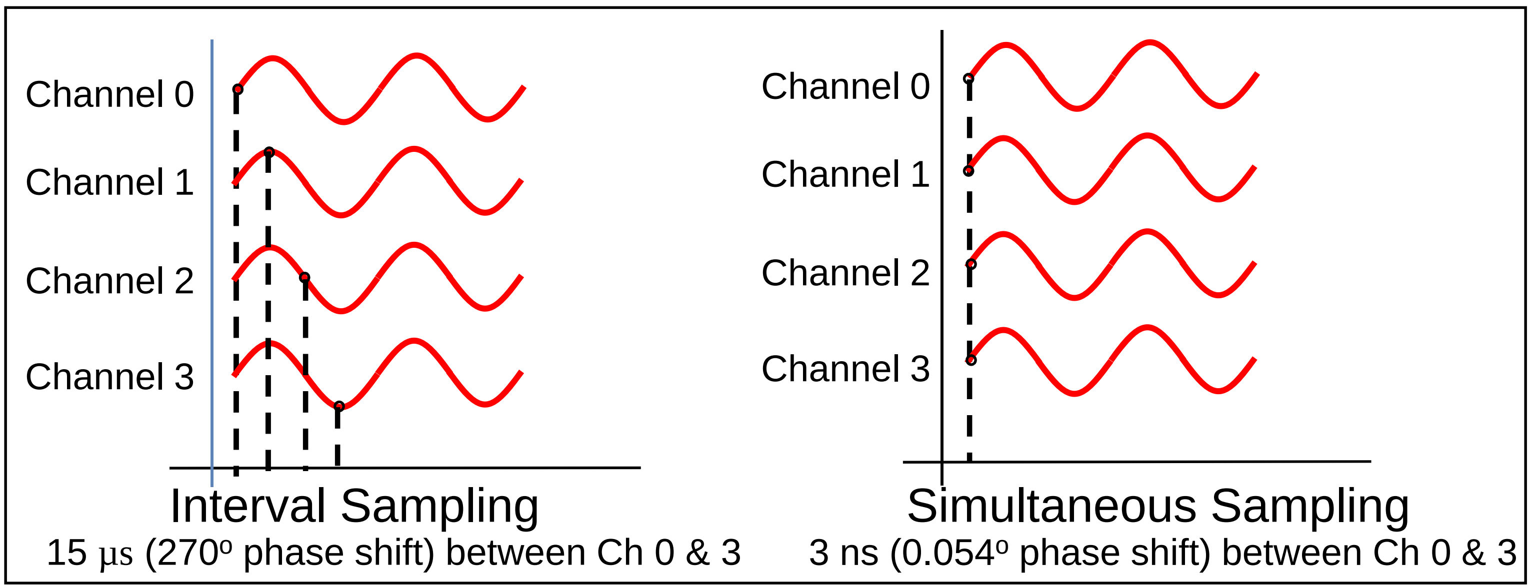
Two Channel Example

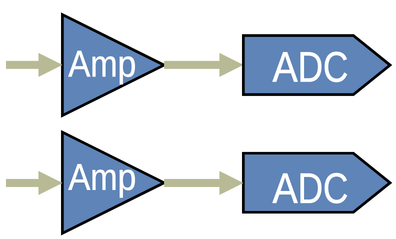


- Samples per Channel per Second = 1 sample/chan/sec
- Sample Clock Timebase Divisor = 1/Samples per Channel per Second = 1sec/chan/sample
- Sample duration = (# of channels - 1) * AI Convert Clock = 5 μs

Simultaneous Sampling

- Used when time relationship between signals is important
- Available on all S-Series devices and some X-Series devices
- Only uses a sample clock to synchronize the taking of samples

