

Electronic Instrumentation and Measurements

MU SIGMA

Introduction to DAC/ADC

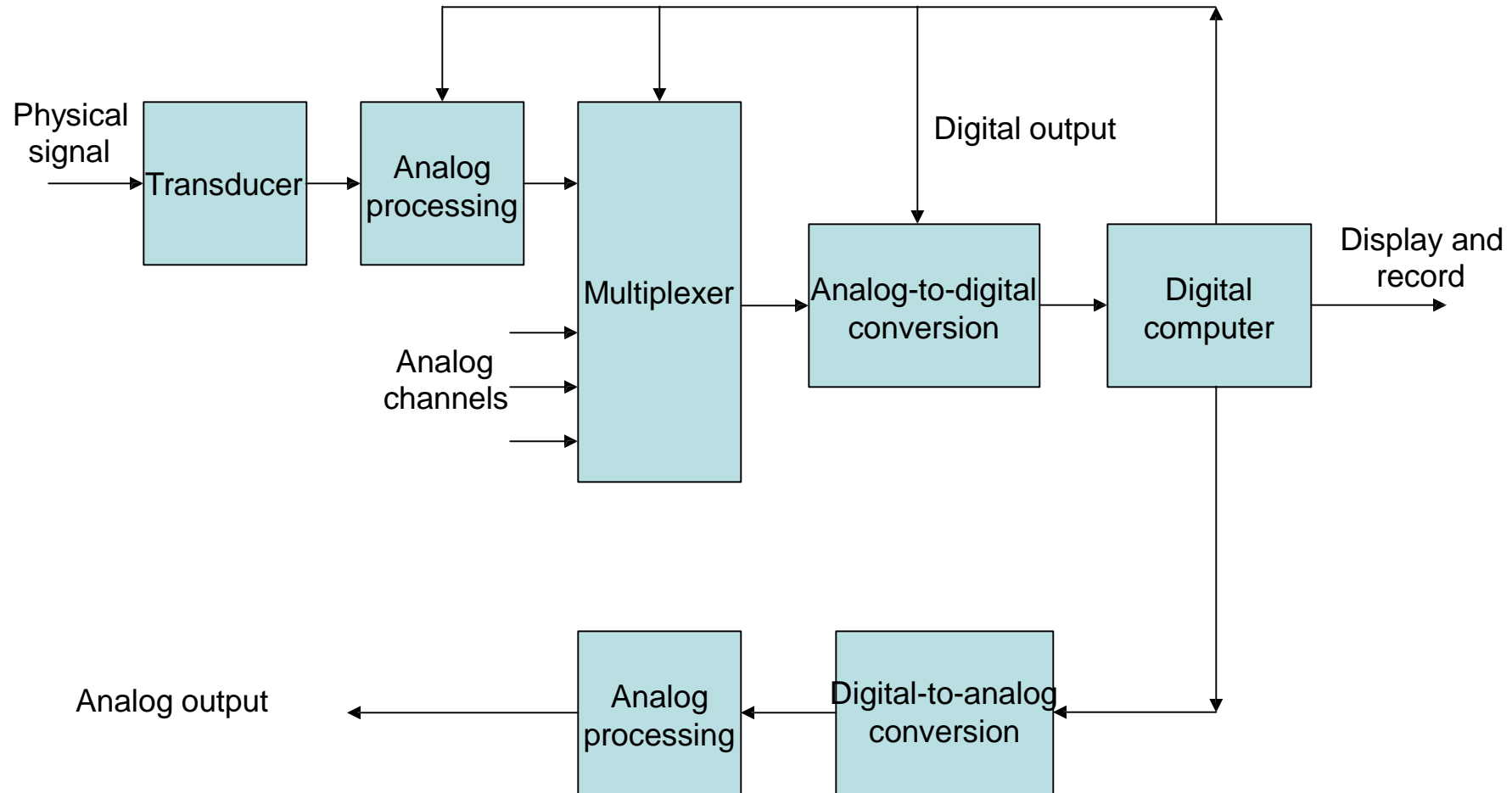
A fundamental part of many mechatronic systems is a measurement system that composed of four basic parts:

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

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).

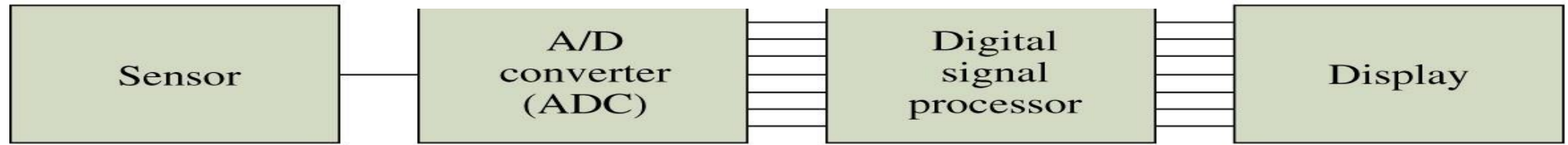
Instrumentation Systems



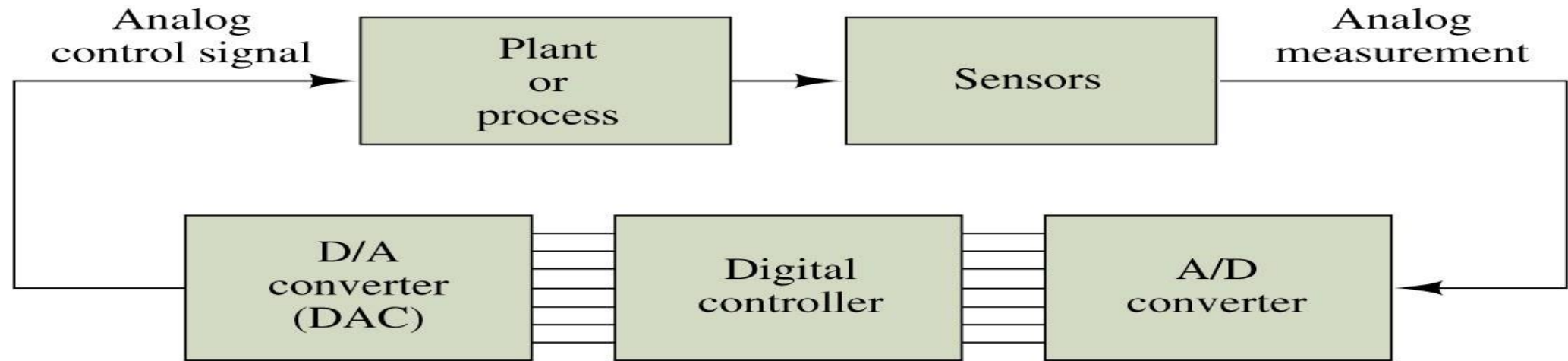
- **Analog-to-digital conversion:** The A/D converts the information from analog to digital form. Often, the time variations of the analog signal must be arrested with a sample-and-hold circuit while A/D conversion is taking place.
- **Digital computer:** This is the brain of the entire operation. This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

Digital Measuring Instrument and a Digital Control System



Digital measuring instrument



Digital control system

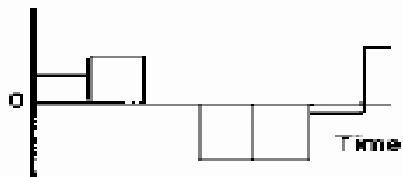
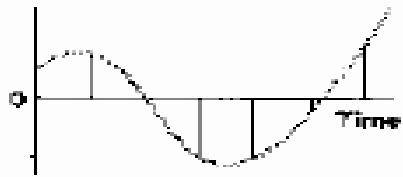
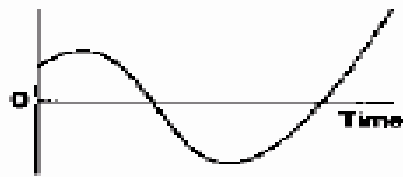
Analog to Digital Conversion

