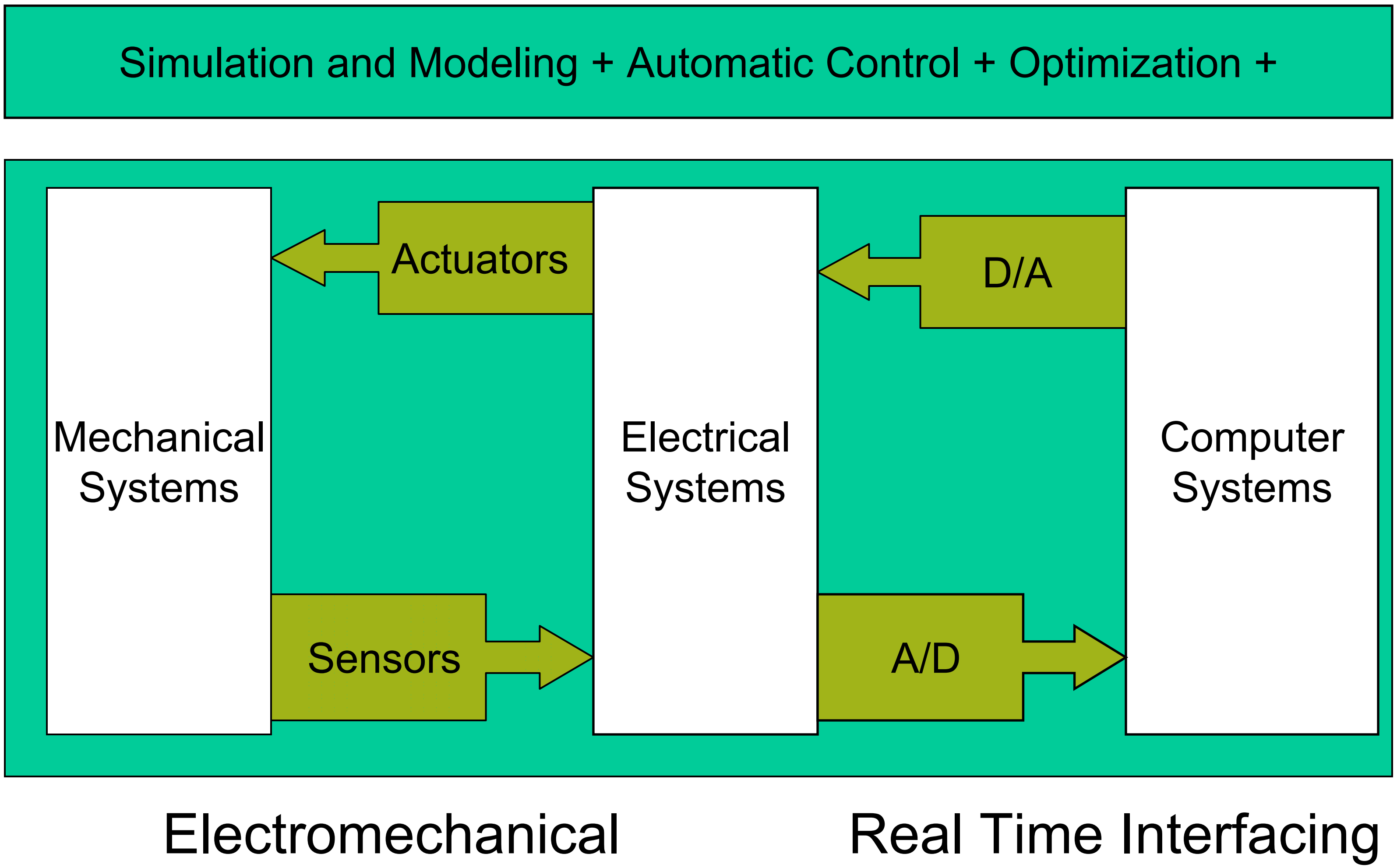
Electronic Instrumentation and Measurements

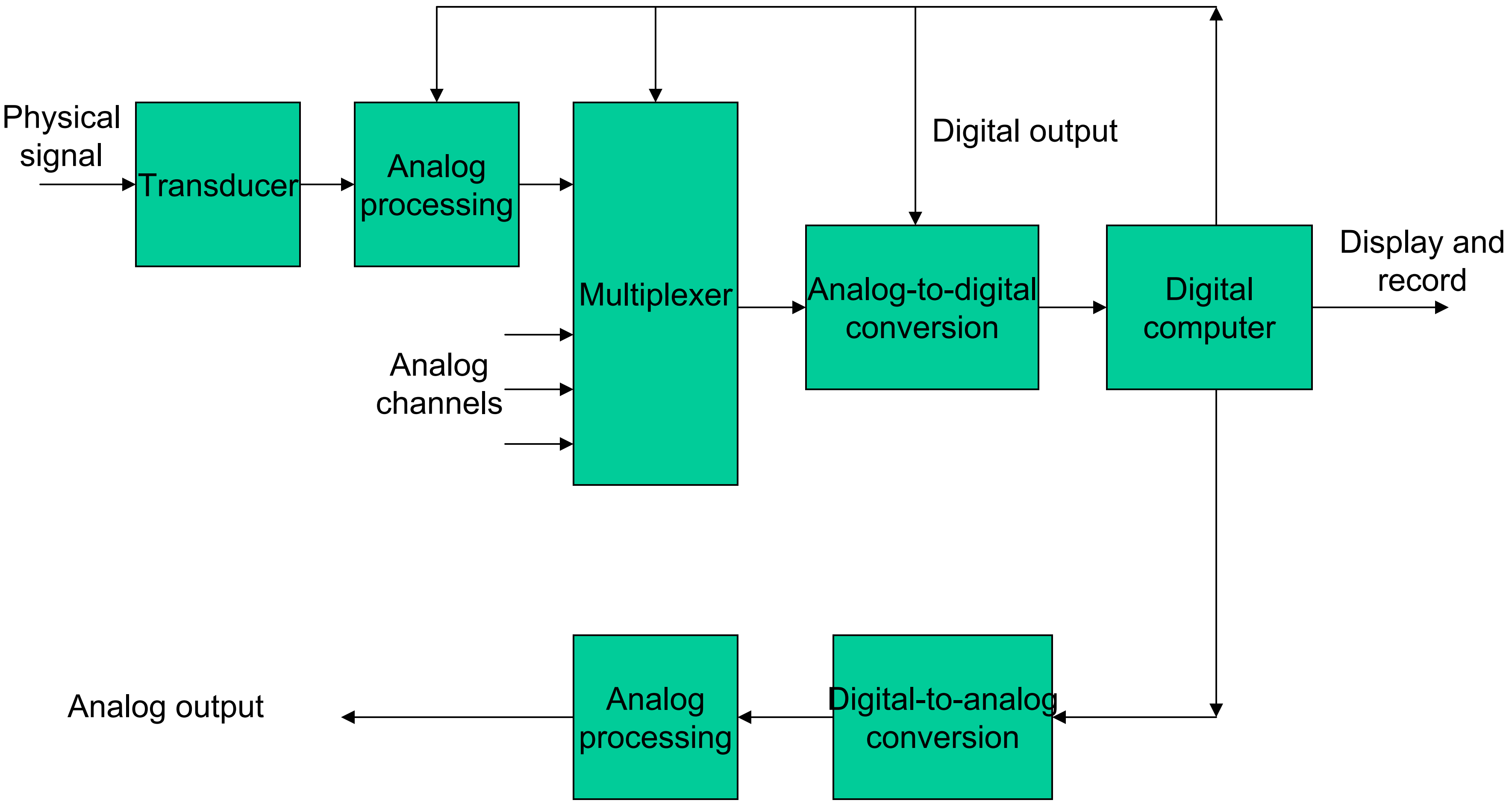
A fundamental part of many electromechanical systems is a measurement system that composed of four basic parts:

- Sensors
- Signal Conditioning
- Analog-to-Digital-Conversion
- Digital Data Transmission

Mechatronics Main Elements



Instrumentation System



Instrumentation System

- **Transducer:** Also called sensor. The transducer produces an electrical output (most of the times analog but can be digital) indicative of some physical measured such as pressure, temperature, or angular position. Many transducers employ bridge circuits (this include a resistor whose resistance changes as a function of the measured signal) or potentiometers. We have studied that in ELG2331.

- **Analog processing:** Amplification and filtering are normally required to prepare the signal for conversion to digital form. These two processes are discussed in Chapter 8.

- **Multiplexer:** Several analog channels are processed sequentially through a multiplexer, which is a digitally controlled switch. The multiplexer accepts parallel inputs from several channels and provides one analog output at a time for conversion to digital form. Multiplexers are discussed in in Section 13.5 (p. 651 of the textbook).

- **Analog-to-digital conversion:** The A/D converts the information from analog to digital form. Often, the time variations of the analog signal must be arrested with a sample-and-hold circuit while A/D conversion is taking place.

- **Digital computer:** This is the brain of the entire operation. This could be a microprocessor dedicated to the instrumentation system or it might be a general-purpose computer that is structured to perform the required data acquisition function simultaneously with other activities. For example a PC can be adapted to accept analog and digital data inputs, and standard programs are available to supervise the data gathering activity.

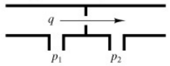
- **Digital-to-analog (D/A) conversion:** Often, the computer must provide outputs in analog form. If, for example, the data monitor were part of the control system, the computer might furnish analog signals as feedback to the controller of the process affecting the physical measurements.

- **Processing of analog outputs:** Analog outputs often require filtering and amplification for controlling process functions.

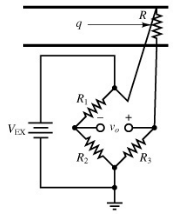
Sensors: Signal Classification

Sensor design always involves the application of some law or principle of physics or chemistry that relates the quantity of interest to some measurement event.

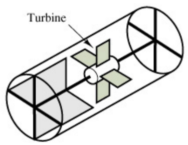
- **Motion, position and dimensional variable:**
  - *Potentiometers; stress and strain gages; capacitive sensors; differential transformers, optical sensors.*
- **Force, torque, pressure and flow:**
  - *Strain gages; piezoelectric sensors; capacitive sensors.*
- **Flow:**
  - *Turbine meters; electromagnetic sensors; imaging sensors.*
- **Temperature:**
  - *Thermocouples; thermometers.*
- **Liquid level:**
  - *Motion transducers; Force transducers.*
- **Humidity:** *Semiconductor sensors and MEMS.*
- **Chemical composition:** *Gas analysis equipment; semiconductor gas sensors.*



Differential-pressure flowmeter: A calibrated orifice and a pair of pressure transducers permit the measurement of flow rate.
(a)



Hot-wire anemometer: A heated wire is cooled by the gas flow. The resistance of the wire changes with temperature.
(b)



Turbine flowmeter: Fluid flow induces rotation of the turbine; measurement of turbine velocity provides an indication of flow rate.
(c)

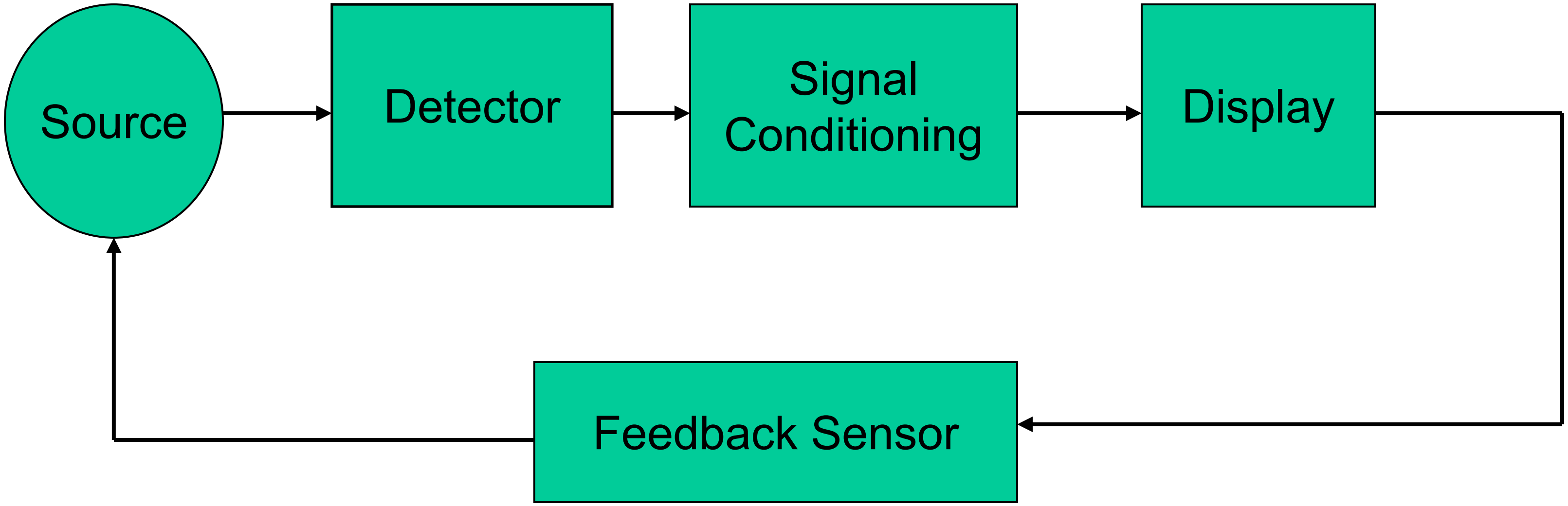
Instrumentation: Sensors and Transducers

- An important component in mechatronic systems that is linked to instrumentation is the sensor, whose function is to provide a mechanism for collecting information about a particular process.

- Sensors transform real-world data into electrical signals. The sensor may be defined as a device that produces an output signal for the purpose of sensing of a physical phenomenon. Sensors are also referred as transducers.

- The extent to which sensors and transducers are used depends upon the level of automation and the complexity of the control system. There is always a need for faster, sensitive, and precise measuring devices, accordingly, sensors are being miniaturized in solid state form by combing several sensors and signal processing mechanisms.