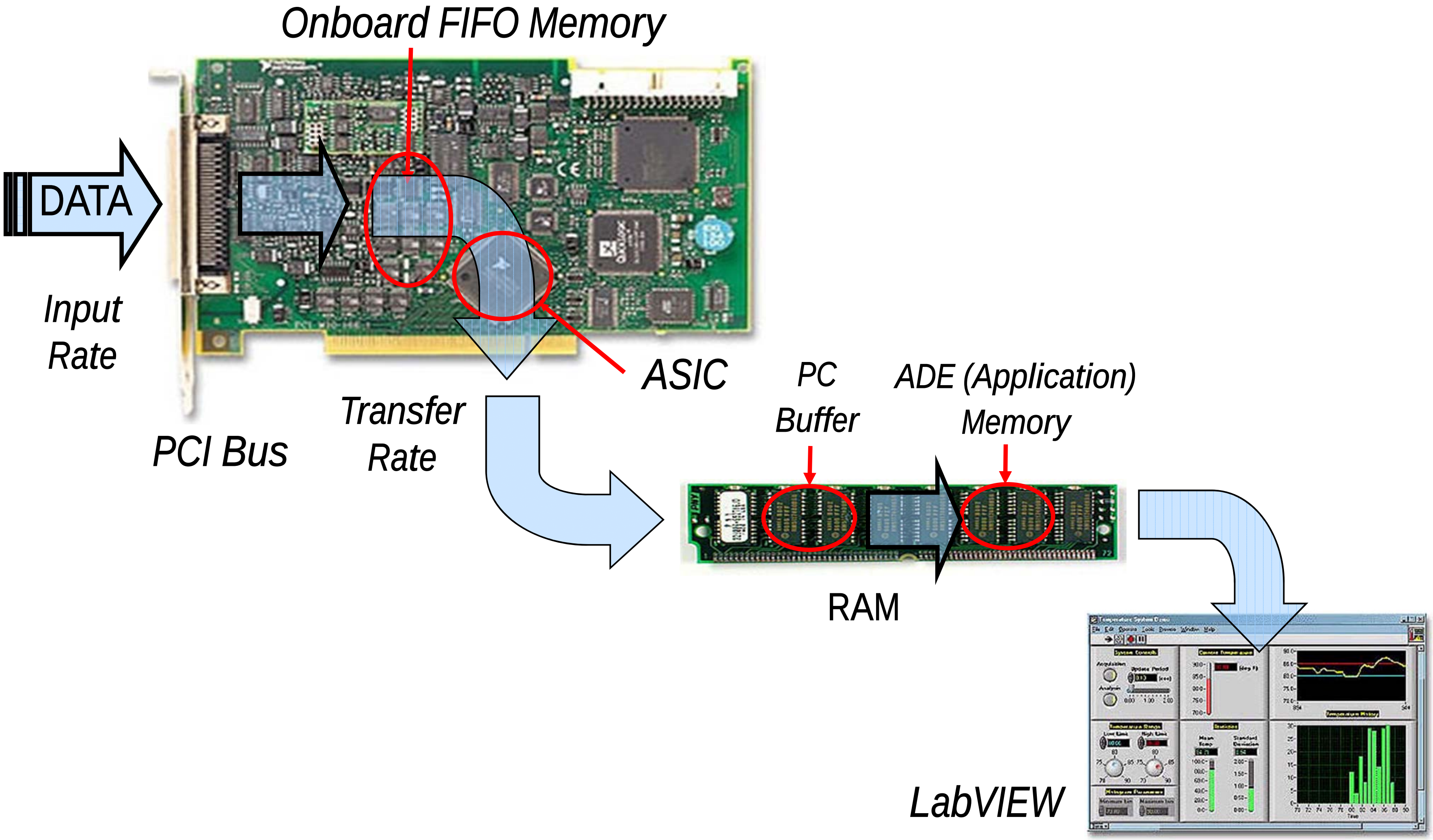




Buffered Analog Input

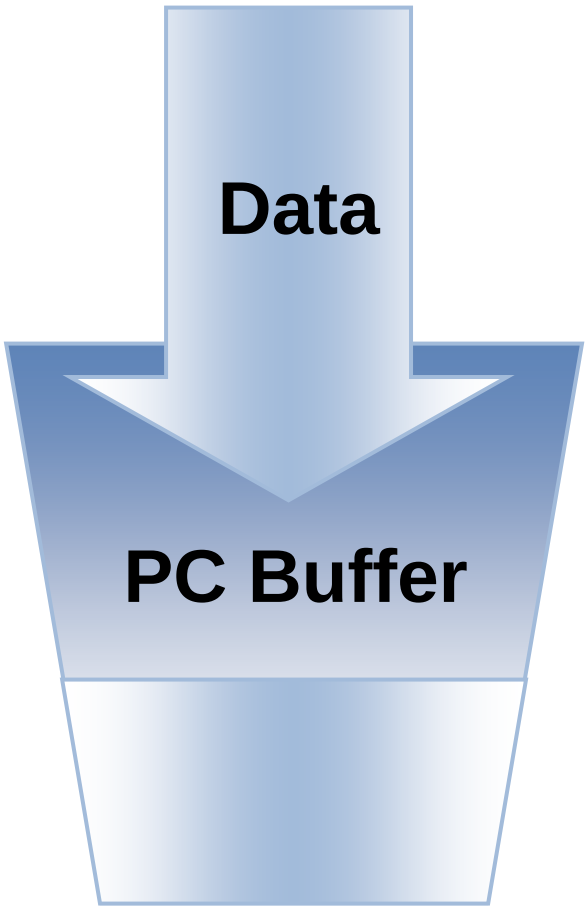
- Buffer – temporary storage in computer memory for acquired or generated data
- Data transfer mechanism transfers samples from your device into the buffer where they await your call to the DAQmx Read VI to copy them to your application
  - Finite transfer
  - Continuous transfer

Data Transfer for an Input Operation



Finite Buffered Acquisition Theory

Bucket Theory

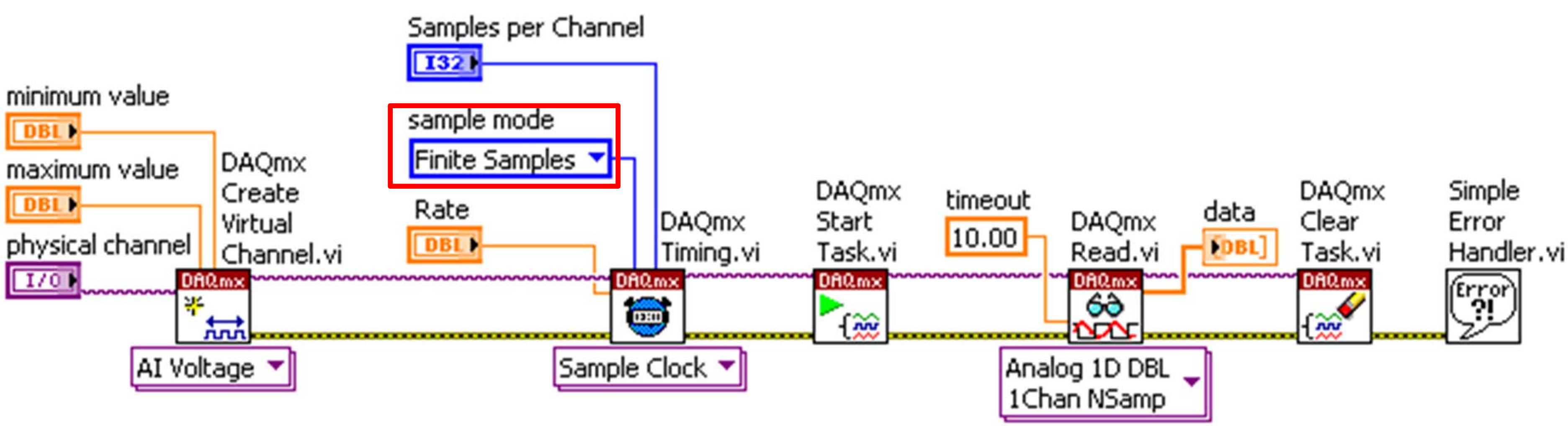


Think of your PC buffer as a bucket that is filling up with water

- Buffer size = size of the bucket
- Sample rate controls how fast water flows into the bucket
- When the bucket is full you pull it into the application
- The PC buffer is actually the allocated memory in the RAM

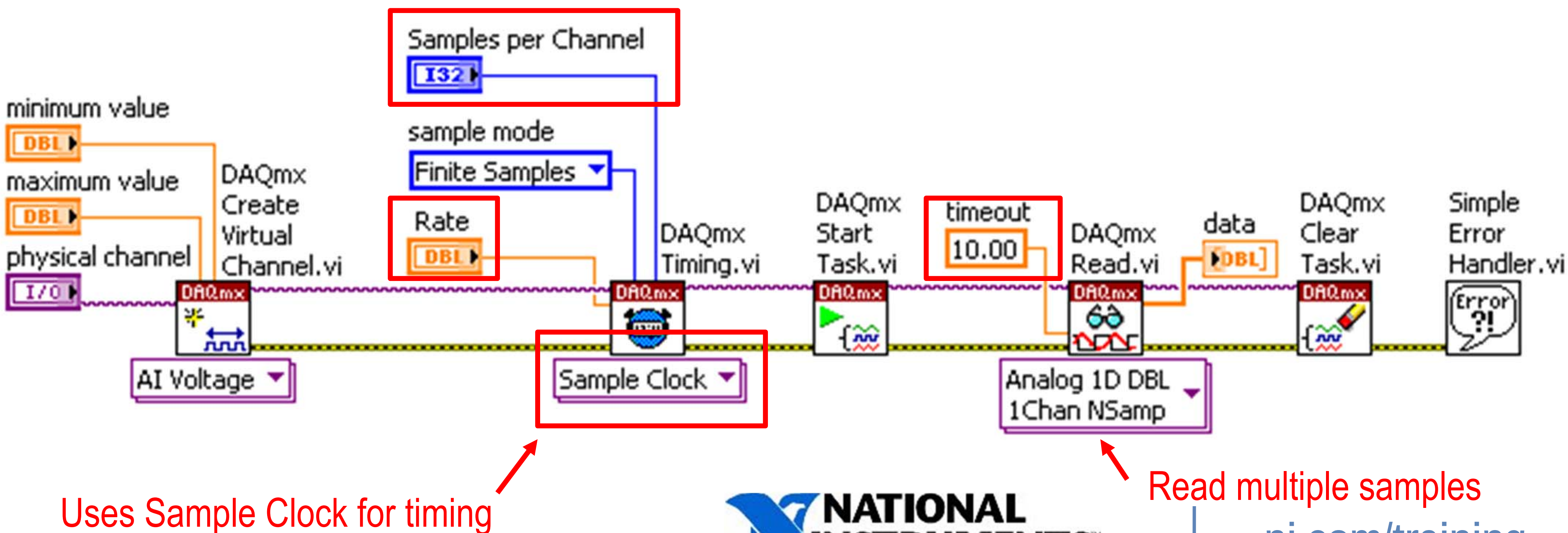
E. Finite Buffered Acquisition

- Perform a hardware-timed, finite buffered acquisition
- Highly recommended for many applications
- Set the sample mode to **Finite Samples**



Finite Buffered Acquisition

- Samples per Channel sets number of finite samples to acquire
  - NI-DAQmx automatically determines necessary buffer size
- Rate sets rate of acquisition
- DAQmx Read VI waits for task to acquire all requested samples, then reads those samples
  - Set timeout to -1 for DAQmx Read VI to wait indefinitely



Exercise 3-4: Finite Acquisition with Analysis

To acquire an array of data using a finite buffered configuration.

