Faculty of Engineering

MEP 382: Design of Applied Measurement Systems

Lecture 1:
Introduction

Disclaimer

Part of this course is based on content from a course taught by John Muratore from NASA

Course Objective

- Enable you to specify, build and use a set of basic instrumentation and computer based data acquisition systems to acquire data from a laboratory experiment, engineering field site or test vehicle and process it using standard algorithms.

- Use LabVIEW and data acquisition devices to construct examples of data acquisition and processing.

- Elements associated with DC and AC circuits, operational amplifiers, computer programming, instrumentation, statistics and digital representation of numbers will be covered.

- By providing concrete examples of working with signals and systems it is the objective of this course to give you a practical feel for these subjects which will encourage you to pursue fundamental principles work in more advanced courses which emphasize their mathematical basis

Teaching Staff

- **Instructors:**
  – Dr. Maged Ghoneima
  – Dr. Mostafa Soliman
- **Assistants:**
  – Eng. Ahmed Allam
  – Eng. Yehia Zakaria

Course Outline

- Lecture 1 – Introduction
- Lecture 2 – Critical Instrumentation Definitions
- Lecture 3 – Revision: DC & AC Circuit Basics
- Lecture 4 – Revision: Digital Logic, Computer, Signals and Systems Basics
- Lecture 5 – Signal Conditioning
- Lecture 6 – D/A & A/D Conversion
- **Lecture 7 – Sensor Systems**
- **Lecture 8 – Errors and calibration**
- **Lecture 9 – Transduction mechanisms (1)**
- **Lecture 10 – Transduction mechanisms (2)**

[Midterm & Project Release]

- Lecture 11 – LabVIEW and Data Acquisition
- Lecture 12 – Digital I/O and counters/timers
- Lecture 13 – Instrument and Communications Standards
- **Lecture 14 – MEMS Introduction**
- **Lecture 15 – Microfabrication processes**
- **Lecture 16 – MEMS technologies**
- **Lecture 17 – MEMS-based sensors (1)**
- **Lecture 18 – MEMS-based sensors (2)**

Interaction

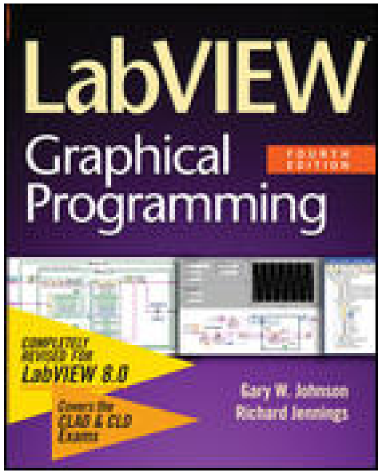
- I prefer dialogue in the class
- I like lots of questions
- If the questions lead us off track, we'll put them off until after class
- If I don't know, I'll tell you
- If it's relevant one of us will get the action to get the answer and report back
- Waiting to ask a question at the end is NOT a good strategy
  - May run short at the end
  - Learning best happens at the point when all of our minds are engaged on a topic
- "Teaching is an act of vulnerability" – I don't know the answers to all of your possible questions, but together we will try to find them

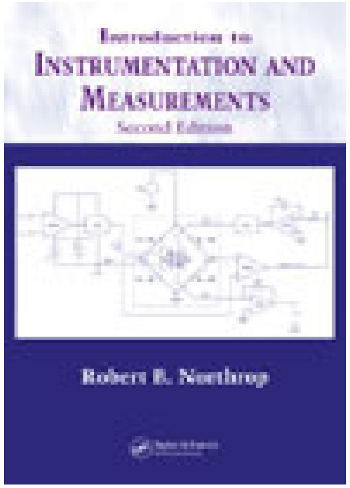
Course Characteristics

- This is not
  - A circuit design course
  - A course to derive underlying mathematics
  - A course that teaches about one product
  - A course about tinkering
- This is a course intended
  - To introduce you to important concepts in a hands-on environment
  - To inspire a curiosity about why things work the way they do
  - To give you tools that you can use in later design courses
  - To help you develop your thinking as an engineer

