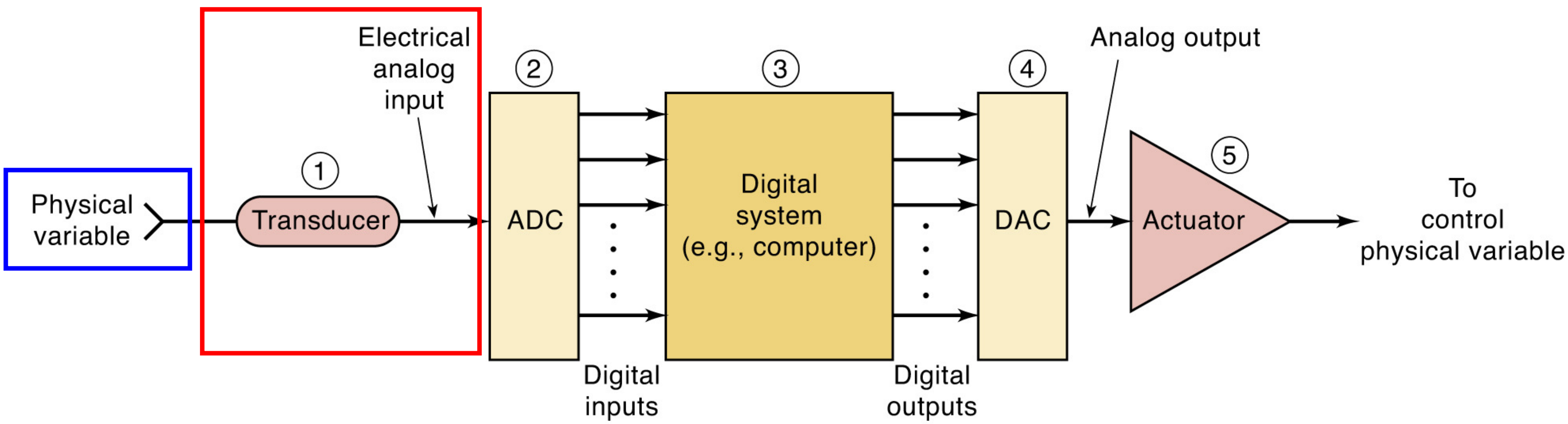
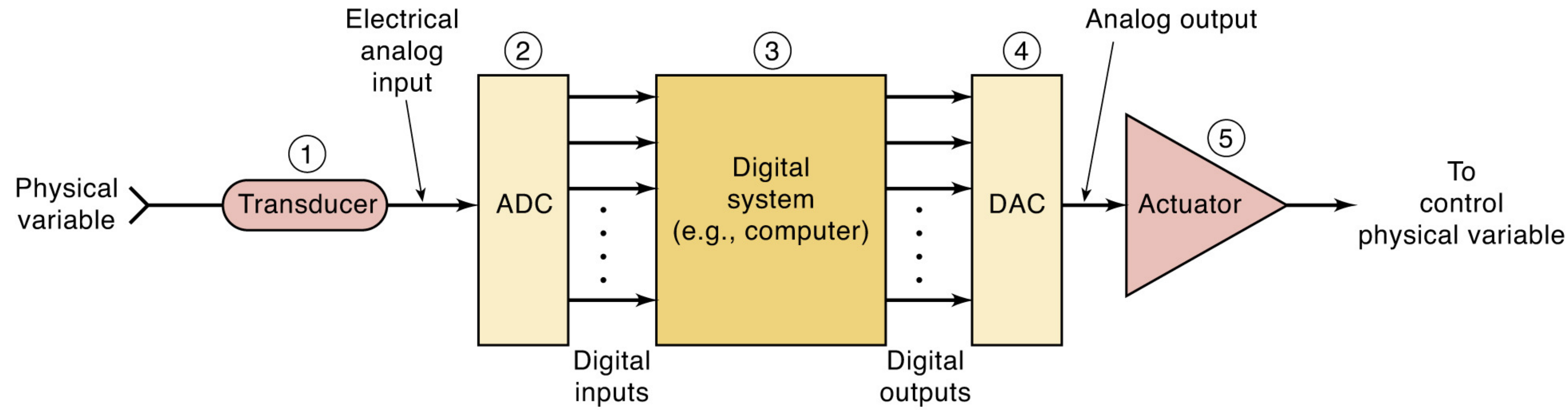
Interfacing With the Digital Analog World

Interfacing With the Analog World

- Most physical variables are analog, and can take on any value within a continuous range of values.
  - Normally a nonelectrical quantity.
- A **transducer** converts the physical variable to an electrical variable.
  - Thermistors, photo-cells, photodiodes, flow meters, pressure transducers, tachometers, etc.