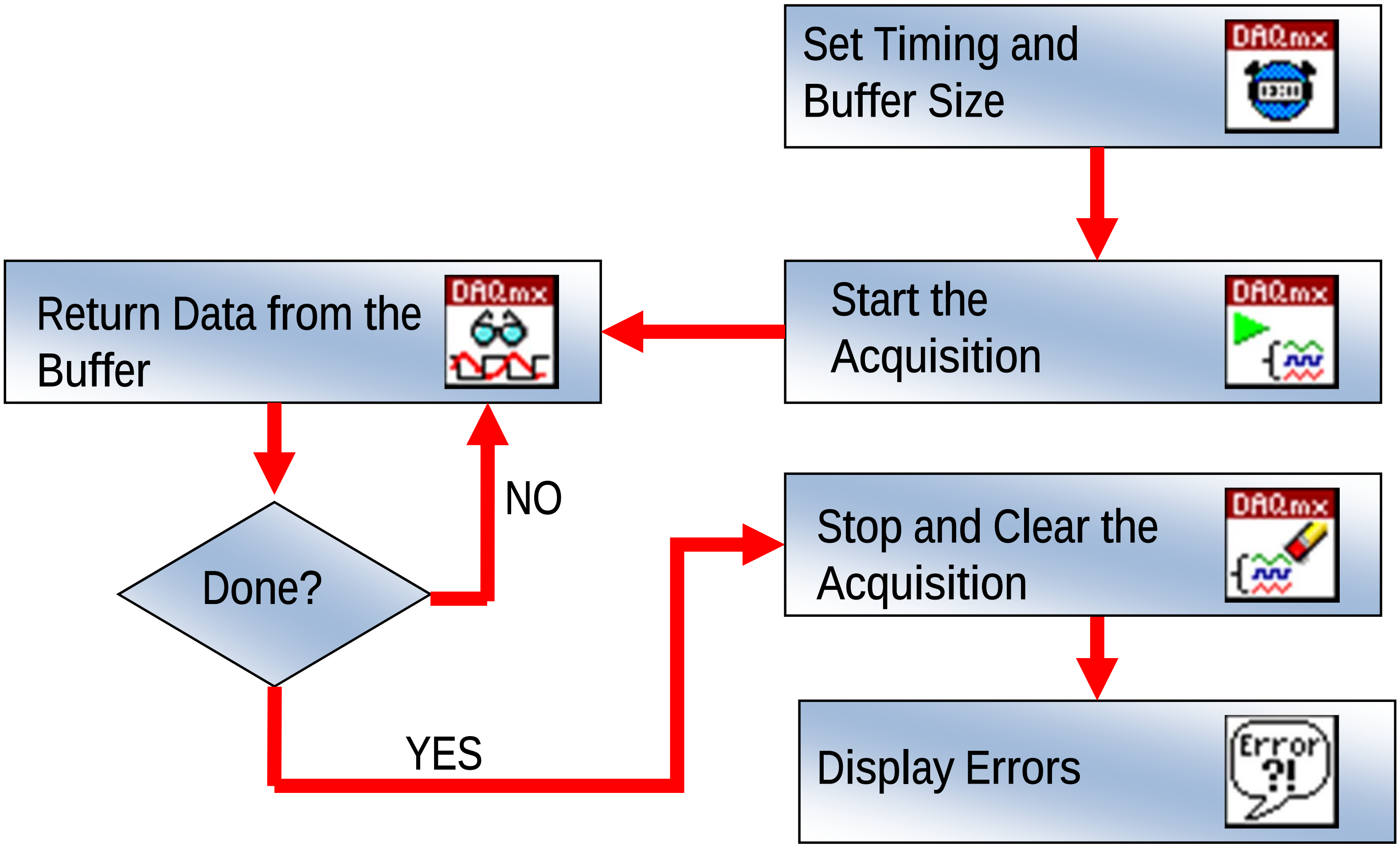
GOAL

Exercise 3-4: Finite Acquisition with Analysis

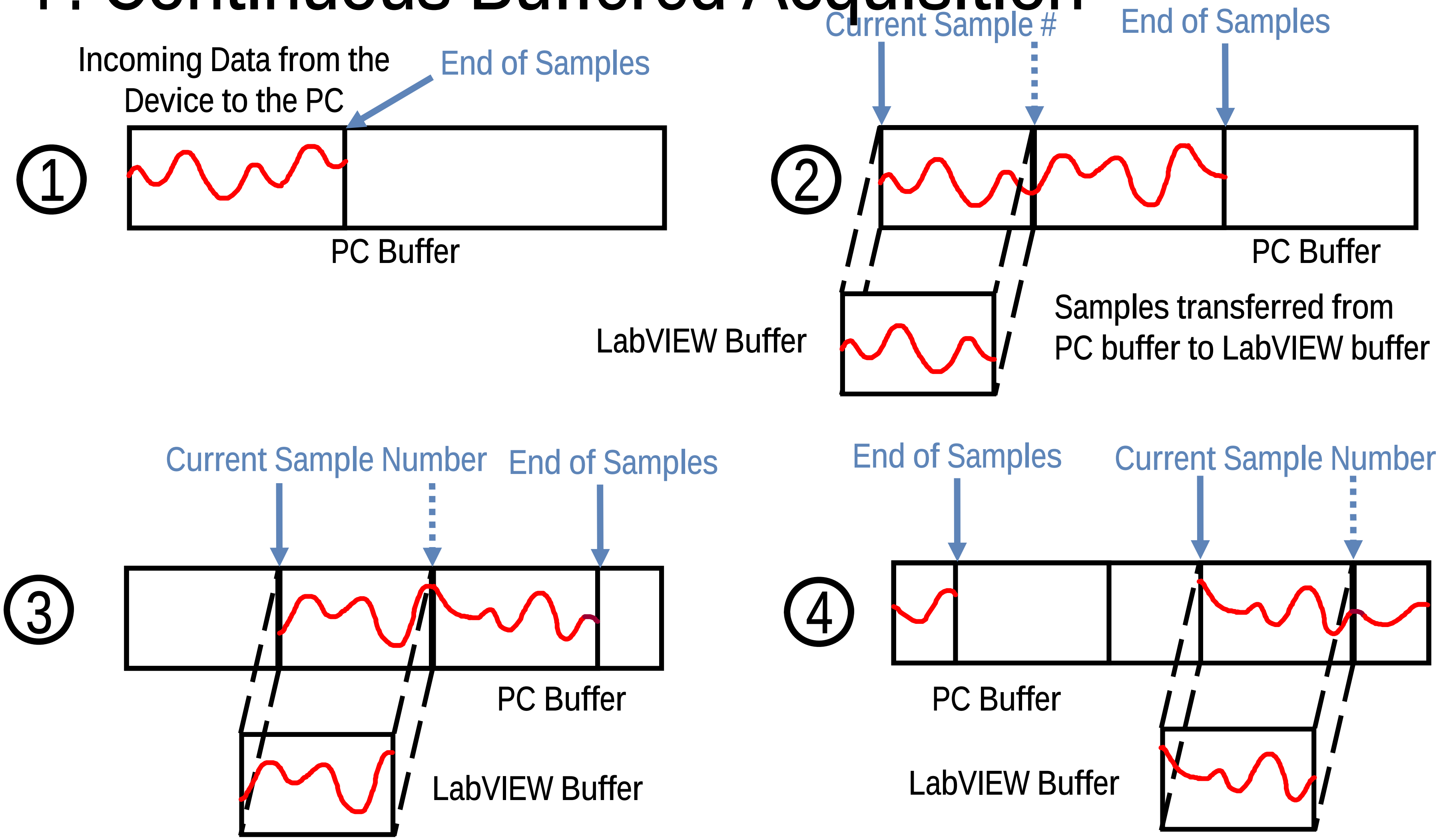
- What determines the rate at which this VI acquires samples?

