ELG4139
Data Acquisition System
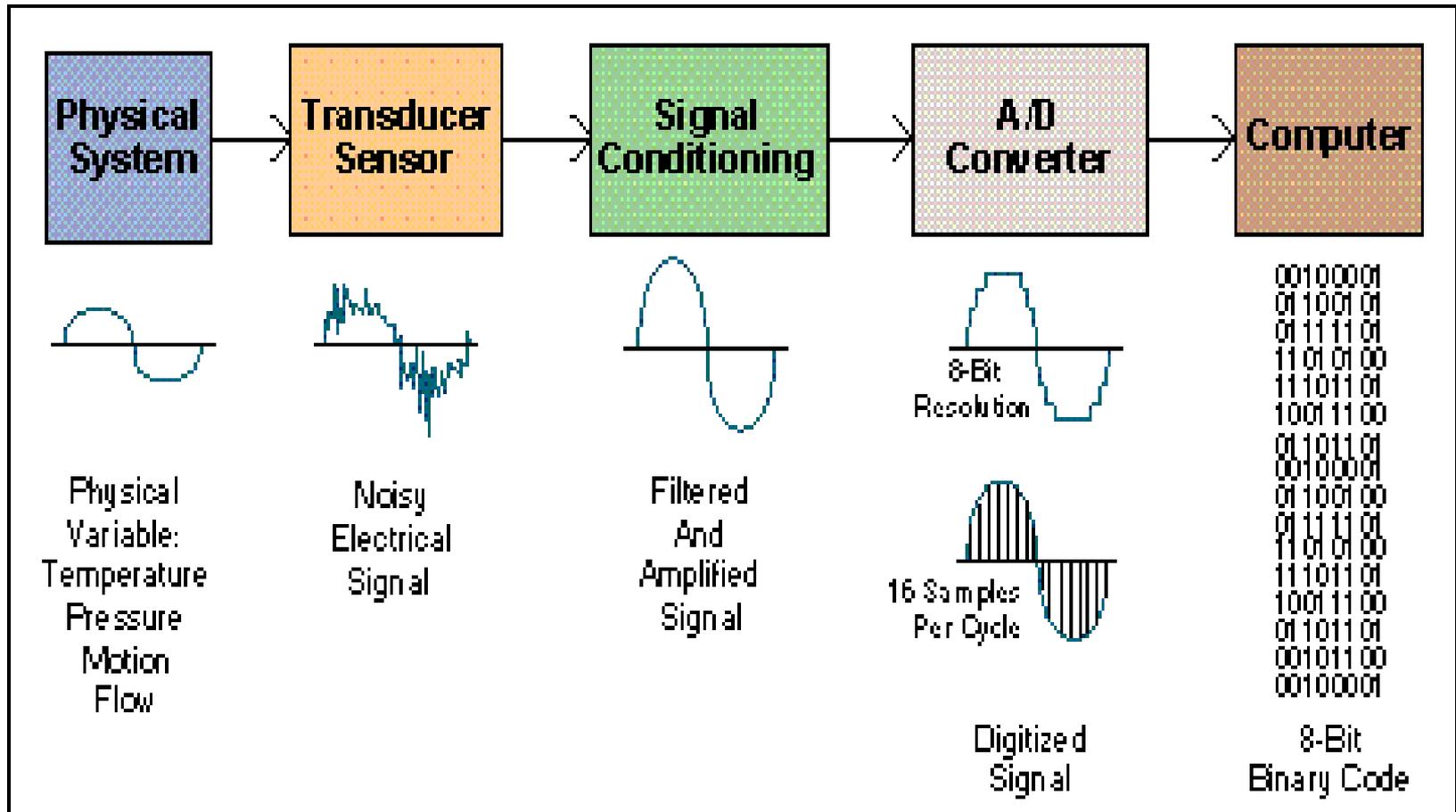
Elements of a Data Acquisition System

Transducer
Generates signal

Filter
Removes unwanted signal components, usually for *anti-aliasing* purposes

Multiplexer
Selects which input channel is connected to its output

Sample and hold
Samples its input signal and holds that voltage as a steady value at its output