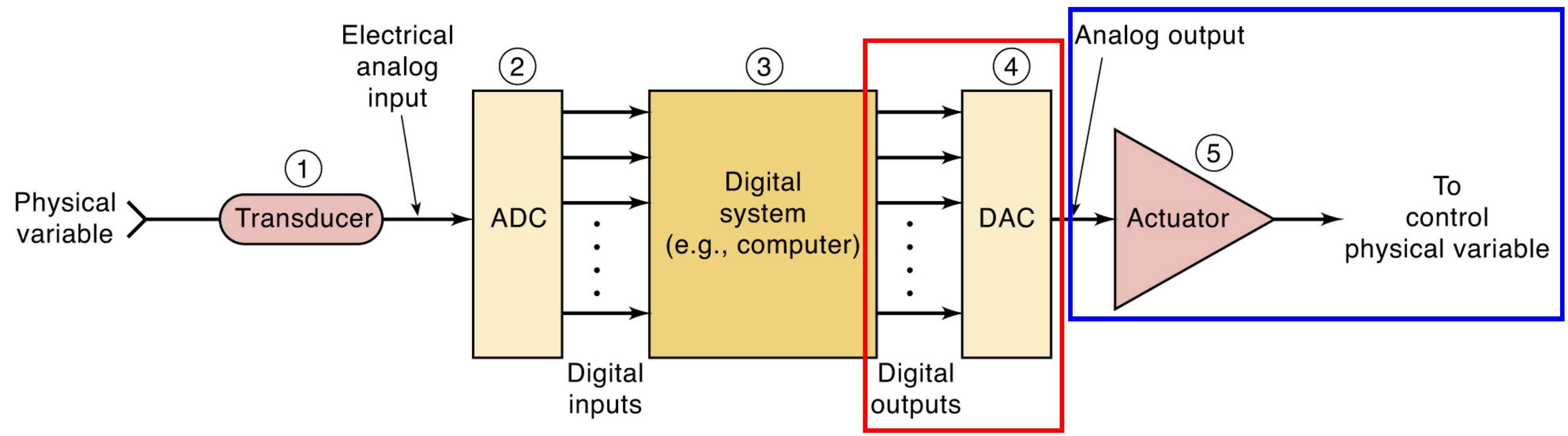


- The transducer's electrical analog output is the analog input to the **analog-to-digital converter**.
- The ADC converts analog input to a digital output
  - Output consists of a number of bits that represent the value of the analog input.
    - The binary output from the ADC is proportional to the analog input voltage.



Digital output from the computer is connected to a **digital-to-analog converter (DAC**).
Converted to a proportional analog voltage/current.

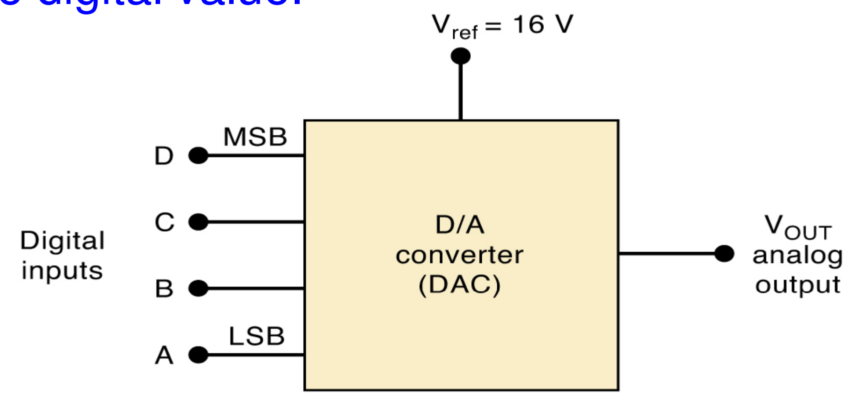
- The analog signal is often connected to some device or circuit that serves as an actuator to control the physical variable.
  - An electrically controlled valve or thermostat, etc.