Course Texts and Software

- Texts:
  - LabVIEW: Graphical Programing (4th Edition) by Gary W. Johnson
  - Instrumentation and Measurement by Northrop
  - Class Notes
- Free Student Edition of LabVIEW can be downloaded from https://www.ni.com/labviewse/





Grading

- 5% - Attendance & Class Contribution
- 5% - Quizzes
- 5% - Labs
- 10% - Midterm Exam
- 10% - Project
- 70% - Final Exam

Philosophical Points

- **What is the difference between a tinkerer and an engineer ?**
  After all, both types of people can successfully make things work

- **My answer:**
  An engineer is one who uses science and mathematics to predict what their creations will do, who measures their performance and who analyzes results to determine their adequacy and to improve their performance

Philosophical Points

- In this course, we are working to teach you to be engineers, therefore we will focus on:
  - Analytical prediction
  - Measurement
  - Analysis

- Being an engineer also involves
  - Being systematic in our thinking processes
  - Logging results and observations

First Definitions

- **Measurement**:
  The quantitative determination of a physical characteristic. In practice, *measurement* is the conversion of a physical quantity or observation to a domain where a human being or computer can determine the value.
- **Instrumentation**:
  devices for converting a physical quantity to a quantity observable by a human or machine (computer). For example, a mercury thermometer converts temperature to a column length that can be seen by the human eye.
- **Data Acquisition:**
  Gathering information from measurement sources, such as sensors and transducers.
- **Sensor :**
  device that responds to a physical stimulus (heat, light, sound, pressure, motion, flow, and so on), and produces a corresponding electrical signal.

Source: www.ni.com – Measurement Encyclopedia

Transducers and Sensors

- As a practical matter, the terms sensors and transducer are used interchangeably in modern usage
- But technically, “a transducer is a device that converts a signal from one physical form to a corresponding signal that has a different physical form. Therefore it is an energy converter”. (from “Sensors and Signal Conditioning” by Pallas-Areny and Webster)

Actuators

- The term actuator is preferred when an electrical signal is converted to mechanical action
- An actuator is defined by NI’s Measurement Encyclopedia as an electromechanical device that physically moves an object.
- Actuators are often classified by the power source they use such as hydraulic or pneumatic as well as electrical
  - Control signals that cause actuation can be mechanical as well as electrical

Sensor Types

Table 18-1. Phenomena and Transducers

Phenomena	Transducer
Temperature	Thermocouples Resistance temperature detectors (RTDs) Thermistors Integrated circuit sensor
Light	Vacuum tube photosensors Photoconductive cells
Sound	Microphone
Force and pressure	Strain gauges Piezoelectric transducers Load cells

Table 18-1. Phenomena and Transducers (Continued)