DISCUSSION

Continuous Buffered Acquisition Flowchart



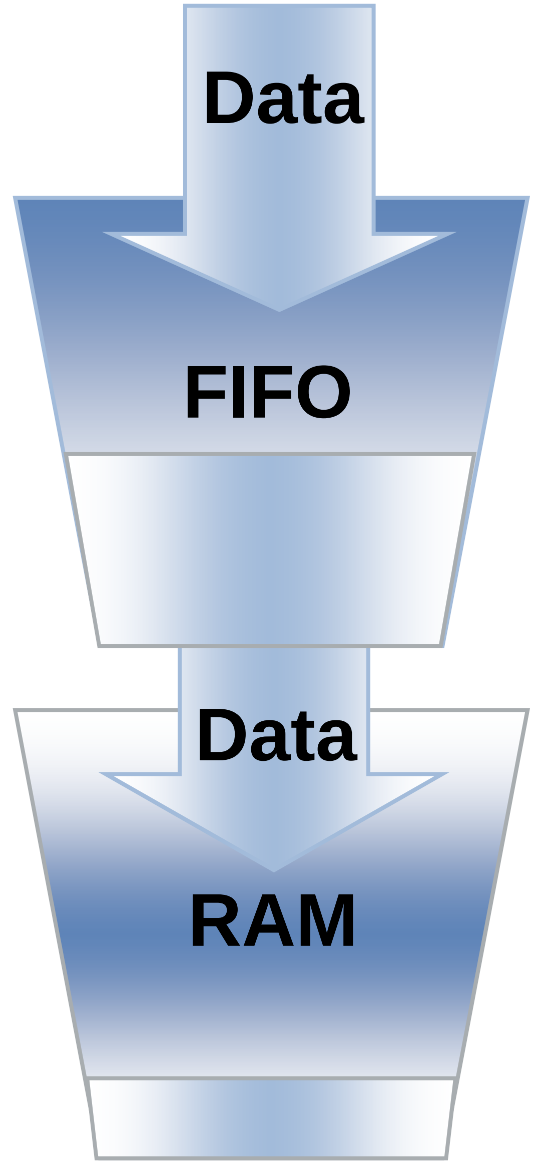
F. Continuous Buffered Acquisition



Continuous Acquisition Theory

With a continuous acquisition you need to make sure you drain your bucket as fast as you fill it

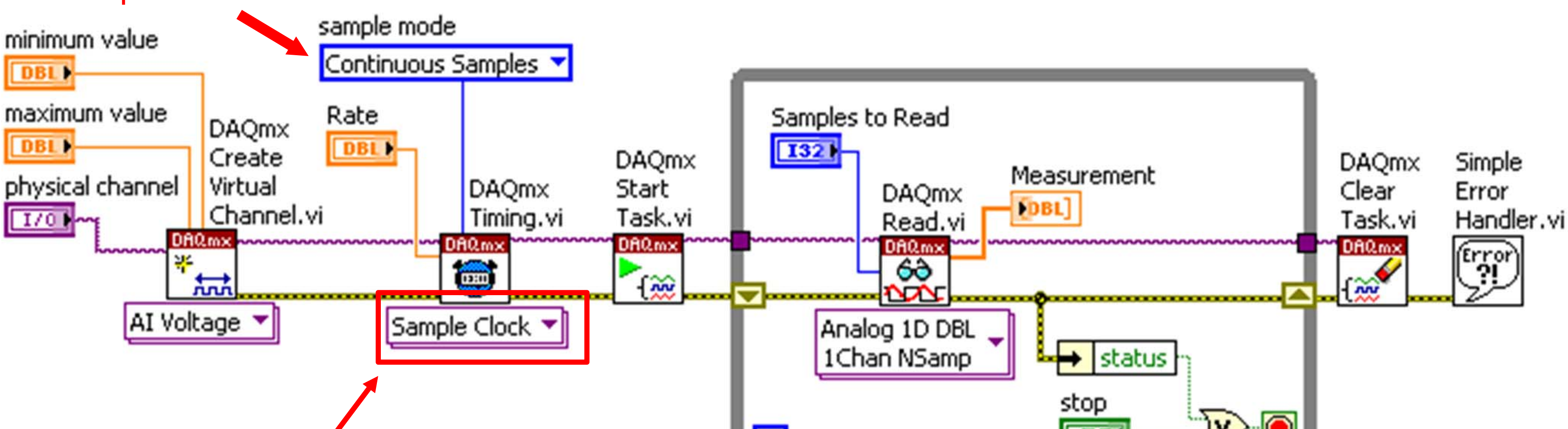
- Buffer size = size of the bucket
- Sample rate controls how fast water flows into the FIFO
- When the FIFO or RAM overflow you lose data
- Number of Samples to Read for DAQmx Read VI controls how fast you drain the RAM
- Available Samples per Channel is the amount of water still in the RAM



Continuous Buffered Acquisition

- Perform a hardware-timed, continuous buffered acquisition
- Set the sample mode to Continuous Samples

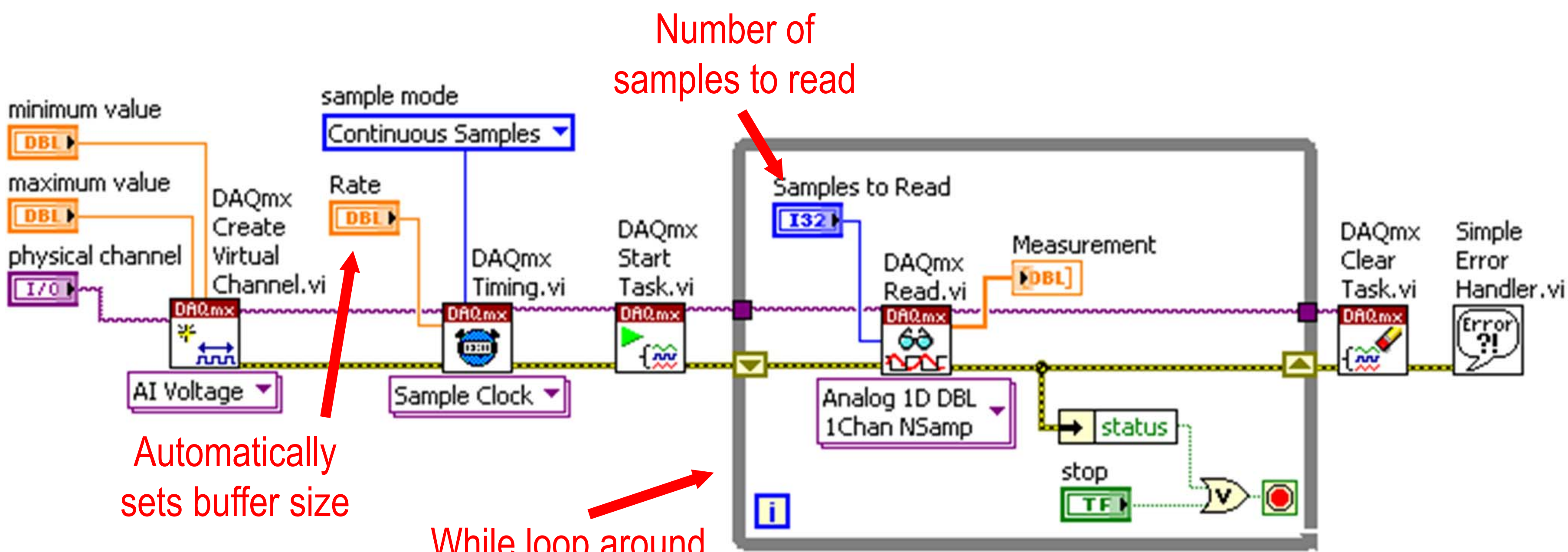
Select continuous samples for sample mode