Digital to Analog Conversion

- Many A/D conversion methods utilize the D/A conversion process.

➢ Converting a value represented in *digital* code to a voltage or current proportional to the digital value.



D	C	B	A	V_{OUT}	
0	0	0	0	0	Volts
0	0	0	1	1	
0	0	1	0	2	
0	0	1	1	3	
0	1	0	0	4	
0	1	0	1	5	
0	1	1	0	6	
0	1	1	1	7	
1	0	0	0	8	
1	0	0	1	9	
1	0	1	0	10	
1	0	1	1	11	
1	1	0	0	12	
1	1	0	1	13	
1	1	1	0	14	
1	1	1	1	15	Volts

•For each input number, the D/A converter output voltage is a unique value—in general:

$$\text{analog output} = K \times \text{digital input}$$

…where *K* is the proportionality factor and is a constant value for a given DAC connected to a fixed reference voltage.

- The quantity of possible output values can be increased, and the difference between successive values decreased—by increasing the input bits.

Allowing output more & more like an analog quantity that varies continuously over a range of values.

A "pseudo-analog" quantity, which approximates pure analog, referred to as analog for convenience.

Each digital input contributes a different amount to the analog output—*weighted* according to their position in the binary number.

D	*C*	*B*	*A*		V_{OUT} (V)
0	0	0	1	→	1
0	0	1	0	→	2
0	1	0	0	→	4
1	0	0	0	→	8

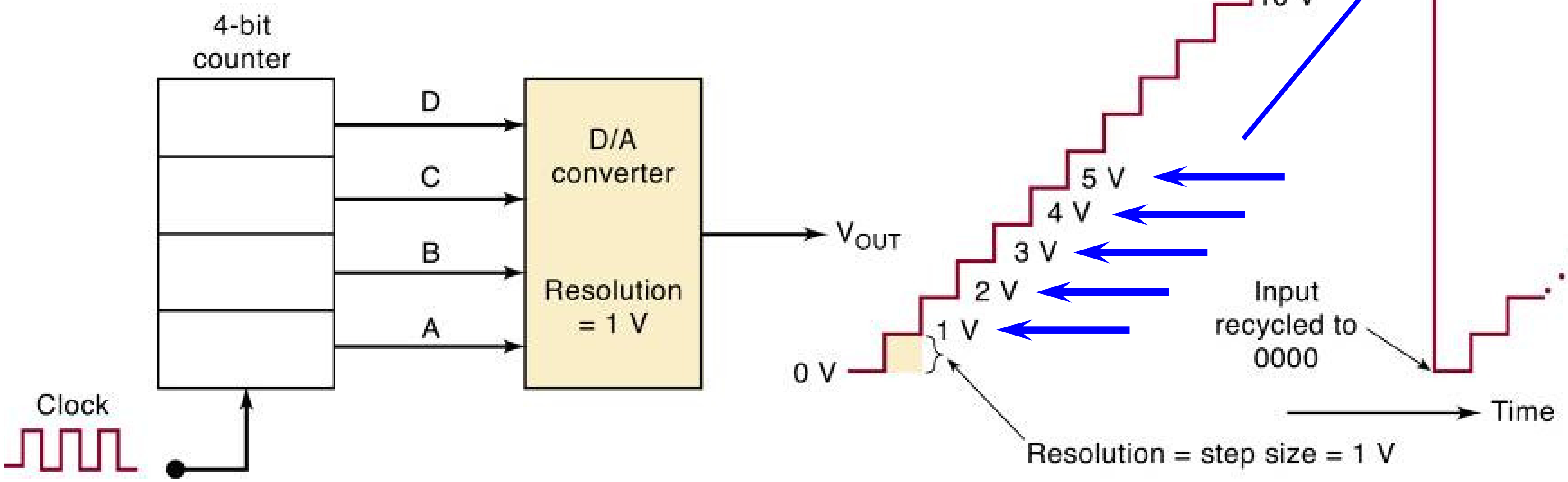
Weights are successively doubled for each bit, beginning with the LSB.