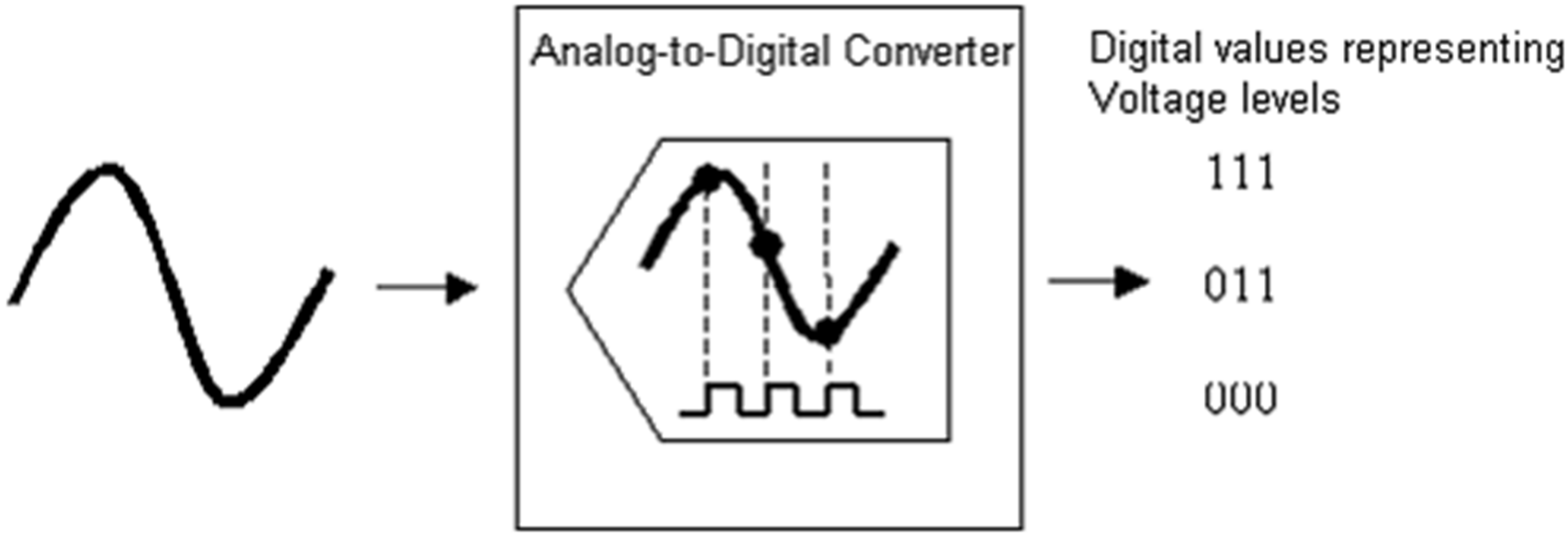
Phenomena	Transducer
Position (displacement)	Potentiometers Linear voltage differential transformer (LVDT) Optical encoder
Fluid flow	Head meters Rotational flowmeters Ultrasonic flowmeters
pH	pH electrodes

Analog vs. Digital

- **Definition of Analog**

  A signal, process or quantity whose amplitude can have a continuous range of values (1V, 1.1V, 1.01V, 1.001V, 1.0001V, 1.00001V etc…) and is continuous in time
- **Definition of an Analog Sensor**
  A sensing device that converts an analog physical quantity (such as temperature or strain) to a proportional analog electrical signal (such as current, charge, or voltage).
- **Definition of Digital**
  An electronic technology where a signal only has two states: off and on, most often called zero and one. In contrast, analog refers to a signal that can have a continuous range of values.
  More general definition: A signal, process or quantity where amplitude is mapped into a series of discrete values and values are only taken at discrete times

Source: www.ni.com – Measurement Encyclopedia



Analog Signal
any value continuously within the range, continuous over time

Diagram From: www.ni.com

Digital Signal
Maps to one of eight discrete values at only has those values at discrete times that it was sampled and converted

Resolution of Analog and Digital Measurements

- **Definition of Resolution**
  Resolution is defined the smallest unit of the Quantity Under Measurement (QUM) that can be detected (Northrop)
- An analog process is theoretically capable of infinite resolution
  - Measuring distance with a ruler is an analog process
    - With bigger and bigger magnification, you can discern smaller and smaller differences
  - Measuring distance with a digital laser ranger has fixed resolution
    - Smallest resolution is fixed. Can’t measure smaller distance between objects no matter how hard you try
- This doesn’t make one type of measurement automatically superior to the other, it is just different
  - A ruler with a human eye could only be good to a .1 inch, but a digital ranger might have a resolution of .0001 inch

Why has digital revolutionized electronics?

- Although analog electronics have the capacity for greater resolution, their components have variability which makes them hard to use and produce in mass quantities.
- High fidelity electronics require high accuracy and precision in analog components and significant design for temperature insensitivity
- Digital electronics are easy to mass produce in a design that gives repeatable and high quality performance
- During this course we are going to show you how a small number of discrete levels of measurement can produce high fidelity signals

End to End Data Acquisition (DAQ)