Uses Sample Clock for timing

Continuous Buffered Acquisition

- Rate sets rate of acquisition
  - NI-DAQmx automatically determines buffer size based on rate
- Rate sets rate of acquisition
- Samples to Read determines the number of samples to read each iteration of the While Loop

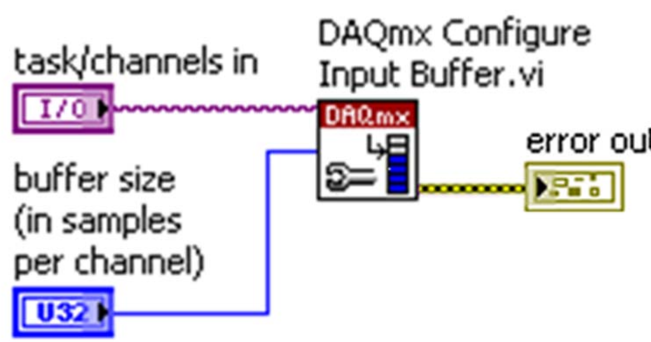


Configuring the Number of Samples to Read for Continuous Acquisition

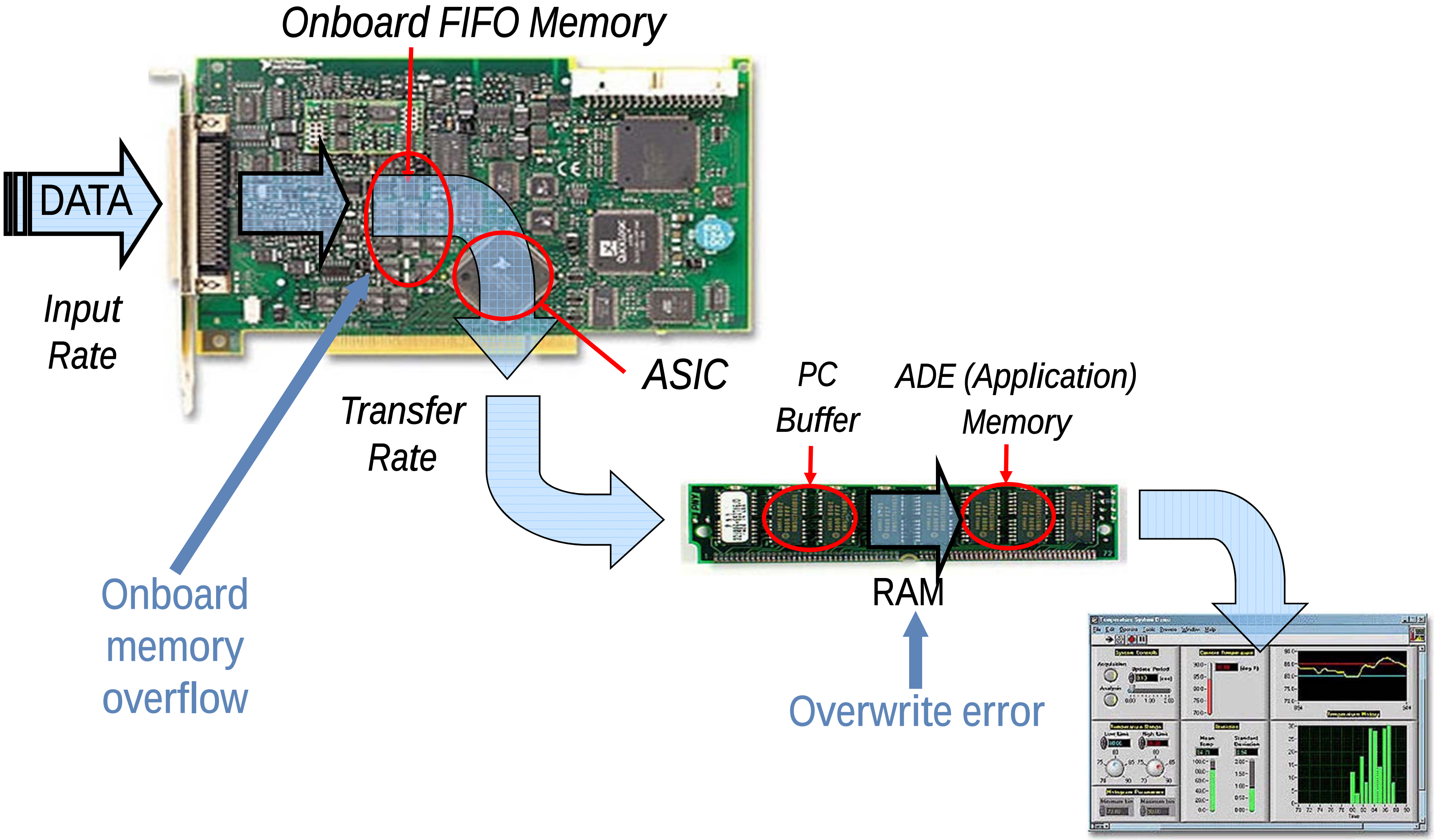
- Rate sets rate of acquisition (sampling rate)
  - NI-DAQmx automatically determines buffer size based on rate

Sample Rate	Buffer Size
No rate specified	10 kS
0-100 S/s	1 kS
100-10,000 S/s	10 kS
10,000–1,000,000 S/s	100 kS
> 1,000,000 S/s	1 MS

You can manually set the buffer size using the DAQmx Configure Input Buffer VI



Possible Errors of Data Transfer



Data Loss with Continuous Acquisition

Overflow Error

- Indicates that NI-DAQmx was unable to retrieve data from the FIFO fast enough
- Consequence:
  - The data in the FIFO will be overwritten
- How to avoid an overflow error:
  - Decrease the Samples per Channel per Second rate
  - Purchase a device with a larger FIFO
  - Purchase a faster computer with a faster bus

Data Loss with Continuous Acquisition

Overwrite Error

- Indicates that you are not reading data from the PC buffer fast enough
- Consequence:
  - Your unread data will be overwritten by newer data
- How to avoid an overwrite error:
  - Increase the buffer size with the DAQmx Timing VI
  - Increase the Number of Samples per Channel to read with DAQmx Read VI
  - Decrease the Samples per Channel per Second acquisition rate with the DAQmx Timing VI
  - Don't do any extra processing in your loop with the DAQmx Read VI

Exercise 3-5: Continuous Acquisition and Logging

To continuously acquire data from a DAQ device and log this data to a file.

