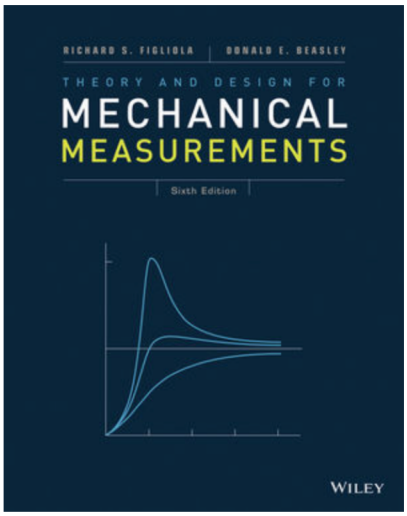


Digital Sampling

Engr325

Instrumentation

Dr Curtis Nelson

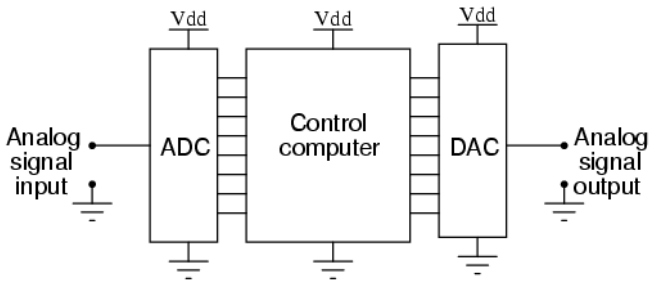
This Lecture

- Digital sampling
  - Sample rate.
  - Bit depth.
  - Other terms.
  - Types of conversion.

Data Acquisition and Control

- Computers are nearly always in the middle of any instrumentation system. They provide a complete interface between sensors and output devices.

Digital control system with analog I/O



Digital Sampling

Analog Signal → Digital Signal

Using transducers that provide an electrical output for measurement typically involves digital conversions.

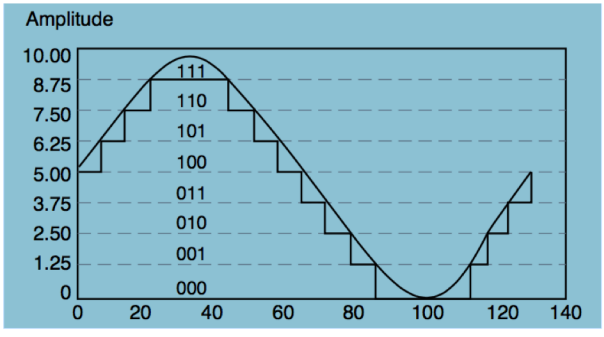
Digital Sampling

Uses binary numbers to represent the analog input value. The more binary digits (BITS) used, the greater the resolution of the signal and the smaller the quantization error (defined later) involved in the process.

Examples:

- **4 bit resolution** provides 16 values (2^4).
- **8 bit resolution** provides 256 values (2^8).
- **12 bit resolution** provides 4096 values (2^{12}).
- **16 bit resolution** provides 65536 values (2^{16}).

