EE 5050

CMOS and BiCMOS Data Conversion Circuits

Lecture 1

Course Information:

Lecture Instructor:

Randy Geiger
2133 Coover
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WEB: www.randygeiger.org

Laboratory Instructor:

Randy Geiger

Course Information:

CMOS and BiCMOS Data Conversion Circuits

Lecture: MW 2:15-3:35 Coover 1016

Labs: F 2:15 – 5:15 Coover 2046

Course WEB Site: http://class.ee.iastate.edu/ee505/

Zoom Link: passcode: 918315

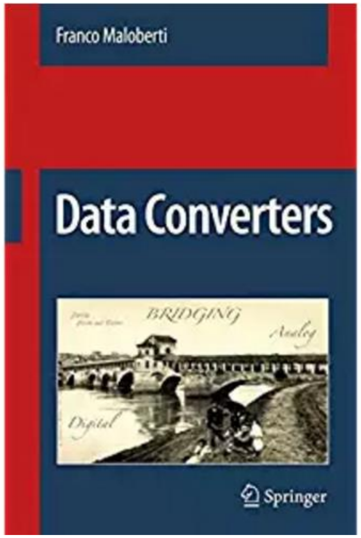
https://iastate.zoom.us/j/95192607150?pwd=AllO5LuRWkhCWivIvX70usEbA8SGsZ.1

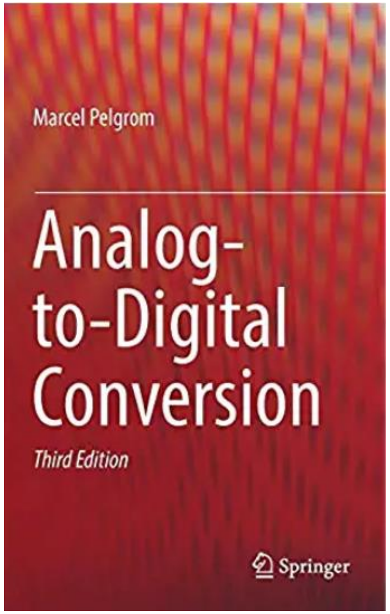
Course Description:

Theory, design and applications of data conversion circuits (A/D and D/A converters) including: architectures, characterization, quantization effects, conversion algorithms, spectral performance, element matching, design for yield, and practical comparators, implementation issues.

Course Information:

Key Reference Texts:



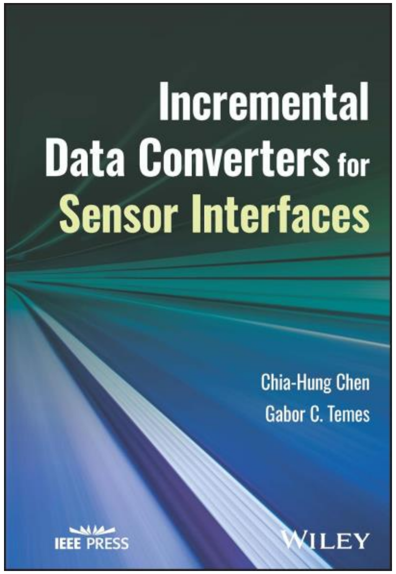


Data Converters, Maloberti, Springer, 2007

Analog-to-Digital Conversion – 3rd Edition by Marcel Pelgrom, Springer, 2016

Course Information:

Key Reference Texts:

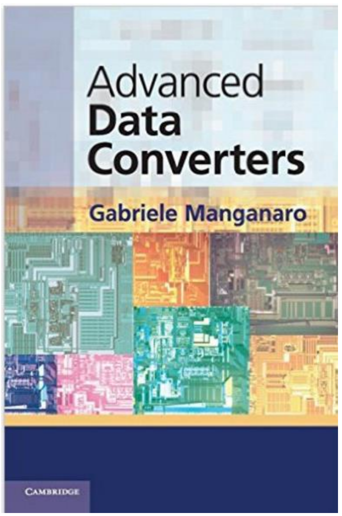


Incremental Data Converters for Sensor Interfaces

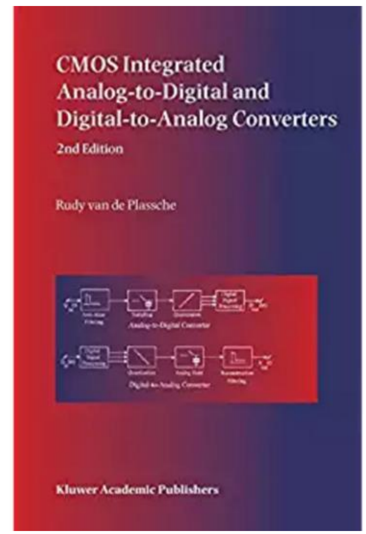
C.H. Chen and Gabor Temes,   Wiley 2023

Course Information:

Other Reference Texts:



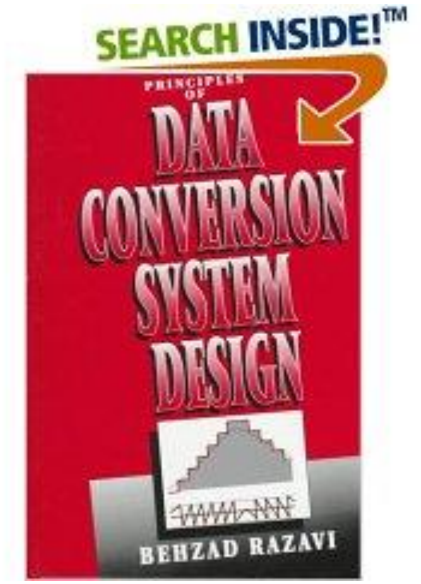
Advanced Data Converters by G. Manganaro, Cambridge, 2012



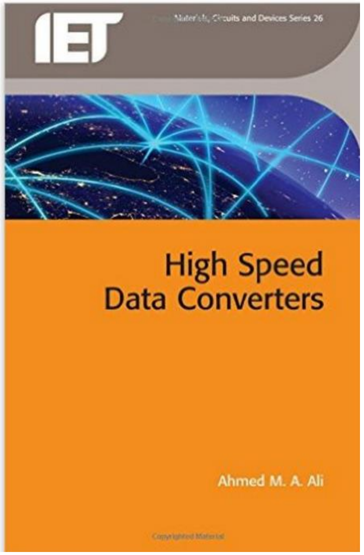
CMOS Integrated Analog-to-Digital and Digital-to-Analog Converters – 2nd Edition by Rudy van de Plassche, Kluwer, 2003

Course Information:

Other Reference Texts:



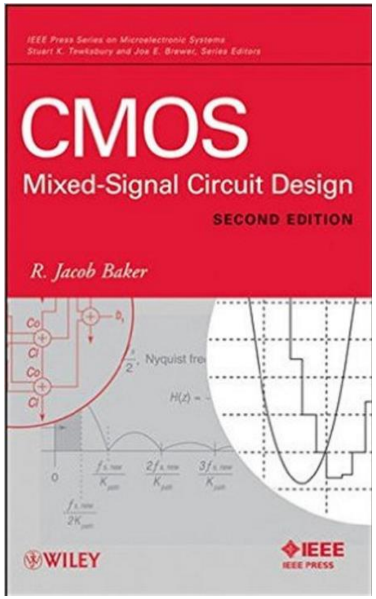
Principles of Data Conversion System Design
by B. Razavi, IEEE Press, 1995

