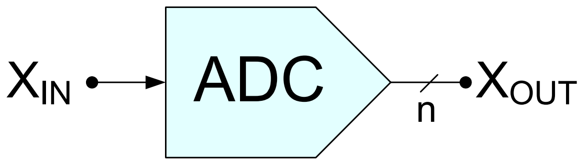
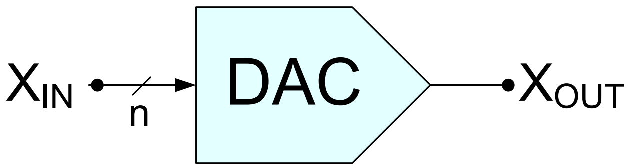
EE 230
Lecture 37

Data Converters

Review from Last Time:

Data Converters





	X_{IN}	X_{OUT}
ADC	Analog	Digital
DAC	Digital	Analog

Analog variables: Voltage, Current, time, charge, occasionally other physical variables

Digital variables: Usually represented in binary form but other forms occasionally used (e.g. gray, Thermometer code)

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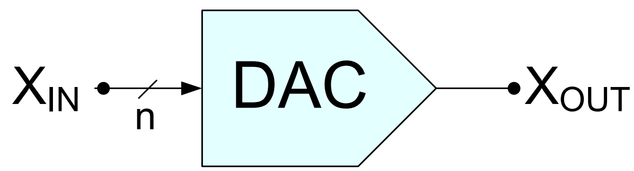

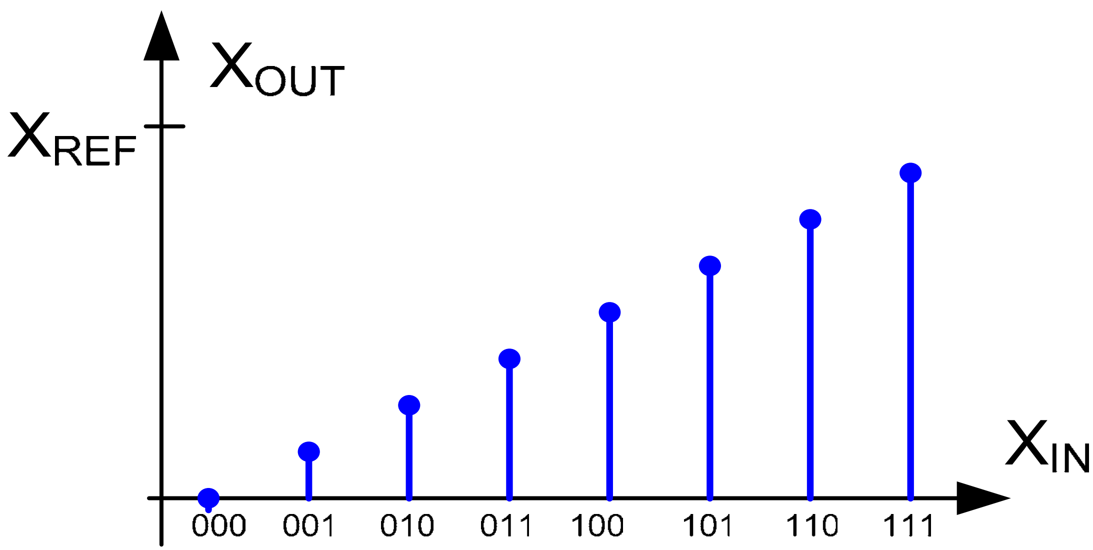

B: $[b_1\, b_2 \ldots . b_n]$

<u>An</u> ideal DAC

(Some specific shifted versions of this DAC would also be termed an ideal DAC)

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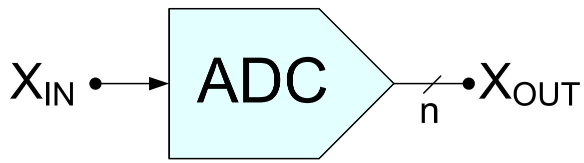