Sensor-Based Measurement System

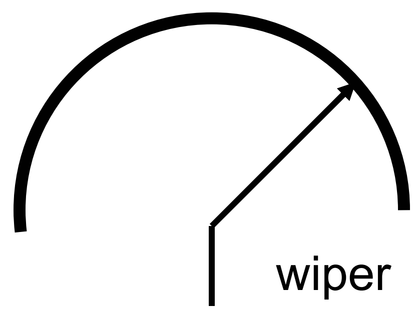


Types of Sensors

- **Active Sensors:** They require external power for their operation.
- **Passive Sensors:** Examples include piezoelectric, thermoelectric, and radioactive.
- **Analog Sensors:** They have an output that is proportional to the variable being measured.
- **Digital Sensors:** They are accurate and precision.
- **Deflection Sensors:** They are used in a physical setup where the output is proportional to the measured quantity that is displayed.
- **Null Sensors:** In this type, any deflection due to the measured quantity is balanced by the opposing calibrated force so that any imbalance is detected.

Resistance Transducers

- A displacement transducer that uses the variable resistance transduction principle may be manufactured with a **rotary** or **linear** potentiometer (rotation or displacement is converted into a potential difference).
- Such potentiometers consist of a wiper that makes contact with a resistive element, and as this point of contact moves, the resistance between the wiper and end leads of the device changes in proportion to the angular displacement.
- Through voltage division, the change in resistance can be used to create an output voltage that is directly proportional to the input displacement.



Inductance Transducers

- Inductance transducers are used for proximity sensing when the presence or absence of an object must be detected with an electronic non-contact sensor. They are also used for motion position detection, motion control, and process control applications.
- Variable inductance transducers are based on Faraday's law of induction in a coil: the induced voltage is equal to the rate at which the magnetic flux through the circuit changes

$$V = N\frac{d\phi}{dt} = N\frac{d(BA)}{dt} = \frac{dN(\phi)}{dt} = \frac{d\varphi}{dt}$$

(ψ is the total flux linkage in the circuit)

$$L = \frac{\psi}{i} = \frac{N\phi}{i}$$

$$\phi = \frac{Ni}{R}$$

$$L = \frac{N^2}{R}; R = \frac{1}{\mu A} = N^2\mu\left(\frac{A}{l}\right)$$

Capacitance Transducers

- The variation in capacitance between two separated members or electrodes is used for the measurement of many physical phenomena.
- A change in capacitance can be brought about by varying any one of the three parameters
  - Distance between the two electrodes
  - Changing the dielectric constant
  - Changing the area of the electrodes
- Variable capacitance transducers have applications in the area of liquid level measurements in chemical plants

$$C = \frac{\varepsilon A}{d}$$

$$\frac{\Delta C}{C} = -\frac{\Delta d}{d}$$

$$\frac{\Delta C}{C} = \frac{\Delta A}{A}$$

Wheatstone Bridge

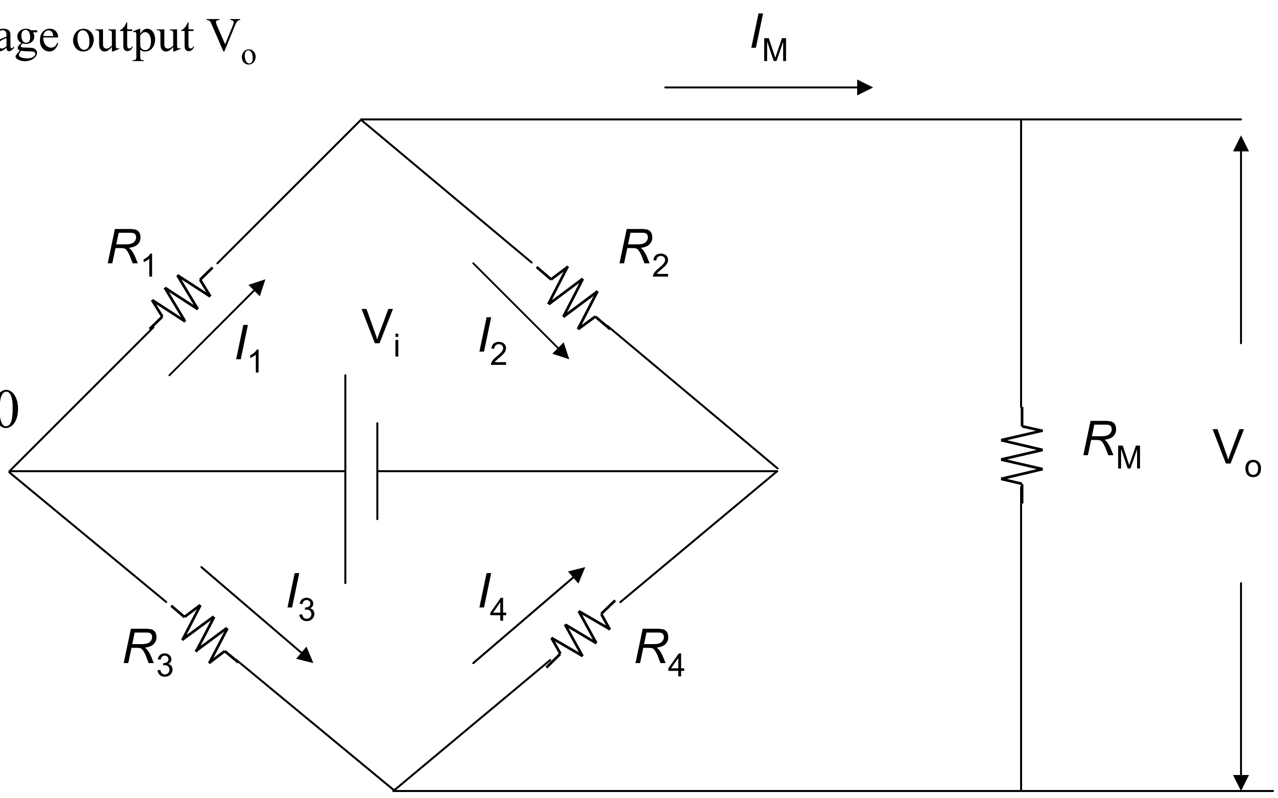
- The bridge converts a relative change of resistance δ = ΔR/R into a proportional voltage output V_o

$$I_1 R_1 - I_3 R_3 = 0$$

$$I_2 R_2 - I_4 R_4 = 0$$

$$\frac{I_1 R_1}{I_2 R_2} = \frac{I_3 R_3}{I_4 R_4}$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$



Temperature Effect in Strain Gage

- The strain gauge environment is often influenced by temperature change. The electrical resistivity of most alloys changes with temperature, increasing as temperature rises and decreasing as it falls. Usually metals used in strain gauges have a temperature coefficient (αo) on the order of 0.004/^{o}C. The resistance at temperature *T* is given by

$$R_T = R_{T_o}(1 + \alpha_o \Delta T)$$

$$\Delta R_T = R_{T_o}\alpha_o \Delta T \text{ (Resistance change due to change in Temperature)}$$