- 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

Continuously
time-varying
signal



Sample
and hold

Conversion

Equally spaced
sequence of
digital numbers

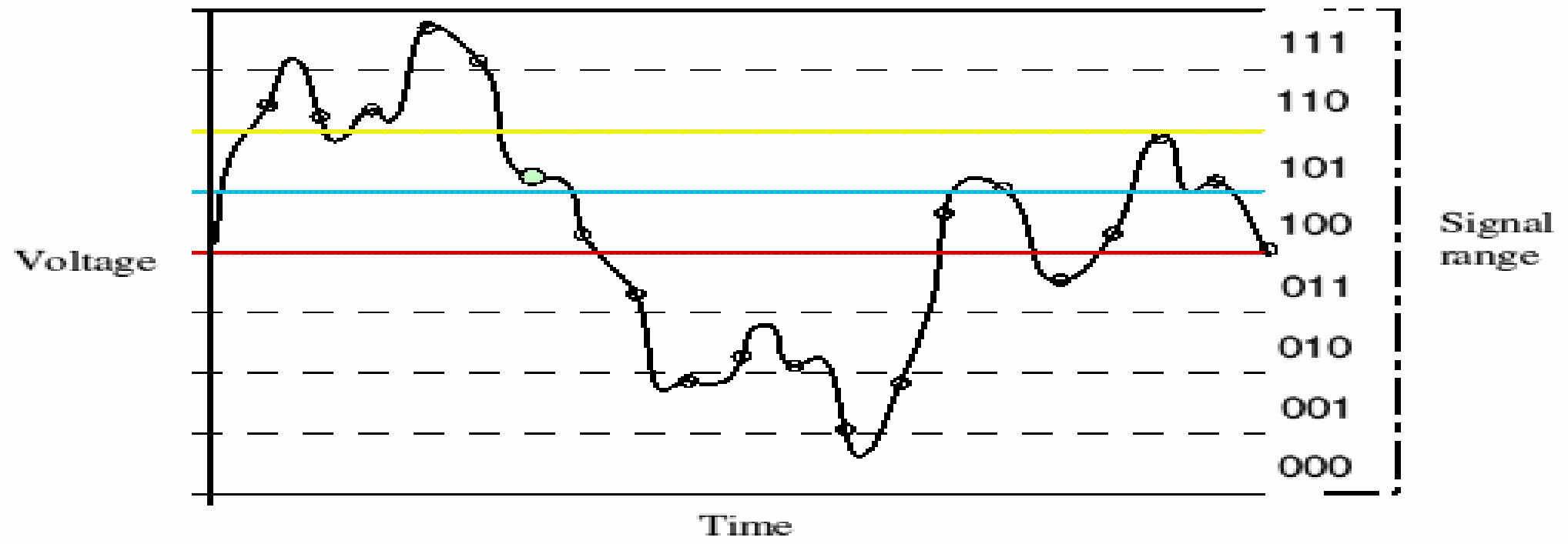
The analog signal is sampled at a discrete time-interval or period, τ_s

The sampling frequency is given by the equation

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

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

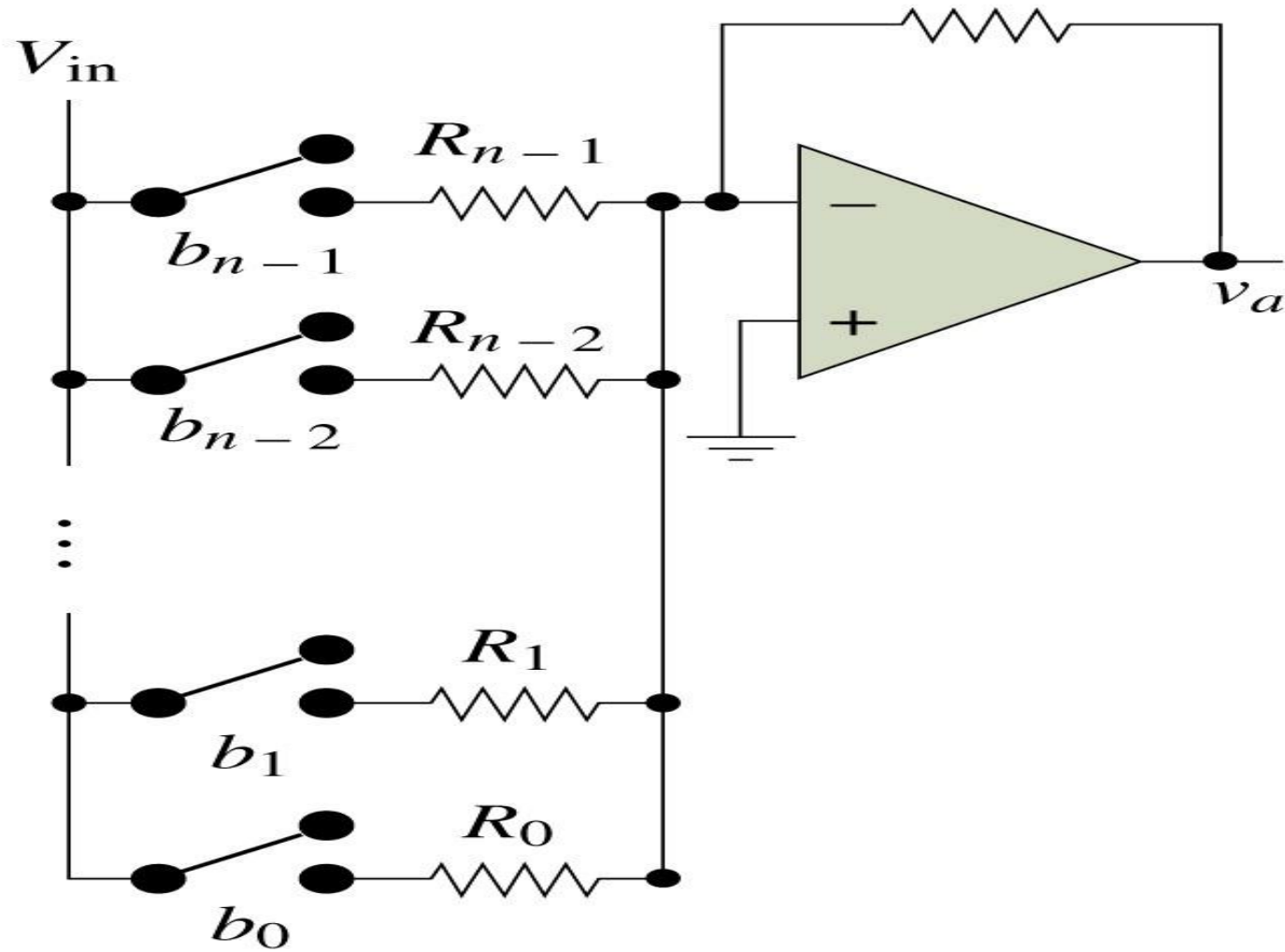
The held value is converted to a digital number.