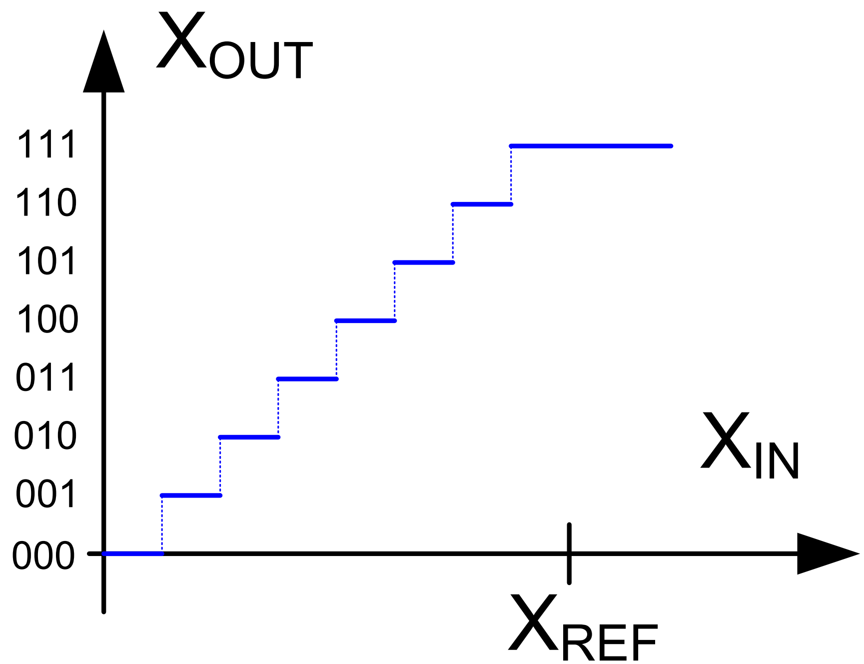

B: [b_1 b_2....b_n]

<u>An</u> ideal ADC

(Some specific shifted versions of this ADC would also be termed an ideal ADC)

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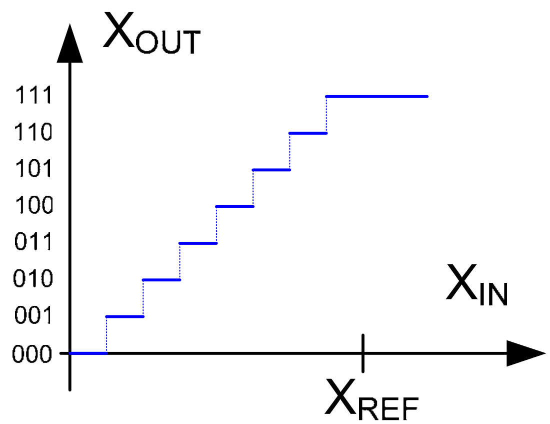

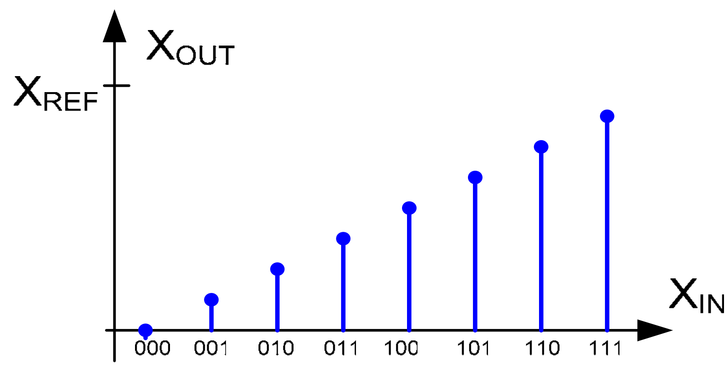

Terminology:

B: [b_1 b_2....b_n]

b_1: Most Significant Bit (MSB)
b_n: Least Significant Bit (LSB)

Resolution: Defines number of distinct levels for DAC or Boolean outputs for ADC. If there are N distinct levels, resolution generally defined as $n = \log_2 N$ thus, $N = 2^n$

