Analog to Digital Converters

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

(unless otherwise marked)

1

Presentation Outline

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

2

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.

3

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.

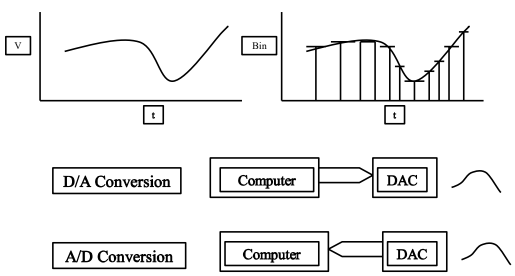
Examples:

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

4

Real world (lab) is analog

Computer (binary) is digital



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

5

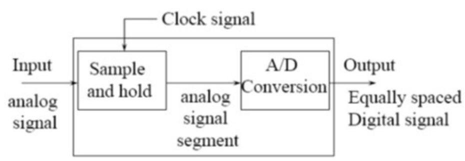
Examples of A/D Applications

- 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

6

Just what does an A/D converter DO?

- Converts analog signals into binary words



7

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

8

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

9

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

10

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

11

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.

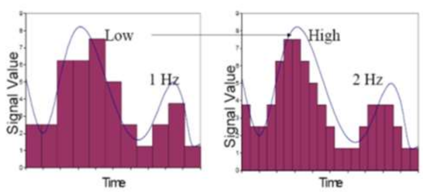
12

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.

13

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.

14

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.

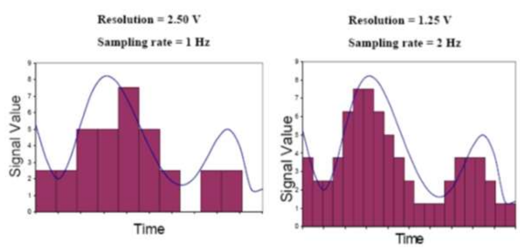
Nyquist Rule:

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

15

Overall Better Accuracy

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



16

A/D Converter Types By Danny Carpenter

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

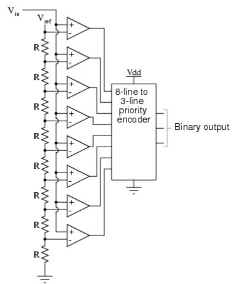
17

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

18

Flash ADC Circuit



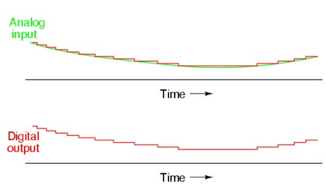
19

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.

20

ADC Output



21

Flash

Advantages

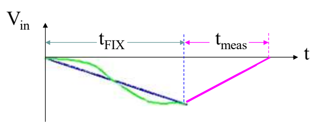
- Simplest in terms of operational theory
- Most efficient in terms of speed, very fast
  - limited only in terms of comparator and gate propagation delays

Disadvantages

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

22

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

23

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

24

Digital-to-Analog Conversion [DAC]

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

25

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.

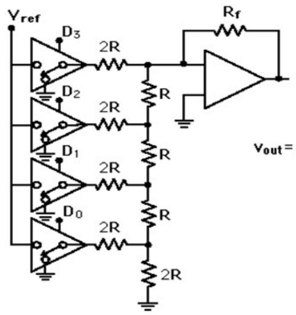
26

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.

27

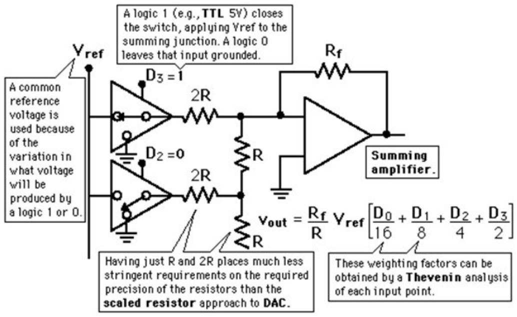
R-2R Ladder DAC



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

28

R-2R Ladder DAC



29

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.

30

Now back to ADC's

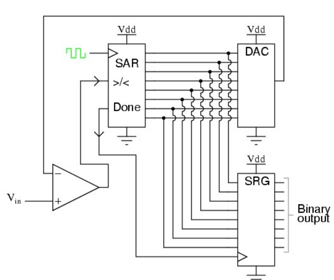
31

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

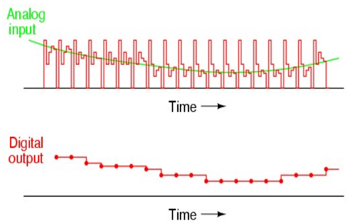
32

Successive Approximation ADC Circuit



33

Output



34

Successive Approximation

Advantages

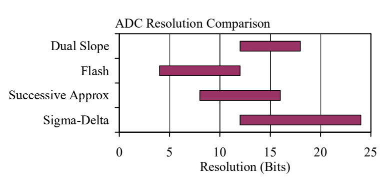
- Capable of high speed and reliable
- Medium accuracy compared to other ADC types
- Good tradeoff between speed and cost
- Capable of outputting the binary number in serial (one bit at a time) format.

Disadvantages

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

35

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

36

Successive Approximation Example

- Spreadsheet examples

37

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

38

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									

39

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							

40

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						

41

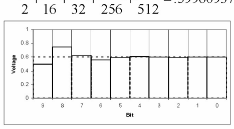
Successive Approximation

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



42