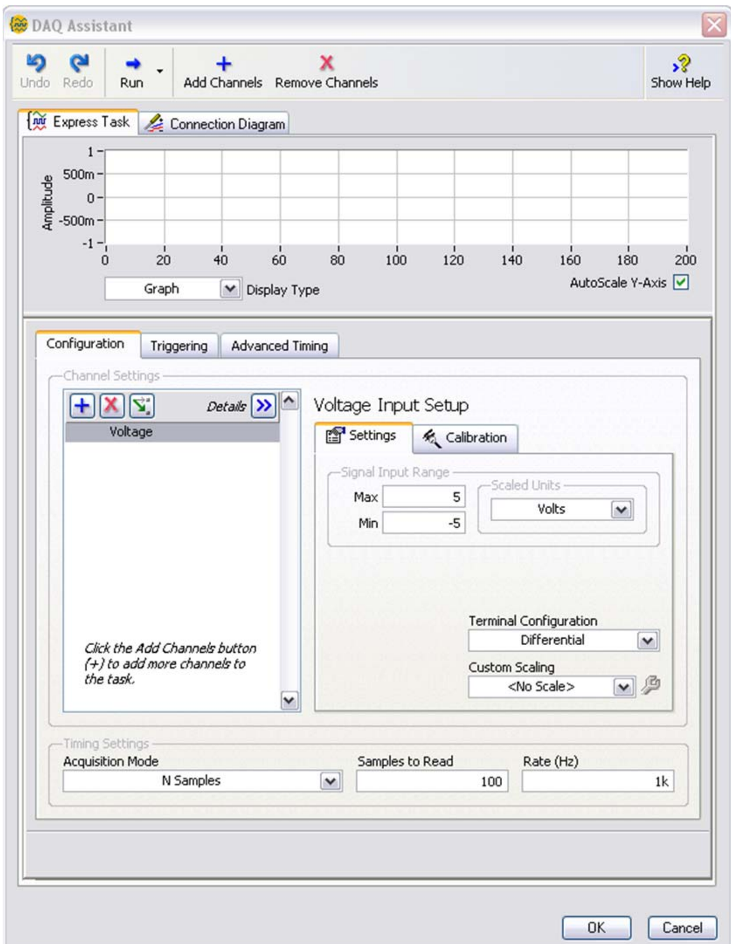
GOAL

Exercise 3-5: Continuous Acquisition and Logging

- What will happen if you add too many processing functions inside the While Loop?

DISCUSSION

G. Triggering – DAQmx Actions and Causes



Action – when a DAQ device does something

- Generating waveform output
- Acquiring data

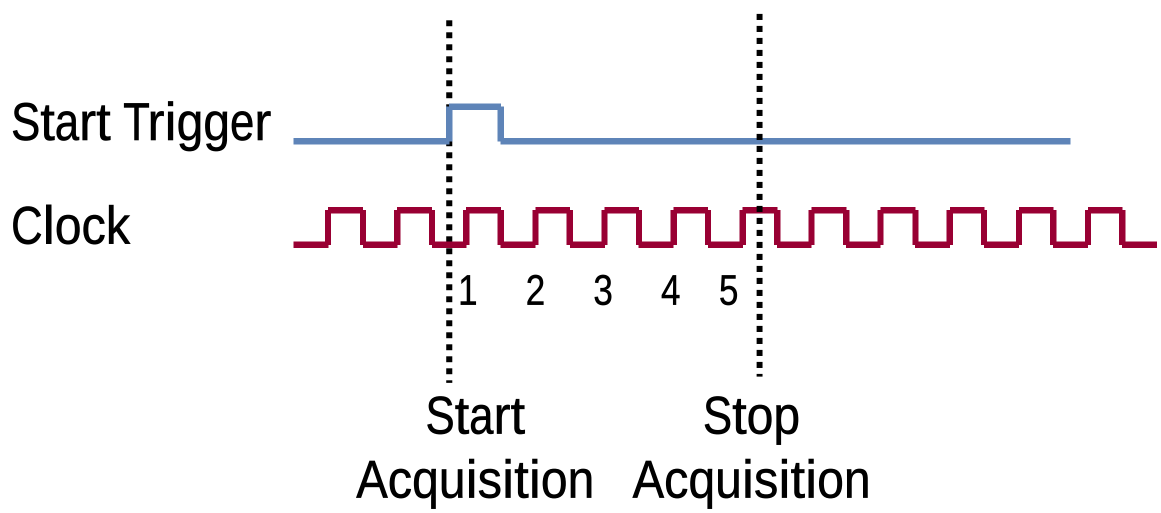
Each action needs a cause or stimulus – a trigger

Trigger is named after the action it causes and the way it was produced

- Action caused: Start, Reference, Pause, Advance (Switch devices)
- Production method: Analog or Digital

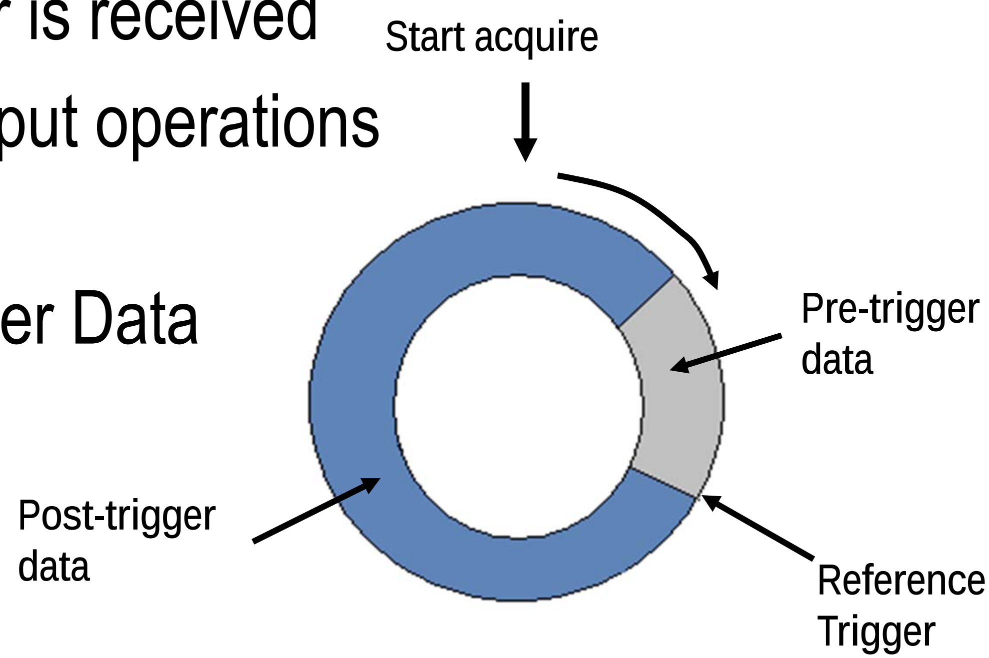
Trigger Actions – Start Triggering

- Valid for input or output operations
- Valid for finite or continuous operations
- Example – Input 5 samples on start trigger:



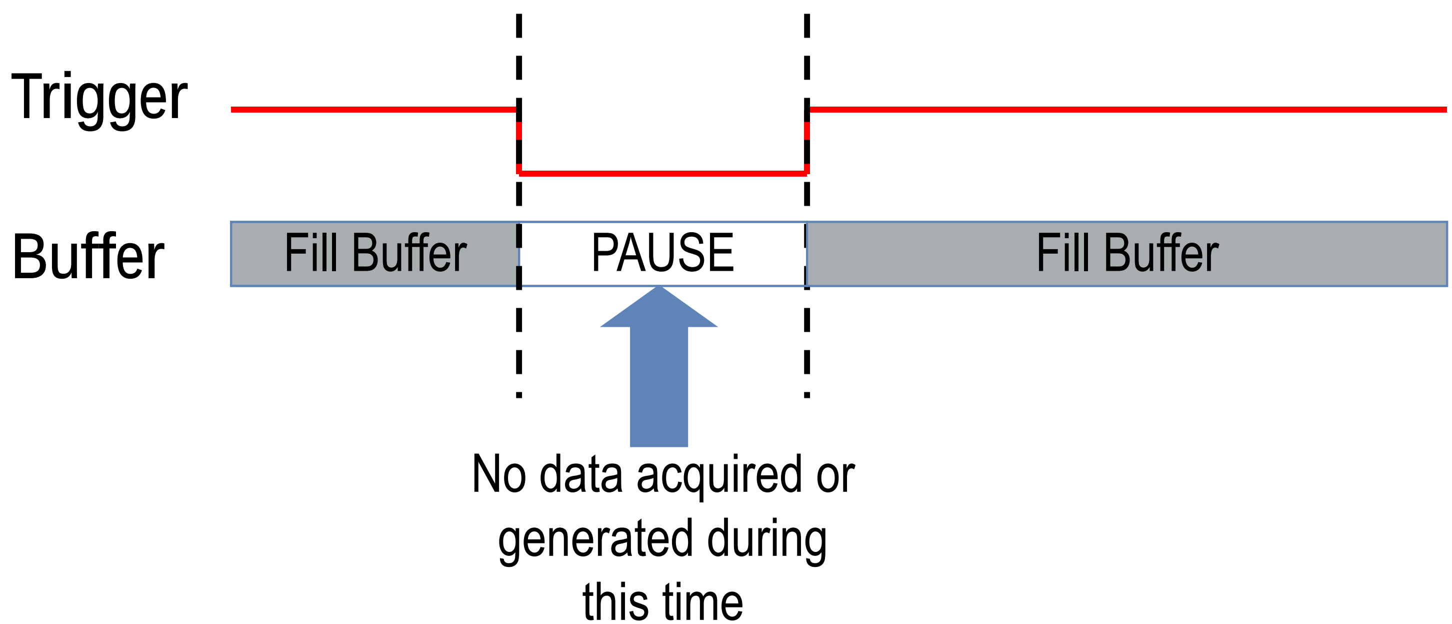
Trigger Actions – Reference Triggering

- Acquisition starts as soon as software is started
- Data in the buffer keeps getting overwritten (first in first out) until the reference trigger is received
- Typically only for finite input operations
- Post-trigger Data =
  Size of Buffer – Pre-trigger Data

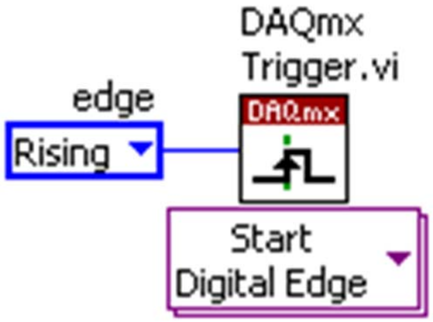


Trigger Actions – Pause Triggering

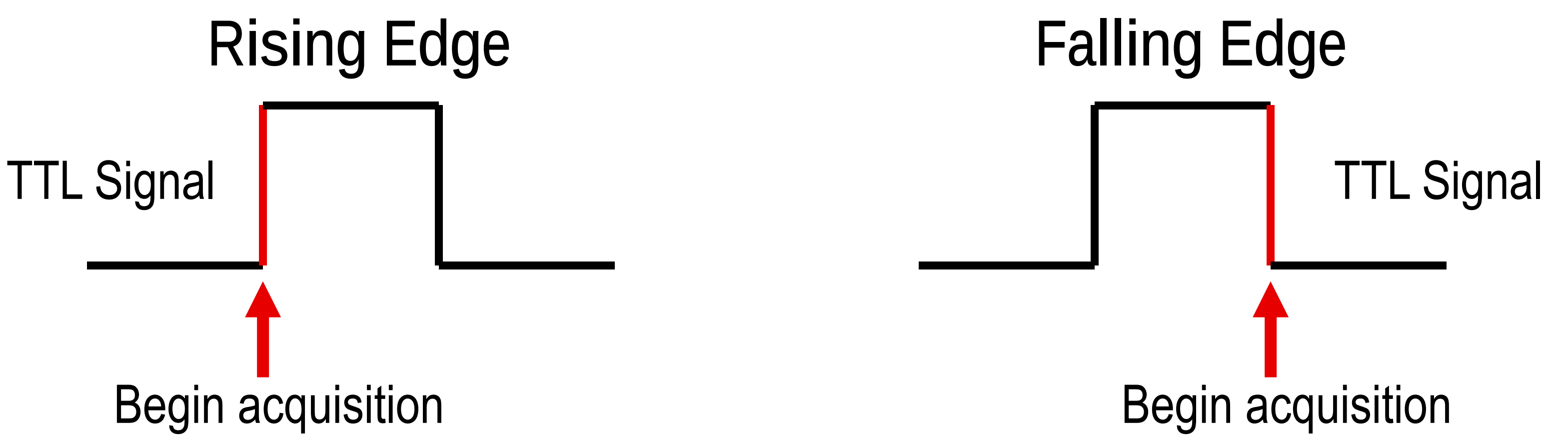
- Allows you to pause an acquisition/generation
- Operation stops when trigger signal is low and resumes when trigger signal is high



Trigger Types – Digital Edge Triggering



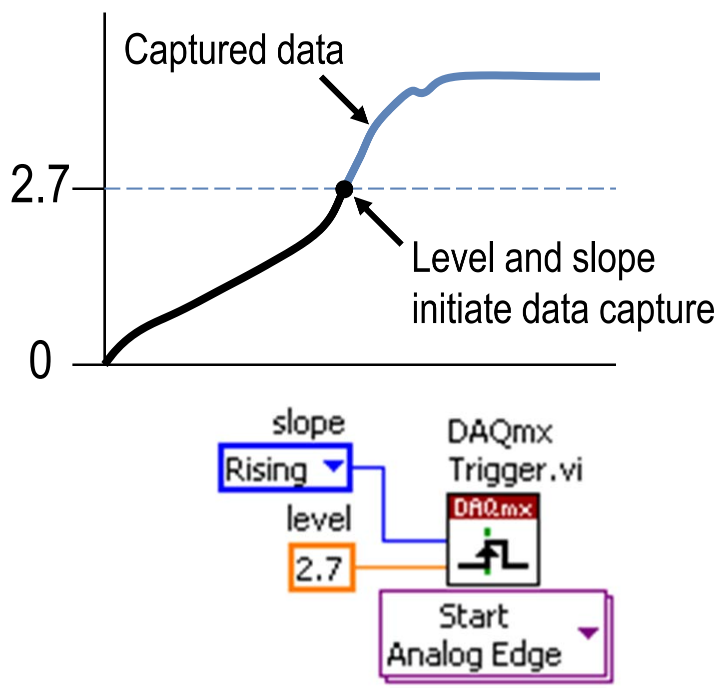
- Accepts TTL/CMOS compatible signals
  - 0 to 0.8V = logic low
  - 2 to 5V = logic high
- Trigger on rising or falling edge of signal



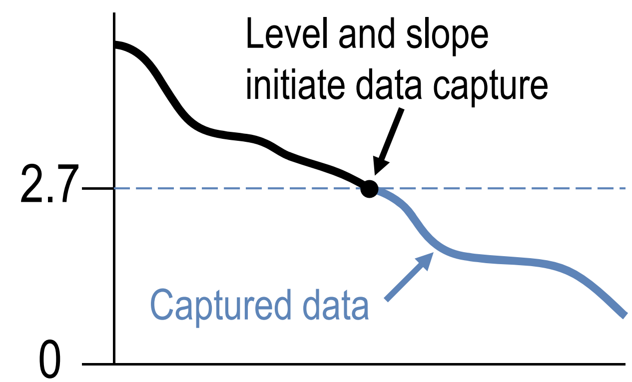
Trigger Types – Analog Edge Triggering

Edge – Trigger off signal level and slope (rising or falling)