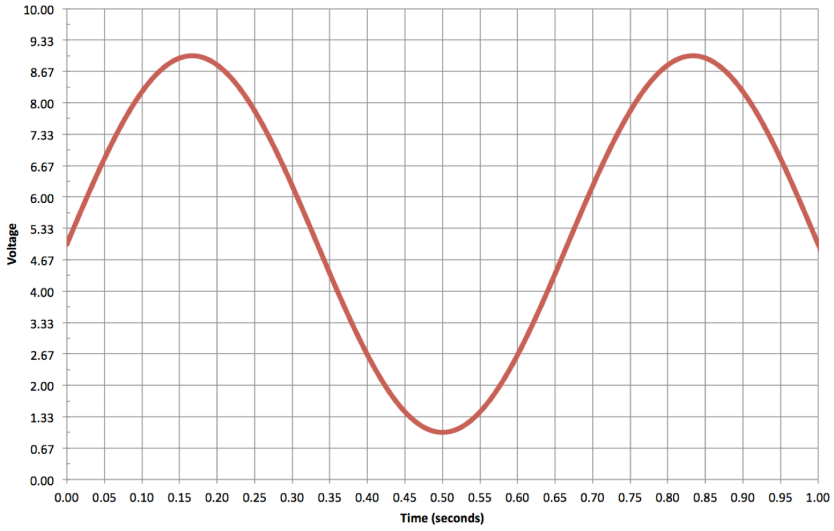
Digitized Sine Wave



Digitized Sine Wave with a Hypothetical 3-Bit ADC

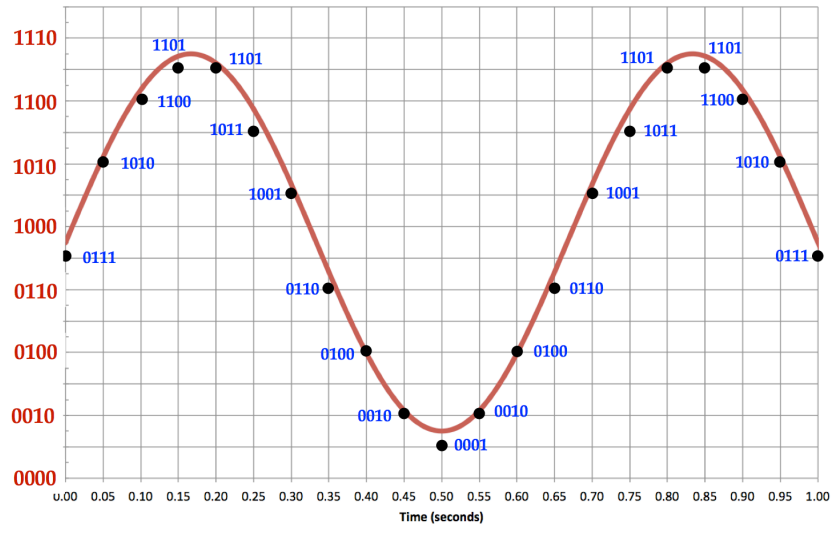
Digital Sampling Example

0-10 volt analog input divided into 16 intervals corresponding to a 4-bit digital conversion.



Digital Sampling Example

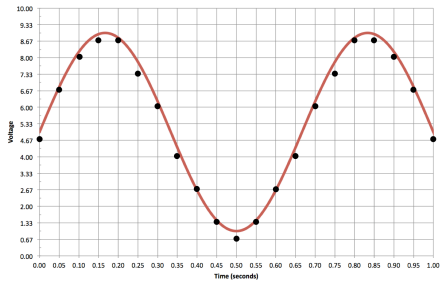
0-10 volt analog input divided into 16 intervals corresponding to 4-bit digital conversion.



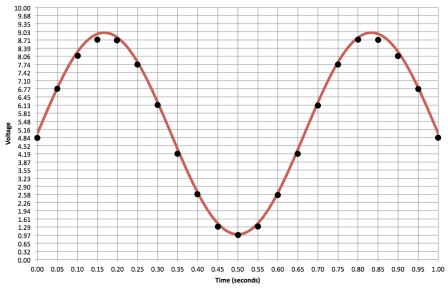
Digital Sampling Example

Comparison of 4-bit vs. 5-bit Sampling

16 divisions: 0000 to 1111



32 divisions: 00000 to 11111



Quantization Error is reduced by using higher resolution (more binary digits).

Range of Value of Digitized Quantities

No of bits	Number of States	Resolution (%)
1	$2^1 = 2$	50
2	$2^2 = 4$	25
3	$2^3 = 8$	12.5
4	$2^4 = 16$	6.25
8	$2^8 = 256$	0.391
10	$2^{10} = 1024$	0.098
12	$2^{12} = 4096$	0.024
16	$2^{16} = 65536$	0.001526
20	$2^{20} = 1048576$	0.000095

Analog-to-Digital (ADC) Conversion Terms

- EFSR - Effective full scale range
  - Also called the *Input Span* for an A/D converter.
  - Examples: 0-5V, -5 to +5v, 0-10V, 0 – 20mA
- Sampling Rate
  - How often an analog signal is sampled.
  - Example: 44,100 samples per second, measured in Hz.
- Sampling Resolution
  - The smallest signal that can be detected by a measurement system. Another way to say it: the smallest voltage increment that causes a bit change.
  - Resolution can be expressed in bits, proportions, or percentage of full scale.
  - Example: 12-bit resolution, one part in 4096 resolution, or 0.0244% of full scale.