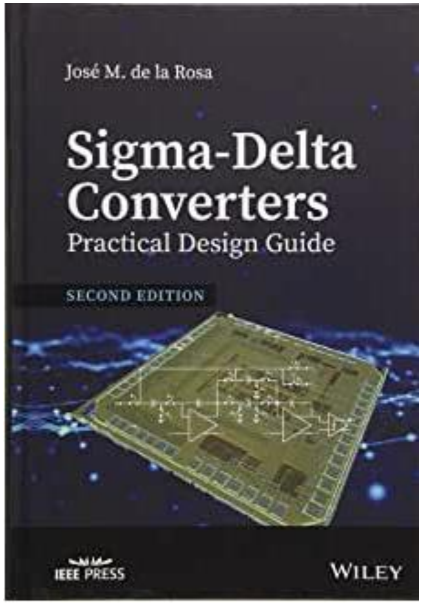


High Speed Data Converters
by A. Ali, IET, 2016

Course Information:

Other Reference Texts:



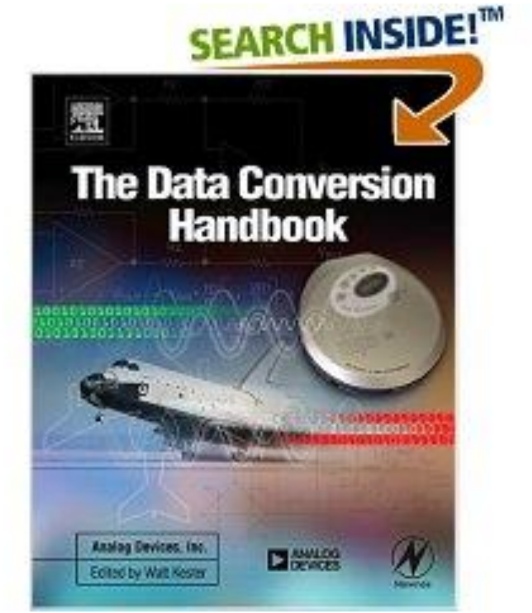


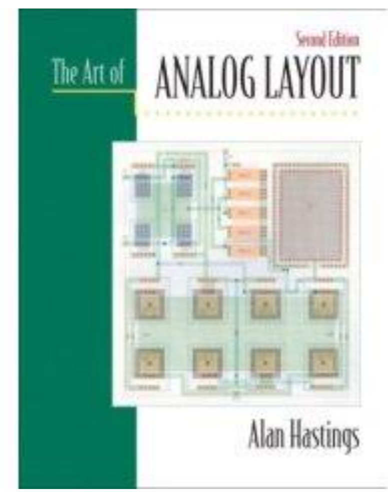
CMOS Mixed-Signal Circuit Design,
2nd Edition, R. Jacob Baker, Wiley, 2008

Sigma-Delta Converters – Practical Design Guide,
2nd Edition, J. de la Rosa, Wiley, 2018

Course Information:

Other Reference Texts:



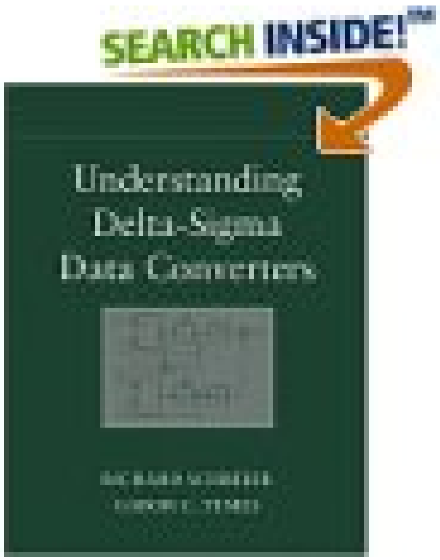


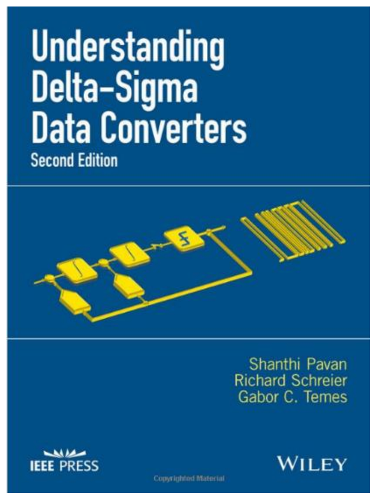
Data Conversion Handbook
by Analog Devices, 2005

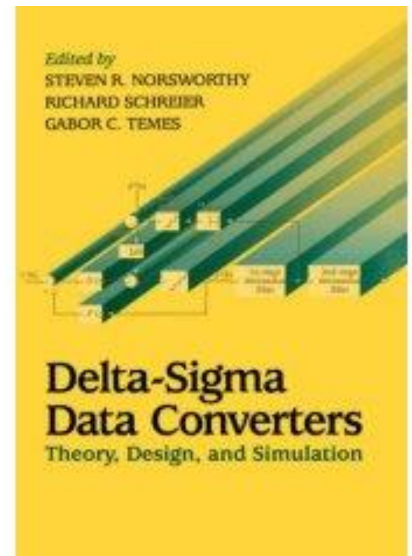
The Art of Analog Layout
by A. Hastings, Prentice Hall, 2001

Course Information:

Other Reference Texts:





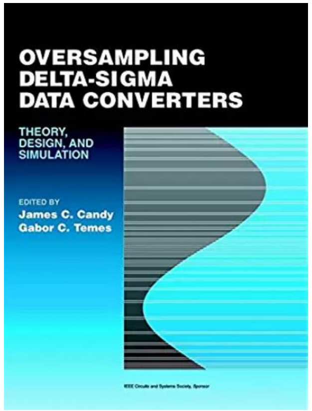


Understanding Delta-Sigma Data Converters
by R. Schreier and G. Temes, Wiley, 2005
by Pavan, Schreier and Temes, Wiley, 2017

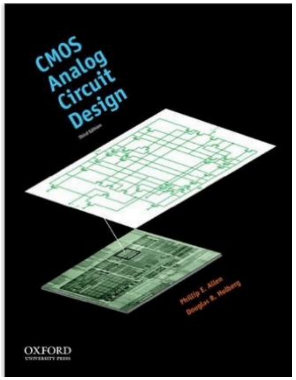
Delta-Sigma Data Converters – Theory, Design, and Simulation
edited by S. Norsworthy, R. Schreier and G. Temes, Wiley, 1997

Course Information:

Reference Texts:



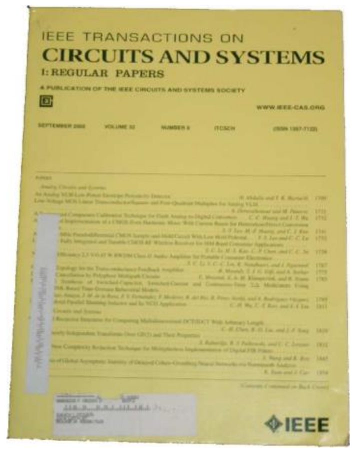
Oversampling Delta-Sigma Data Converters: Theory, Design, and Simulation 1st Edition
By Candy and Temes, 1991.