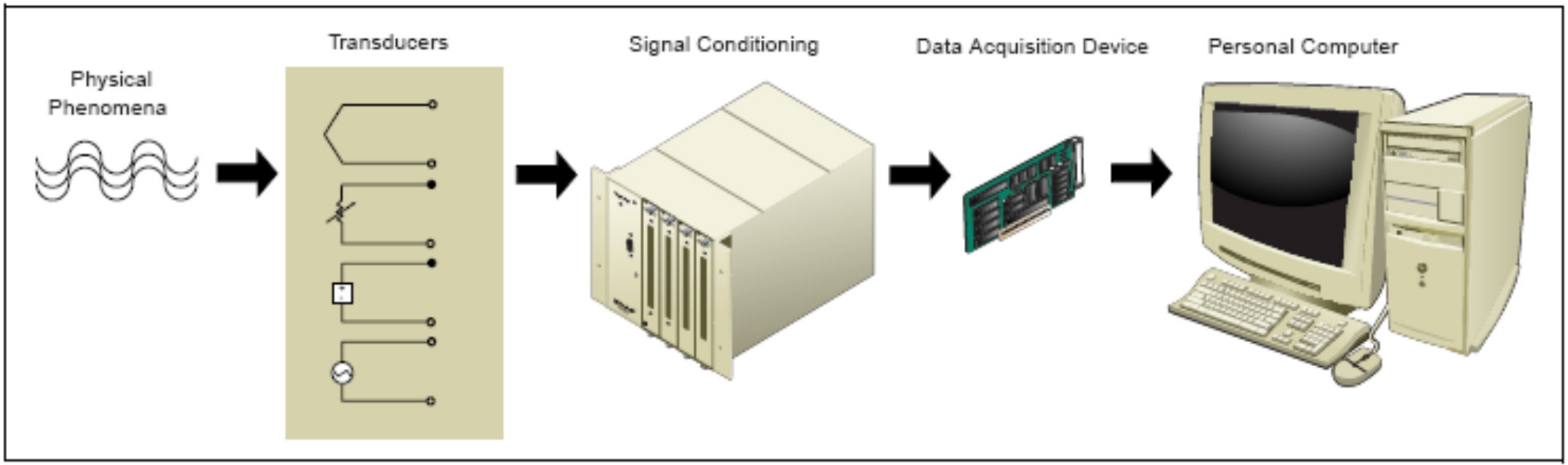
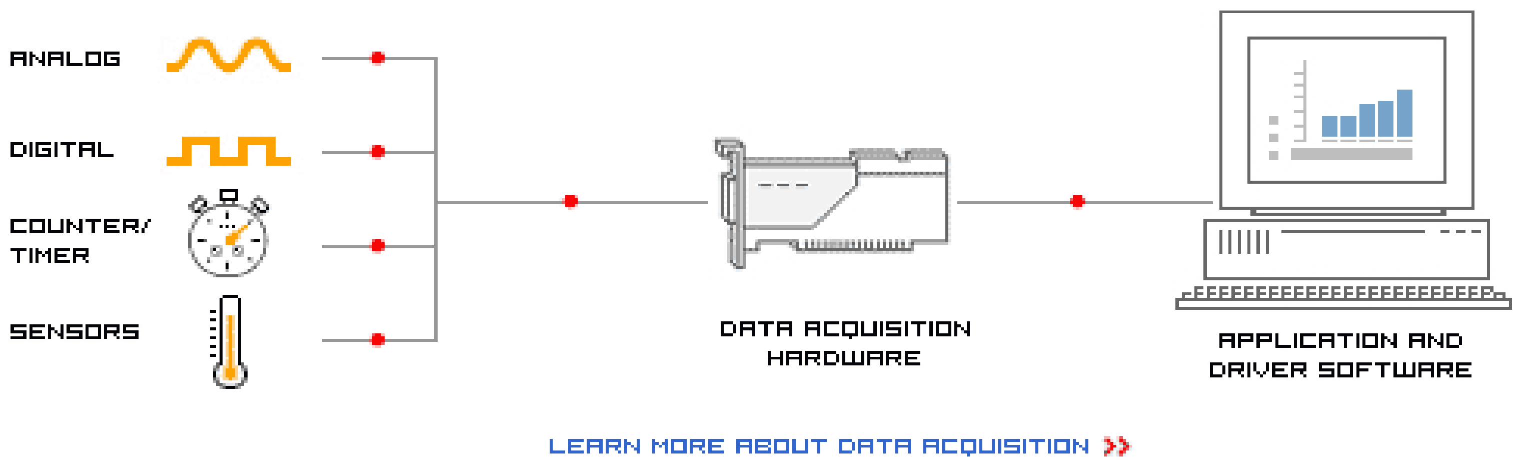


Figure 1. Signal conditioning is an important component of a PC-based DAQ system.