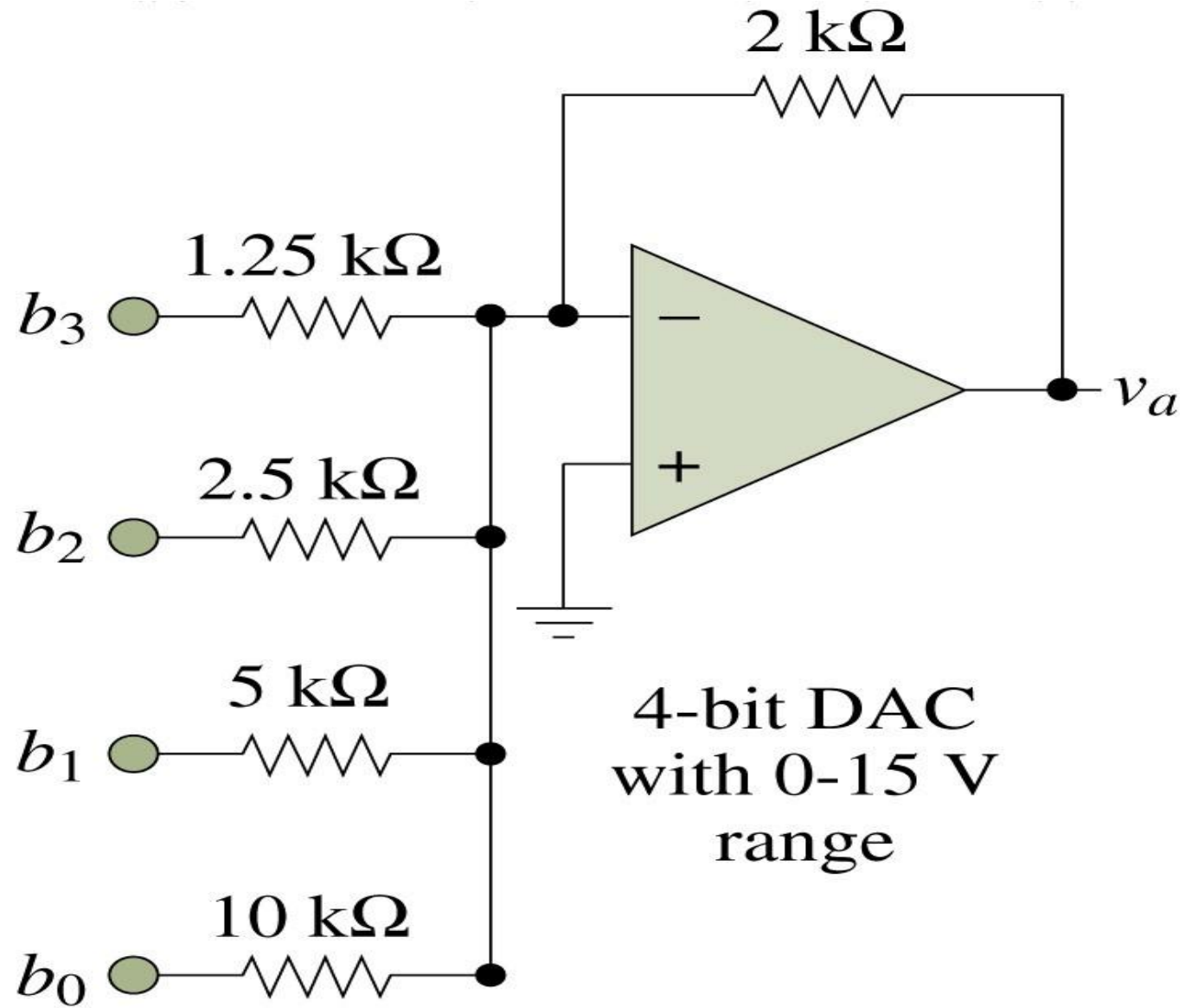
Turning analog waves into digital signals.

1011011011111101100011001010010001001100101011100101101100.

An n -Bit Digital-to-Analog Converter

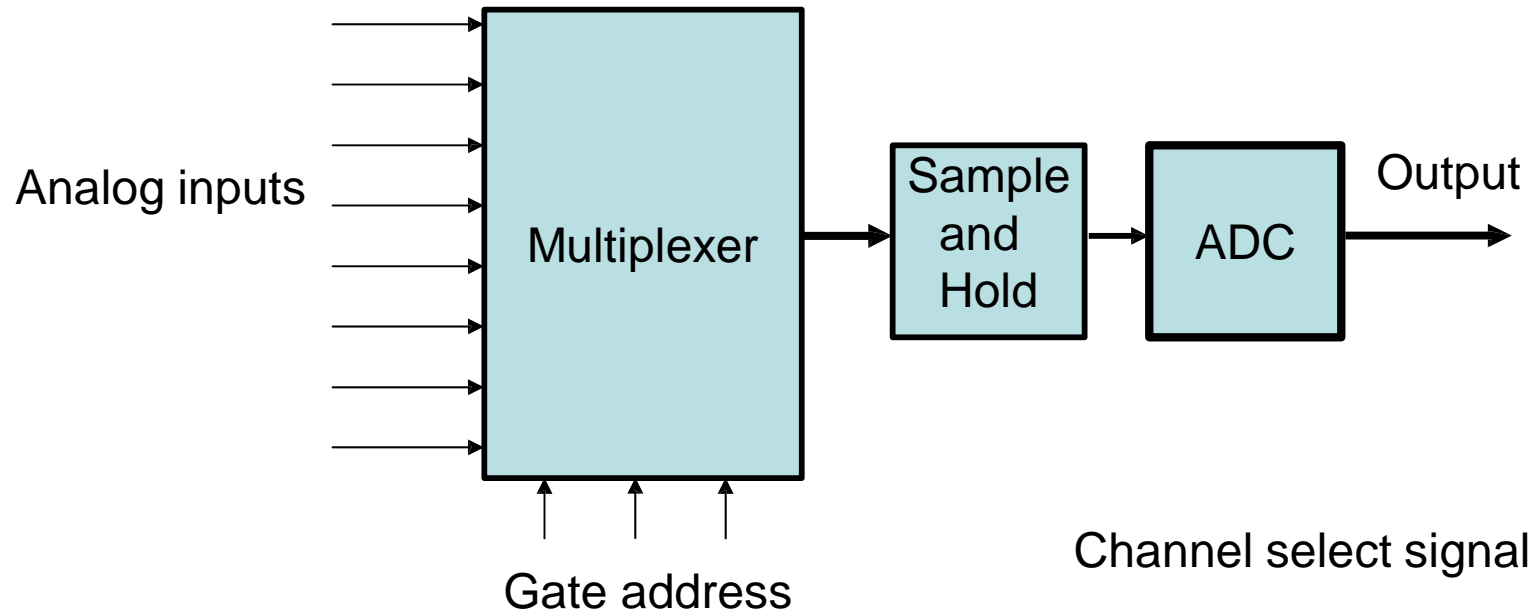


A 4-bit DAC



Multiplexers

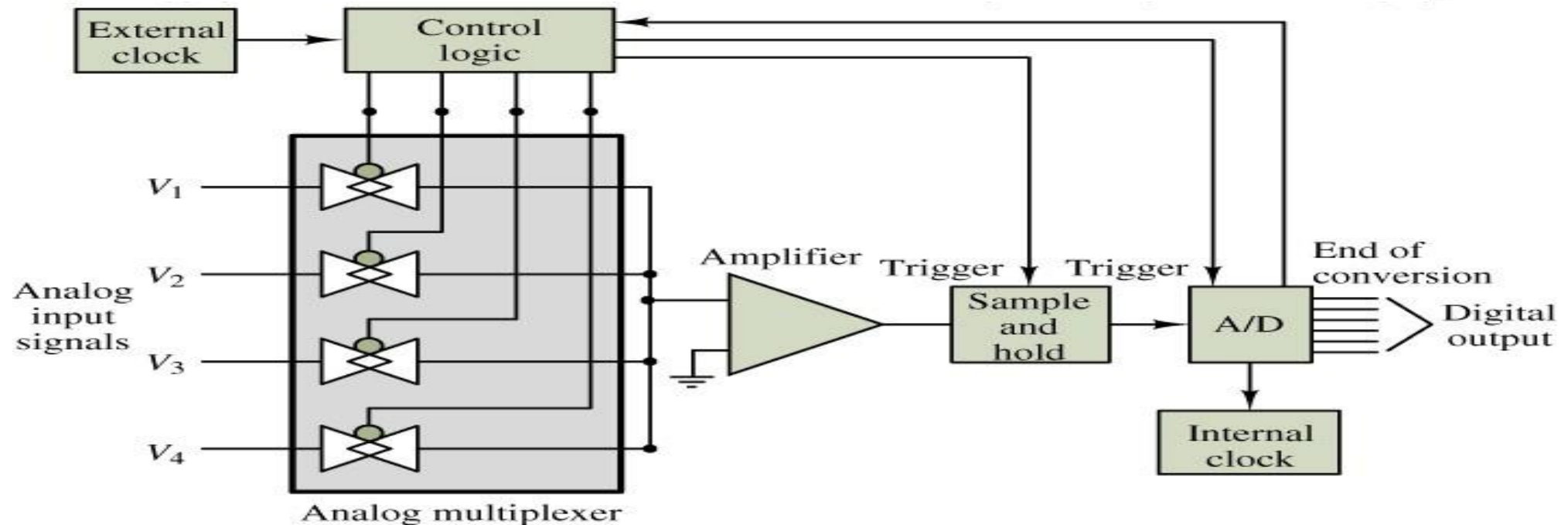
- Several analog channels are processed sequentially through a multiplexer, which is a digitally controlled switch. The multiplexer accepts parallel inputs from several channels and provides one analog output at a time for conversion to digital form.