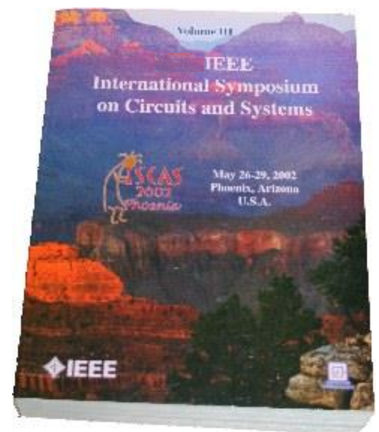


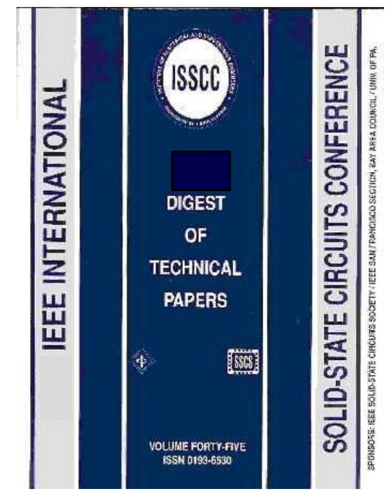
CMOS Analog Circuit Design
by Allen and Holberg, Oxford, 2011.

Course Information:

Reference Materials:







Course Information:

Grading: Points will be allocated for several different parts of the course. A letter grade will be assigned based upon the total points accumulated. The points allocated for different parts of the course are as listed below:

1 Exam	100 pts
1 Final	100 pts.
Homework	100 pts.total
Lab and Lab Reports	100 pts.total
Design Project	100 pts.

Note: In the event that one of the exams is not given, the weight of the remaining exam will be increased to somewhere between 100 pts and 200 pts.

Course Information:

Design Project:

The design project will be assigned by mid-term. Additional details about the design project will be given after relevant material is covered in class. The design should be ready for fabrication and post-layout simulations are to be included as a part of the project.

Course Information:

E-MAIL:

I encourage you to take advantage of the e-mail system on campus to communicate about any issues that arise in the course. I typically check my e-mail several times a day. Please try to include “EE 5050" in the subject field of any e-mail message that you send so that they stand out from what is often large volumes of routine e-mail messages.

Topical Coverage

- Data Converter Operation, Characterization and Specifications
  - Transfer Characteristics
  - Noise
  - Spectral characterization
- Component Matching and Yield
- Nyquist-Rate Data Converter Design
  - DACs
    - Architectures
    - Building Blocks
    - Analysis, Simulation, and Yield
  - ADCs
    - Architectures
    - Building Blocks
    - Analysis, Simulation, and Yield
- Over-Sampled Data Converters
  - Operation
  - Architectures
  - Building Blocks

Signals

Types of signals:

Continuous amplitude vs discrete amplitude

Continuous time vs discrete time

Finite resolution vs infinite resolution

Probability of any continuous-amplitude signal value being exactly equal to a specific value is 0

Probability of any time being exactly equal to a specific time value is 0

If x is a continuous variable (time, voltage, current,….) then in the context of data converters, there is no distinction in the following sets of numbers

$$(x_1,x_2) \quad [x_1,x_2] \quad (x_1,x_2] \quad [x_1,x_2)$$

It may be more convenient to include boundary points when using programs such as Matlab to characterize data converters but results should not depend upon whether end points are included or excluded

Signals

Digital representations (many exist)

unary (thermometer), binary, decimal, gray (RBC),BCD, hexadecimal,……

In the context of data converters, the digital representation is almost always represented by sets whose elements are {0,1}

Binary and occasionally unary are invariably the codes that are used when building ADCs and DACs

Unless specifically stated to the contrary, it will be assumed throughout this course that the input or output codes in a data converter are binary

Data Converters

Types:

A/D (Analog to Digital)

Converts Analog Input to a Digital Output

D/A (Digital to Analog)

Converts a Digital Input to an Analog Output

A/D is the world's most widely used mixed-signal component

D/A is often included in a FB path of an A/D

A/D and D/A fields will remain hot indefinitely

- technology advances make data converter design more challenging
- embedded applications
- designs often very application dependent

Data Converters

- Data converters are ratio-metric devices and outputs are all relative to a reference (i.e. traceability to a primary or secondary standard is not an issue)
- Can be thought of as an amplifier where the output is a ratio-metric version of the input
- Units of output of ADC are dimensionless and units of input to DAC are dimensionless
- Units of input to ADC can be arbitrary and units of output of DAC can be arbitrary

Data Converters

Two Major Classes for both ADCs and DACs:

- Nyquist Rate

  One output for each clock sample

  Concept of Nyquist Rate Data Conversion Evolved in the 20's to 50's

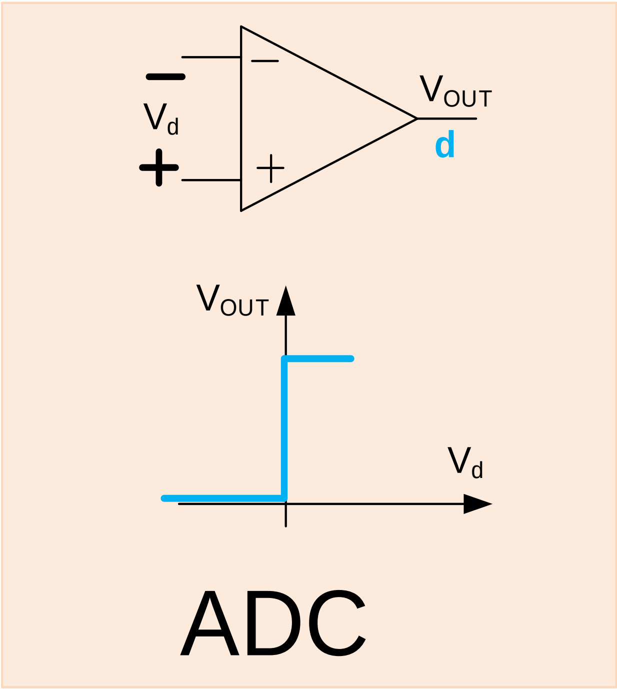
- Delta Sigma

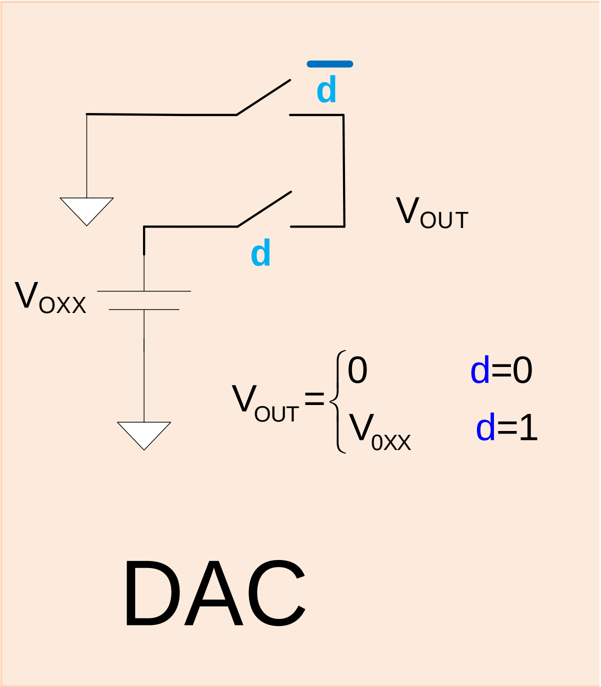
  Several clock samples to provide a single output

  Concept introduced in 1954 by Cutler of Bell Labs
  Inose and colleagues from Tokyo adopted idea in 1962
  Candy and Temes instrumental in popularizing approach in mid 70's