V_{OUT} can be considered to be the weighted sum of the digital inputs.

D	C	B	A	V_{OUT}	
0	0	0	0	0	Volts
0	0	0	1	1	
0	0	1	0	2	
0	0	1	1	3	
0	1	0	0	4	
0	1	0	1	5	
0	1	1	0	6	
0	1	1	1	7	
1	0	0	0	8	
1	0	0	1	9	
1	0	1	0	10	
1	0	1	1	11	
1	1	0	0	12	
1	1	0	1	13	
1	1	1	0	14	
1	1	1	1	15	Volts

- The **Resolution** of a D/A converter is defined as the smallest change that can occur in analog output as a result of a change in digital input.

Always equal to the weight of the LSB, called the **step size**, it is the amount V_{OUT} will change as digital input value changes from one step to the next.



- Resolution (step size) is the same as the DAC input/output proportionality factor:

$$\text{analog output} = K \times \text{digital input}$$

…where *K* is the proportionality factor and is a constant value for a given DAC connected to a fixed reference voltage.

Digital to Analog Conversion

- Many DACs can also produce negative voltages by making slight changes to the analog circuitry on the output of the DAC.

	Signed 2's Complement	DAC Inputs	DAC V_{out}
Most positive	01111111	11111111	$\sim + V_{ref}$
Zero	00000000	10000000	0 V
Most negative	10000000	00000000	$-V_{ref}$

Other DACs may have the extra circuitry built in and accept 2's complement signed numbers as inputs.