ADC Example

- An 8-bit ADC with an input range of 10 V could detect a minimum of 10/256 = 0.0391 V. The higher the resolution, the smaller the detectable voltage change.
- How many bits are needed to detect a change of 100μV?

  $10/x = 0.0001$ $x = 100{,}000$ $2^n = 100{,}000$ $n = 17$ bits

- How many bits are needed to obtain a resolution of 0.01%?

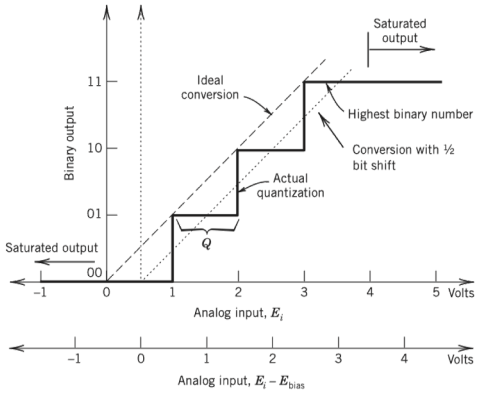
  14 bits

More ADC Conversion Terms

- Accuracy
  - The difference between the actual output voltage and an accepted standard.
- Least Significant Digit or Bit (LSB)
  - The rightmost digit or bit
  - Example: 001 (the 1 is the LSB)
- Most Significant Digit or Bit (MSB)
  - The leftmost digit or bit
  - Example: 100 (the 1 is the MSB)

More ADC Conversion Terms

- Quantization error
  - The inherent uncertainty in an A/D conversion due to the finite resolution of the system.
  - Quantization error is usually defined as ± 1LSB or ± ½ LSB



Final ADC Term

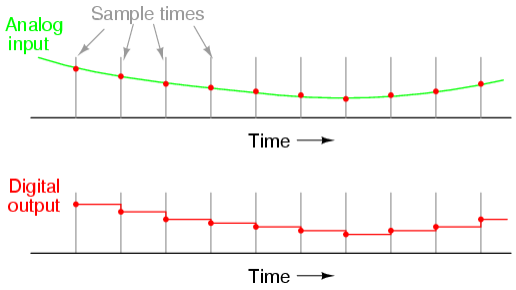
- SNR (signal to noise ratio)
  - **Signal-to-noise ratio** (abbreviated **SNR** or ***S/N***) is a measure used that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.
  - Signal-to-noise ratio is sometimes used informally to refer to the ratio of useful information to false or irrelevant data in a conversation or exchange.
  - $SNR = 20\log_{10}(V_{signal}/V_{noise})$
  - $SNR = 10\log_{10}(P_{signal}/P_{noise})$

Conversion Rate

- When the sample period is too long or too slow, substantial details of the analog signal will be missed. It is imperative that an ADC's sample time is fast enough to capture essential changes in the analog waveform. In data acquisition terminology, the highest-frequency waveform that an ADC can theoretically capture is called the *Nyquist frequency*, equal to one-half of the ADC's sample frequency. If an ADC circuit has a sample frequency of 5000 Hz, the highest-frequency waveform it can successfully resolve will be the Nyquist frequency of 2500 Hz.