ADC
Converts its analog input to a digital output

Voltage reference

Amplify and offset
Amplifies signal and adds DC offset to match ADC input range

Input select

Sample

Start conversion

Output result

Conversion complete

Digital output

CPU control

Data Acquisition Hardware

Analog Signal

Data Acquisition System

Computer

Terminal

Data Acquisition System turns your PC into a Measurement and Automation System

Computer Bus

Designing a DAS: Factors to Consider

- Is it a fixed or a mobile application?
- Type of input/output signal: digital or analog?
- Frequency of input signal ?
- Resolution, range, and gain?
- Continuous operation?
- Compatibility between hardware and software. Are the drivers available?
- Price!
- Functions: A/D, D/A, Digital I/O, signal conditioning (amplification, pre-filtering), timer, trigger, buffer
- Features Like:
  - A/D resolution (Number of bits used)
  - Maximum sampling rate
 - Number of channels
  - Total throughput
  - Aperture time

Analog Inputs (A/D)

- Analog to digital (A/D) conversion changes analog voltage or current levels into digital information. The conversion is necessary to enable the computer to process or store the signals.

- The most significant criteria when selecting A/D hardware are:

  1. Number of input channels
  2. Single-ended or differential input signals
  3. Sampling rate (in samples per second)
  4. Resolution (usually measured in bits of resolution)
  5. Input range (specified in full-scale volts)
  6. Noise and nonlinearity
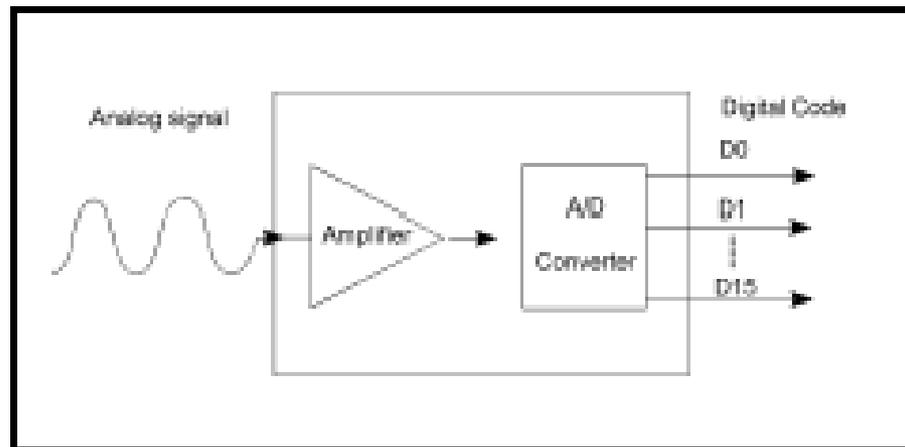
Transducers and Actuators

- A **transducer (sensor)** converts temperature, pressure, level, length, position, etc. into voltage, current, frequency, pulses or other signals.
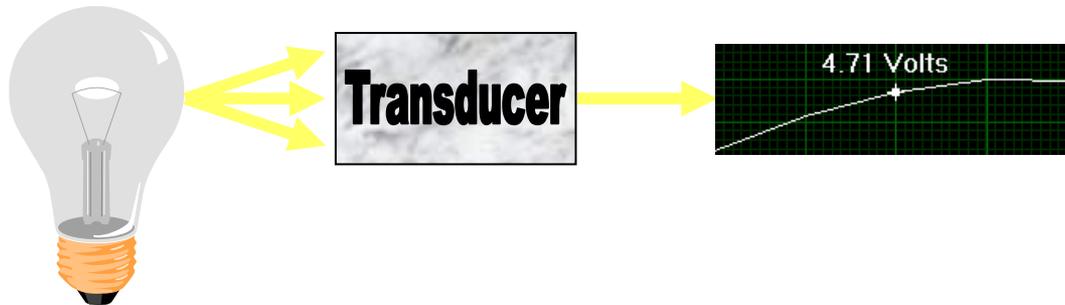
- An **actuator** is a device that activates process control equipment by using pneumatic, hydraulic, or electrical power. For example, a valve actuator opens and closes a valve to control fluid rate.

Types of Sensors

- **Pressure Sensors**
  - Fuel
  - Fluid
  - Air
  - Tire'
  - Blood
  - Altitude, etc.
- **Temperature Sensors**
  - Thermocouples
  - Thermistors, etc.
- **Accelerometers**
  - Acceleration
  - Vibration
  - Mechanical shock, etc.
- **Strain Gages/Load Cells**
  - Weighting of cargo
  - Tension measurement
- **Acoustic Sensors**
  - Avalanche warning
 - Ocean graphic data collection, etc.

