# Analog to Digital Converters

By: Byron Johns, Danny Carpenter Stephanie Pohl, Harry “Bo” Marr

http://ume.gatech.edu/mechatronics_course/FADC_F05.ppt

(unless otherwise marked)

## Presentation Outline

- Introduction: Analog vs. Digital?
- Examples of ADC Applications
- Types of A/D Converters
- Successive Approximation ADC

## Analog Signals

Analog signals – directly measurable quantities in terms of some other quantity

Examples:

- Thermometer – mercury height rises as temperature rises
- Car Speedometer – Needle moves farther right as you accelerate
- Stereo – Volume increases as you turn the knob.

## Digital Signals

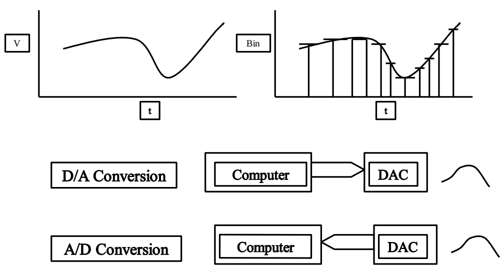
Digital Signals – have only two states. For digital computers, we refer to binary states, 0 and 1. “1” can be on, “0” can be off.

Examples:

- Light switch can be either on or off
- Door to a room is either open or closed

Real world (lab) is analog

Computer (binary) is digital



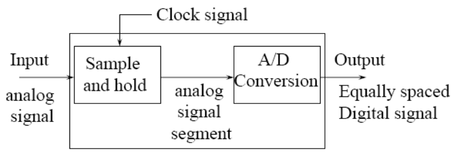

From: James Mackey
http://www.harding.edu/jmackey/physics350/adc/adc_dac/520converter.ppt

## Examples of A/D Applications

- Microphones - take your voice varying pressure waves in the air and convert them into varying electrical signals
- Strain Gages - determines the amount of strain (change in dimensions) when a stress is applied
- Thermocouple – temperature measuring device converts thermal energy to electric energy
- Voltmeters
- Digital Multimeters

## Just what does an A/D converter DO?

- Converts analog signals into binary words




## Analog → Digital Conversion 2-Step Process:

- Quantizing - breaking down analog value is a set of finite states
- Encoding - assigning a digital word or number to each state and matching it to the input signal

## Step 1: Quantizing

Example:

You have 0-10V signals. Separate them into a set of discrete states with 1.25V increments. (How did we get 1.25V? See next slide…)

| Output States | Discrete Voltage Ranges (V) |
|---|---|
| 0 | 0.00-1.25 |
| 1 | 1.25-2.50 |
| 2 | 2.50-3.75 |
| 3 | 3.75-5.00 |
| 4 | 5.00-6.25 |
| 5 | 6.25-7.50 |
| 6 | 7.50-8.75 |
| 7 | 8.75-10.0 |

## Quantizing

**The number of possible states that the converter can output is:**

$$N=2^n$$

where n is the number of bits in the AD converter

Example: For a 3 bit A/D converter, $N=2^3=8$.

**Analog quantization size:**

$Q=(V_{max}-V_{min})/N$ = (10V – 0V)/8 = 1.25V

## Encoding

- Here we assign the digital value (binary number) to each state for the computer to read.

| Output States | Output Binary Equivalent |
|---|---|
| 0 | 000 |
| 1 | 001 |
| 2 | 010 |
| 3 | 011 |
| 4 | 100 |
| 5 | 101 |
| 6 | 110 |
| 7 | 111 |

## Accuracy of A/D Conversion

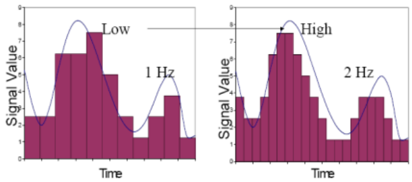
There are two ways to best improve accuracy of A/D conversion:

- increasing the resolution which improves the accuracy in measuring the amplitude of the analog signal.
- increasing the sampling rate which increases the maximum frequency that can be measured.

## Resolution

- Resolution (number of discrete values the converter can produce) = Analog Quantization size (Q)
  (Q) = Vrange / 2^n, where Vrange is the range of analog voltages which can be represented
- limited by signal-to-noise ratio (should be around 6dB)
- In our previous example: Q = 1.25V, this is a high resolution. A lower resolution would be if we used a 2-bit converter, then the resolution would be 10/2^2 = 2.50V.

## Sampling Rate




Frequency at which ADC evaluates analog signal. As we see in the second picture, evaluating the signal more often more accurately depicts the ADC signal.