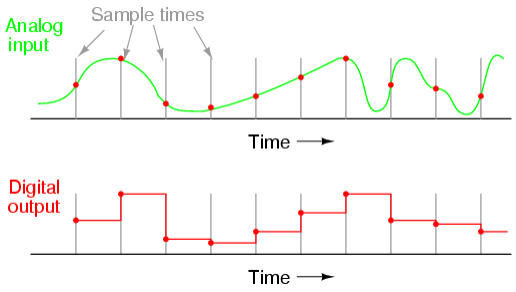
Conversion Rate

- Consider the following illustration of ADC conversion rate versus signal type:



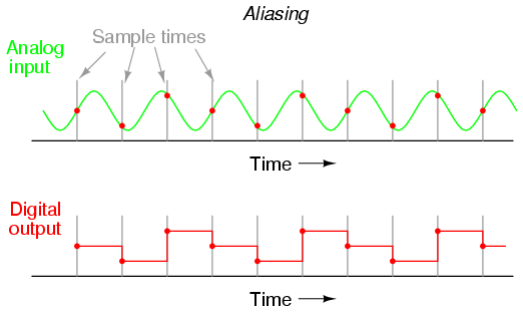
Conversion Rate

- But consider *this* example with the same sample time:



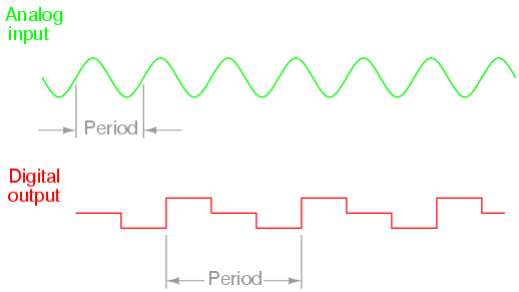
Aliasing

- If an ADC is subjected to an analog input signal whose frequency exceeds the Nyquist frequency, the converter will output a digitized signal of falsely low frequency. This phenomenon is known as *aliasing*. Observe the following illustration to see how aliasing occurs:



Aliasing

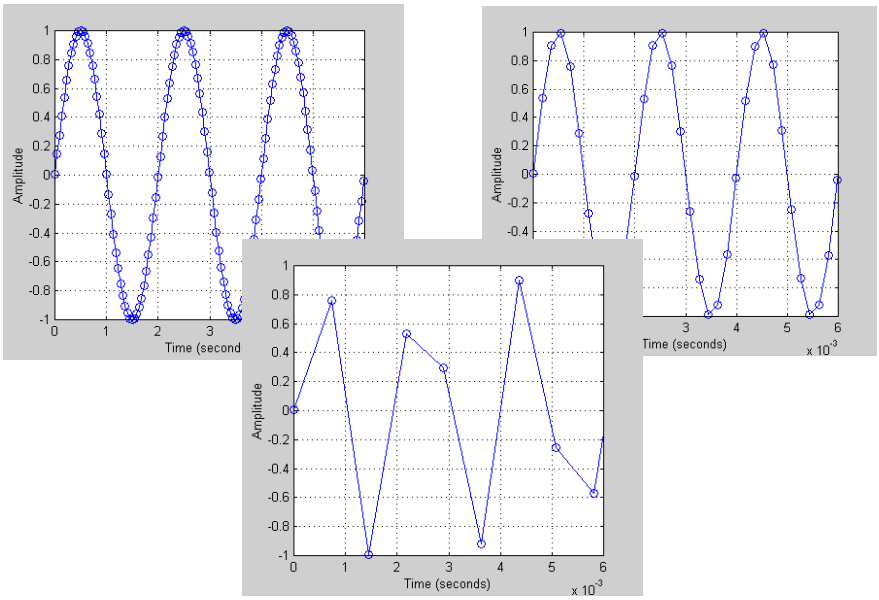
- Note how the period of the output waveform is much longer than that of the input waveform, and how the two waveform shapes aren't even similar:



Aliasing

- It should be understood that the Nyquist frequency is an *absolute* minimum frequency limit for an ADC, and does not represent the highest *practical* frequency measurable. To be safe, one shouldn't expect an ADC to successfully resolve any frequency greater than one-fifth to one-tenth of its sample frequency.
- A practical means of preventing aliasing is to place a low-pass filter before the input of the ADC, to block any signal frequencies greater than the practical limit. This way, the ADC circuitry will be prevented from seeing any excessive frequencies and thus will not try to digitize them. It is generally considered better that such frequencies go unconverted than to have them be "aliased" and appear in the output as false signals.