Graphics from www.ni.com DAQ Fundamentals

Elements of an End to End Data Acquisition System

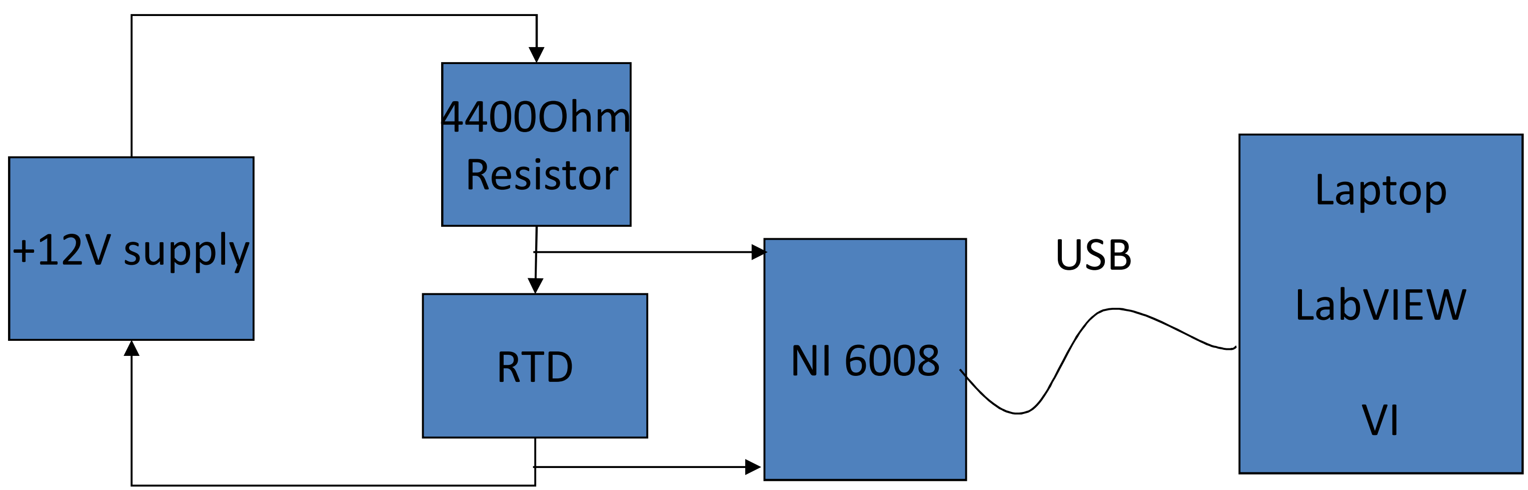
- **Transducer/Sensor**
  - May generate their own electrical signal (thermocouple or piezoelectric) or require external excitation (power)
  - Converts one physical Quantity Under Measurement (QUM) into another
  - Typical output is in volts to microvolts
- **Signal Conditioning**
  - Provides external excitation
  - Completes the circuit (bridges)
  - Linearizes
  - Filters (typically low pass filter which only allows low frequency signals through)
  - Amplifies
  - Isolates one part of a system electrically from other parts of the system
  - Typical output is in volts

