Instrumentation and data acquisition
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Lecture 3: Sensors, signals, ADC and DAC

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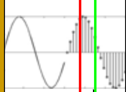
Acquire, process and output data

Part 1 **Sensors**

Acquire and convert measured phys. parameter to electrical signal

Examples

- -Light intensity
- -Temperature
- -Sound
- -Pressure
- -Humidity
- -pH
- -Radiation
- -Motion
- -Etc.



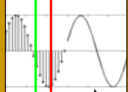
ADC

Part 2 **Computers**

Store and/or process the input signal/data to obtain information

Examples

- -PC
- -Calculator
- -Mobile phone
- -PDA
- -DVD player
- -Industrial robot
- -Digital camera
- -Toys
- -Etc.



DAC

Part 1 **Actuators**

Act on physical parameter/world based on signal/data

Examples

- -Electrical motor
- -Loud speaker
- -Pump
- -Lifting columns
- -Valve
- -Switch
- -Display (LCD,CRT)
- -Light bulb
- -Etc.

Part I: Sensors

- Sensors
- Signal generators and signals
- ADC and DAC

Thermometer

- A thermometer measures temperature through the regular variation of some physical property of the material inside the thermometer.

Types of thermometers

- Liquid-in-glass thermometer
  - mercury-in-glass
  - alcohol-in-glass
- Other materials which can vary with temperature: resistance, current, length, color, infra-red
  - Rotary thermometer
  - Resistance thermometer
  - Liquid crystal thermometer
  - Thermistor thermometer
  - Thermocouple thermometer
  - Infra-red thermometer

Liquid-in-glass thermometer

- Maximum thermometer
  - Can be mounted in any orientation
  - Usually mercury filled
  - Usually are liquid-in-glass thermometers that record maximum observed temperature
- Minimum thermometer
  - Usually horizontally mounted
  - Usually alcohol filled
  - Floating index lowers with decreasing temperature
  - Usually are liquid-in-glass thermometers that record minimum observed temperatures

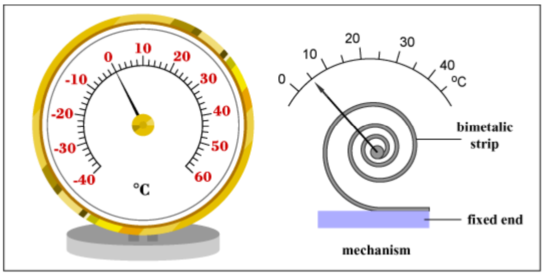
Resistance thermometer

- Also called resistance temperature detectors or resistive thermal devices (RTDs).
- Exploit the predictable change in electrical resistance of some materials with changing temperature.
- As made of platinum, they are often called platinum resistance thermometers (PRTs). They are slowly replacing the use of thermocouples in many industrial applications below 600 °C, due to higher accuracy and repeatability.

Thermocouple

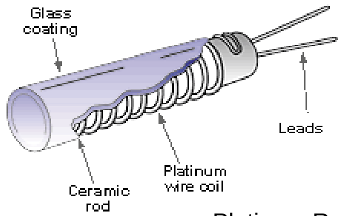
- A thermocouple is a junction between two different metals that produces a voltage related to a temperature difference. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert heat into electric power.
- They are inexpensive and interchangeable and can measure a wide range of temperatures.
- The main limitation is accuracy: relatively high system errors.

Examples



Rotary thermometer

Infra-red thermometer



Platinum Resistance Thermometer

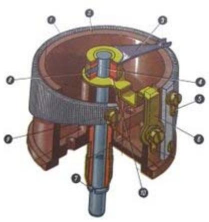
Potentiometer

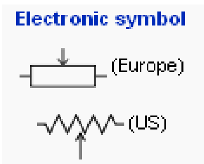
- A three-terminal resistor with a sliding contact that forms an adjustable voltage divider. If only two terminals are used (one side and the wiper), it acts as a variable resistor.
- Used to control electrical devices such as volume controls on audio equipment. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick.

Potentiometer

- Potentiometers are rarely used to directly control significant power (more than a watt).
- Instead they are used to adjust the level of analog signals (e.g. volume controls on audio equipment), and as control inputs for electronic circuits. For example, a light dimmer uses a potentiometer to control the switching of a TRIAC (Triode for Alternating Current) and so indirectly control the brightness of lamps.