Data Converters

Electronic Data Conversion Process:

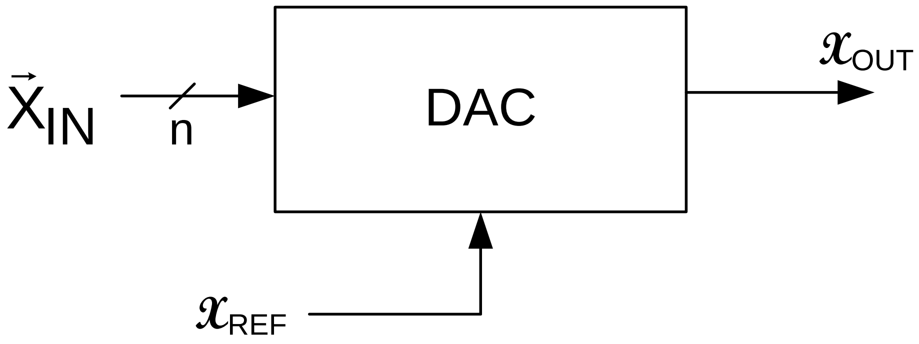




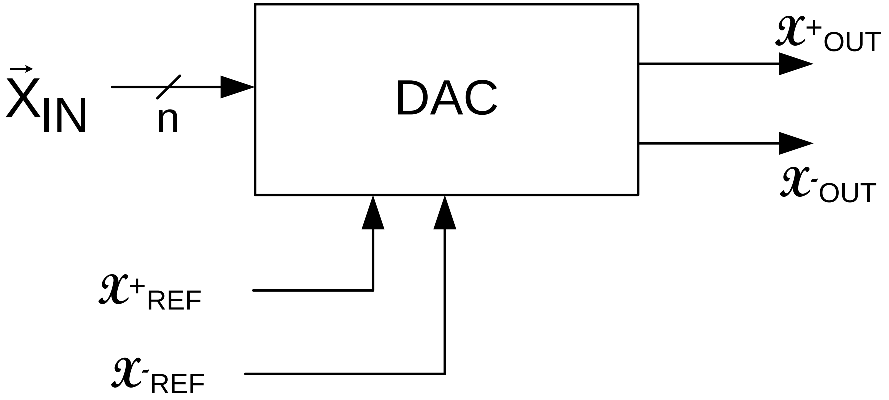
- The comparator is the basic analog to digital conversion element in all ADCs
- The switch is the basic digital to analog conversion element in all DACs
- Data converters incorporate one or more basic ADC or DAC cells
- Design of comparator or switch is often critical in data converters
- Performance of data converters often dependent upon performance of comparator, switch, and matching

D/A Converters

Basic structure:

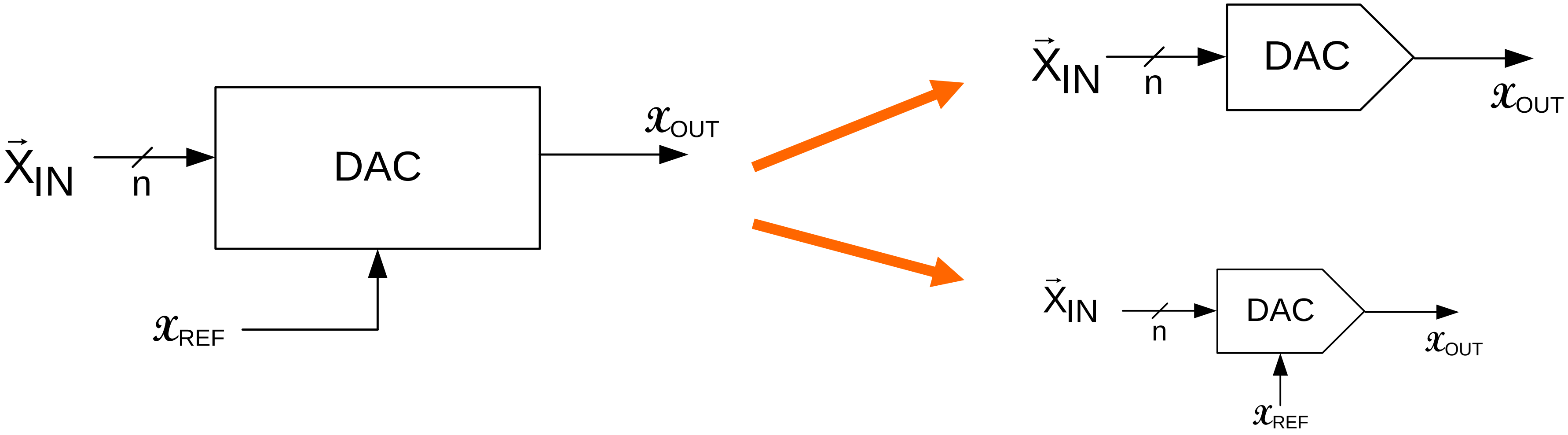


Basic structure with differential outputs::



D/A Converters

Notation:



Reference always exists even in not explicitly shown

D/A Converters

(assuming binary coding)

$$\vec{X}_{IN} = <b_{n-1}, b_{n-1}, \ldots b_1, b_0>$$

b_0 is the Least Significant Bit (LSB)

b_{n-1} is the Most Significant Bit (MSB)

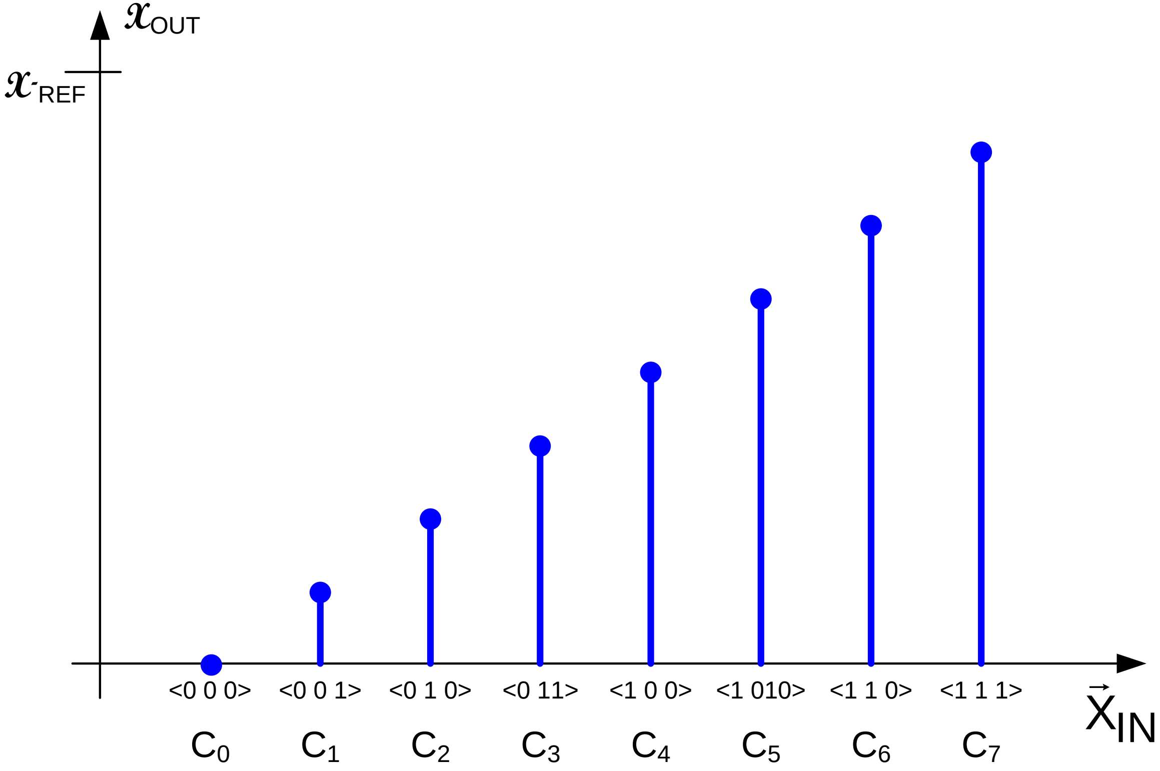
Note: some authors use different index notation