Piezoelectric Strain Sensors

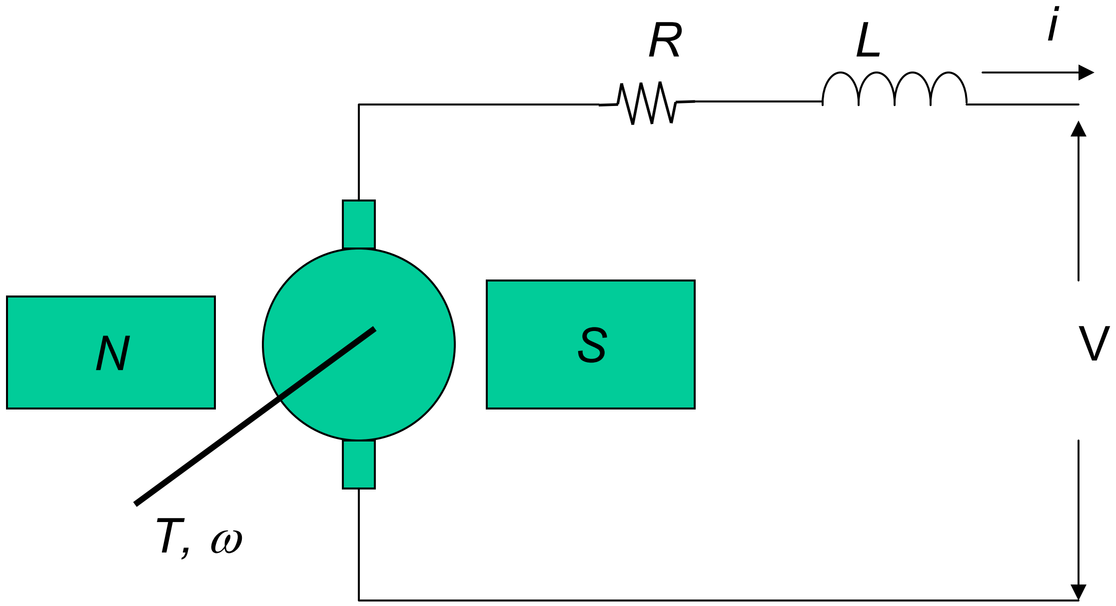
- The piezoelectric effect consists of generating an electric charge when a material is subject to a mechanical deformation or in producing a mechanical deformation when it is subject to an electric charge. The piezoelectric effect, in piezoelectric materials, can be induced by applying a high electric field while the material is heated above a specific temperature called Curie temperature.
- The strain transducers can also be used to measure indirectly force, torque, pressure, velocity, or acceleration.
- The main parameters of a piezoelectric sensor are: Curie temperature (^{o}C), dielectric constant c (F/m), Young or elastic modulus E (N/m^2), piezoelectric charge coefficient, d_{ij} (C/N), and piezoelectric voltage coefficient, g_{ij} (Vm/N). The first subscript (i) indicates the direction perpendicular to the electrodes, and the second subscript (j) indicates the direction of the applied stress.

$$d_{ij} = \frac{\text{Charge density produced in direction i}(C/m^2)}{\text{mechanical stress applied in direction j}(N/m^2)}$$

$$g_{ij} = \frac{\text{Charge density produced in direction i}(V/m)}{\text{mechanical stress applied in direction j}(N/m)}$$

Velocity Measurement: Tachometer

- A permanent magnet DC generator can be used for analog measurement of angular velocity. ω is the angular velocity to be measured, T is the torque required to drive the generator, L and R are the inductance and the capacitance of the rotor, I is the current in the rotor windings, and V is the voltage output at the rotor windings terminals.

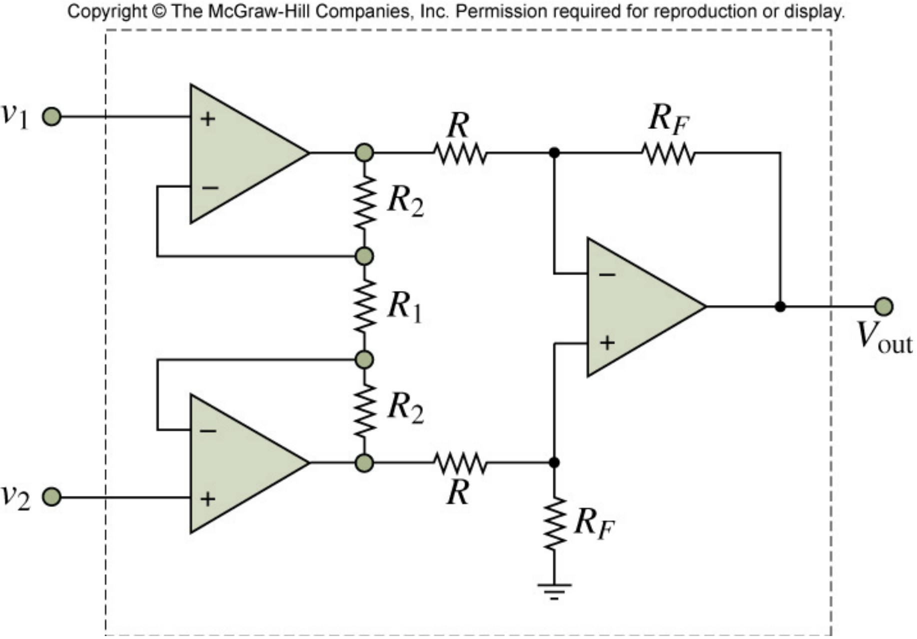


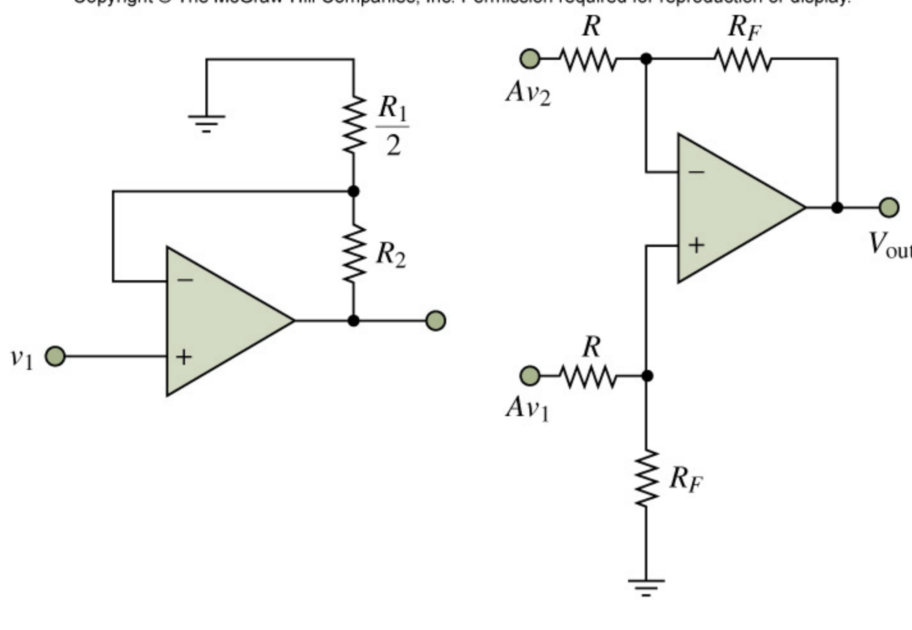
Instrumentation Amplifier (IA) is a differential amplifier with very high input impedance. It is used to amplify low-level signals prior to signal conditioning (e.g., filtering)