Signal Conditioning

Amplification + Filtering + Isolation + Linearization

- Signal conditioning circuits improve the quality of signals generated by transducers (sensors) before they are converted into digital signals by the data-acquisition hardware.

- Examples of signal conditioning are signal scaling, amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection, and so on.

- One of the most common signal conditioning functions is amplification.

- For maximum resolution, the voltage range of the input signals should be approximately equal to the maximum input range of the A/D converter. Amplification expands the range of the transducer signals so that they match the input range of the A/D converter.

Amplification

- Used on low-level signals (for example, thermocouples)

- Maximizes use of Analog-to-Digital Converter (ADC) range and increases accuracy

- Increases Signal to Noise Ratio (SNR)
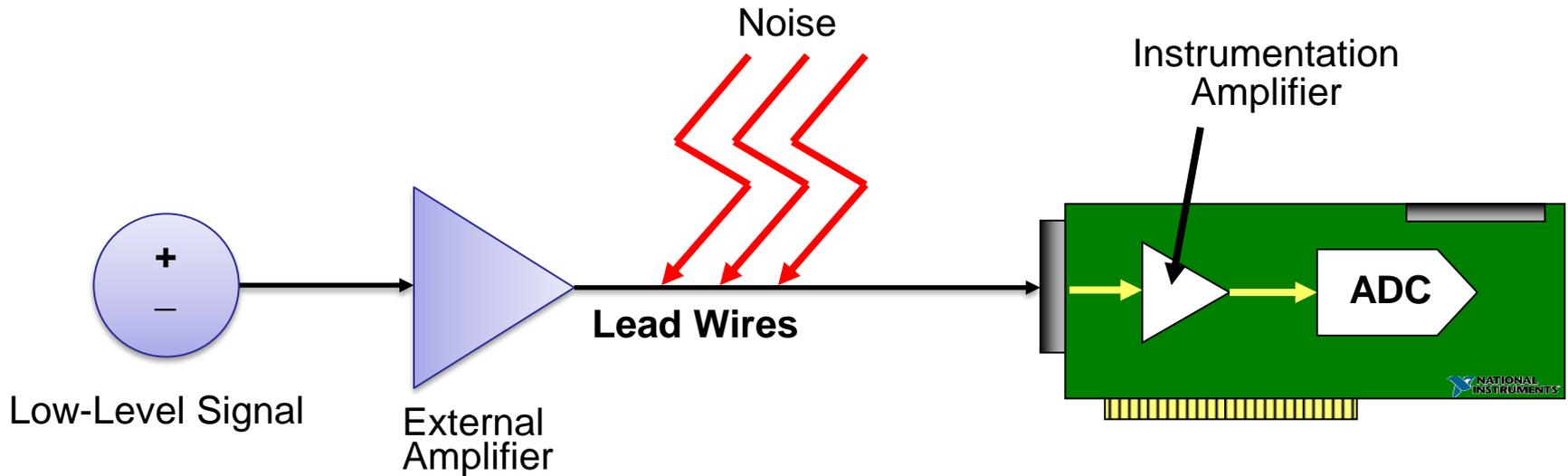
Multiplexing

- **Multiplexing** is a set of techniques that allows the simultaneous transmission of multiple signals across a single data link. Multiplexer combines the incoming lines into one [single stream].

- **Demultiplexer** (DEMUX) separates the stream back into its component transmissions (one to many) and directs them to their corresponding lines.