An Ideal DAC is characterized at low frequencies by its static performance

D/A Converters

$\vec{X}_{IN}$=<b_{n-1},b_{n-1},...b_1,b_0>

<u>An</u> Ideal DAC transfer characteristic (3-bits) (Nyquist Rate)

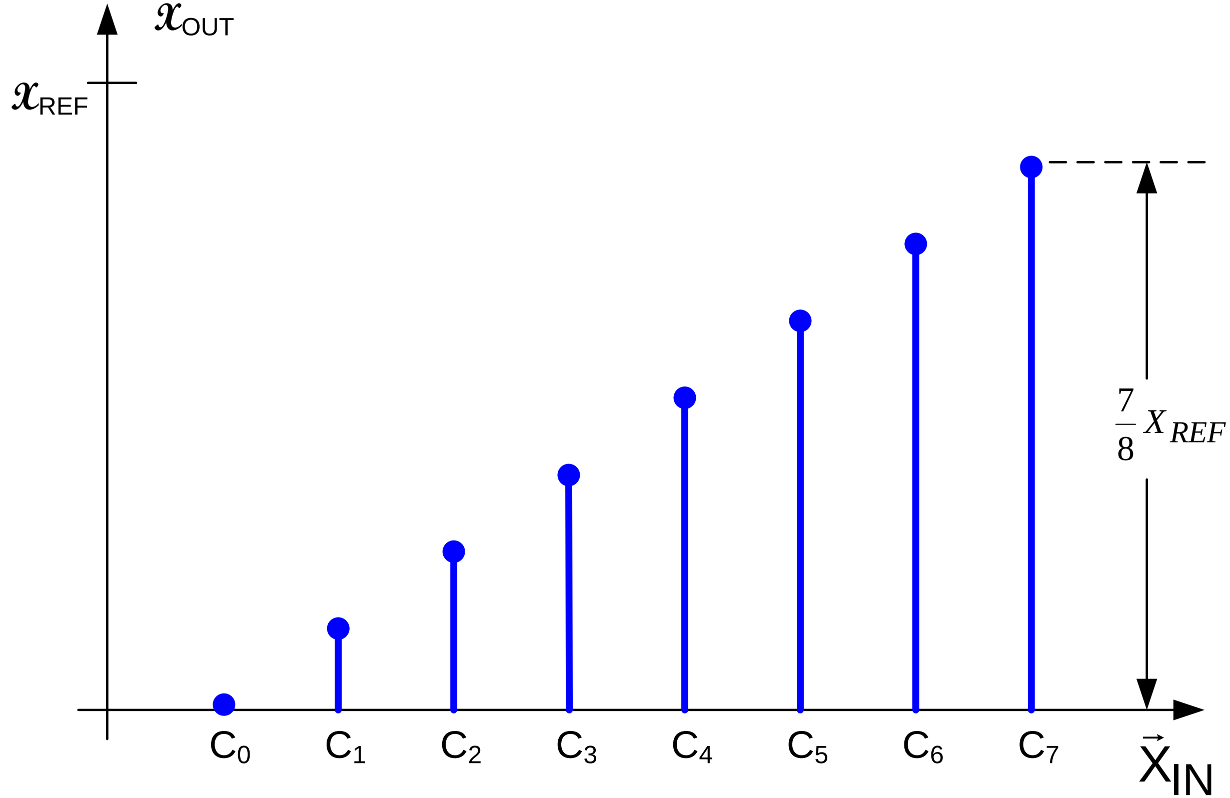


Code C_k is used to represent the decimal equivalent of the binary number <b_{n-1} .. b_0)>

D/A Converters

$$\vec{X}_{IN} = \langle b_{n-1}, b_{n-1}, \ldots b_1, b_0 \rangle$$

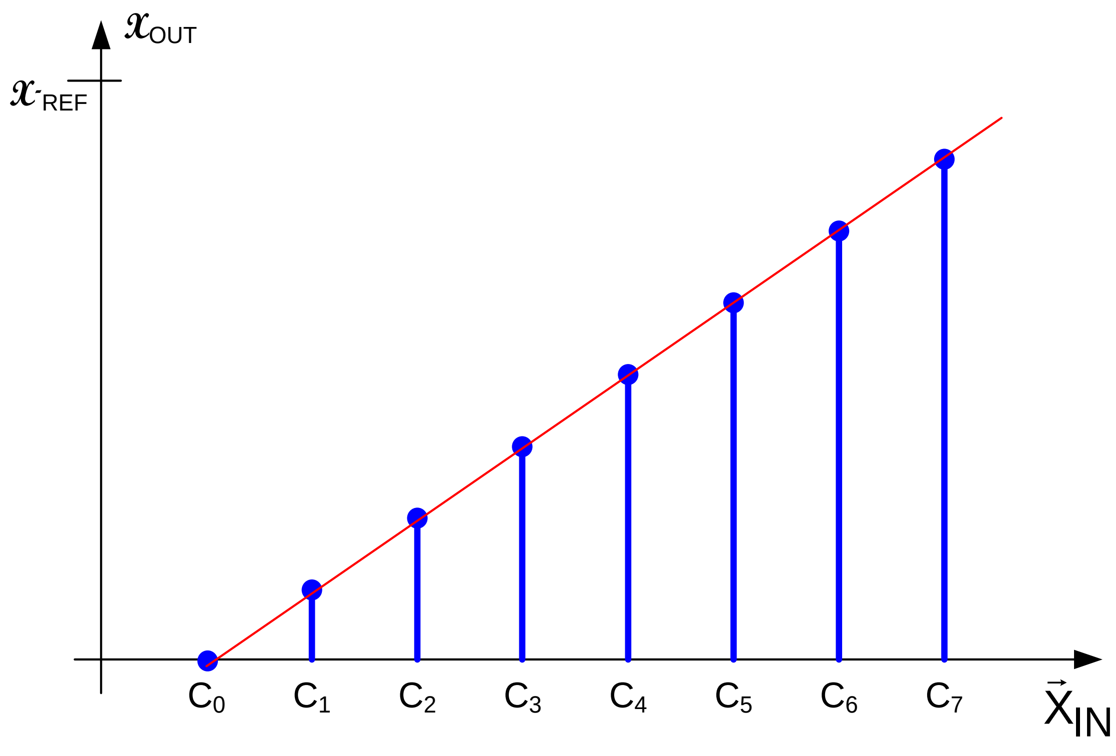
An Ideal DAC transfer characteristic (3-bits)