Input (a) and output (b) Stages of Instrumentation Amplifier

See page 404-405 of the textbook

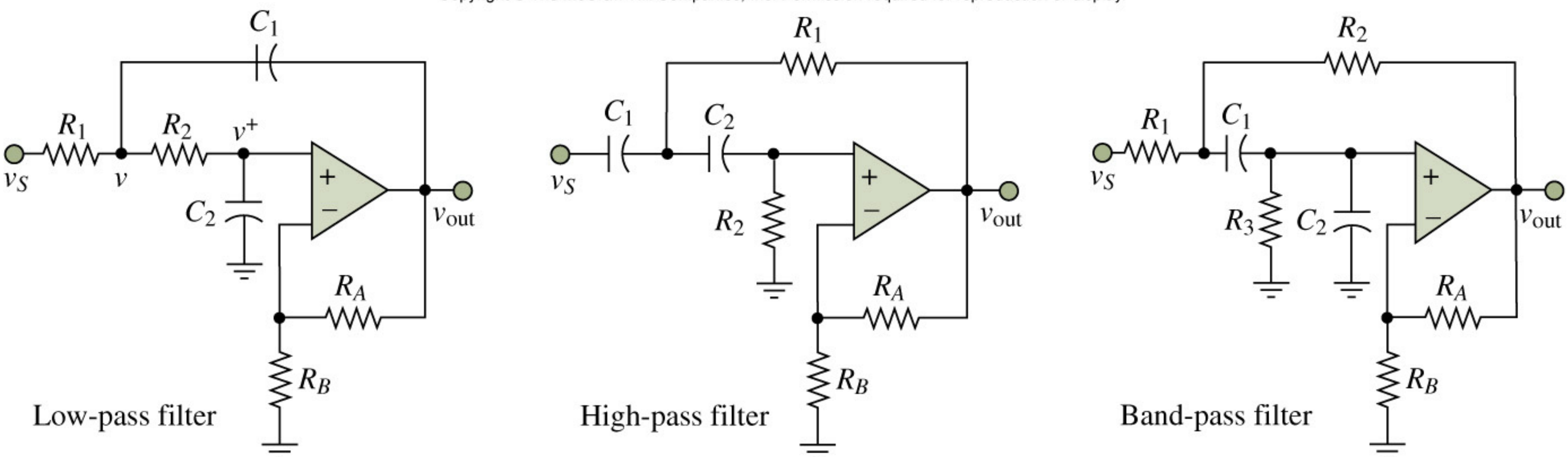
$$A_v = \frac{v_{out}}{v_1 - v_2} = \frac{R_F}{R}\left(1 + \frac{2R_2}{R_1}\right)$$



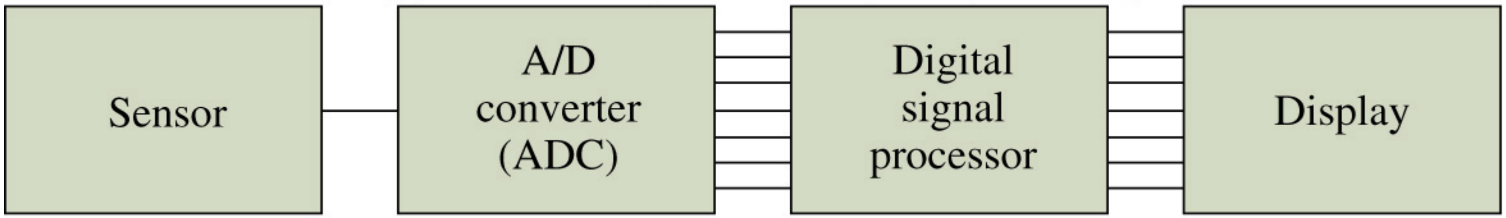


(a) (b)

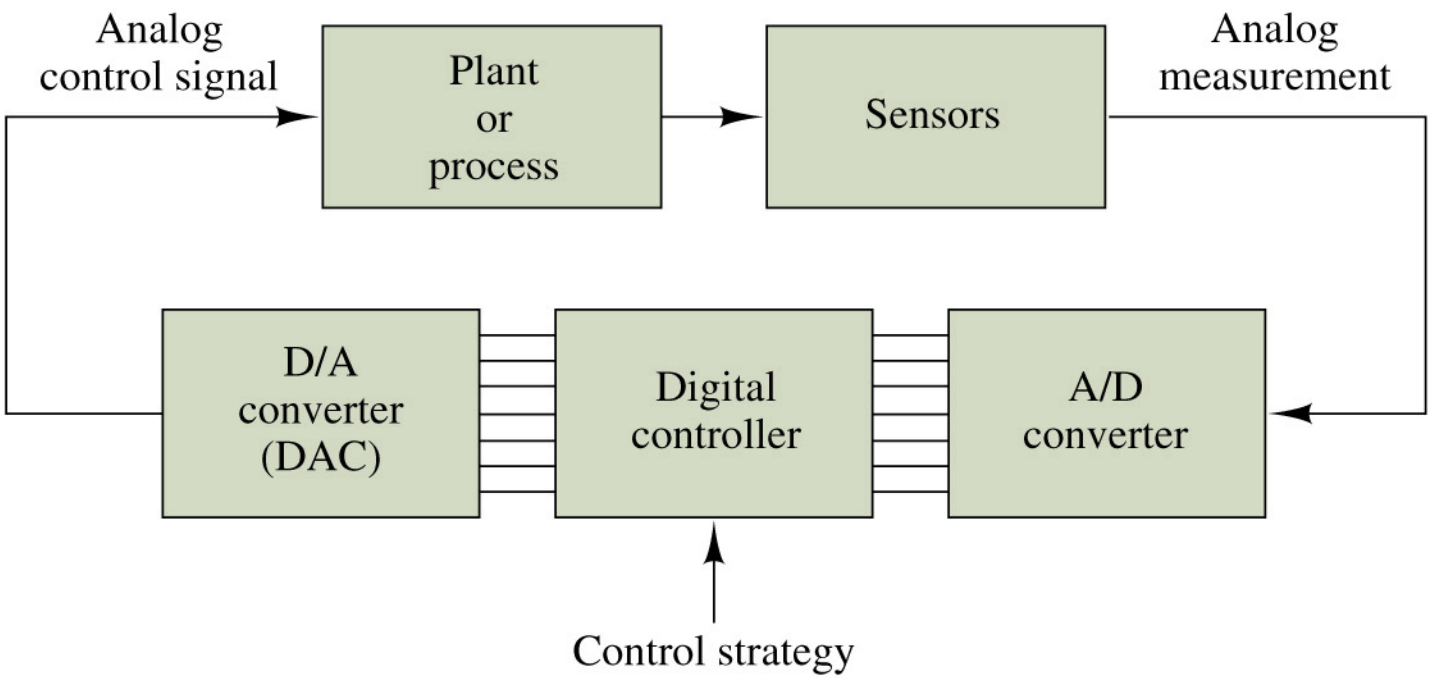
Active Filters



Digital Measuring Instrument and a Digital Control System



Digital measuring instrument



Digital control system

Analog to Digital Conversion

- ADC, or digitizing, converts analog waveforms to digital representations that can be processed and stored in digital form.