1 link, 4 channels

M U X

D E M U X
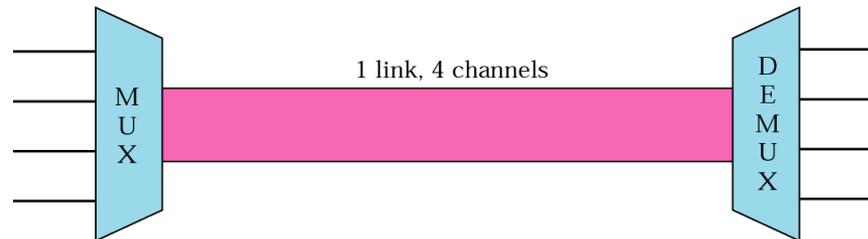
A/D Convertion

- Aliasing.
  - ✓ Acquired signal gets distorted if sampling rate is too small.
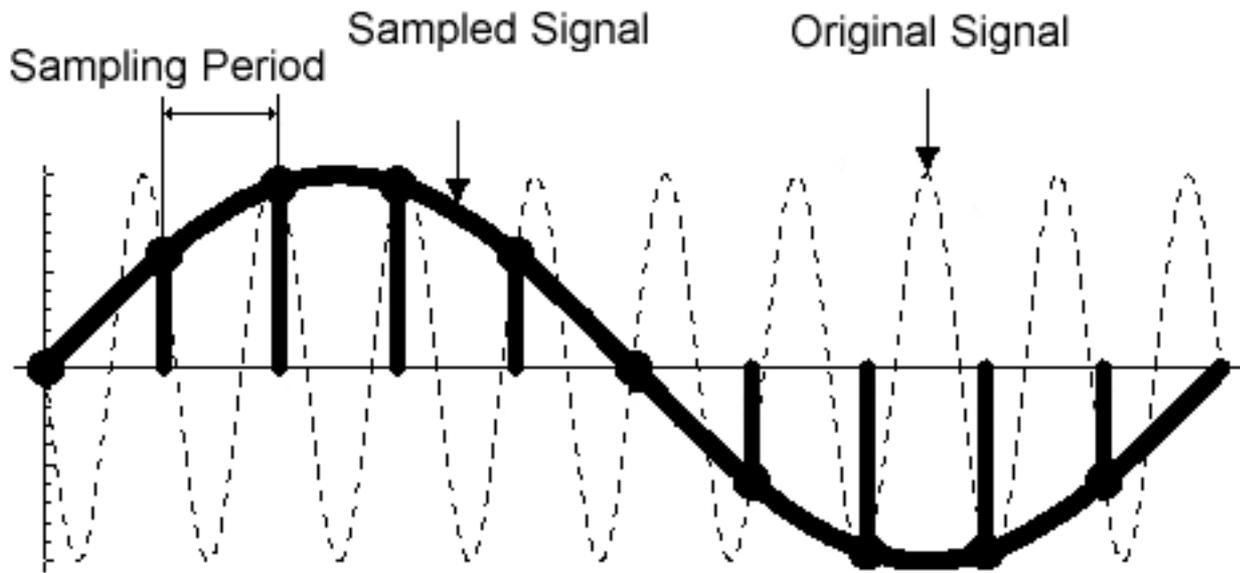
Analog-to-Digital Conversion (ADC)

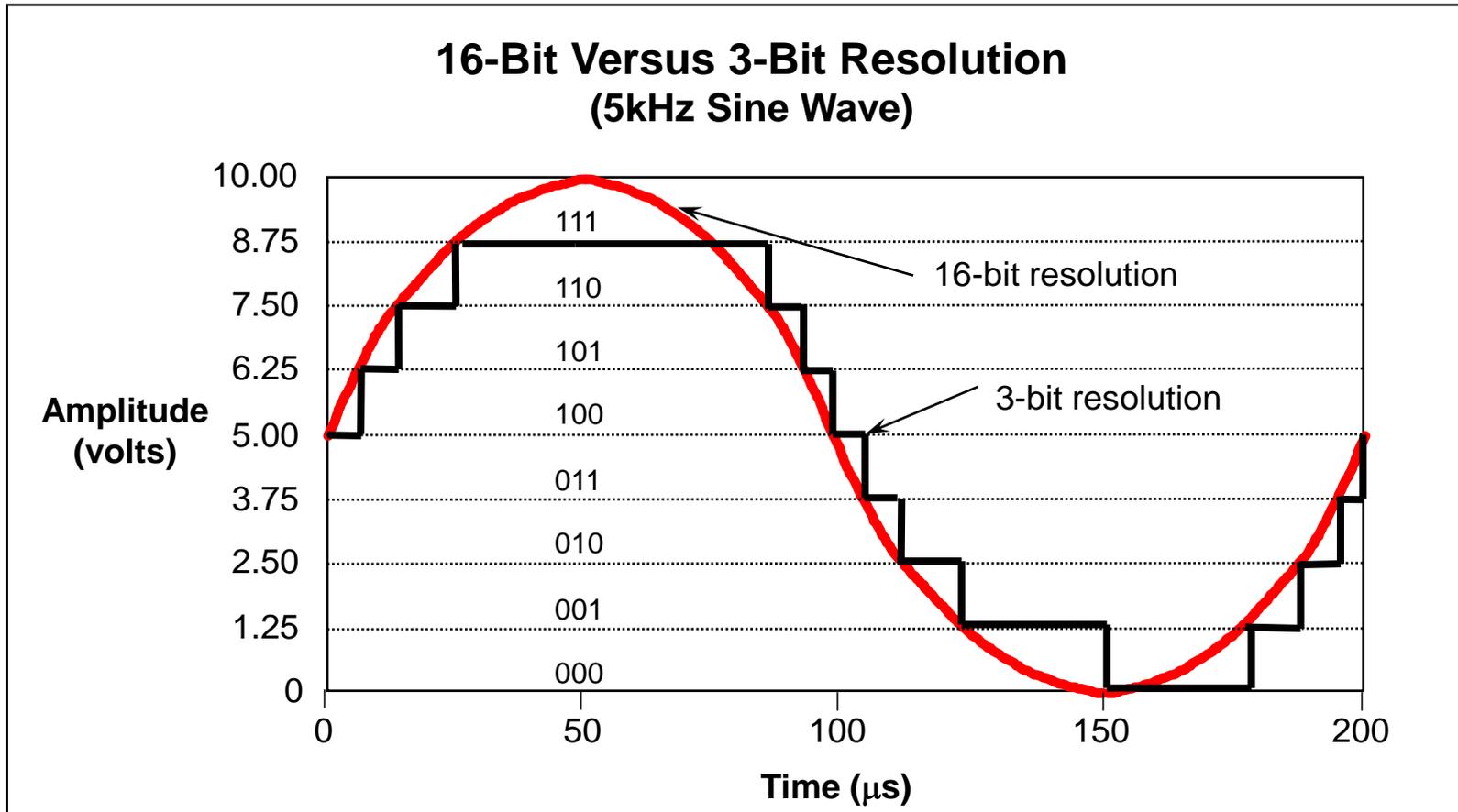To convert analog signals into digital signals