Slope = Rising
Level = 2.7



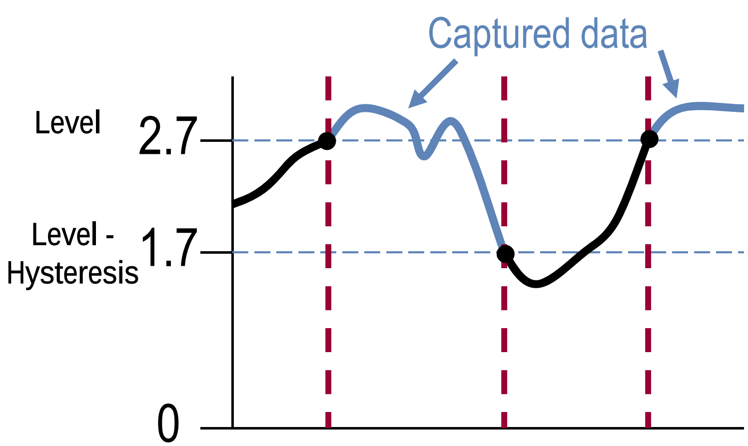
Slope = Falling
Level = 2.7



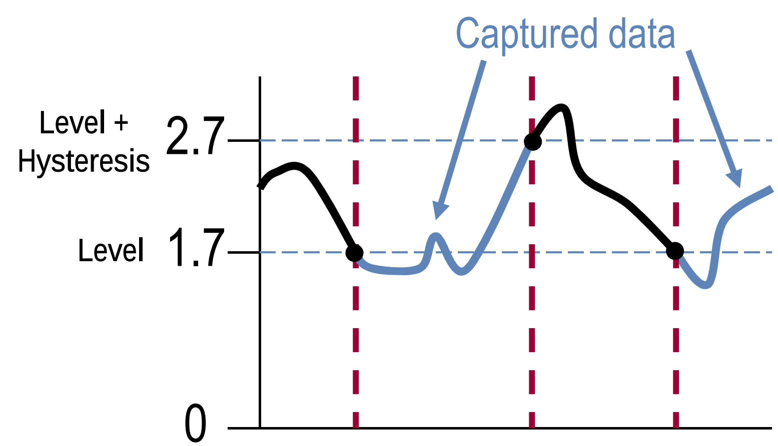
Trigger Types – Analog Edge Triggering

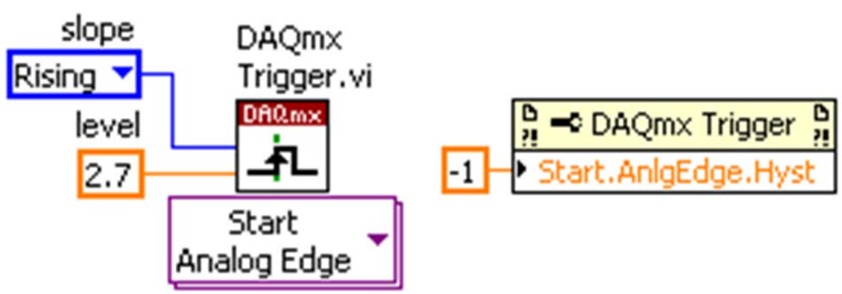
Hysteresis – adds a window above or below the trigger level to reduce false triggering due to noise or jitter

Slope = Rising, Level = 2.7,
Hysteresis = -1



Slope = Falling, Level = 1.7,
Hysteresis = 1





Trigger Types – Analog Triggering Support

Not all DAQ devices support analog triggering

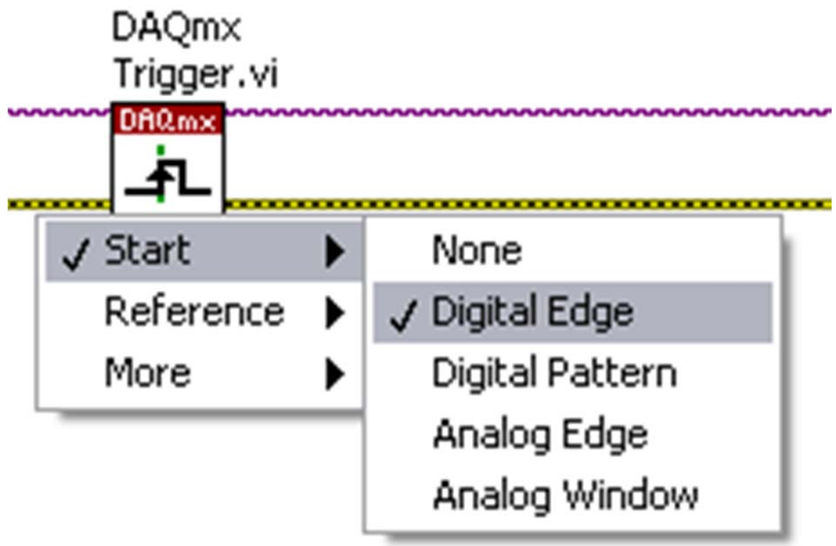
- Most M Series and X Series devices support analog triggering
- Some C Series Modules support analog triggering

Check ni.com to see if your device supports analog triggering

Triggering Analog Input

Begin data acquisition based on:

- Digital Edge (rising or falling)
- Digital Pattern (digital pattern of 0's and 1's)
- Analog Edge (slope and level)
- Analog Window (specify upper and lower window limits)



Exercise 3-6: Triggered Continuous Acquisition

Write a VI to trigger analog input on a digital edge.

GOAL

Exercise 3-6: Triggered Continuous Acquisition

- How would you change the VI if you also needed to acquire 100 samples of pre-trigger data?

DISCUSSION

Summary—Quiz

1. Which of the following grounding modes should you not use with a grounded signal source?
   a) Differential
   b) Referenced single-ended
   c) Non-referenced single-ended

Summary—Quiz Answer

1. Which of the following grounding modes should you not use with a grounded signal source?
   a) Differential
   b) Referenced single-ended
   c) Non-referenced single-ended

Summary—Quiz

2. The Nyquist Theorem helps to determine the sampling rate. What problem does this help with?
   a) Spying
   b) Noise
   c) Aliasing
   d) Isolation

Summary—Quiz Answer

2. The Nyquist Theorem helps to determine the sampling rate. What problem does this help with?
   a) Spying
   b) Noise
   c) Aliasing
   d) Isolation

Summary—Quiz

3. Which of the following operations can the DAQmx Read VI be used for?
   a) Single-point
   b) Multi-sample
   c) Multi-channel
   d) All of the above

Summary—Quiz Answer

3. Which of the following operations can the DAQmx Read VI be used for?

   a) Single-point

   b) Multi-sample

   c) Multi-channel

   d) All of the above

Summary—Quiz

4. Software-timed, single-point reads are good for getting information on the shape of a waveform

   a) True

   b) False

Summary—Quiz Answer

4. Software-timed, single-point reads are good for getting information on the shape of a waveform

   a) True

   b) False

Summary—Quiz

5. Buffered acquisitions require the use of a clock signal.
   a) True
   b) False

Summary—Quiz Answer

5. Buffered acquisitions require the use of a clock signal.
   a) True
   b) False