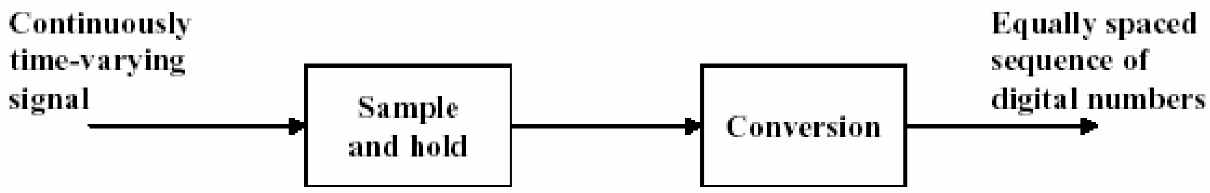
- The analog wave is “sampled,” or read, hundreds or thousands of times per second to map out the wave digitally. Digital music requires extremely high sampling rates (44,100 samples/sec), while it is usually acceptable to sample voice at 11,000 samples/sec or higher. There is also a factor that determines the precision of the captured signal-the more bits used to record the value of the sampled signal, the higher its resolution and the better its sound when played back.

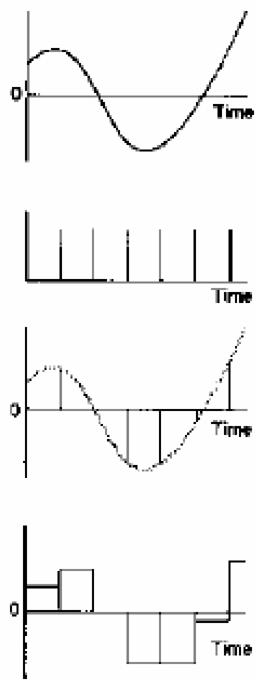
- However, the more bits used, the more disk space is required for storage or bandwidth for transmission. For example, one minute of sampling at 44.1 kHz using 16 bits per sample requires 5.292 MB of disk space.

- The telephone companies convert analog voice to digital at their central offices for transmission across trunk lines to other central offices or to long-distance systems. Voice converted to digital requires a 64-kbit/sec channel.

- ADCs are used in a variety of information-processing applications. Information collected from analog phenomena such as sound, light, temperature, and pressure can be digitized and made available for digital processing. A codec (coder/decoder) is the device that transforms the analog signals to digital signals. The process involves sampling, quantizing, and digitizing. The amplitude of a signal is measured at various intervals. The tighter these intervals, the more accurate the recording.

ADC





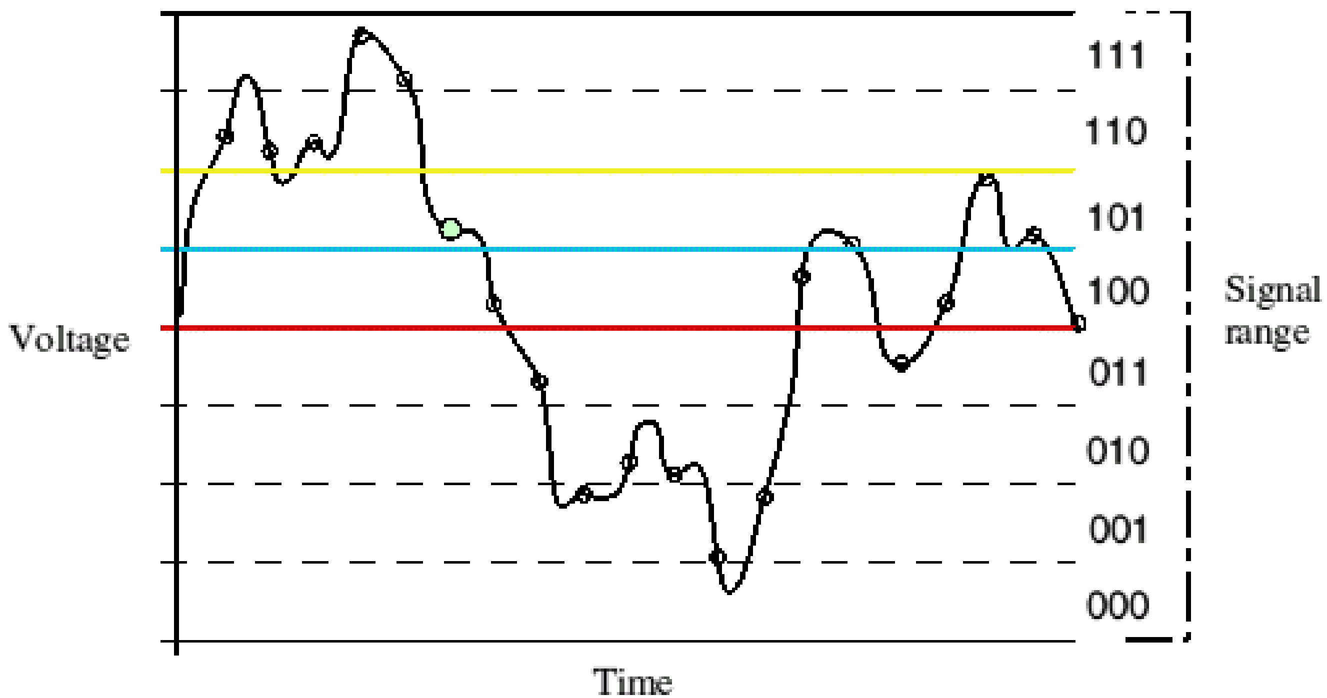
The analog signal is sampled at a discrete time-interval or period, τ_s

The sampling frequency is given by the equation

$$f_s = 1/\tau_s \quad \text{[samples/sec]}$$

The sampled value is held until the next sample is taken.

