EEE205 – Digital Electronics (II)

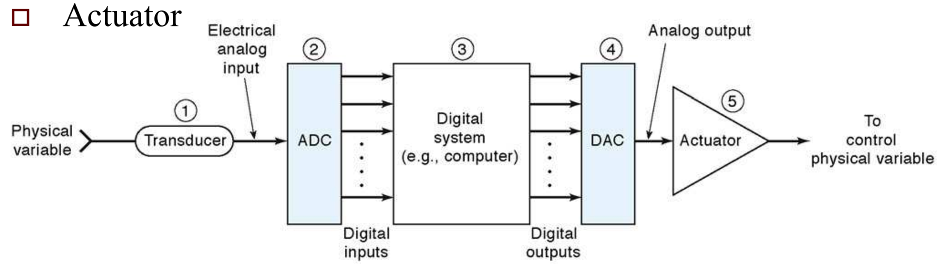
Lecture 17

DAC and ADC

Dr. Ming Xu
Dept of Electrical & Electronic Engineering
XJTLU

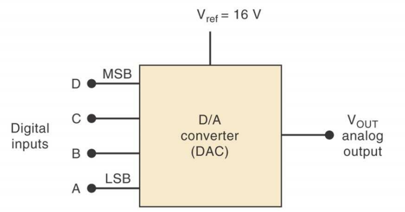
Interfacing With the Analog World

- Transducer
- ADC
- Computer
- DAC
- Actuator



Digital to Analog Conversion

- The conversion process:
  - Digital code is converted to a proportional voltage/current
  - Reference voltage determines the max DAC output
- Analog (pseudo analog) output



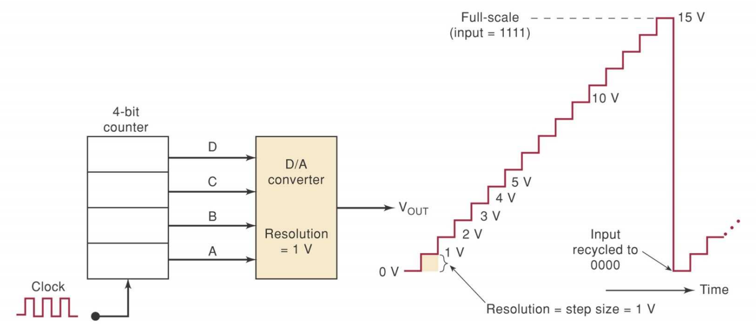
(a)

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

(b)

Digital to Analog Conversion

- Resolution (step size) = analog full-scale output divided by $2^n - 1$, where n is the number of bits.
- Analog output = resolution × digital input

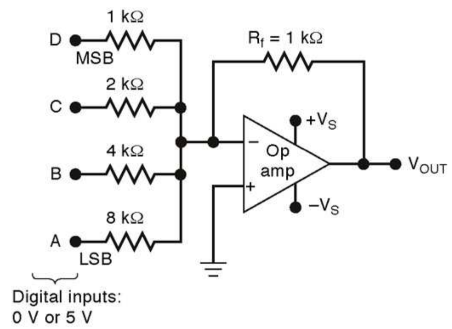


Digital to Analog Conversion

- Bipolar DACs
  - Many DACs produce both positive and negative values
  - 2’s complement can be used to represent negative voltages

D/A Converter Circuitry

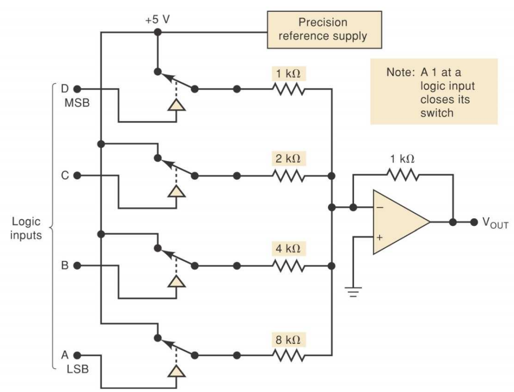
- A summing operational amplifier with a resolution of .625 V. $V_{OUT} = -(V_D + V_C/2 + V_B/4 + V_A/8)$



Input code					
D	C	B	A	V_{OUT} (volts)	
0	0	0	0	0	
0	0	0	1	−0.625	← LSB
0	0	1	0	−1.250	
0	0	1	1	−1.875	
0	1	0	0	−2.500	
0	1	0	1	−3.125	
0	1	1	0	−3.750	
0	1	1	1	−4.375	
1	0	0	0	−5.000	
1	0	0	1	−5.625	
1	0	1	0	−6.250	
1	0	1	1	−6.875	
1	1	0	0	−7.500	
1	1	0	1	−8.125	
1	1	1	0	−8.750	
1	1	1	1	−9.375	← Full-scale

D/A Converter Circuitry

- The digital inputs cannot be taken directly from FFs or logic gates
- Each digital input controls a semi-conductor switch to a precision reference supply.