Potentiometer

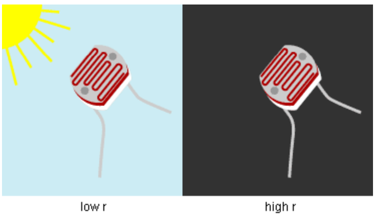


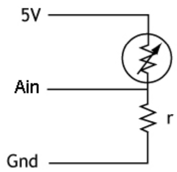


Wikipedia.org

Photoelectric cell or photocell

- Whose electrical characteristics (e.g., current, voltage or resistance) vary with light.
- Most common, a type of resistor. When light strikes the cell, it allows current to flow more freely. When dark, its resistance increases dramatically.





Part II: Signal generators and signals

- Sensors
- Signal generators and signals
- ADC and DAC

Function generator/signal generator

- A function generator is a piece of electronic test equipment or software used to generate electrical waveforms, which can be either repetitive, or single-shot (triggering source is required, internal or external).

Triangle wave

- Analog function generators usually generate a triangle waveform as the basis for all of its other outputs.
- The triangle is generated by repeatedly charging and discharging a capacitor from a constant current source. This produces a linearly ascending or descending voltage ramp. As the output voltage reaches upper and lower limits, the charging and discharging is reversed using a comparator, producing the linear triangle wave.
- By varying the current and the size of the capacitor, different frequencies may be obtained.

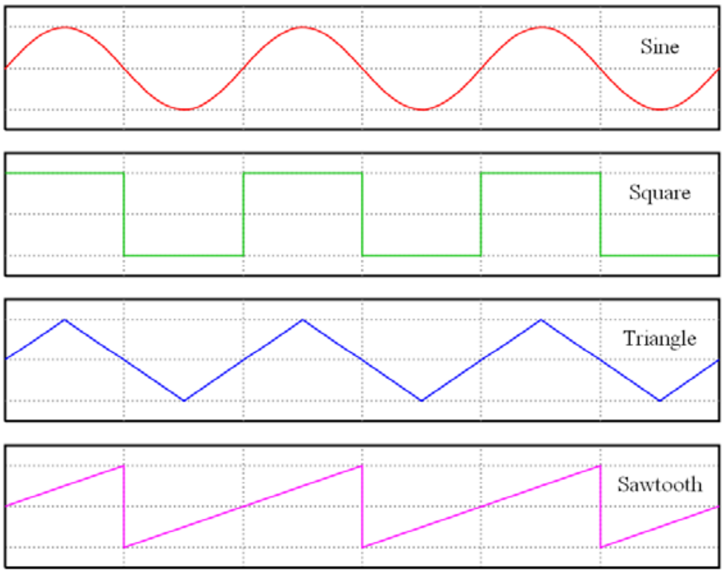
Square wave

- A 50% duty cycle square wave is easily obtained by noting whether the capacitor is being charged or discharged, which is reflected in the current switching comparator's output. Most function generators also contain a non-linear diode shaping circuit that can convert the triangle wave into a reasonably accurate sine wave. It does so by rounding off the hard corners of the triangle wave in a process similar to clipping in audio systems.

Pulse train

- Ideal pulse train has rectangular pulses.
- A pulse wave or pulse train is a kind of non-sinusoidal waveform that is similar to a square wave, but does not have the symmetrical shape associated with a perfect square wave. The pulse wave is also known as the rectangular wave, the periodic version of the rectangular function.

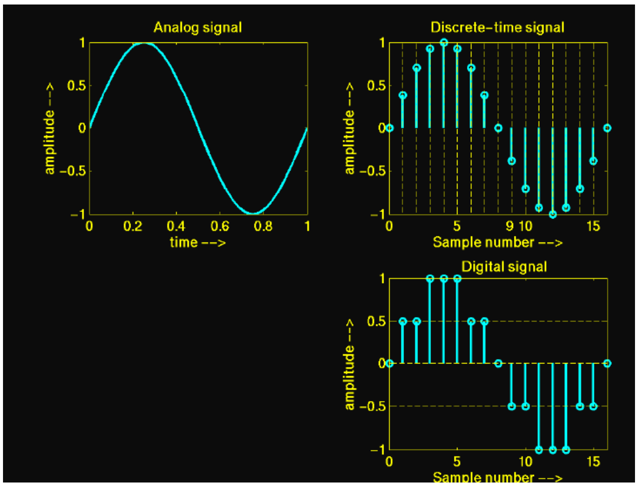
Signals



Types of signals

- The independent variable may be either continuous or discrete
  - Continuous-time signals
  - Discrete-time signals are defined at discrete times and represented as sequences of numbers
- The signal amplitude may be either continuous or discrete
  - Analog signals: both time and amplitude are continuous
  - Digital signals: both are discrete
- Computers and other digital devices are restricted to discrete time
- Signal processing systems classification follows the same lines