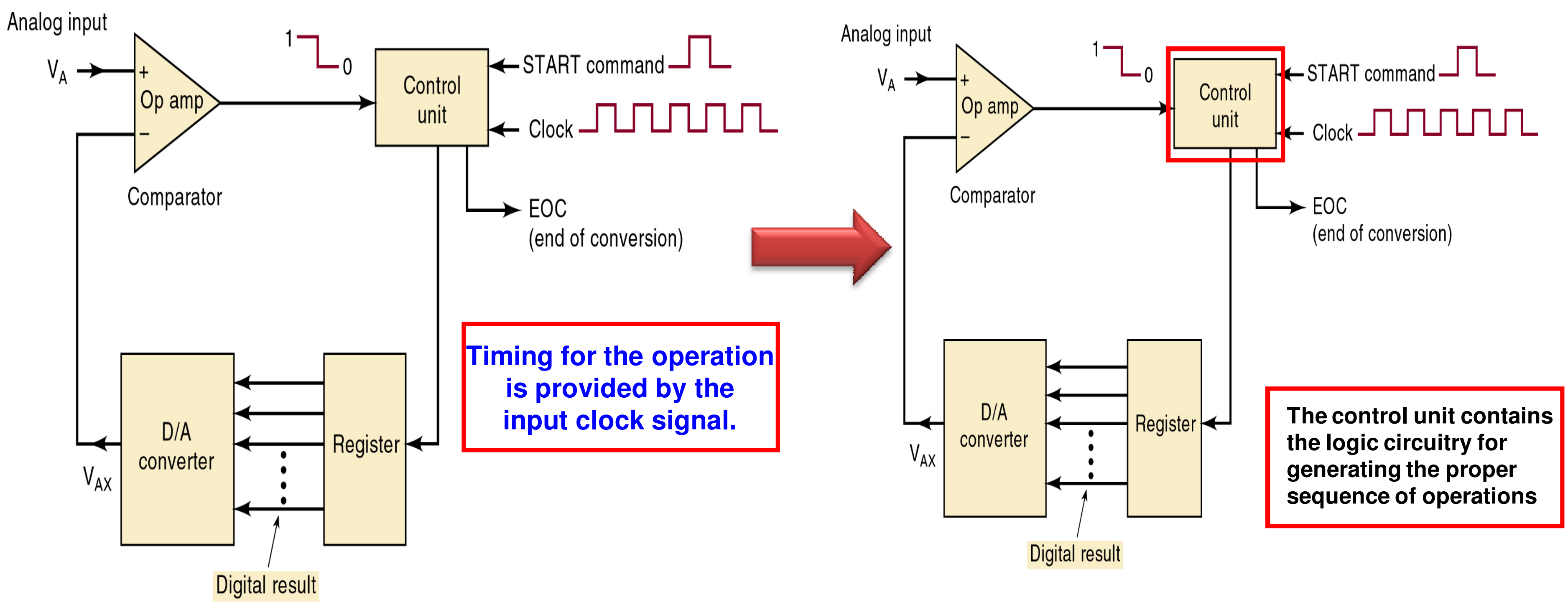
DAC Applications

- Used when a digital circuit output must provide an analog voltage or current.
  - **Control**—use a digital computer output to adjust motor speed or furnace temperature.
  - **Automatic testing**—computer generated signals to test analog circuitry.
  - **Signal reconstruction**—restoring an analog signal after it has been converted to digital.
  - **Digital amplitude control**—used to reduce the amplitude of an analog signal.
  - **Serial DACs**—with a built-in serial in/parallel out shift register—many have more than one DAC on the same chip.

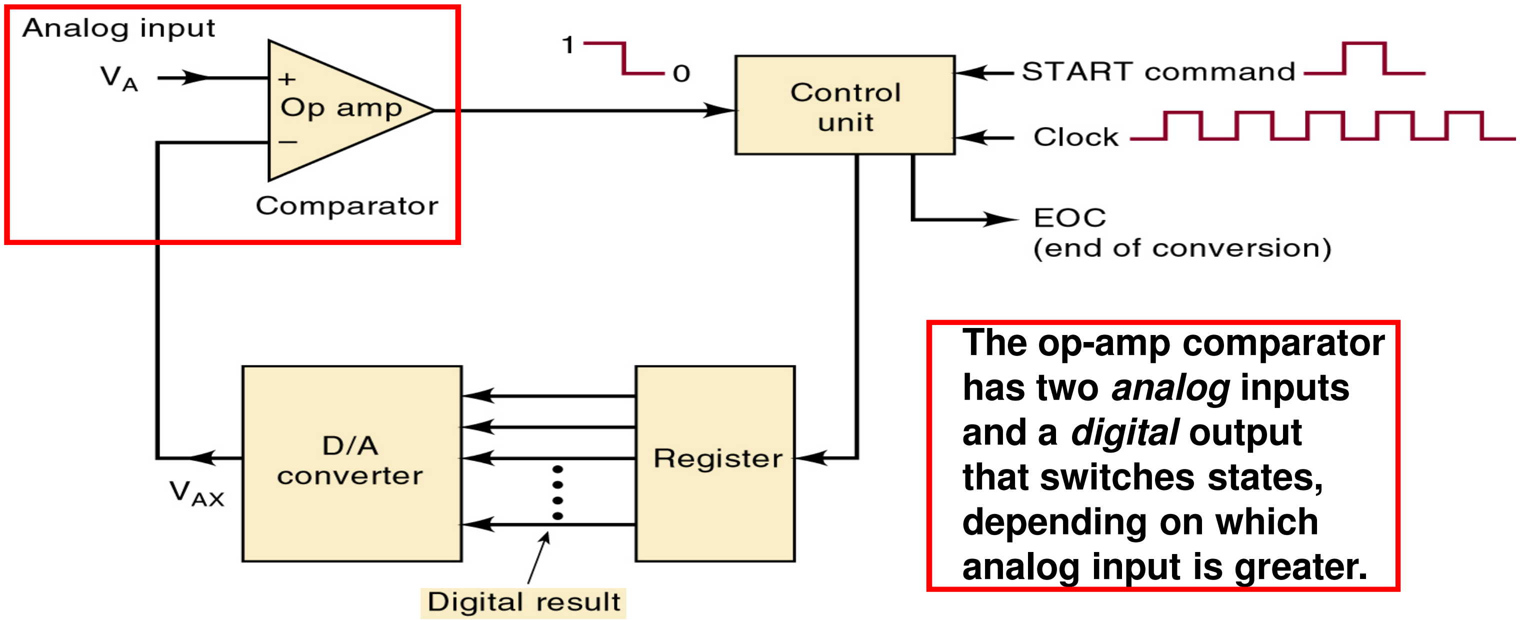
Analog to digital Conversion

- An analog-to-digital converter takes an analog input voltage and, after a certain amount of time, produces a digital output code that represents the analog input.
  - Several important types of ADCs utilize a DAC as part of their circuitry.
- The Op amp comparator ADC
  - Variations differ in how the control section continually modifies numbers in the register

General diagram of one class of ADCs.