D/A Converters

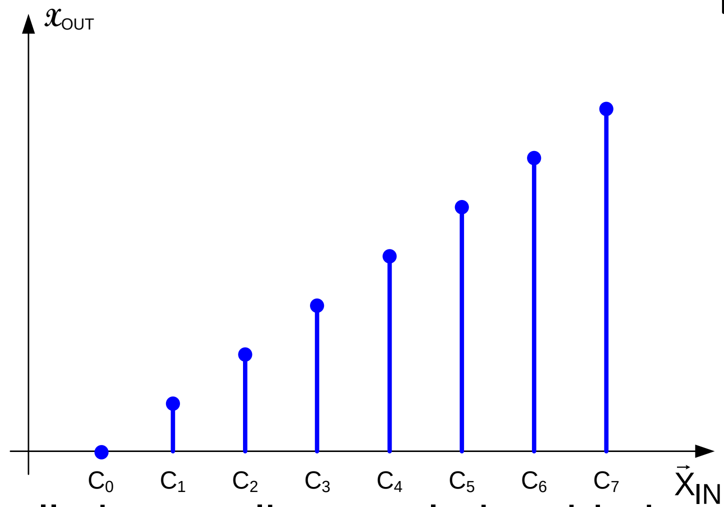
$$\vec{X}_{IN}=<b_{n-1},b_{n-1},\ldots b_1,b_0>$$

An Ideal DAC transfer characteristic (3-bits)



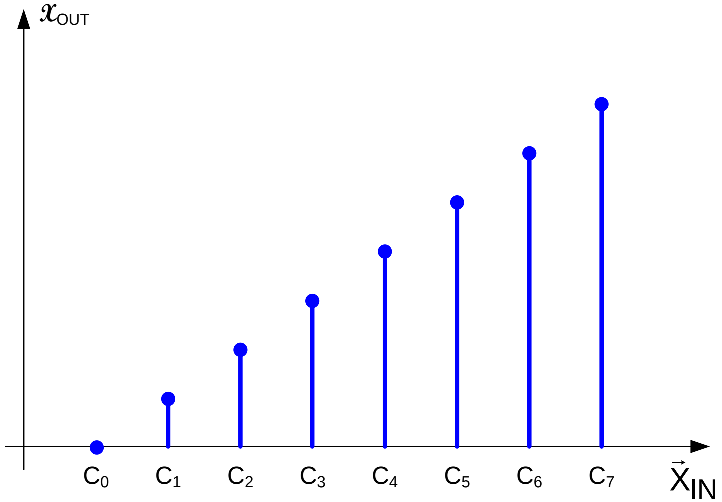
All points of this ideal DAC lie on a straight line

D/A Converters



- Most D/A ideally have a linear relationship between binary input and analog output
- Output represents a discrete set of continuous variables
- Typically this number, N, is an integral power of 2, i.e. $N=2^n$
- $\vec{X}_{IN}$ is always dimensionless
- $\mathcal{X}_{OUT}$ could have many different dimensions
- An ideal nonlinear characteristic is also possible (waveform generation and companding)
- Will assume a linear transfer characteristic is desired unless specifically stated to the contrary

D/A Converters



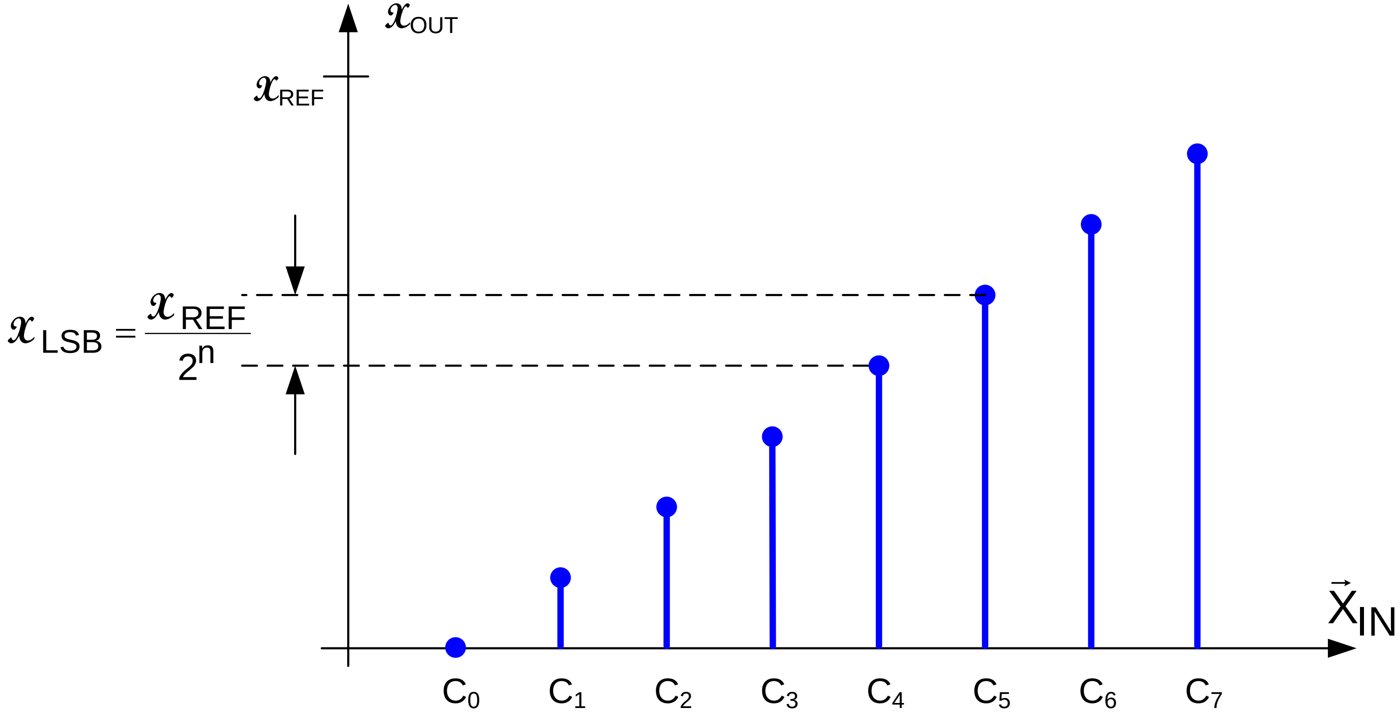
For this ideal DAC

$$X_{OUT} = X_{REF}\left(\frac{b_{n-1}}{2} + \frac{b_{n-2}}{4} + \frac{b_{n-3}}{8} + \ldots + \frac{b_1}{2^{n-1}} + \frac{b_0}{2^n}\right)$$

$$X_{OUT} = X_{REF}\sum_{j=1}^{n}\frac{b_{n-j}}{2^j}$$

- Number of outputs gets very large for n large
- Spacing between outputs is $X_{REF}/2^n$ and gets very small (relative to X_{REF}) for n large