X_{REF}: specifies the full-scale range of the data converter. Input range for ADC or output range for DAC is usually $X_{REF}\left(\frac{2^n-1}{2^n}\right) \overset{n\ \text{large}}{\simeq} X_{REF}$

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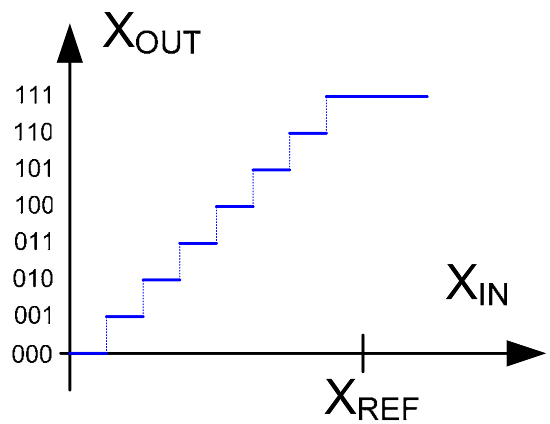
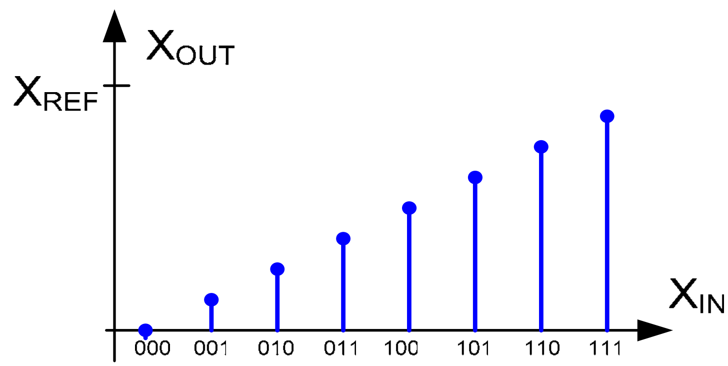




Terminology:

LSB (or X_{LSB}) : Analog change (in input to ADC or output of DAC) corresponding to one LSB digital change

$$X_{LSB} = \frac{X_{REF}}{2^n}$$

Transition Points (for ADC): values of X_{IN} where output changes by 1 LSB

(an n-bit ADC has N-1 transition points partitioning input into N distinct intervals)

Decimal Equivalent: Decimal equivalent of **B: [b_1 b_2….b_n]**

$$D(B) = \left(\frac{b_1}{2} + \frac{b_2}{4} + \ldots + \frac{b_n}{2^n}\right) \rightarrow D(B) = \sum_{k=1}^{n} \frac{b_k}{2^k}$$

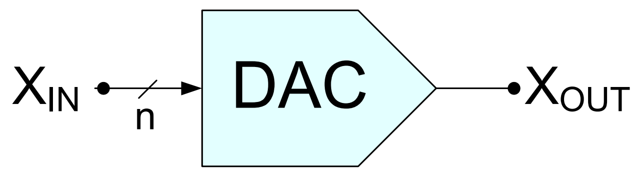
Review from Last Time:

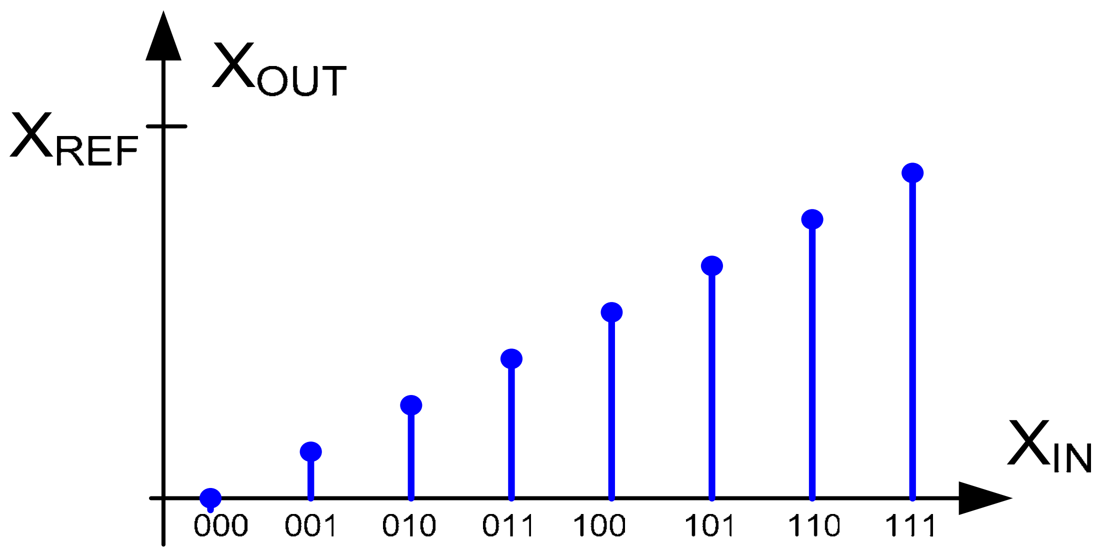
Number of levels for different resolution

n	N	
1	2^1	2
2	2^2	4
3	2^3	8
4	2^4	16
5	2^5	32
6	2^6	64
7	2^7	128
8	2^8	256
9	2^9	512

n	N	
10	2^{10}	1024
11	2^{11}	2048
12	2^{12}	4096
13	2^{13}	8192
14	2^{14}	16384
15	2^{15}	32768
16	2^{16}	65536
20	2^{20}	1,048,576
24	2^{24}	16,772,216

Data Converters



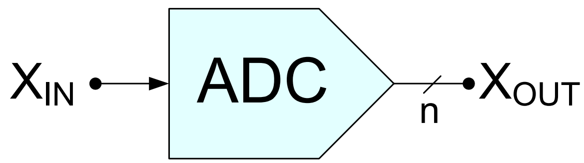


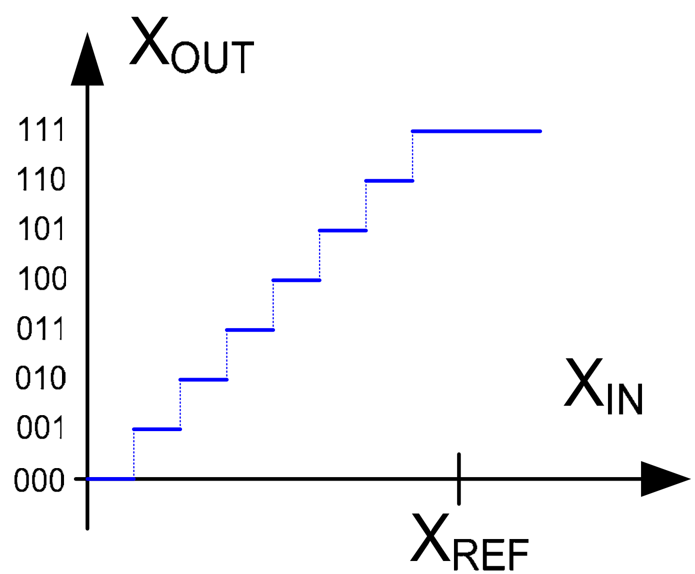
B: [b_1 b_2....b_n]

An ideal DAC

$$X_{OUT} = X_{REF} D(X_{IN}) = X_{REF} \sum_{k=1}^{n} \frac{b_k}{2^k}$$

Data Converters





B: [b_1 b_2....b_n]

An ideal ADC

$$X_{OUT} = B \qquad X_{REF} D(B) < X_{IN} < X_{REF} D(B) + X_{LSB}$$

Example

Determine V_{LSB} for a 16-bit ADC if X_{REF} is a voltage of 1V.

$$X_{LSB} = \frac{1V}{2^{16}} = 15.25\mu V$$

Observe X_{LSB} is very small and for a 16-bit ADC, must resolve an input signal to $\pm X_{LSB}/2 = \pm 7.5\mu V$