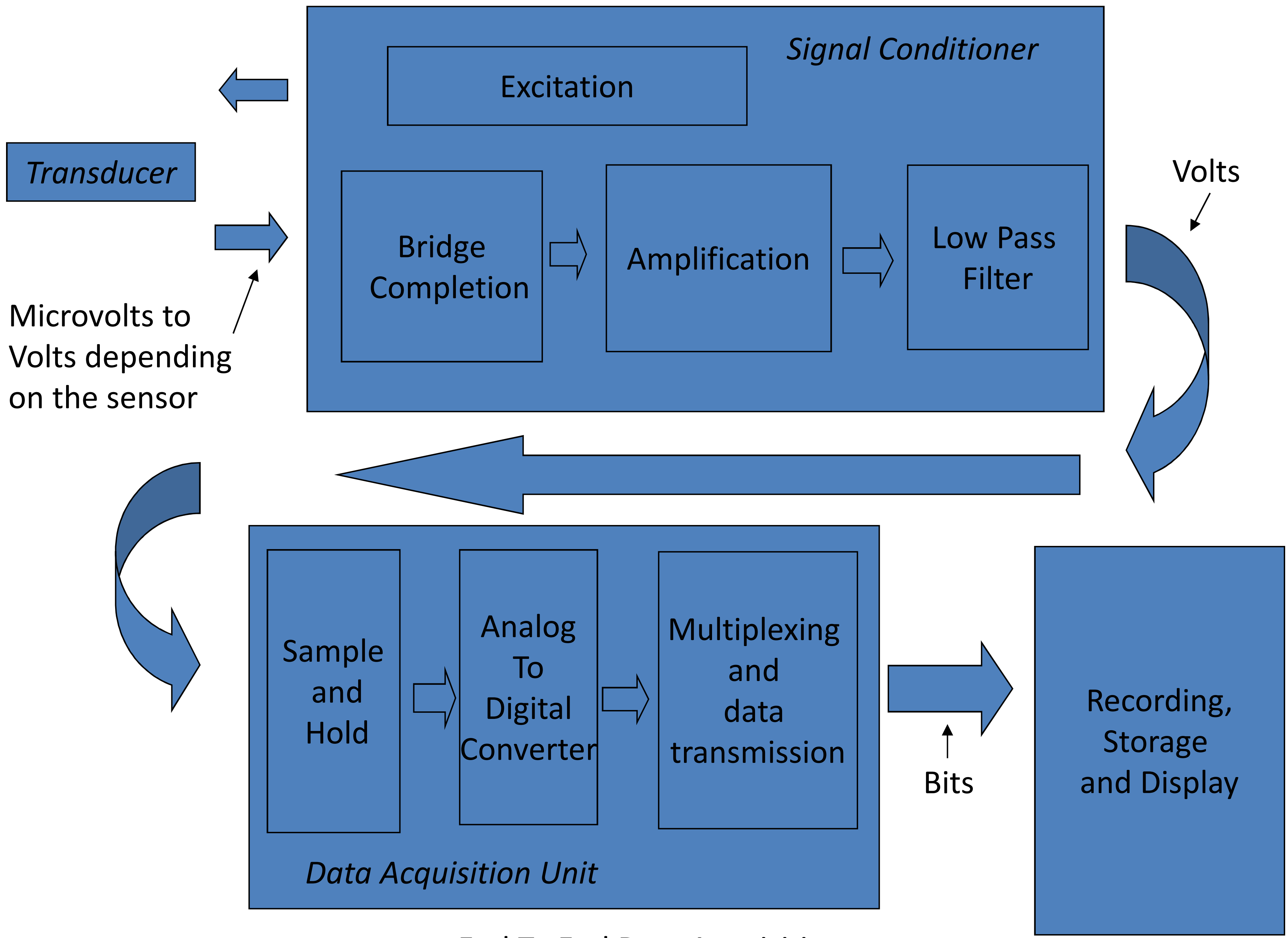
Elements of an End to End Data Acquisition System (Continued)

- **Data Acquisition Unit (DAU)**
  - Samples and holds
  - Digitizes
  - Multiplexes (combines with other measurements)
  - Converts for transmission
  - Transmits
  - Typical output is in binary digits (bits)
- **Recording, Storage and Display**

Example Temperature Measurement

- Transducer/Sensor is Platinum Resistance Temperature Detector (RTD)
- Signal Conditioning is power supply for excitation (power) and resistor to complete the circuit
- Data Acquisition Unit is the NI 6008
- It communicates over a Universal Serial Bus (USB) to the laptop computer
- The laptop Computer is running a LabVIEW Virtual Instrument (VI)
- *Example is RTD Acq One Sample w loop and waveform chart.vi*