D/A Converters

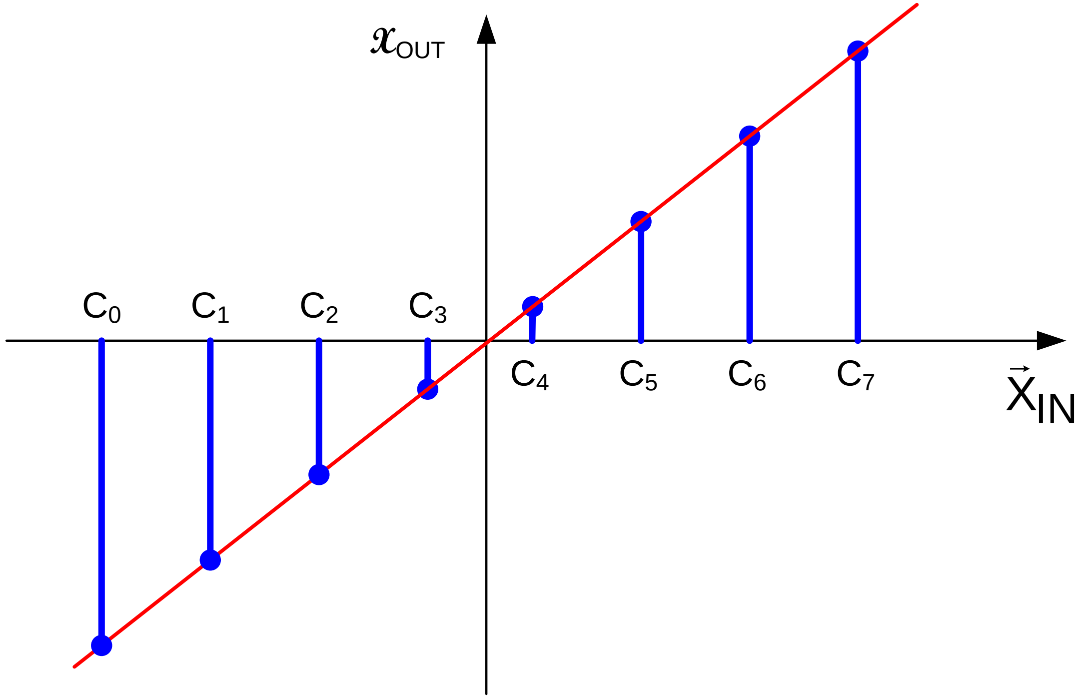


- Ideal steps all equal and termed the LSB
- x_{LSB} gets very small for small x_{REF} and large n

e.g. If x_{REF}=1V and n=16, then N=2^{16} =65,536, x_{LSB}=15.25μV

D/A Converters

An alternate ideal 3-bit DAC



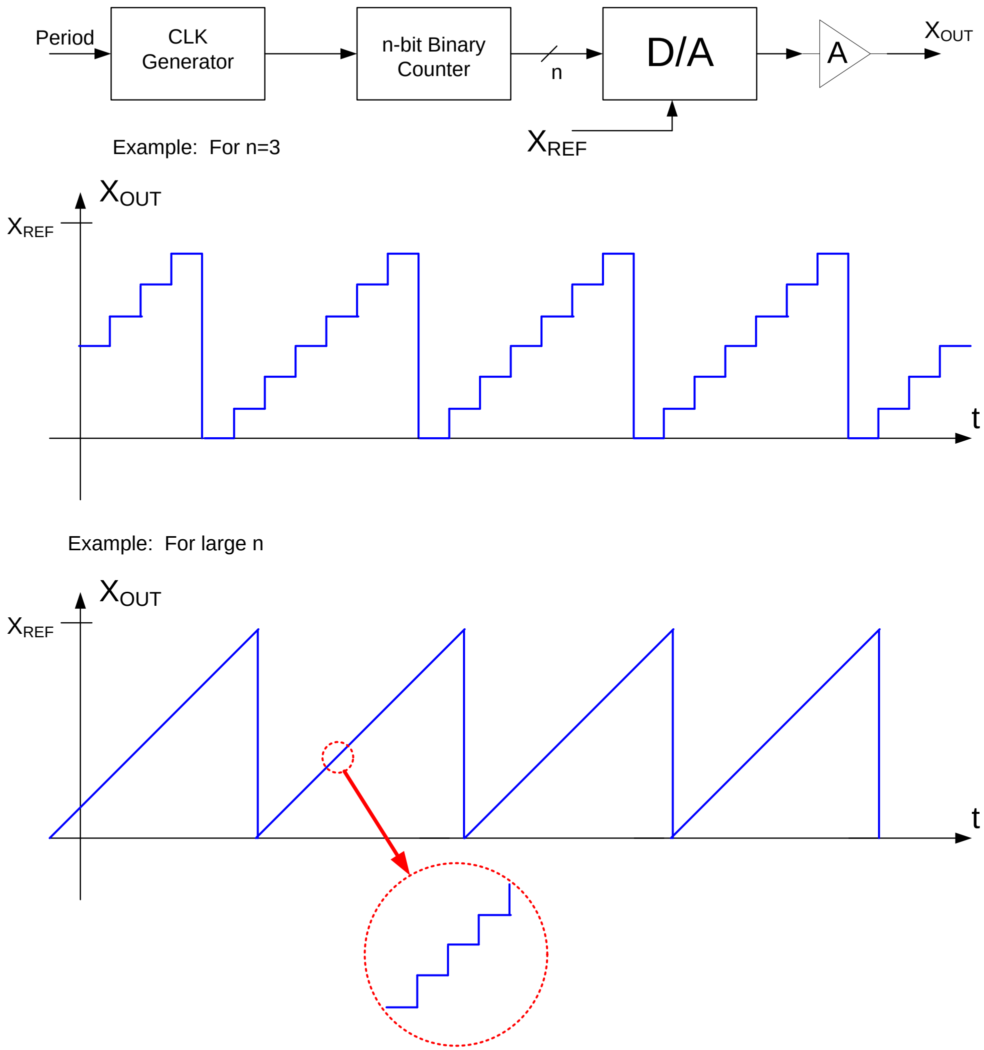
Irrespective of which form is considered, the increment in the output for one Boolean bit change in the input is x_{LSB} and the total range is 1LSB less than x_{REF}

Applications of DACs

- Waveform Generation
- Voltage Generation
- Analog Trim or Calibration
- Industrial Control Systems
- Feedback Element in ADCs
- ….