Types of signals



Digital signal processing

- Modifying and analyzing information with computers – so being measured as sequences of numbers.
- Representation, transformation and manipulation of signals and information they contain

Discrete-time signals

- Sequences of numbers

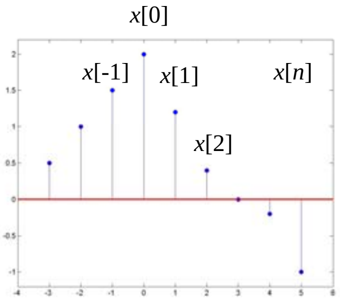
$$x = \{x[n]\}, \qquad -\infty < n < \infty$$

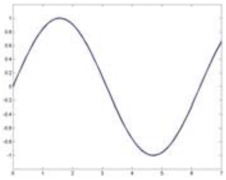
where n is an integer

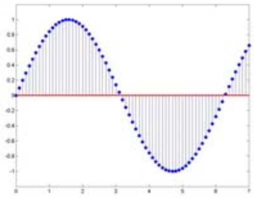
- Periodic sampling of an analog signal

$$x[n] = x_a(nT), \qquad -\infty < n < \infty$$

where T is called the sampling period.







Sequence operations

- The product and sum of two sequences x[n] and y[n]: sample-by-sample production and sum, respectively.
- Multiplication of a sequence x[n] by a number α : multiplication of each sample value by α.
- Delay or shift of a sequence x[n]

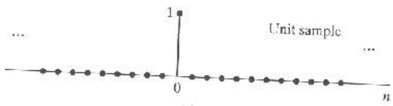
$$y[n] = x[n - n_0]$$

where n is an integer

Basic sequences

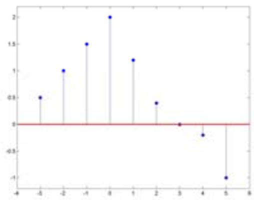
- Unit sample sequence (discrete-time impulse, impulse)

$$\delta[n] = \begin{cases} 0, & n \neq 0, \\ 1, & n = 0, \end{cases}$$



- Any sequence can be represented as a sum of scaled, delayed impulses

$$x[n] = a_{-3}\delta[n+3] + a_{-2}\delta[n+2] + ... + a_5\delta[n-5]$$



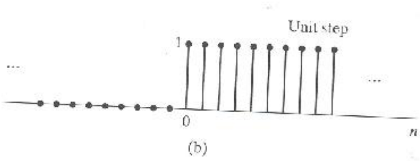
- More generally

$$x[n] = \sum_{k=-\infty}^{\infty} x[k]\delta[n-k]$$

Unit step sequence

- Defined as

$$u[n] = \begin{cases} 1, & n \geq 0, \\ 0, & n < 0, \end{cases}$$



- Related to the impulse by

$$u[n] = \delta[n] + \delta[n-1] + \delta[n-2] + ...$$

or

$$u[n] = \sum_{k=-\infty}^{\infty} u[k]\delta[n-k] = \sum_{k=0}^{\infty} \delta[n-k]$$

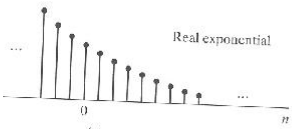
- Conversely,

$$\delta[n] = u[n] - u[n-1]$$

Exponential sequences

- Extremely important in representing and analyzing LTI systems.
- Defined as

$$x[n] = A\alpha^n$$



- If A and α are real numbers, the sequence is real.
- If $0 < \alpha < 1$ and A is positive, the sequence values are positive and decrease with increasing n.
- If $-1 < \alpha < 0$, the sequence values alternate in sign, but again decrease in magnitude with increasing n.
- If $|\alpha| > 1$, the sequence values increase with increasing n.