Sample & Hold; Quantization; Resolution; Coding

Quantization: Transformation of a continuous analog input into a set of discrete output state:

- Coding: the assignment of a digital code word or number to each output states
- Number of possible state: $N=2^n$, n is # of bits
- Quantization resolution: $Q=(V_{max}-V_{min})/N$
- Quantization Error.

- **Sampling:** Numerical evaluate the signal at discrete distance in time, $y_k=y(k\Delta t)$
  - Digitized Signal: a sequence of numbers that is an approximation to an analog signal
  - Sampling time/Period: time duration between two consecutive samples, Δt
  - Sampling rate (Hz): $1/\Delta t$
  - Nyquist frequency: $2f_{max}$
  - Sampling theory: $f_s >$ Nyquist Frequency
  - Sample and hold circuit is needed to arrest change in an input while A/D conversion is being performed.

Resolution

– 3-bit resolution can represent 8 voltage levels
– 16-bit resolution can represent 65,536 voltage levels

16-Bit Versus 3-Bit Resolution
(5kHz Sine Wave)

111
110
101
100
011
010
001
000

16-bit resolution
3-bit resolution

Amplitude (volts)

10.00
8.75
7.50
6.25
5.00
3.75
2.50
1.25
0

0   50   100   150   200

Time (μs)