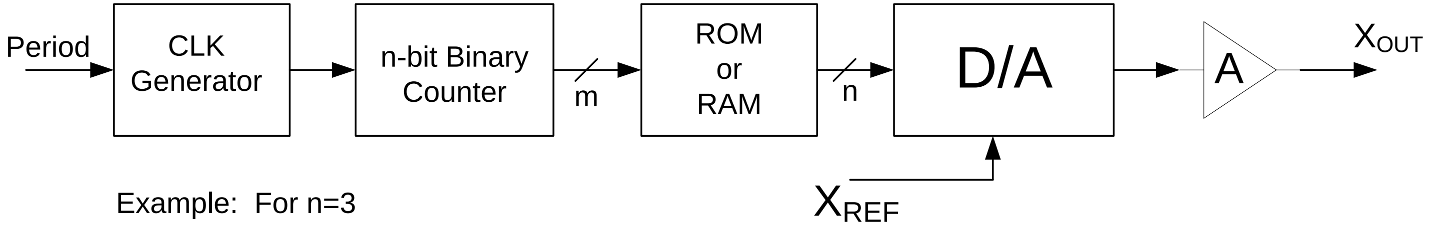
Waveform Generation with DACs

Ramp (Saw-tooth) Generator

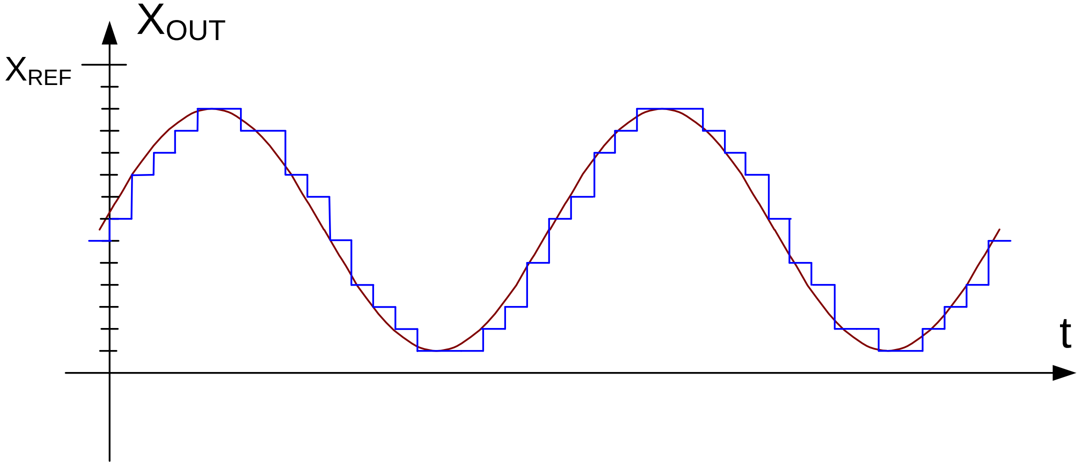


Waveform Generation with DACs

Sine Wave Generator



Example: For n=3

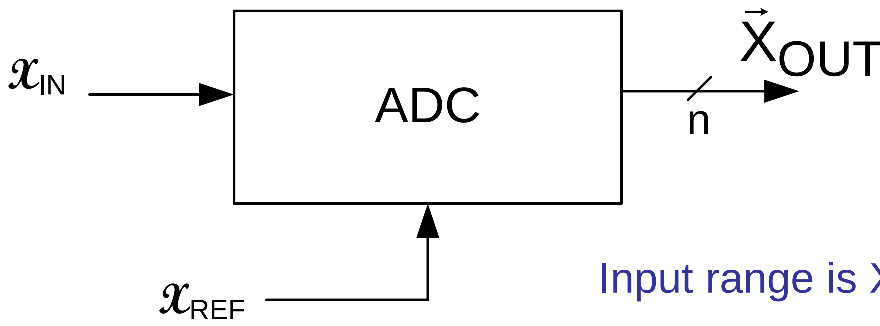


Distortion of the desired waveforms occurs due to both time and amplitude quantization

Often a filter precedes or follows the buffer amplifier to smooth the output waveform

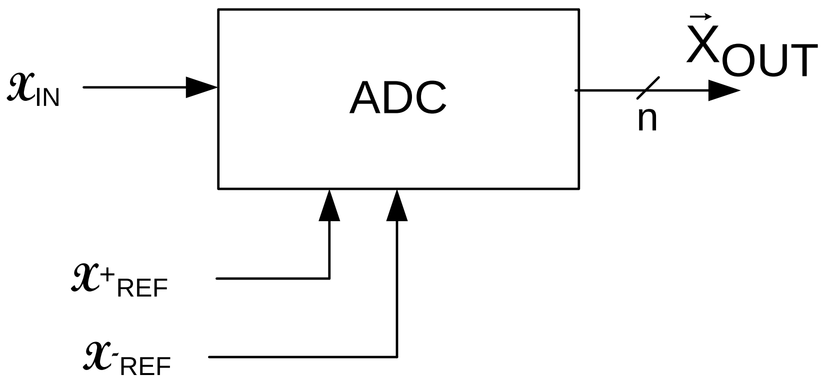
A/D Converters

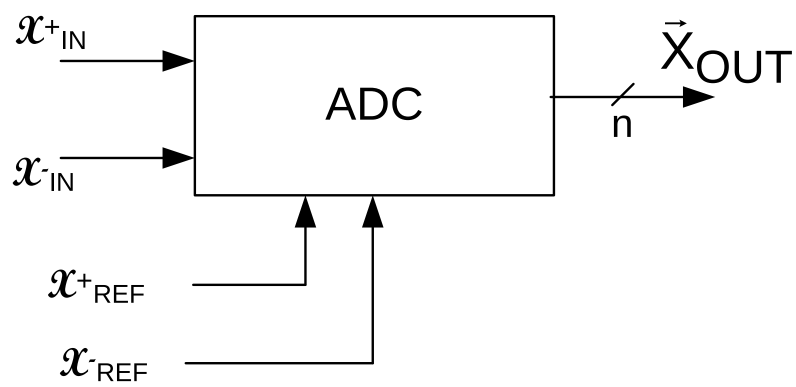
Basic structure:



Input range is X_{REF}

Basic structure with differential inputs/references:



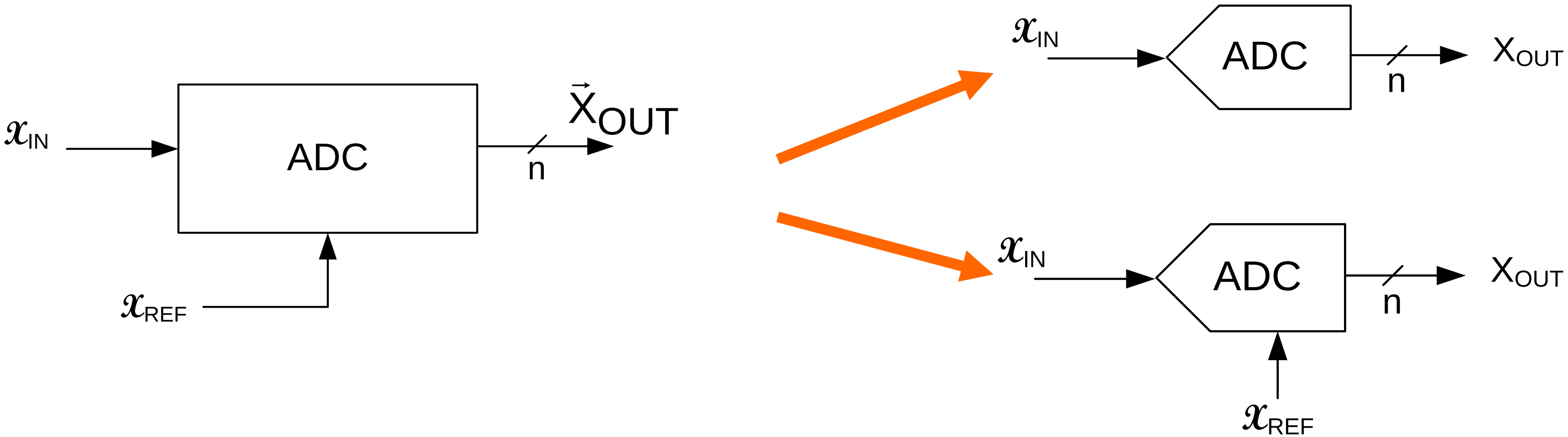


Input range is $X^{+}_{REF} - X^{-}_{REF}$

Typically Input range is $2(X^{+}_{REF} - X^{-}_{REF})$

A/D Converters

Notation:



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A/D Converters

(assuming binary coding)

$$\vec{X}_{OUT} = \langle d_{n-1}, d_{n-2}, \ldots d_0 \rangle$$

d_0 is the Least Significant Bit (LSB)

d_{n-1} is the Most Significant Bit (MSB)

An Ideal ADC is characterized at low frequencies by its static performance

Stay Safe and Stay Healthy !

End of Lecture 1