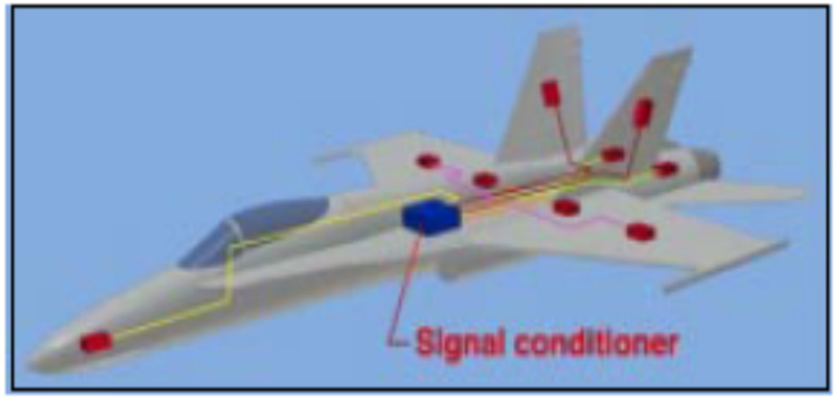




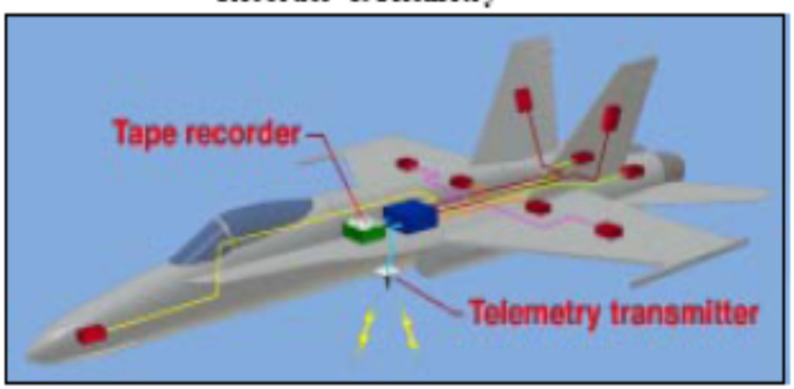
End To End Data Acquisition

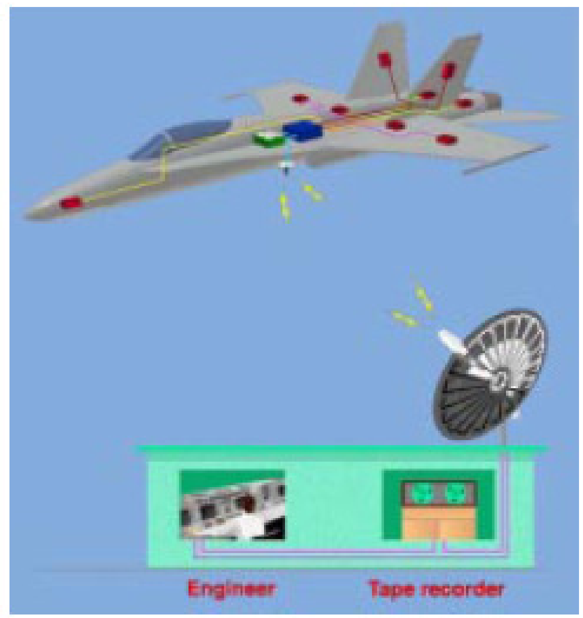
Aircraft Flight Test Data System

Sensors (Transducers)



Wiring To Signal Conditioning Unit

Recorder &Telemetry




Ground Station and Control Room

From "Introduction To Flight Testing by NASA DFRC

Large Ground Test Instrumentation System

Signal
Conditioning
And Data
Acquisition
Units

Wiring
to sensors

This is the wiring, signal conditioning and data acquisition units for an F18 Aircraft Static Fatigue Test System

“and this console is only one out of five total”

- Phil Ellerbrock, Boeing Intellibus Team

From “plug and Play Sensors Forum by Mihir Ravel, National Instruments