Data Acquisition System

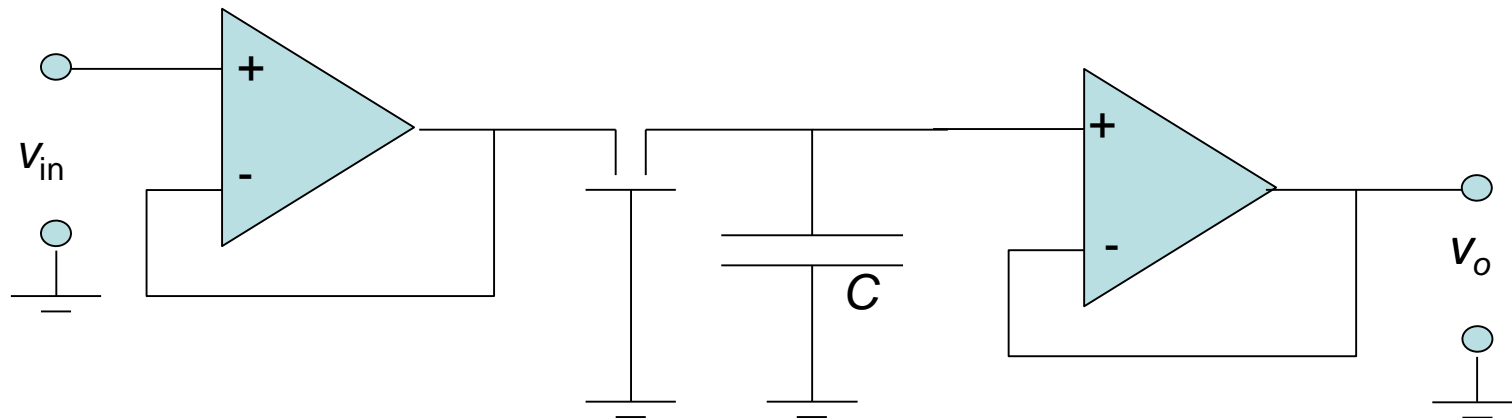
Microprocessors, microcontrollers, single-board computers, and personal computers are in widespread use in mechatronic and measurement systems today, and it is increasingly important for engineers to understand how to directly access information and analog data from the surrounding environment with these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