$x[n] = 2 \cdot (0.5)^n$

$x[n] = 2 \cdot (-0.5)^n$

$x[n] = 2 \cdot 2^n$

Combining basic sequences

- An exponential sequence that is zero for n<0

$$x[n] = \begin{cases} A\alpha^n, & n \geq 0, \\ 0, & n < 0 \end{cases}$$

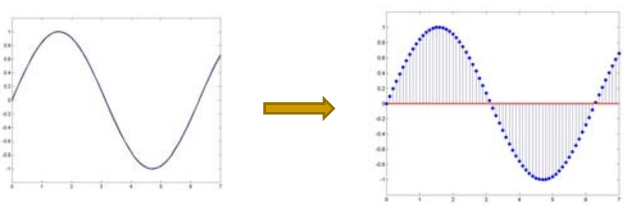
$$x[n] = A\alpha^n u[n]$$

Part III: ADC and DAC

- Sensors
- Signal generators and signals
- ADC and DAC

Analog-to-digital converter

- Sampling
  - What the ADC circuit does is to take samples from the analog signal from time to time. Each sample will be converted into a number, based on its voltage level.



Analog-to-digital converter

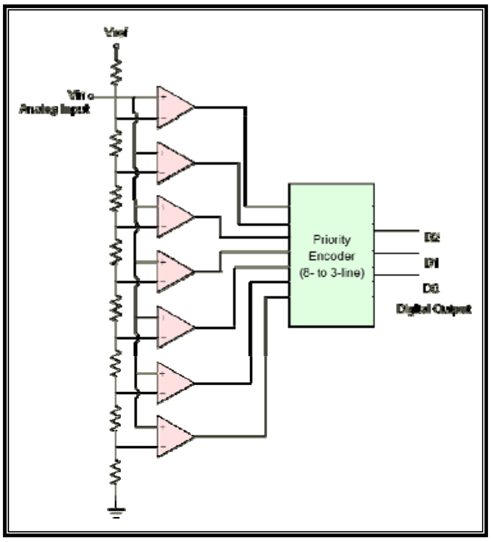
- Resolution
  - ADC divides the “y” axis in “n” possible parts between the maximum and the minimum values of the original analog signal.
  - If “n” is too small, what will happen is that two sampling points close to each other will have the same digital representation, thus not corresponding exactly to the original value, making the analog waveform available at the DAC output to not have the best quality.

ADC principle and designs

- Principle of operation
  - The principle is to use the comparator principle to determine whether or not to turn on a particular bit of the binary number output.
  - It is typical for an ADC to use a DAC to determine one of the inputs to the comparator.
- Designs
  - Parallel design (flash ADC).
  - Digital-to-Analog Converter-based design.
  - Integrator-based design.
  - Sigma-Delta design.
  - Pipeline design.

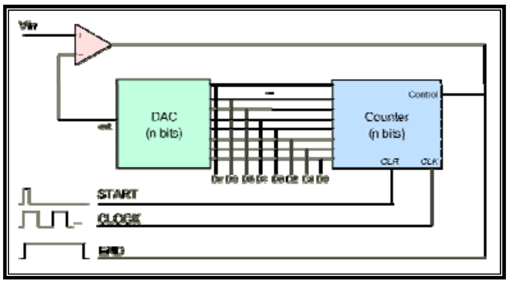
Parallel design (flash ADC)

- Compare the input voltage of the analog signal to a reference voltage.
- For example, if the reference voltage is of 5 volts, this means that the peak of the analog signal would be 5 volts. On an 8-bit ADC when the input signal reached 5 volts we would find a 255 (11111111) value on the ADC output, i.e. the maximum possible value.
- It is the fastest type of ADC available, but requires a comparator for each value of output. (63 for 6-bit, 255 for 8-bit, etc.)