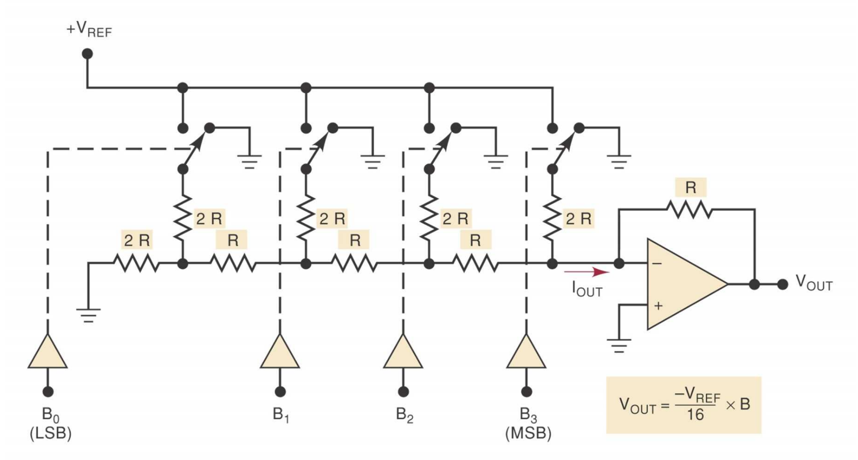


D/A Converter Circuitry

- R/2R ladder
  - Circuits with binary weighted resistors cause a problem due to the large difference in R values between LSB and MSB
  - The R/2R ladder uses resistances that span only a 2 to 1 range

D/A Converter Circuitry

- R/2R ladder DAC



DAC Specifications

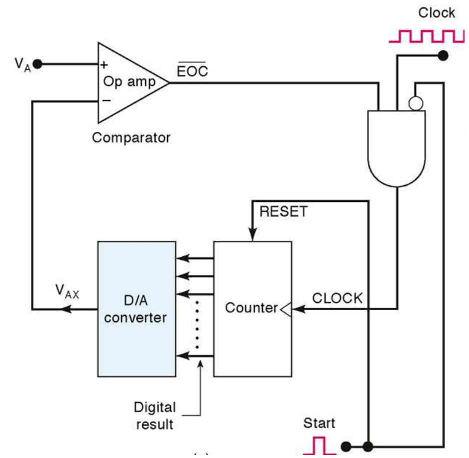
- Many DACs are available as ICs or self contained packages. Key specifications are:
  - Resolution
  - Accuracy
  - Offset error
  - Settling time
  - Monotonicity

Analog to digital Conversion

- ADC – digital code represents the analog input
- Generally more complex and time consuming than DAC
- Several types of ADC use DAC circuits
- The Op amp comparator ADC
  - Variations differ in how the control section continually modifies numbers in the register

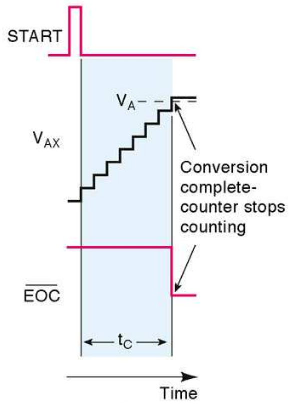
Digital Ramp ADC

- A binary counter is used as the register and allows clock to increment the counter a step at a time until $V_{AX} \geq V_A$



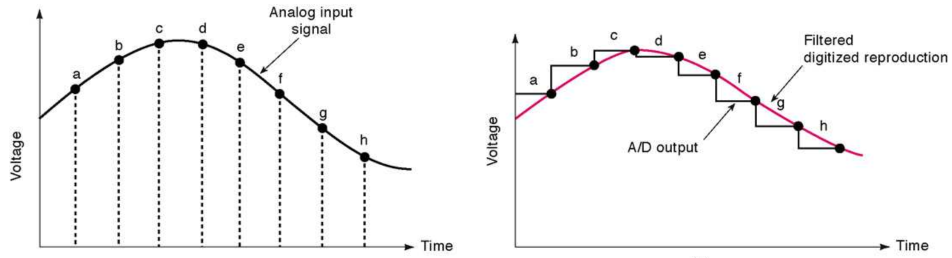
Digital Ramp ADC

- A/D resolution and accuracy
  - Measurement error is unavoidable
  - Reducing the step size can reduce but not eliminate potential error
  - This is called quantization error