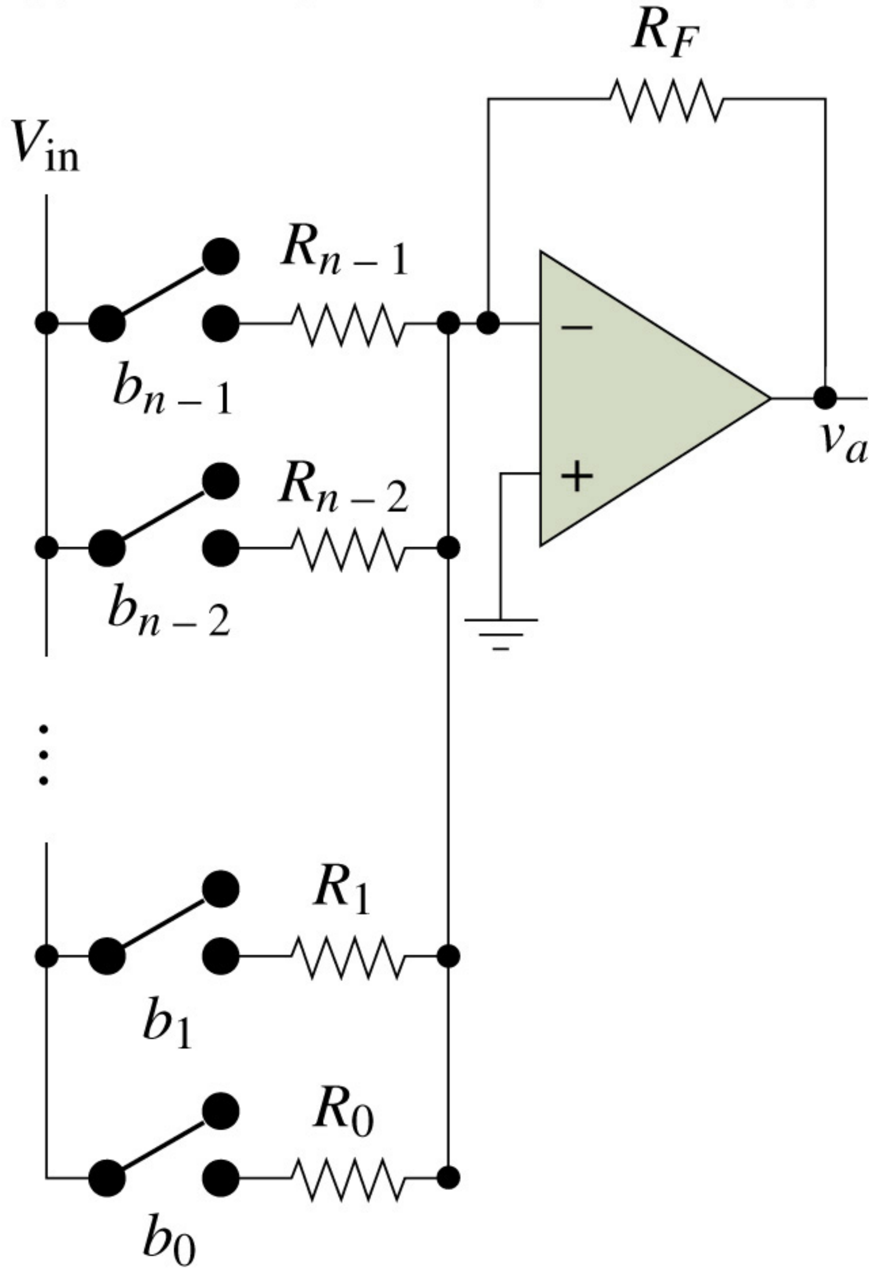
The held value is converted to a digital number.



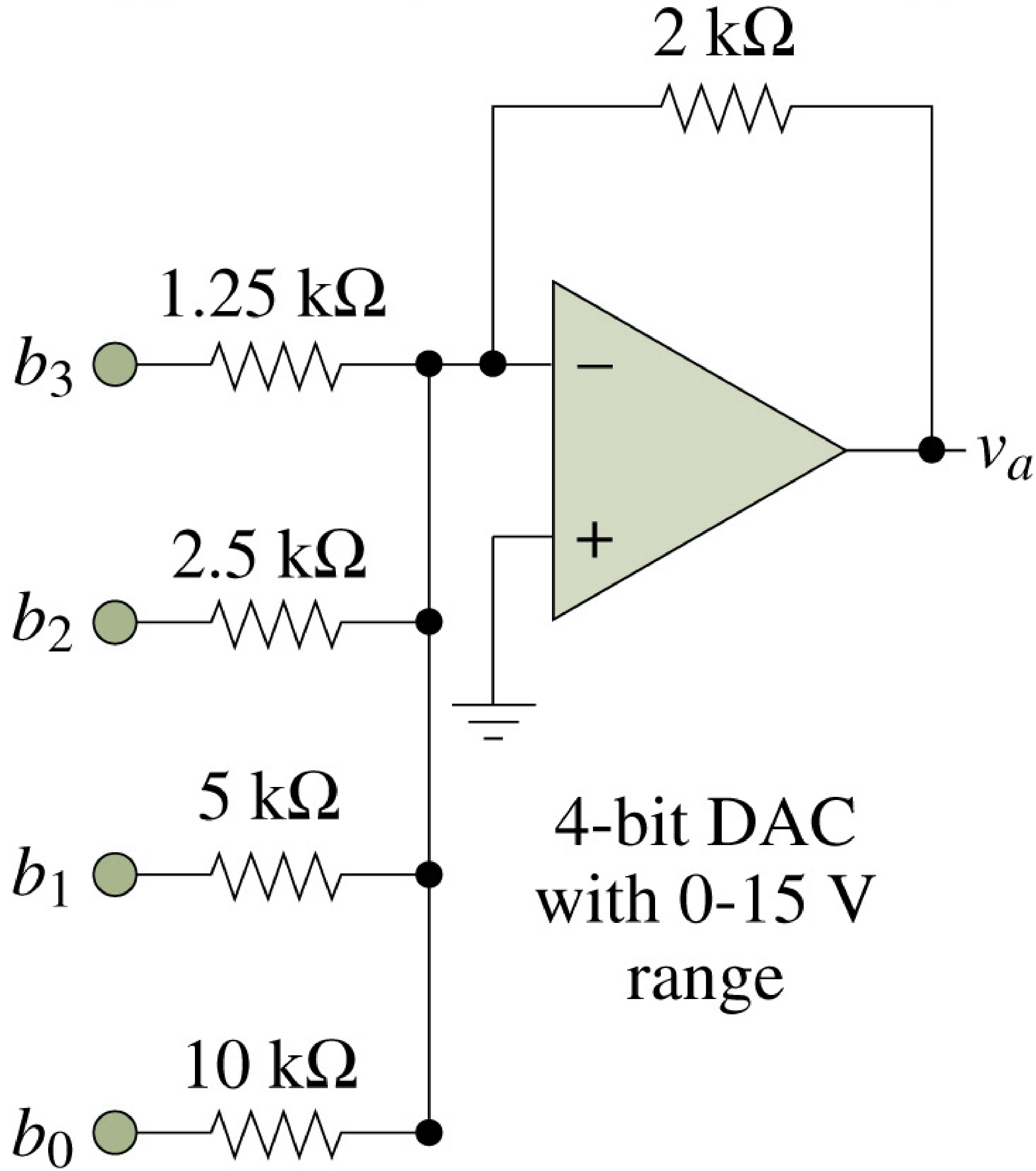
Turning analog waves into digital signals.

101101101111111011000110010100100010011001010111001011101100.