General diagram of one class of ADCs.



The op-amp comparator has two *analog* inputs and a *digital* output that switches states, depending on which analog input is greater.

- **Basic operation of ADC types:**
  - **The START command pulse initiates the operation.**
  - **At a rate determined by the clock, the control unit continually modifies the binary number in the register.**
  - **The binary number in the register is converted to an analog voltage (V_{AX}), by the DAC.**
  - **The comparator compares V_{AX} with analog input V_A.**
    - **While $V_{AX} < V_A$,comparator output stays HIGH.**
    - **When V_{AX} exceeds V_A by at least an amount equal to V_T (threshold voltage), comparator out-put goes LOW and stops modifying the register number.**
  - **The control logic activates the end-of-conversion signal, *EOC*, when the conversion is complete.**

- One of the simplest versions of the general ADC uses a binary counter as the register and allows the clock to increment the counter one step at a time until $V_{AX} > V_A$.
- Called a **digital-ramp ADC** because the waveform at V_{AX} is a step-by-step ramp.

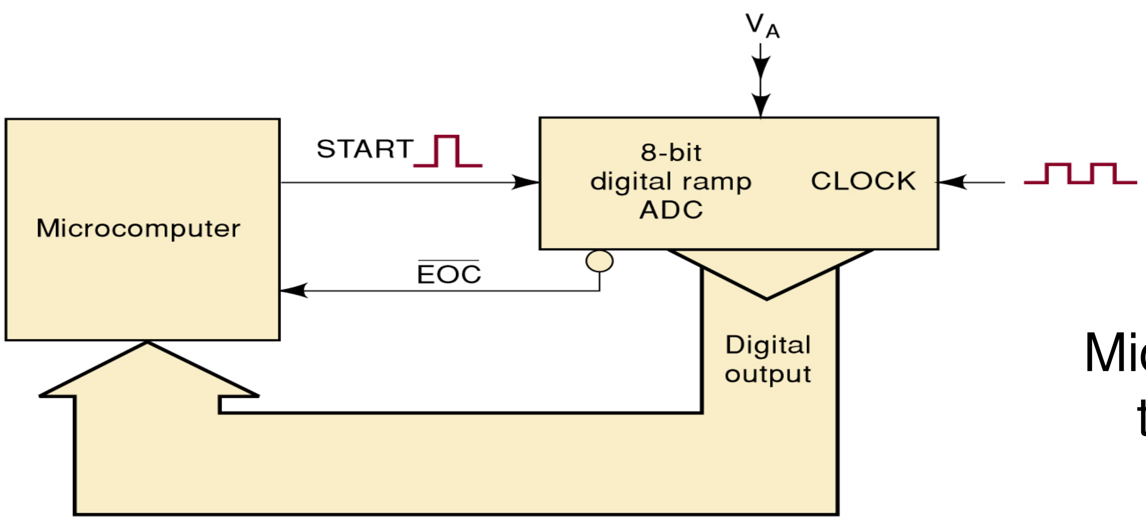
A/D resolution and accuracy.

•Measurement error is unavoidable.

•Reducing the step size can reduce but not eliminate potential error—called **quantization error**.

•Data Acquisition: The process by which the computer acquires digitized analog data is called *data acquisition*.

•Acquiring a single data point's value is referred to as **sampling** the analog signal. That data point is often called a *sample*



Microcomputer connected to a digital-ramp ADC for data acquisition.