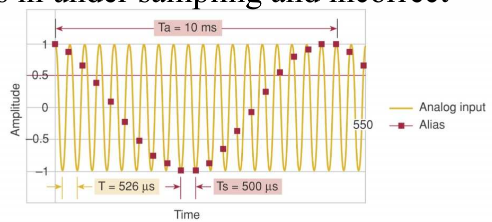
Data Acquisition

- Digitizing analog data and transferring to memory is data acquisition
- Acquiring a single data point value is sampling
- Reconstructing a digitized signal



Data Acquisition

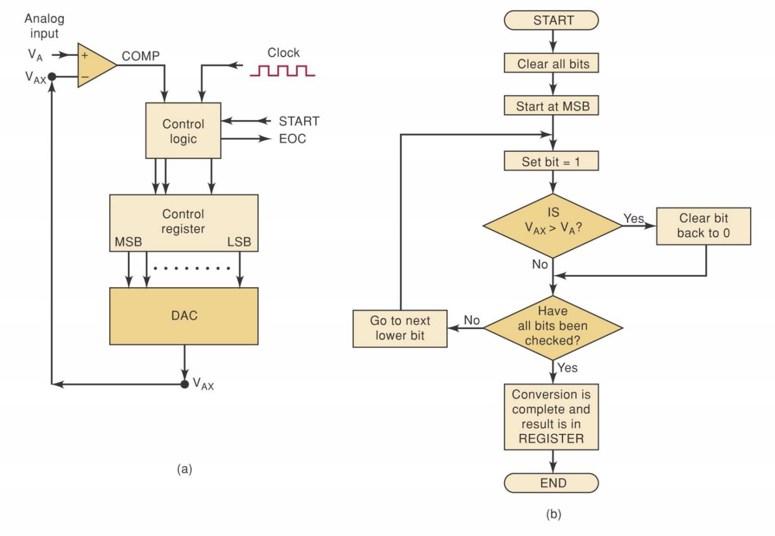
- Aliasing
  - Caused by under sampling
  - Harry Nyquist
    - The sampling frequency must be at least twice the highest input frequency
    - Sampling at a frequency less than twice the input frequency results in under sampling and incorrect reproduction



Successive Approximation ADC

- Widely used ADC
- More complex than digital ramp but has a shorter conversion time
- Conversion time is fixed and not dependent on the analog input
- Many SACs are available as ICs.

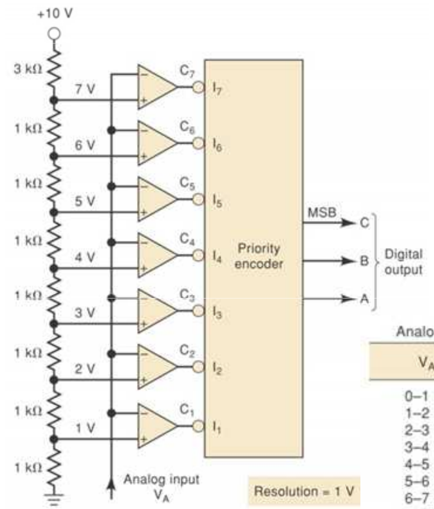
Successive Approximation ADC



Flash ADCs

- High speed conversion
- Much more complex circuitry
  - 6 bit flash ADC requires 63 analog comparators
  - 8 bit flash ADC requires 255 comparators
  - 10 bit flash ADC requires 1023 comparators
- A 3 bit flash converter is described in figure 11-22
- Conversion time – No clock signal is used, so the conversion is continuous. This makes for very short conversion times, typically under 17 ns.

Flash ADCs



Analog in	Comparator outputs							Digital outputs		
V_A	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C	B	A
0–1 V	1	1	1	1	1	1	1	0	0	0
1–2 V	0	1	1	1	1	1	1	0	0	1
2–3 V	0	0	1	1	1	1	1	0	1	0
3–4 V	0	0	0	1	1	1	1	0	1	1
4–5 V	0	0	0	0	1	1	1	1	0	0
5–6 V	0	0	0	0	0	1	1	1	0	1
6–7 V	0	0	0	0	0	0	1	1	1	0
> 7 V	0	0	0	0	0	0	0	1	1	1

Other A/D Conversion Methods

- There are many other methods of A/D conversion. Each has pros and cons:
  - Up/down digital-ramp ADC (tracking ADC)
  - Dual slope integrating ADC
  - Voltage to frequency ADC
  - Sigma/delta modulation
- The method used will depend on the application