An *n*-Bit Digital-to-Analog Converter



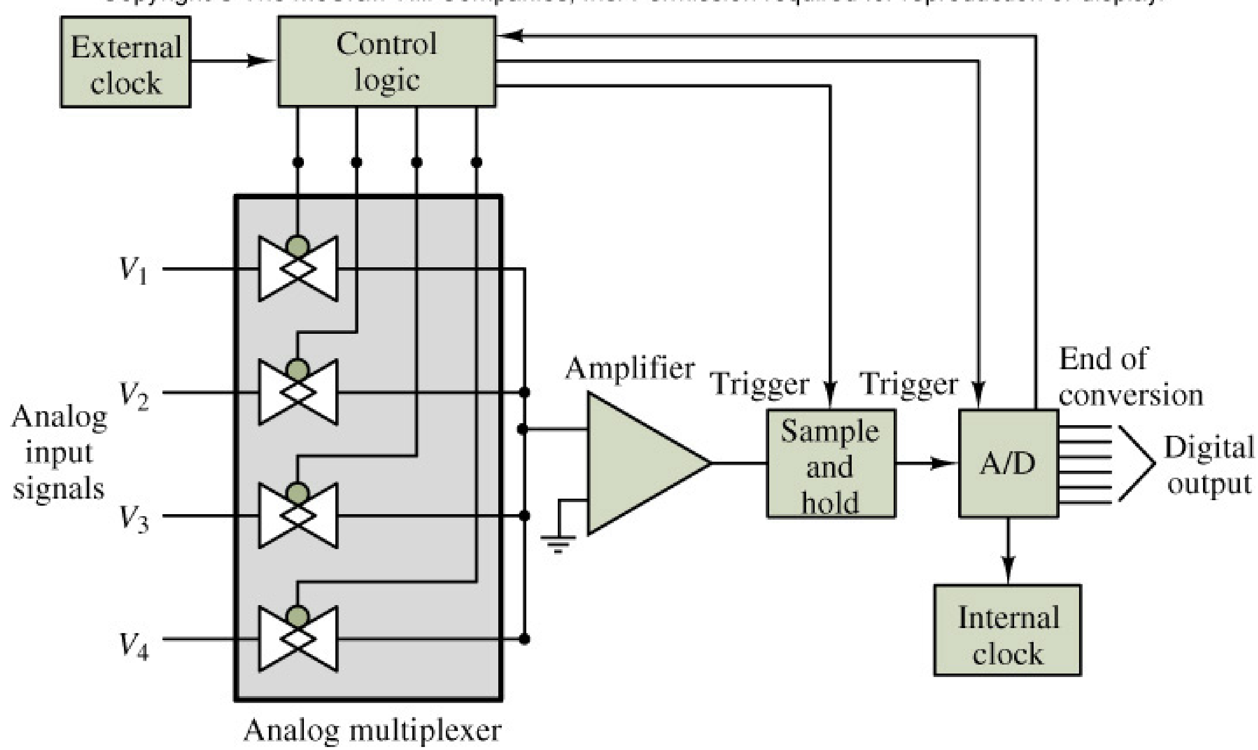
A 4-bit DAC



Data Acquisition System

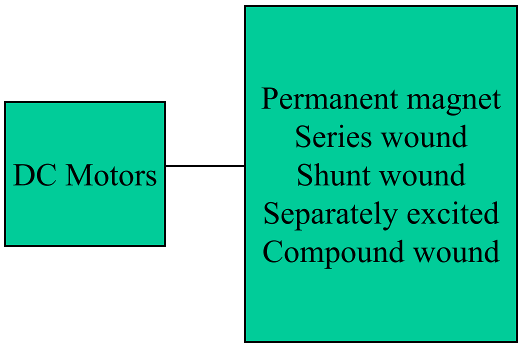
Microprocessors, microcontrollers, single-board computers, and personal computers are in widespread use in mechatronic and measurement systems today, and it is increasingly important for engineers to understand how to directly access information and analog data from the surrounding environment with these devices.

Data Acquisition means storing data from sensors using a microprocessor or a computer.

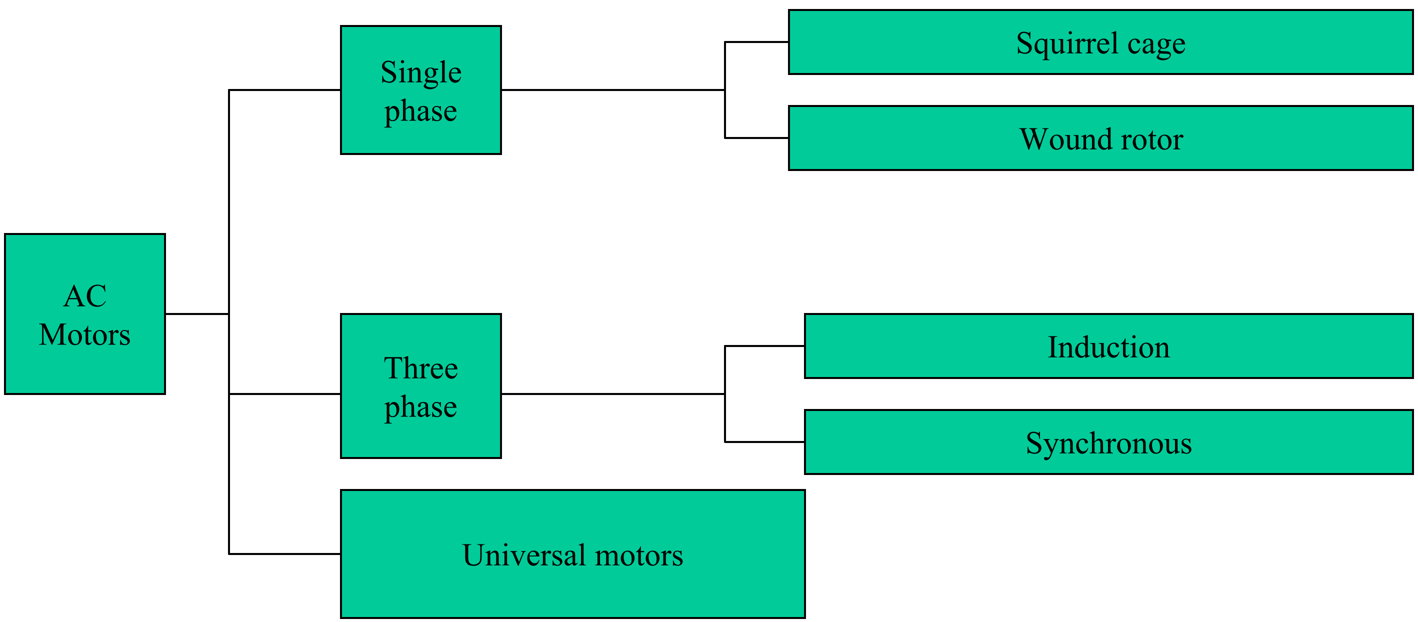


Actuators

Relays and Motors



Torque-speed characteristic; speed control; reversible; regenerative breaking



List of Mechatronic Systems

- Air bag safety, antilock break system; remote automatic door locks; cruise control, etc.
- Copy machines, fax machines, dcanners.
- MRI equipment; ultrasonic probes; and other medical equipment.
- Autofocus cameras; VCRs; CD players; camcoders; and other consumer products.
- Welding robots; automatic guided vehicles.
- Flight control actuators; landing gear system; and cockpit control system.
- Washing machines; dishwashers; automatic ice makers.
- Garage door openers; security system; and other home support systems.
- Variable speed drills; digital torque wrenches.
- Factory automation system.
- More!