Aliasing Illustration



Common Sampling Frequencies

- Which rates can represent the range of frequencies audible by human ears?

Sampling Rate	Uses
44.1 kHz (44100)	CD, DAT
48 kHz (48000)	DAT, DV, DVD-Video
96 kHz (96000)	DVD-Audio
22.05 kHz (22050)	Old samplers

Common Sampling Resolutions

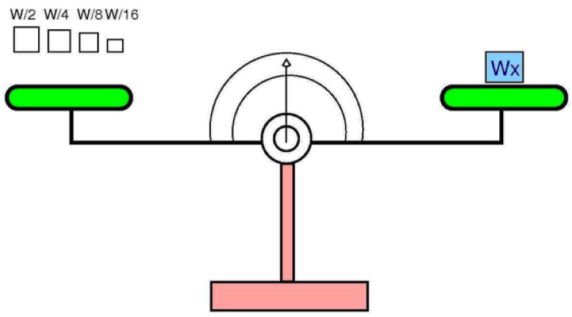
Word length	Uses
8-bit integer	Low-res web audio
16-bit integer	CD, DAT, DV, sound files
24-bit integer	DVD-Video, DVD-Audio
32-bit floating point	Software (usually only for internal representation)

Analog-to-Digital Conversion Techniques

1. Successive Approximation (SA) ADC
2. Flash/Parallel ADC
3. Dual-slope Integrating ADC
4. Servo/Binary-counter/Ramp ADC

Type	Speed	Resolution	Noise Immunity	Cost
1.	Medium	10-16 bits	Poor	Low
2.	Fast	4-8 bits	None	High
3.	Slow	12-18 bits	Good	Low
4.	Slow	14-24 bits	Good	Medium

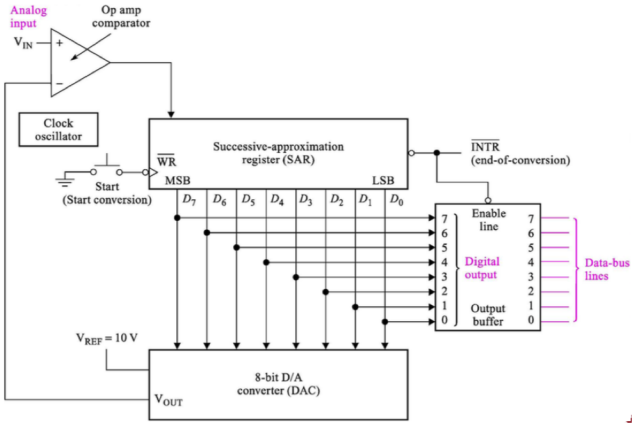
Successive Approximation ADC



SA ADC is like a platform balance

Measurement is possible if unknown wt. Wx <W

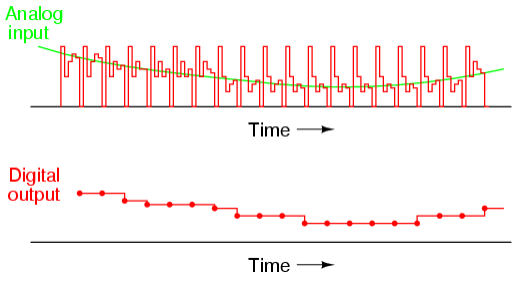
Successive Approximation ADC



- This method works by trying all values of bits starting with the most-significant bit and finishing at the least-significant bit. The register monitors the comparator's output to see if the binary count is less than or greater than the analog signal input, adjusting the bit values accordingly.

Successive Approximation ADC

- Plotted over time, the operation of a successive-approximation ADC looks like this:



- Note how the updates for this ADC occur at regular intervals.

A/D Converter Board

http://www.mstarlabs.com/dataacquisition/840/840spec.html