## Aliasing

- Occurs when the input signal is changing much faster than the sample rate.

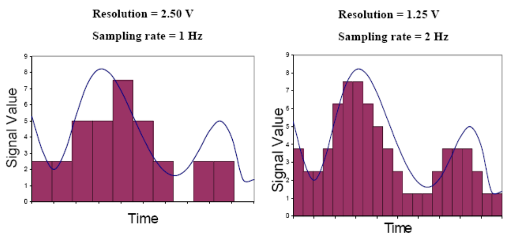
  For example, a 2 kHz sine wave being sampled at 1.5 kHz would be reconstructed as a 500 Hz (the aliased signal) sine wave.

<u>Nyquist Rule:</u>

- Use a sampling frequency at least twice as high as the maximum frequency in the signal to avoid aliasing.

## Overall Better Accuracy

- Increasing both the sampling rate and the resolution you can obtain better accuracy in your AD signals.



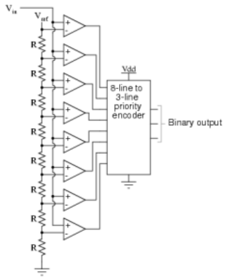

## A/D Converter Types By Danny Carpenter

- Converters
  - Flash ADC
  - Dual Slope (integrating) ADC
  - Successive Approximation ADC

## Flash ADC

- Consists of a series of comparators, each one comparing the input signal to a unique reference voltage.
- The comparator outputs connect to the inputs of a priority encoder circuit, which produces a binary output

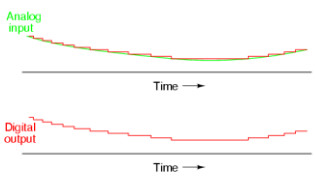
## Flash ADC Circuit




## How Flash Works

- As the analog input voltage exceeds the reference voltage at each comparator, the comparator outputs will sequentially saturate to a high state.
- The priority encoder generates a binary number based on the highest-order active input, ignoring all other active inputs.

## ADC Output



# Flash

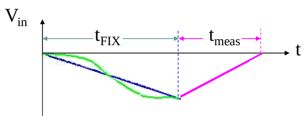
Advantages

- Simplest in terms of operational theory
- Most efficient in terms of speed, very fast
  - limited only in terms of comparator and gate propagation delays

Disadvantages

- Lower resolution
- Expensive
- For each additional output bit, the number of comparators is doubled
  - i.e. for 8 bits, 256 comparators needed

# Dual Slope Converter




- The sampled signal charges a capacitor for a fixed amount of time
- By integrating over time, noise integrates out of the conversion
- Then the ADC discharges the capacitor at a fixed rate with the counter counts the ADC's output bits. A longer discharge time results in a higher count

# Dual Slope Converter

Advantages

- Input signal is averaged
- Greater noise immunity than other ADC types
- High accuracy

Disadvantages

- Slow
- High precision external components required to achieve accuracy

# Digital-to-Analog Conversion [DAC]

http://www-personal.engin.umd.umich.edu/~jwvm/ece414/PowerPoint/8_A-D converter.ppt

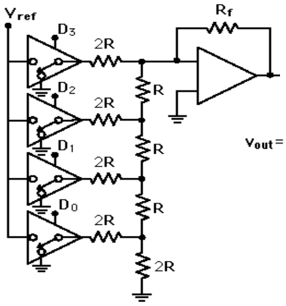
## Digital-to-Analog Conversion

- When data is in binary form, the 0's and 1's may be of several forms such as the TTL form where the logic zero may be a value up to 0.8 volts and the 1 may be a voltage from 2 to 5 volts.
- The data can be converted to clean digital form using gates which are designed to be on or off depending on the value of the incoming signal.

## Digital-to-Analog Conversion

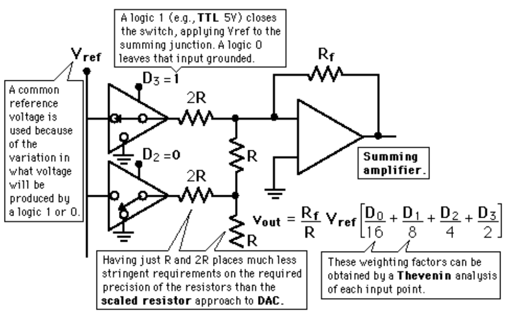
- Data in clean binary digital form can be converted to an analog form by using a summing amplifier.
- For example, a simple 4-bit D/A converter can be made with a four-input summing amplifier.