Typical ADC Architecture for Applications

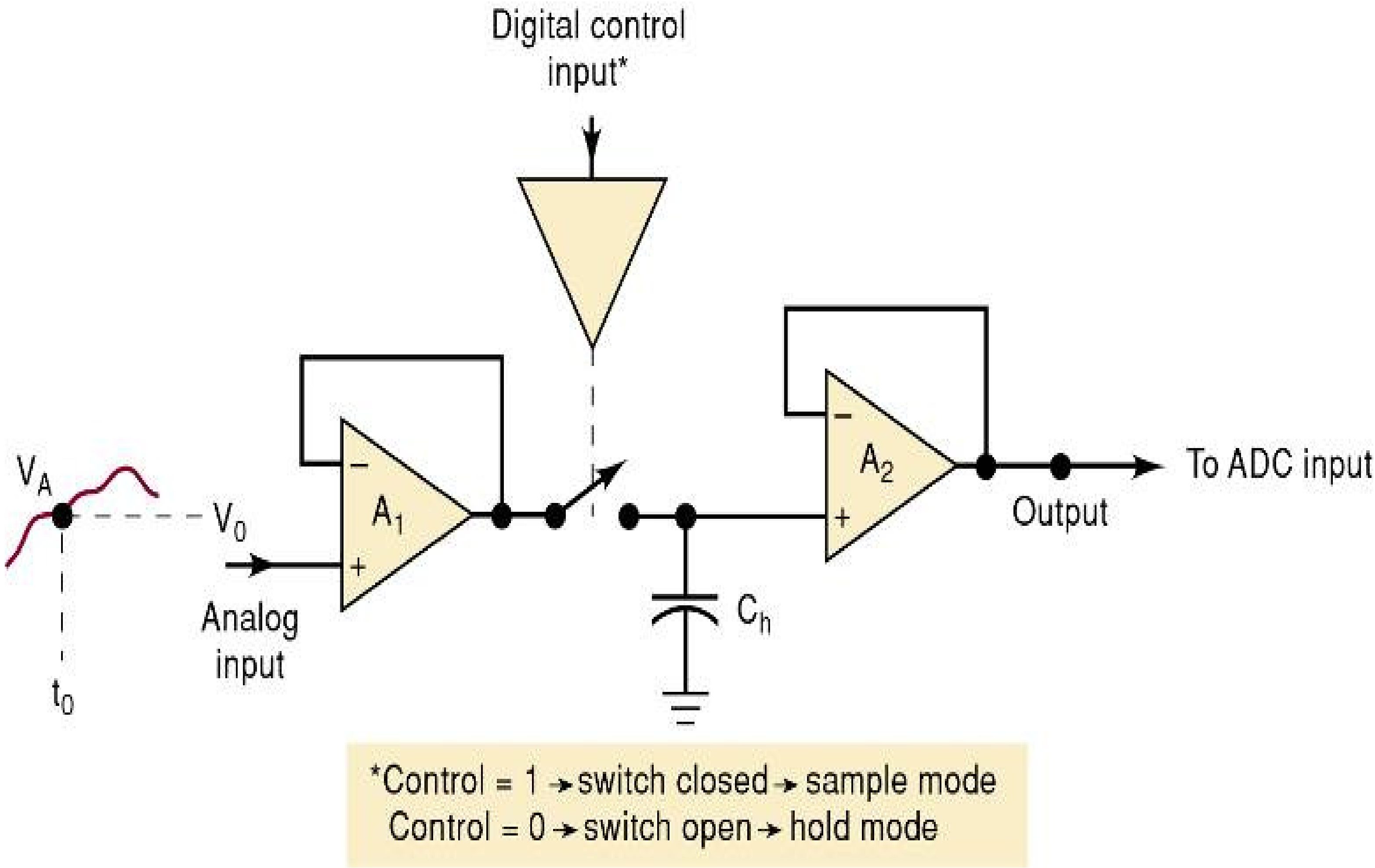
- **Most ADC applications fall into one of four areas:**
  - Precision industrial measurement.
  - Voice/audio.
  - Data acquisition.
  - High speed.

- Analog voltage connected directly to an ADC input conversion can be adversely affected if analog voltage is changing during the conversion time.

- Stability of conversion can be improved by using a **sample-and-hold** (**S/H**) **circuit**.
  - To hold the analog voltage constant while the A/D conversion is taking place.