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

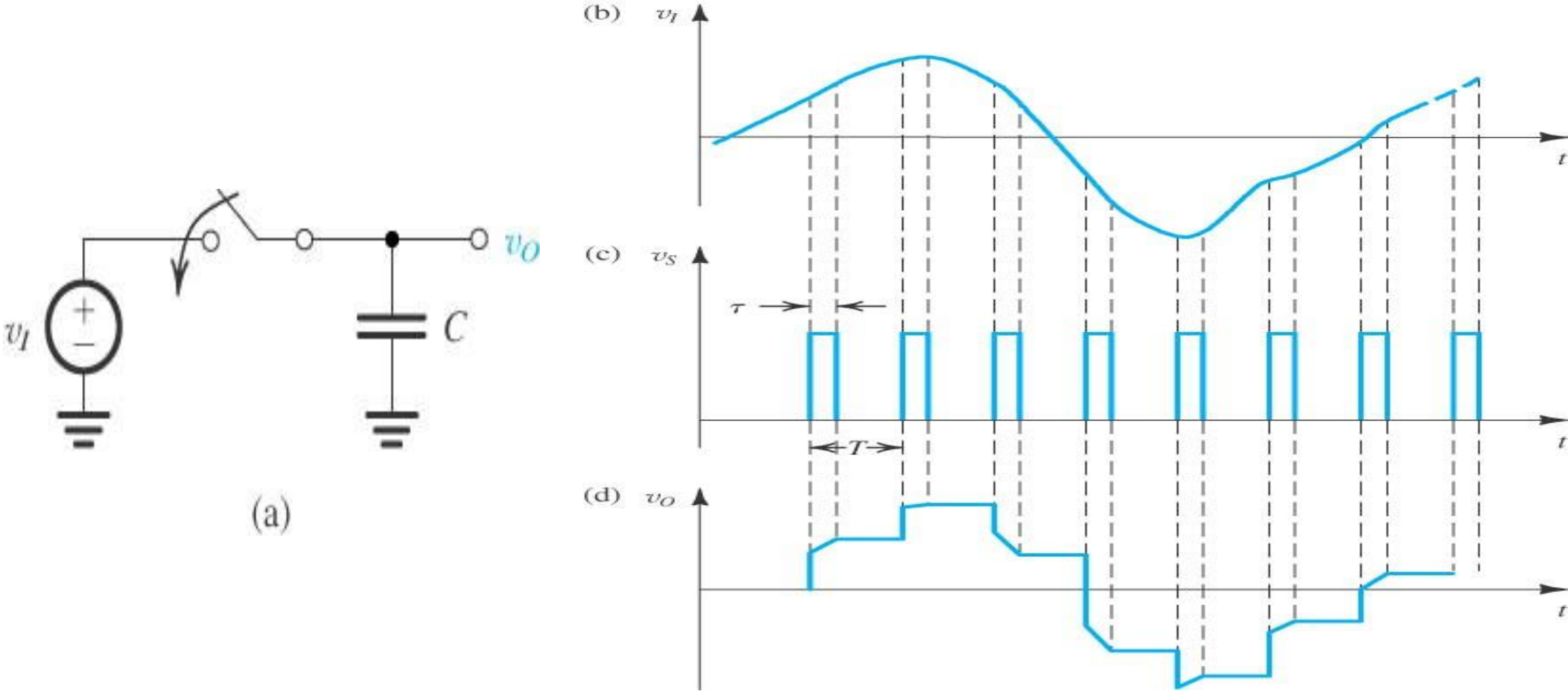


Sample and Hold

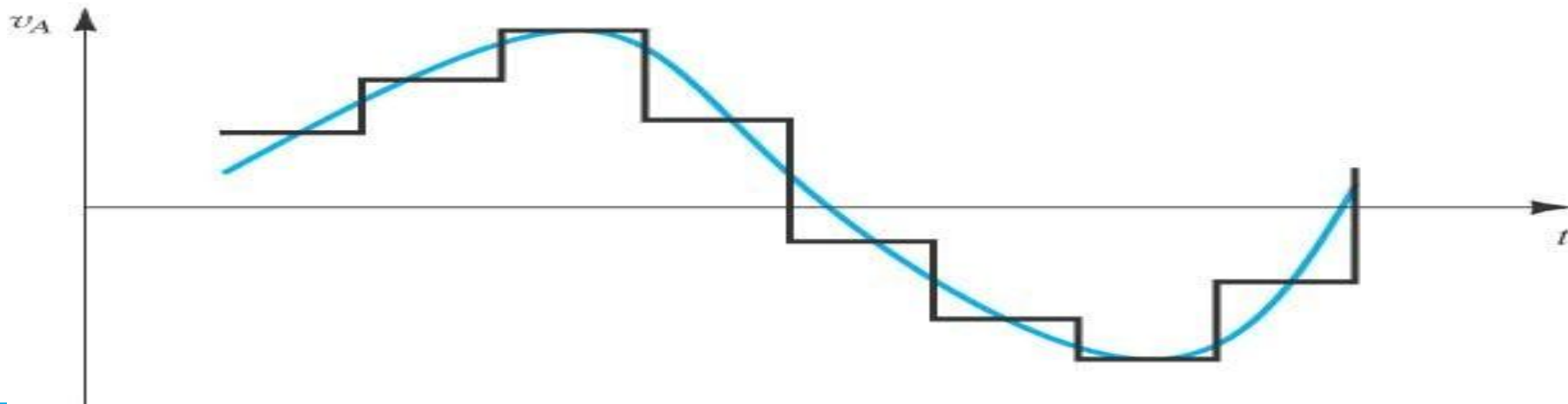
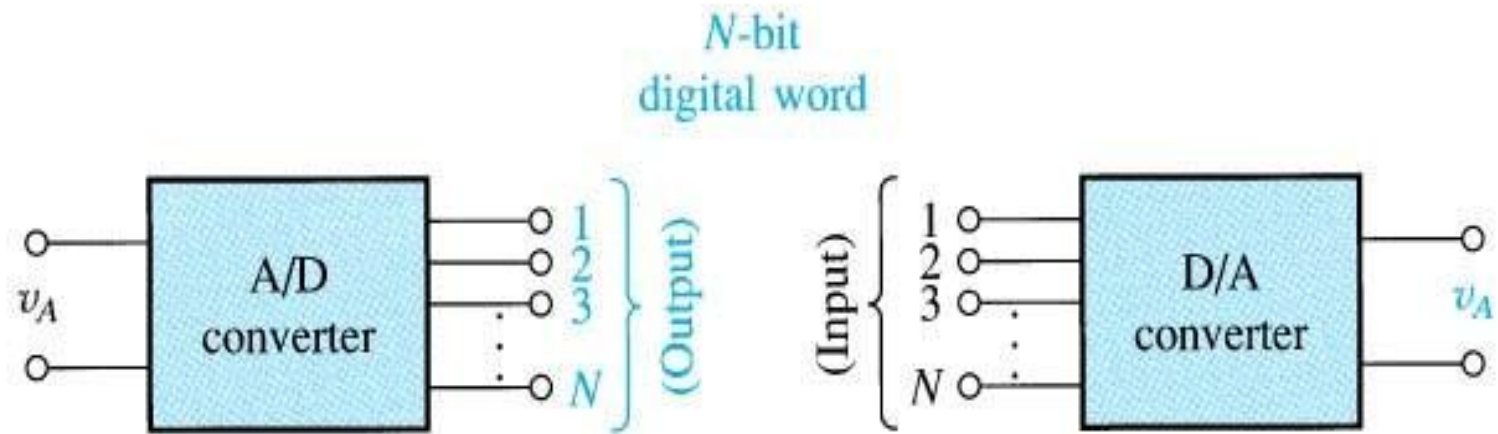
- Many inputs can be monitored simultaneously. They are sampled to discrete times through a multiplexer (electronic multipole switch).
- A sample and hold circuit may be required to arrest change in the input while A/D conversion is being performed.
- Sample and hold circuit uses two voltage follower amplifiers to buffer input and output.
- An FET switch is activated long enough for the capacitor to charge to the input voltage, and then the capacitor holds the voltage while A/D conversion is taking place.