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

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
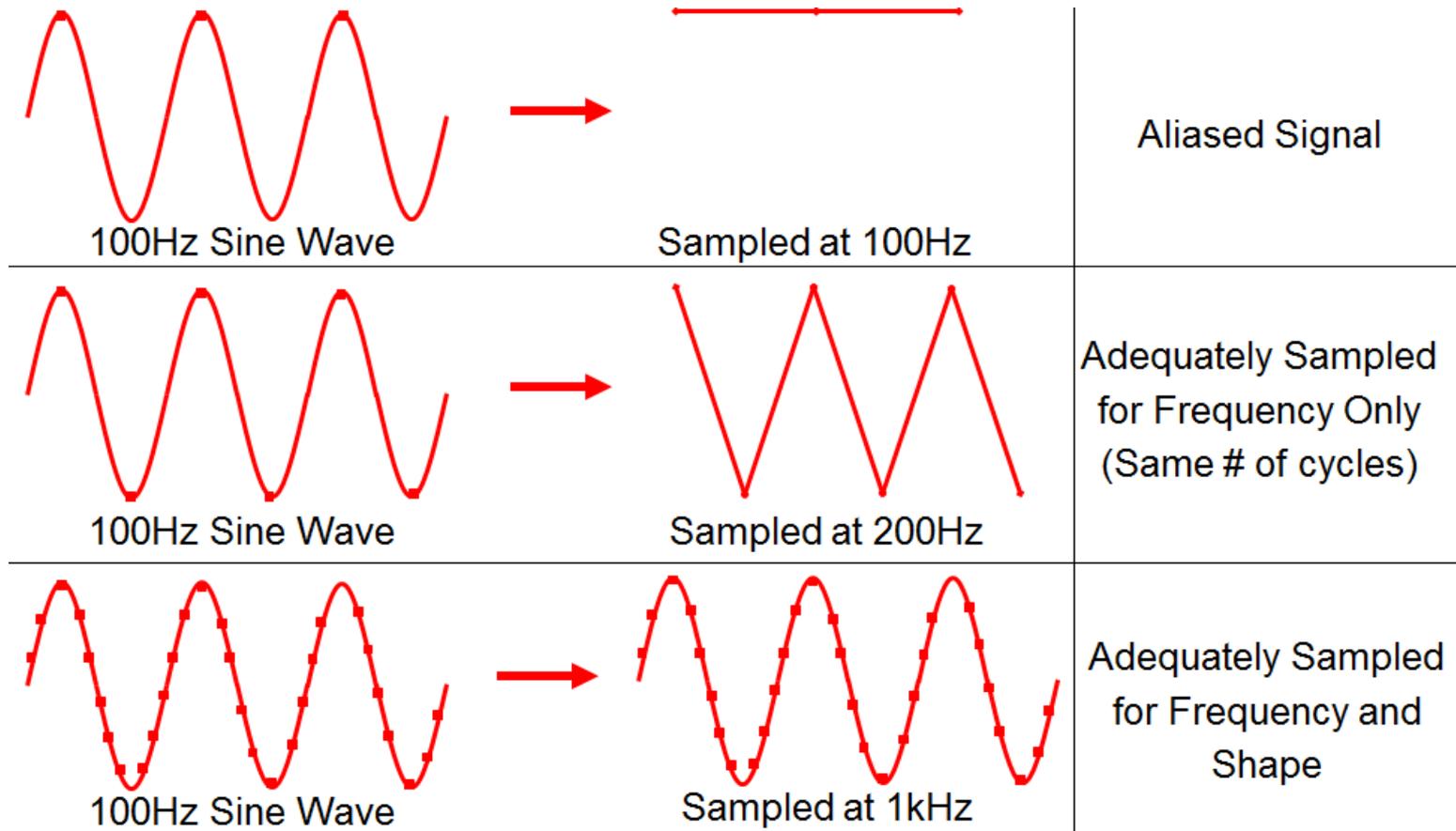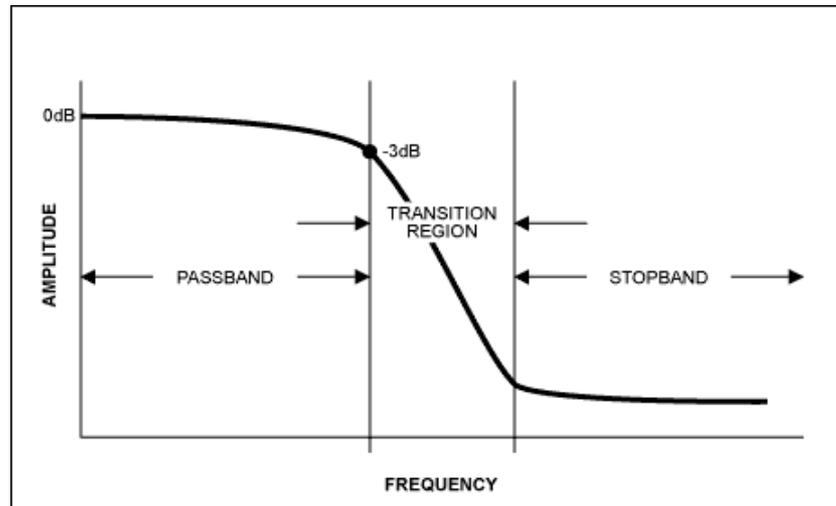
Data Acquisition Software

- It may be the most critical factor in obtaining reliable, high performance operation.

- Transforms the PC and DAQ hardware into a complete DAQ, analysis, and display system.

- Different alternatives:

  - Programmable software.