## R-2R Ladder DAC




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

## R-2R Ladder DAC




## R-2R Ladder DAC

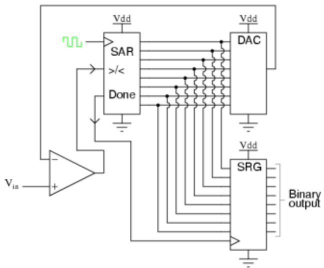
- The summing amplifier with the R-2R ladder of resistances shown produces the output where the D's take the value 0 or 1.
- The digital inputs could be TTL voltages which close the switches on a logical 1 and leave it grounded for a logical 0.
- This is illustrated for 4 bits, but can be extended to any number with just the resistance values R and 2R.

# Now back to ADC's

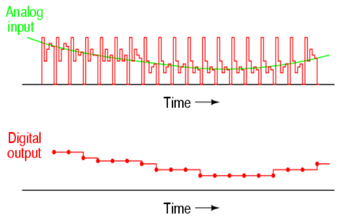
## Successive Approximation ADC By Stephanie Pohl

- A Successive Approximation Register (SAR) is added to the circuit
- Instead of counting up in binary sequence, this register counts by trying all values of bits starting with the MSB and finishing at the LSB.
- The register monitors the comparators output to see if the binary count is greater or less than the analog signal input and adjusts the bits accordingly

## Successive Approximation ADC Circuit



## Output




## Successive Approximation

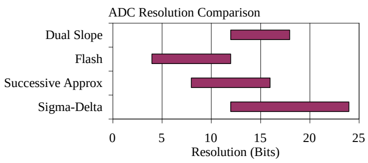
Advantages

- Capable of high speed and reliable
- Medium accuracy compared to other ADC types
- Good tradeoff between speed and cost
- Capable of outputting the binary number in serial (one bit at a time) format.

Disadvantages

- Higher resolution successive approximation ADC's will be slower
- Speed limited to ~5Msps

## ADC Types Comparison




| Type | Speed (relative) | Cost (relative) |
|---|---|---|
| Dual Slope | Slow | Med |
| Flash | Very Fast | High |
| Successive Appox | Medium – Fast | Low |
| Sigma-Delta | Slow | Low |

## Successive Approximation Example

- Spreadsheet examples

## Successive Approximation Example

- 10 bit resolution or 0.0009765625V of Vref
- Vin= .6 volts
- Vref=1volts
- Find the digital value of Vin

| Bit | Voltage |
|---|---|
| 9 | .5 |
| 8 | .25 |
| 7 | .125 |
| 6 | .0625 |
| 5 | .03125 |
| 4 | .015625 |
| 3 | .0078125 |
| 2 | .00390625 |
| 1 | .001952125 |
| 0 | .0009765625 |

## Successive Approximation

- MSB (bit 9)
  - Divided $V_{ref}$ by 2
  - Compare $V_{ref}/2$ with $V_{in}$
  - If $V_{in}$ is greater than $V_{ref}/2$ , turn MSB on (1)
  - If $V_{in}$ is less than $V_{ref}/2$ , turn MSB off (0)
  - $V_{in}$ =0.6V and V=0.5
  - Since $V_{in}$>V,  MSB = 1 (on)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |

## Successive Approximation

- Next Calculate MSB-1 (bit 8)
  - Compare $V_{in}$=0.6 V to V=$V_{ref}$/2 + $V_{ref}$/4= 0.5+0.25 =0.75V
  - Since 0.6<0.75, MSB is turned off
- Calculate MSB-2 (bit 7)
  - Go back to the last voltage that caused it to be turned on (Bit 9) and add it to $V_{ref}$/8, and compare with $V_{in}$
  - Compare $V_{in}$ with (0.5+$V_{ref}$/8)=0.625
  - Since 0.6<0.625, MSB is turned off

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | | | | | | | |

## Successive Approximation

- Calculate the state of MSB-3 (bit 6)
  - Go to the last bit that caused it to be turned on (In this case MSB-1) and add it to $V_{ref}$/16, and compare it to $V_{in}$
  - Compare $V_{in}$ to V= 0.5 + $V_{ref}$/16= 0.5625
  - Since 0.6>0.5625, MSB-3=1 (turned on)

| MSB | MSB-1 | MSB-2 | MSB-3 | ... | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | | | | | | |

## Successive Approximation

- This process continues for all the remaining bits.

•Digital Results:

| MSB | MSB-1 | MSB-2 | MSB-3 | ... | | | | | LSB |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |

•Results: $\frac{1}{2}+\frac{1}{16}+\frac{1}{32}+\frac{1}{256}+\frac{1}{512}=.599609375\text{ V}$