Example

Determine the number of bits of resolution, n, required in an ADC if it is to be used in a DMM that has accuracy corresponding to m decimal digits

Resolution of an m-digit DMM is $V_{REF}/10^m$

Thus equating the resolution of an ADC represented in binary form to that of the DMM, we obtain the expression

$$\frac{V_{REF}}{2^n} = \frac{V_{REF}}{10^m}$$

It thus follows that $m = n\log_{10}2$

Solving for n, we obtain $n = \dfrac{m}{\log_{10}2}$

If m=6, n=20

If V_{REF}=1V, V_{LSB}=0.95μV

If m=7, n=23+

If V_{REF}=1V, V_{LSB}=112nV

Very high resolution is required in applications such as this!

Data Converter Implementations

- Discrete implementations of data converters are seldom used
  - Not cost effective
  - Too large
  - Vary difficult to maintain acceptable accuracies of components
- Integrated data converters usually have voltage or current as input or output variables
  - If conversion of other physical units is required, a transducer precedes or follows a voltage or current data converter

Types of Data Converters

ANALOG DEVICES

Analog to Digital Converters

- A/D Converters
- Audio A/D Converters
- Capacitance to Digital Converters
- Energy Measurement
- Isolated A/D Converters
- Synchro/Resolver to Digital Converters
- Temperature to Digital Converters
- Touchscreen Controllers
- Video Decoders
- Voltage to Frequency Converters

Digital to Analog Converters

- D/A Converters
- Audio D/A Converters
- Digital Potentiometers
- Video Encoders

(Analog Devices is one of several companies that is a big player in the Data Converter marketplace. Others include TI, National, Maxim and Cyrus)

Data Converter Selection

ANALOG DEVICES

Digital-to-Analog Converters

Resolution/Update Rate Selection Matrix

Resolution, Bits	10-100 MSPS	≥100 MSPS
16	●	●
14	●	●
12	●	●
10	●	●
8	●	●

Update Rate, MSPS

Digital-to-Analog Converters

DAC Resolution vs Settling Time Selection Matrix

Resolution, Bits	≥10 µs	10 µs-1 µs	1 µs-100 ns	100 ns-10 ns
13-18	●	●	●	●
12	●	●	●	●
10	●	●	●	●
8		●	●	●

Settling Time

Data Converter Selection

Analog-to-Digital Converters

Resolution/Throughput Rate Selection Matrix

Resolution, Bits	<10 ksps	10 ksps to 100 ksps	100 ksps to 1 MSPS	1 MSPS to 10 MSPS	10 MSPS to 100 MSPS	100 MSPS +
17+	●	●	●	●		
14-16	●	●	●	●	●	●
12-13		●	●	●	●	●
10-11		●	●	●	●	●
8-9			●	●	●	●
<8					●	

Throughput Rate

Engineering Issues for Using Data Converters

1. Inherent with Data Conversion Process

- Amplitude Quantization
- Time Quantization

(Present even with Ideal Data Converters)

2. Nonideal Components

- Uneven steps
- Offsets
- Gain errors
- Response Time
- Noise

(Present to some degree in all physical Data Converters)

How do these issues ultimately impact performance ?

Engineering Issues for Using Data Converters

Inherent with Data Conversion Process

- Amplitude Quantization
- Time Quantization
- Present even with Ideal Data Converters

- Somewhat challenging to characterize
- Avoid over-specification
  - Power
  - Cost

- Key questions to ask
  - How much resolution is needed ?
  - What range is needed ?
  - How fast must the converter operate ?
  - What are the implications of noise ?

Engineering Issues for Using Data Converters

Nonideal Components

- Uneven steps
- Offsets
- Response Time
- Noise
- Present to some degree in all physical Data Converters

- Somewhat challenging to characterize
  - Many parameters (specifications) have been given
  - Mathematical analysis often complicated
  - Often statistical in nature
  - Computer simulations help but still leave some questions unanswered
- Somewhat challenging to predict affects on system performance
  - Depends upon application
  - Computer simulations help but still leave some questions unanswered