  - Data acquisition software packages.

- Involves the use of a programming language, such as:

  - C++, visual C++; BASIC, Visual Basic + Add-on tools (such as VisuaLab with VTX); Fortran; Pascal.

- Or does not require programming. Examples includes TestPoint, SnapMaster, LabView, DADISP, DASYLAB, etc.

Anti-aliasing Filter

- A way of avoiding the problem of aliasing is to apply an anti-aliasing filter to the signal, prior to the sampling stage, to remove any frequency components above the "folding" or Nyquist frequency (half the sampling frequency).
- An anti-aliasing filter is a low-pass filter.

ELG4139: Midterm 1
Design of a Data Acquisition System Assuming a Case Study

Draw the block diagram and design each subsystem (Amplifier; Filter; Sample and Hold; ADC; DAC) and set up specifications of other subsystems (Sensor; Multiplexer; Microcontroller; Actuator). Draw the circuit diagram and specify the specification of each subsystem!

Design a microcomputer-based system to sense 4 analog input signals and produce 4 analog outputs. The inputs come from sensors that produce signals with a bandwidth of 1 kHz, but are known to pick up higher-frequency noise. These signals are to be measured to an accuracy of at least 1%. The output signals are to drive actuators with maximum operating bandwidth of 300 Hz, but which are affected by higher-frequency signals. The actuators require signals to an accuracy of at least 1%.

Another Case Study
Design of Myoelectrically Controlled Partial-Hand Prosthesis System
Draw the block diagram and design each subsystem based on the given information.
Draw the circuit diagram of each subsystem!

- **Suppose** you are asked to design myoelectrically controlled partial-hand prosthesis system. The proposed prosthesis consists of three main parts: 1) electromyogram (EMG) signal-processing circuits; 2) the microcontroller and the embedded program; and 3) the prosthesis mechanism.

- The typical amplitude of EMG ranges from 10–1000 μV. The EMG signals generated from a contracting muscle and detected by physiological signal **electrodes** are first sent to the **instrumentation amplifier**, then to **bandpass filter**, and a **precision rectifier circuits**.

- Three **electrodes** are required to acquire the EMG. Two of these **electrodes** (**electrodes** I and II) are attached to the bicepps and serve as the differential inputs to the **instrumentation amplifier**, while the third (ground, GND) is arbitrarily attached to a different location on the arm as a ground reference and is connected to the ground of the system.

- The resulting signals are used as inputs to a **microcontroller** and are converted to digital ones by a **comparator** embedded in the microcontroller. According to the digital signals, the program built in the microcontroller can make precise decisions and then output PWM signals to control the **servomotor** to drive the prosthesis.

- The amplifier is used as a first stage differential amplifier with a gain of 20. This amplifier exhibits **a high common-mode rejection ratio (CMRR) and effectively reduces noise**. This component is also selected for its compactness. Differential inputs allow the direct current (dc) component to be eliminated from the electrodes.

- A bandpass filter with a gain 100, consisting of a high-pass and a low-pass filter, was designed with a low power op amp. The cutoff frequency of the low-pass filter was 500 Hz while that of the high-pass filter was 50 Hz. Meanwhile, the total gain of the combination of the instrument amplifier and the bandpass filter is 3000. This gain is high enough to amplify the obtained EMG signals to a level suitable for processing during the subsequent precision rectifier stage. After the signal passes through the bandpass filter, the precision rectifier reshapes the pulses that can be fed successively into the comparator embedded in the microcontroller.

- To save energy and for convenience, a 9-V is used to power the entire system. However the available voltage is 12-V. Moreover, a resistor divider is utilized to generate 4.5 and 4.5 V dc; both can serve as dc sources for op amps in a signal-processing circuit. The 4.5-V source also supplies the microprocessor and the servomotor.

- The power consumption and compactness must be considered so that selecting a motor is challenging. A servomotor commonly used for control applications consumes much current and is oversized and expensive. Because a stepping motor loses step under some conditions, it unsuitable in this application. Following a survey of products, an R/C servomotor is adopted herein to drive the prosthesis mechanism. The R/C servomotor, equipped with a position feedback control circuit and a decelerating gearbox assembly, provides a simple control mechanism. The R/C servomotor is controlled by a PWM signal, which can drive the motor to a desired position according to the width of the pulse. In this design, the Mitsubishi M51660L control chip is adopted as an R/C servomotor controller.