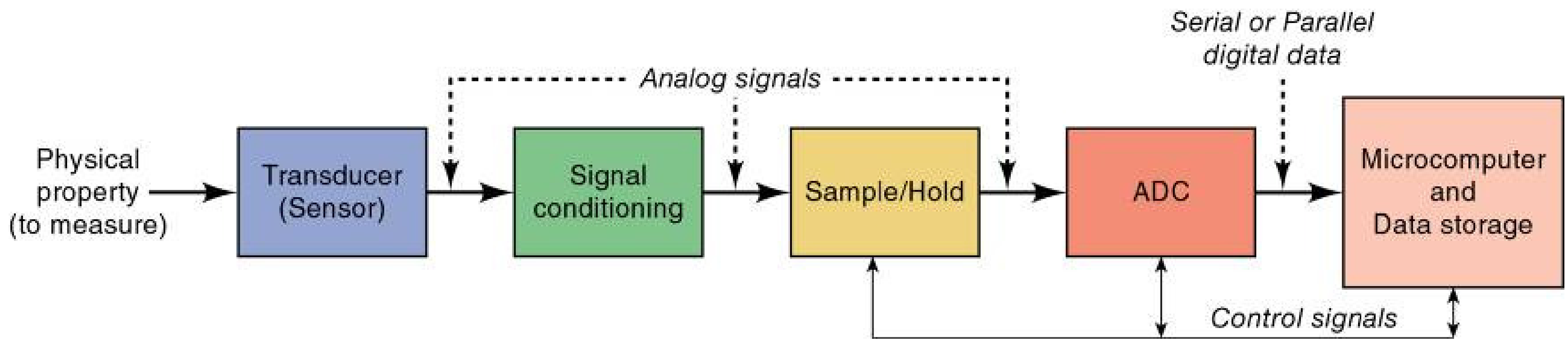
- In a computer-controlled data acquisition system the sample-and-hold switch would be controlled by a digital signal from the computer.
  - The amount of time the switch would have to remain closed is called the **acquisition time**

Simplified diagram of a sample-and-hold circuit.

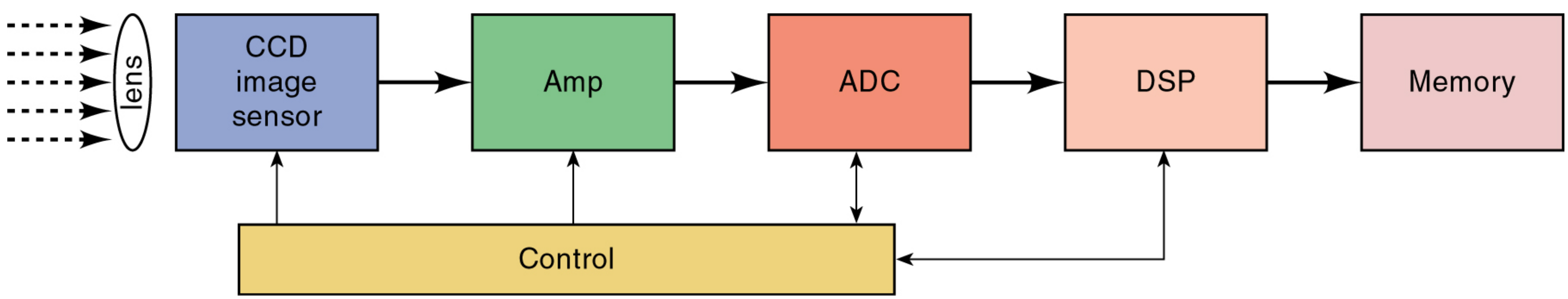


Applications of Analog Interfacing

Block diagram of a data acquisition system.



- A familiar application that interfaces analog devices to a digital system is a digital camera.
  - Transducer typically a charge-coupled device (CCD).
- Analog signals are read out of the CCD by shifting the electric charges through successive capacitors under the control of drivers and timing circuits.
  - Amplified (signal conditioning) and then digitized by the ADC.



- The DSP block applies image signal-processing algorithms to the digital data before storing the information in a memory device.
  - Data are usually compressed.

- **Data compression** is the process of encoding information with fewer bits representing the data.
  - Only works when both the sender and receiver of the information understand the specific encoding scheme.