Data Converters



A/D and D/A converters



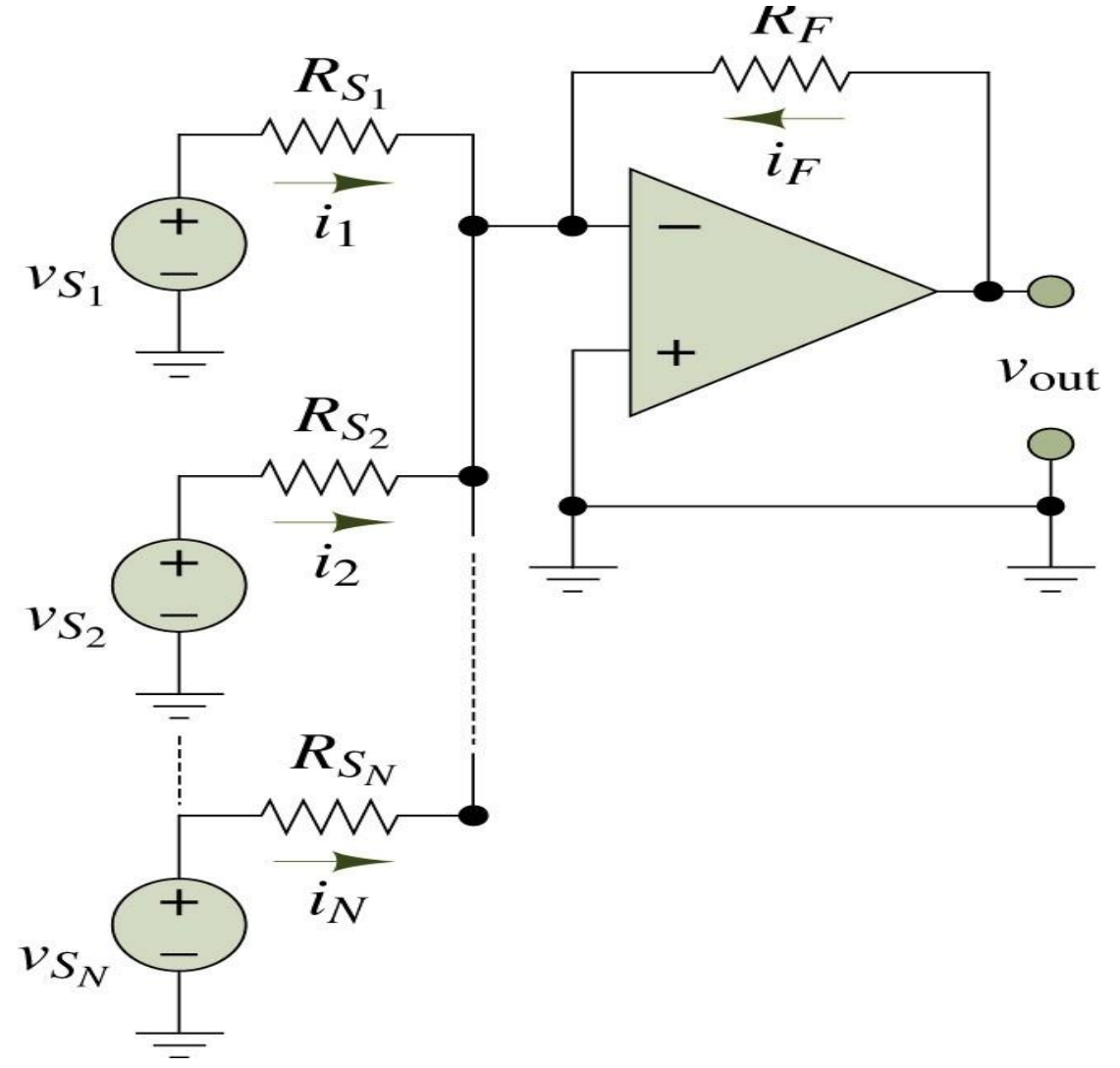
Summing Amplifier

$$i_1 + i_2 + \dots + i_N = -i_F$$

$$i_n = \frac{v_{S_n}}{R_{S_n}} \dots n = 1, 2, \dots, N$$

$$i_F = \frac{v_{out}}{R_F}$$

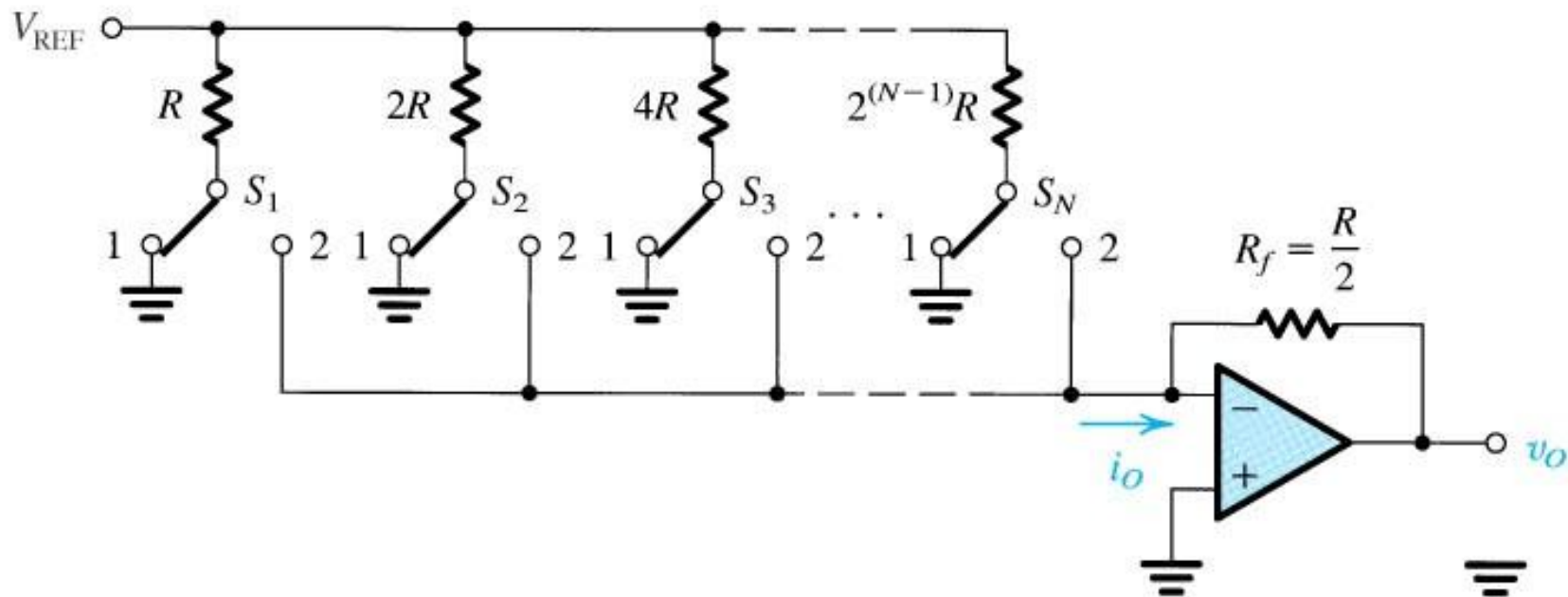
$$v_{out} = - \sum_{n=1}^N \frac{R_F}{R_{S_n}} v_{S_n}$$



An N-bit D/A converter using a binary-weighted resistive ladder network

$$i_o = \frac{V_{ref}}{R} b_1 + \frac{V_{ref}}{2R} b_2 + \dots + \frac{V_{ref}}{2^{N-1} R} b_N$$

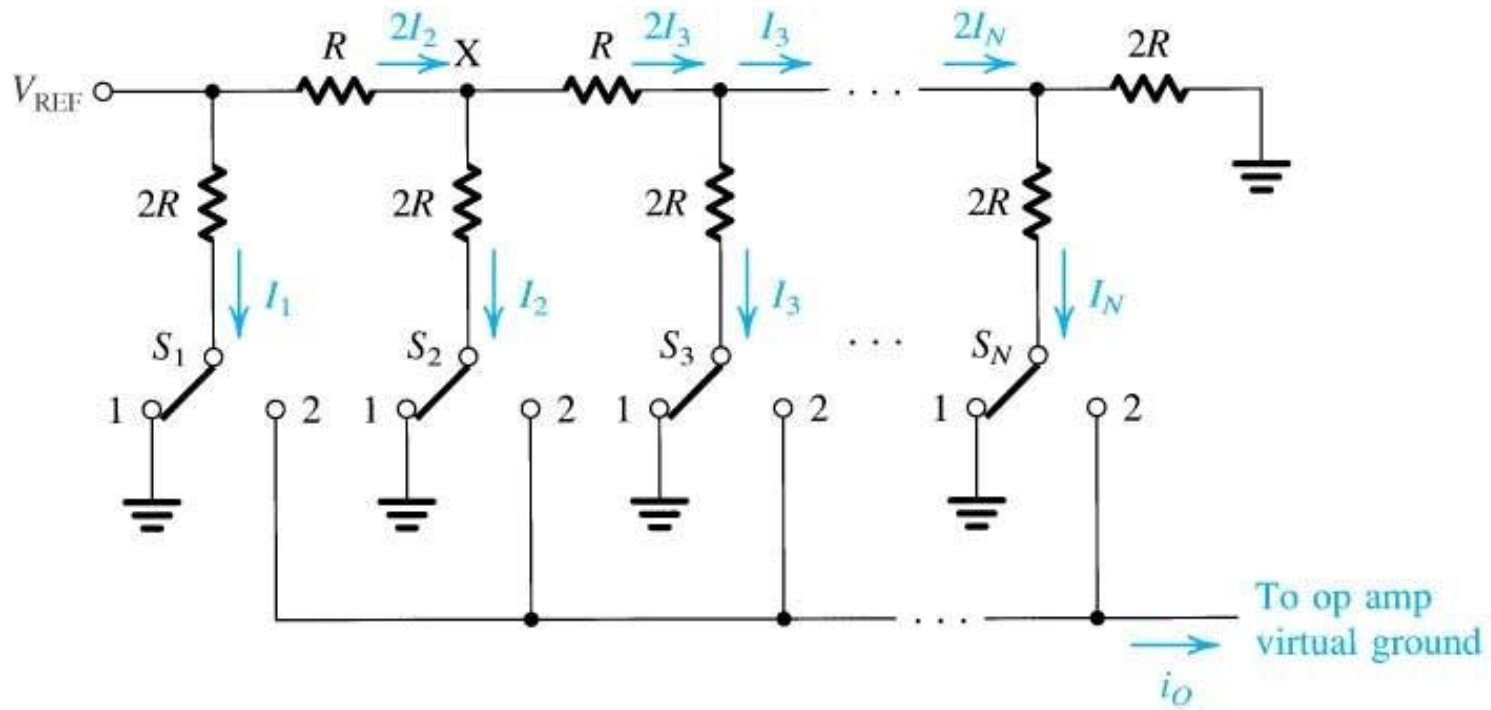
$$i_o = \frac{2V_{ref}}{R} D; \quad v_o = -i_o R_f = -V_{ref} D$$