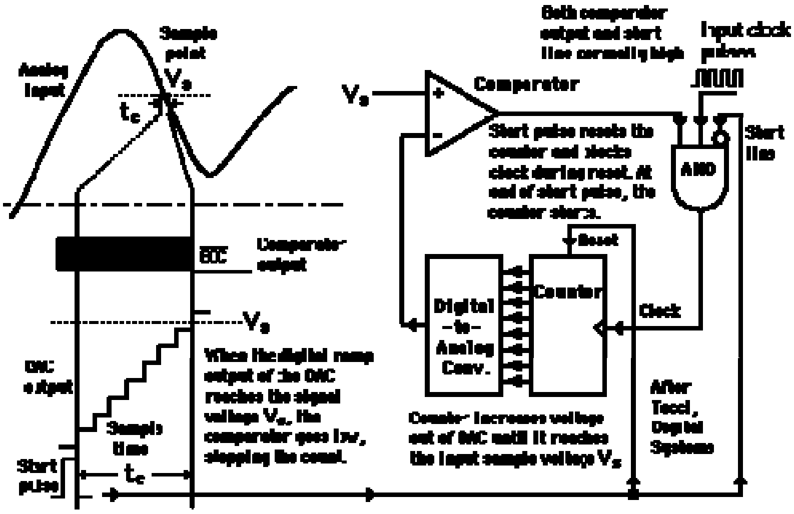


DAC converter based design

- Design an ADC using a DAC as part of its circuit. One example: the ramp counter.
- V_{in} is the analog input and D_n through D_0 are the digital outputs. The control line found on the counter turns on the counter when it is low and stops the counter when it is high.
- The basic idea is to increase the counter until the value found on the counter matches the value of the analog signal. When this condition is met, the value on the counter is the digital equivalent of the analog signal.



Digital-Ramp ADC



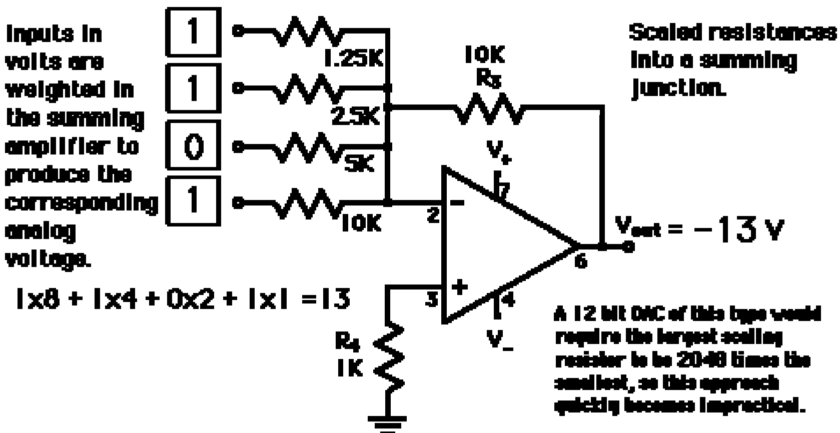
Applications example: audio CD

- Music is actually sound waves (analog). To store these analog data in a CD, we have to first convert them into digital storable data - ADCs are used.
- In case of audio CD, a high sampling rate is used (44,100 Hz) to achieve a good sound resolution.
- When playing the audio CD, an inverse process is done: A DAC is used to re-convert the digital data stored in the CD back to its original format (analog data).

Digital-to-analog conversion

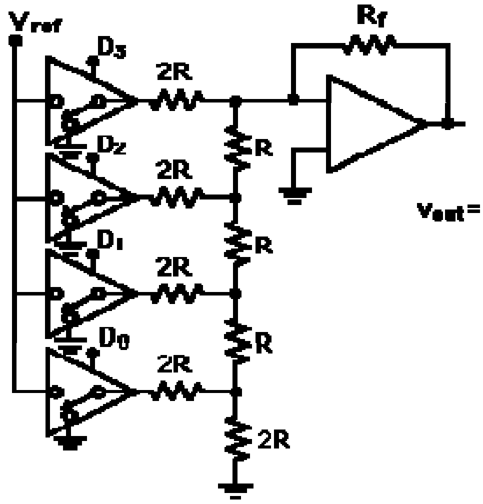
- Data in clean binary digital form can be converted to an analog form.
- Approaches
  - Weighted summing amplifier
  - R-2R Network Approach

Weighted sum DAC



- This approach is not satisfactory for a large number of bits because it requires too much precision in the summing resistors.
- This problem is overcome in the R-2R network DAC.

R-2R ladder DAC



$$V_{out} = \frac{R_f}{R} V_{ref} \left[\frac{D_0}{16} + \frac{D_1}{8} + \frac{D_2}{4} + \frac{D_3}{2} \right]$$

Summary

- Sensors
- Signal generators and signals
- ADC and DAC