DAC Utilizing an R-2R Ladder Network

$$I_1 = 2I_2 = 4I_3 = \dots = 2^{N-1} I_N$$

$$i_o = \frac{V_{ref}}{R} D$$



DAC Utilizing an R-2R Ladder Network

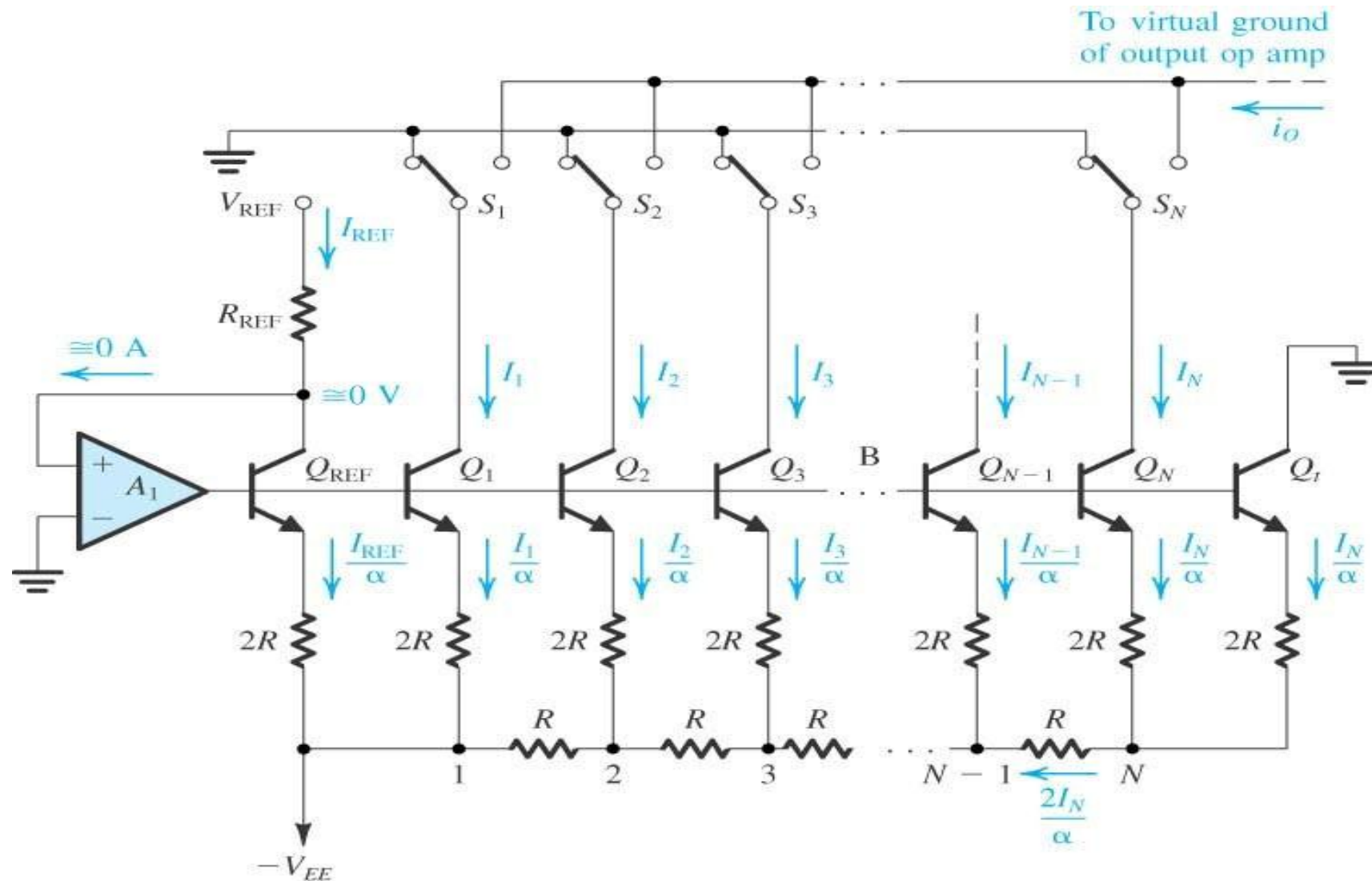


Table 1.1 Definitions of standard units

| <i>Physical quantity</i> | <i>Standard unit</i> | <i>Definition</i> |
|--------------------------|----------------------|---|
| Length | metre | The length of path travelled by light in an interval of $1/299\,792\,458$ seconds |
| Mass | kilogram | The mass of a platinum–iridium cylinder kept in the International Bureau of Weights and Measures, Sèvres, Paris |
| Time | second | 9.192631770×10^9 cycles of radiation from vaporized caesium-133 (an accuracy of 1 in 10^{12} or 1 second in 36 000 years) |
| Temperature | kelvin | The temperature difference between absolute zero and the triple point of water is defined as 273.16 kelvin |
| Current | ampere | One ampere is the current flowing through two infinitely long parallel conductors of negligible cross-section placed 1 metre apart in a vacuum and producing a force of 2×10^{-7} newtons per metre length of conductor |
| Luminous intensity | candela | One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz ($\text{Hz} \times 10^{12}$) and with a radiant density in that direction of 1.4641 mW/steradian. (1 steradian is the solid angle which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius) |
| Matter | mole | The number of atoms in a 0.012 kg mass of carbon-12 |

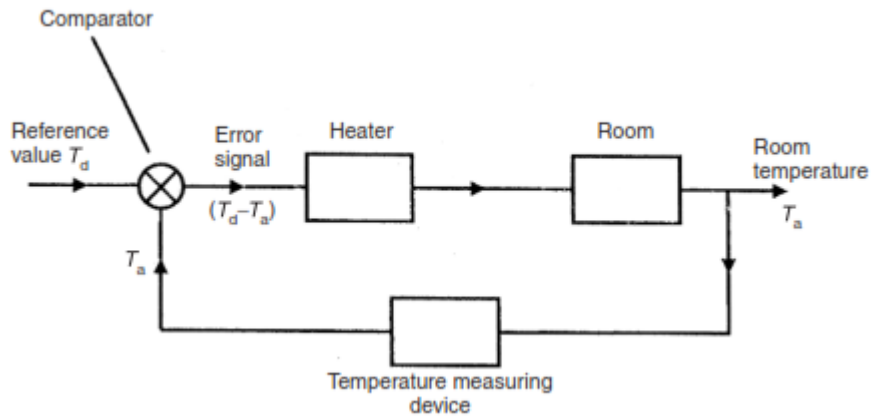


Fig. 2.1 Passive pressure gauge.

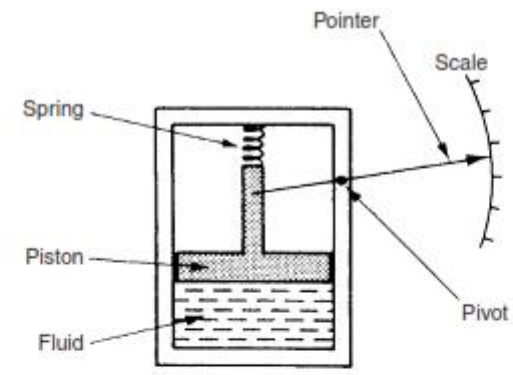


Fig. 2.2 Petrol-tank level indicator.

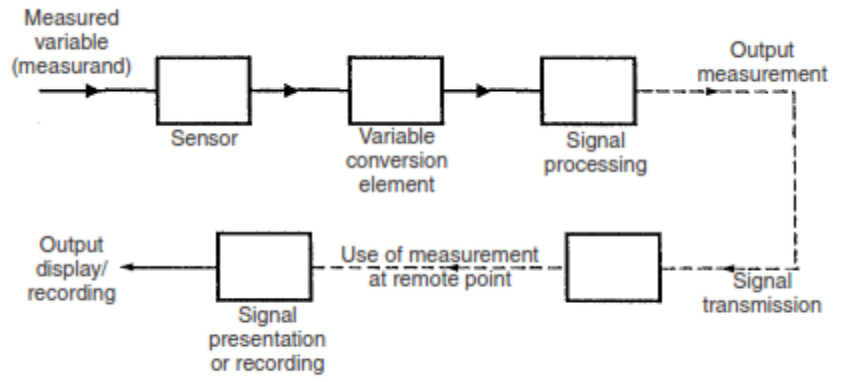
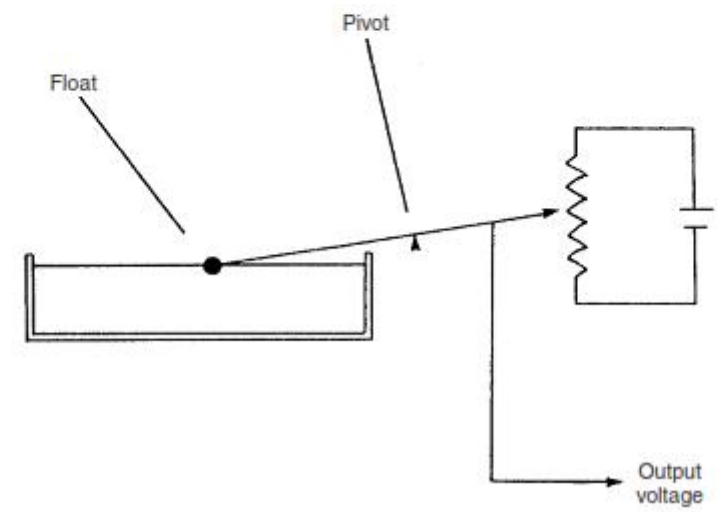


Fig. 1.2 Elements of a measuring instrument.

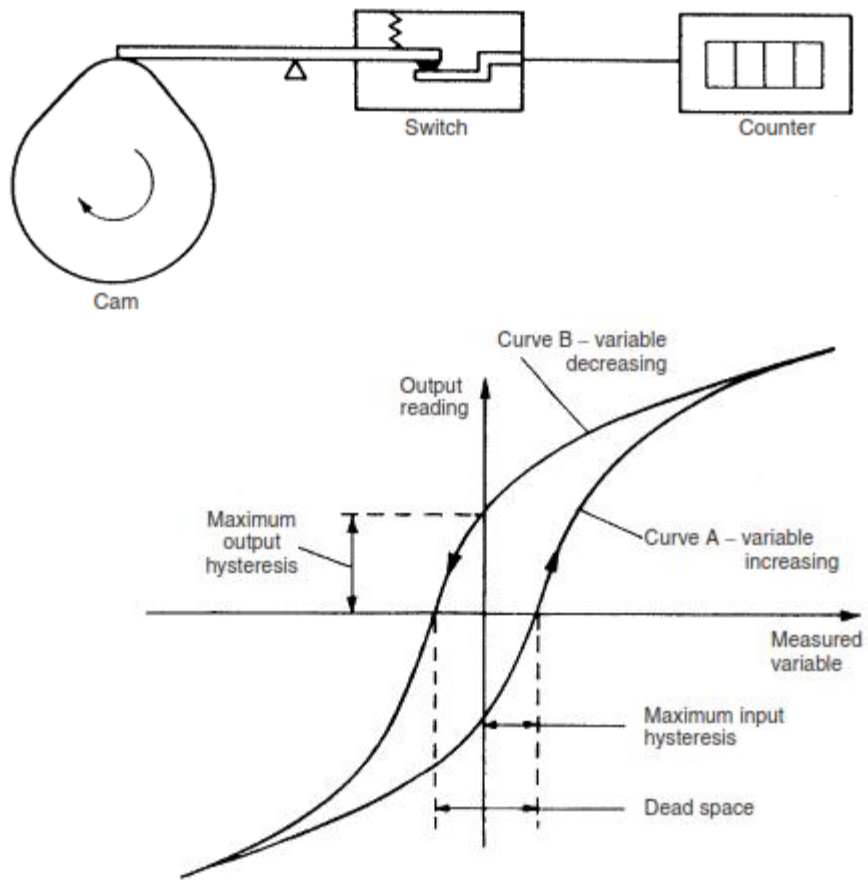


Fig. 2.8 Instrument characteristic with hysteresis.

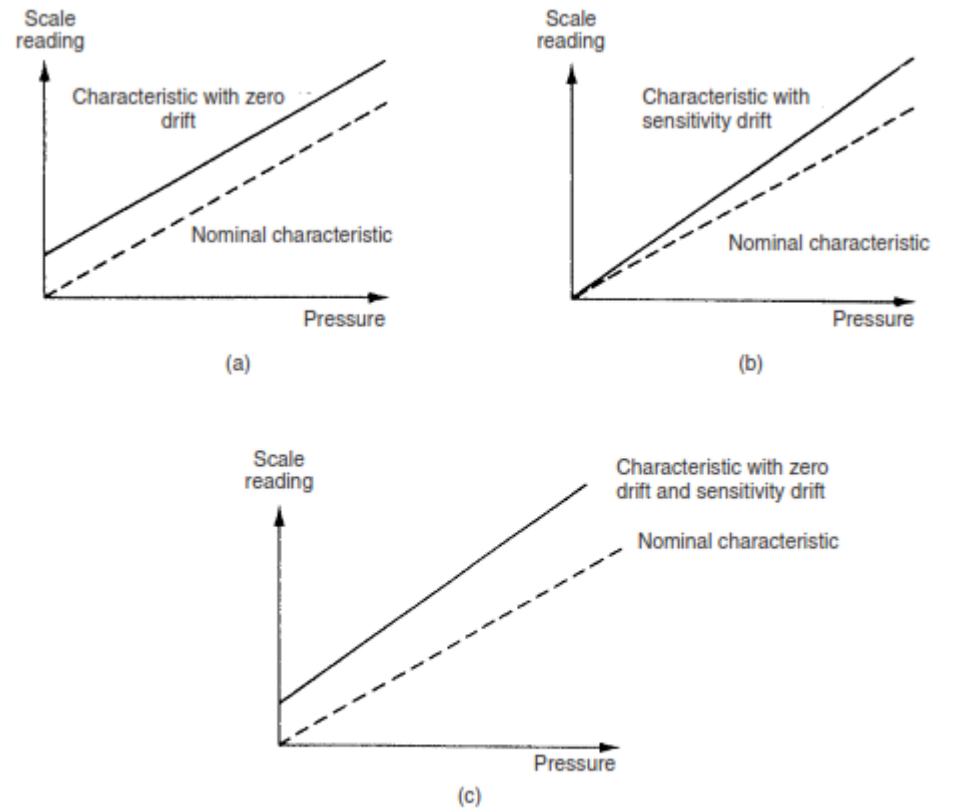


Fig. 2.7 Effects of disturbance: (a) zero drift; (b) sensitivity drift; (c) zero drift plus sensitivity drift.

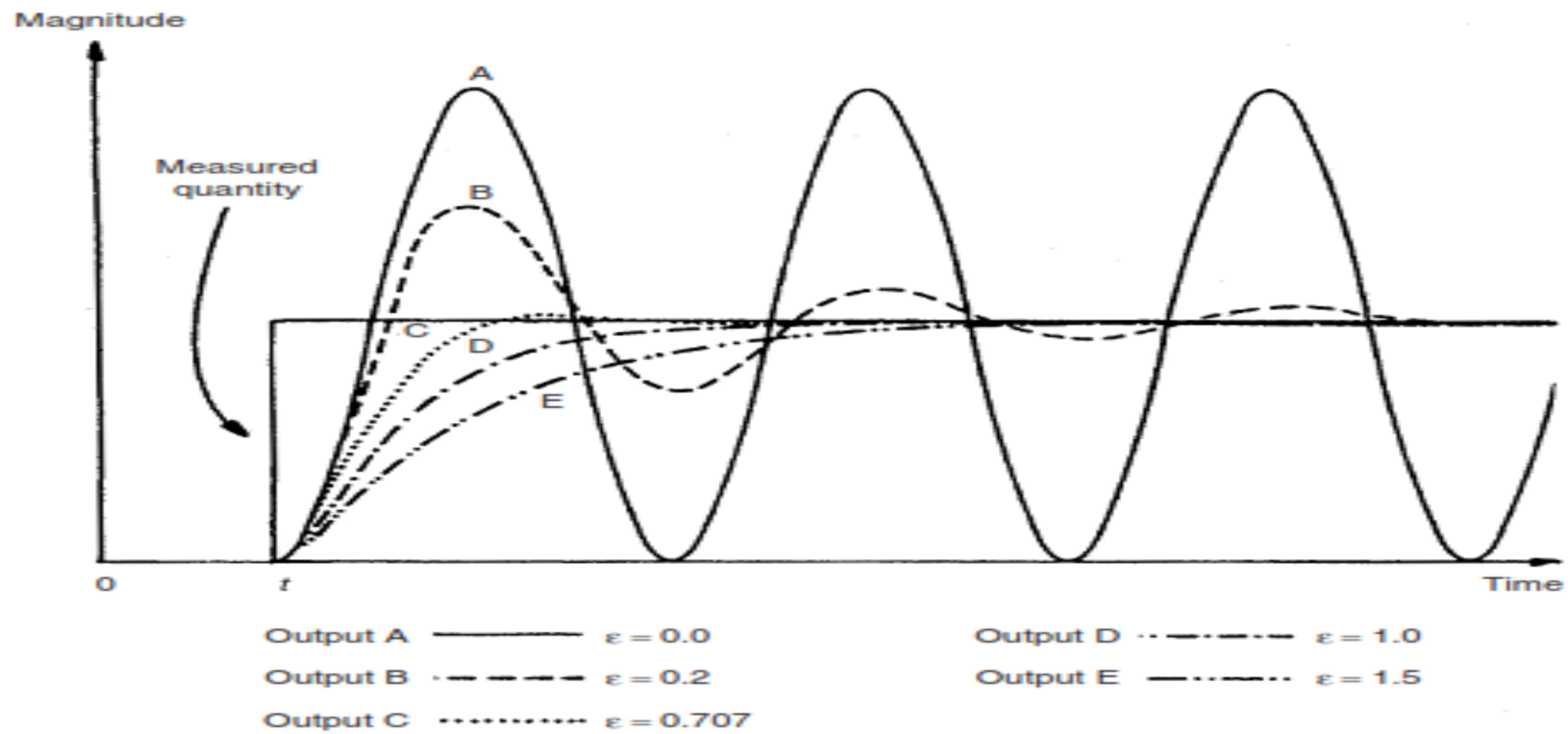


Fig. 2.12 Response characteristics of second order instruments.