Analog to Digital Converter

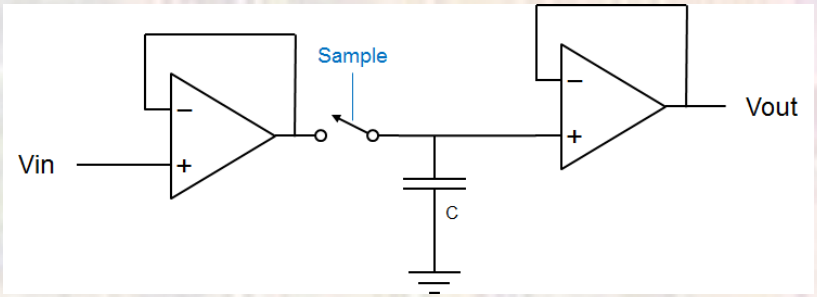
Last updated 1/11/24

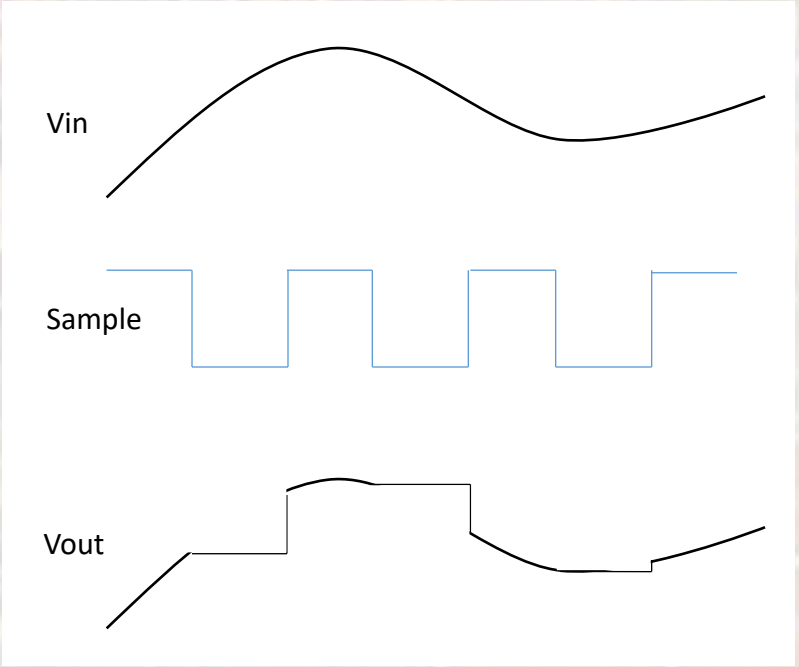
A/D

- Analog to Digital Conversion
  - Most of the real world is analog
    - temperature, pressure, voltage, current, …
  - To work with these values in a computer we must convert them into digital representations
  - Three steps to this conversion
    - Sampling
    - Quantizing
    - Encoding

A/D

- Sampling
  - A to D Conversion takes a finite amount of time
  - What if the input changes during this time?
  - We must take a snapshot of the input → Sample and Hold

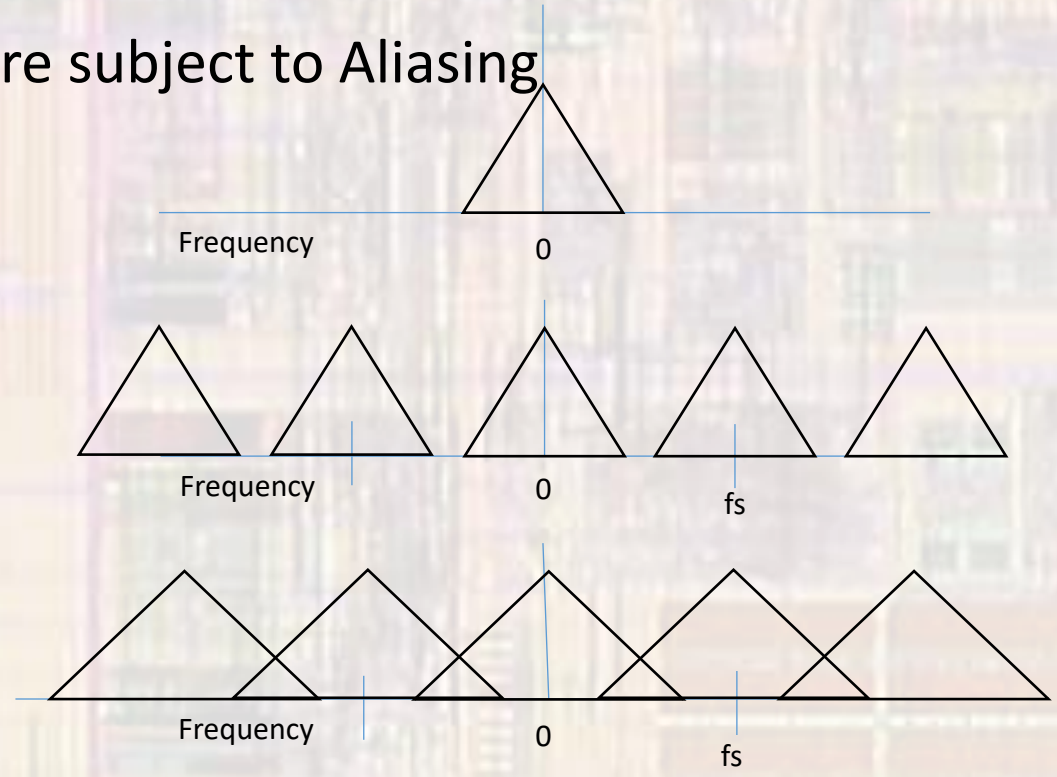




A/D

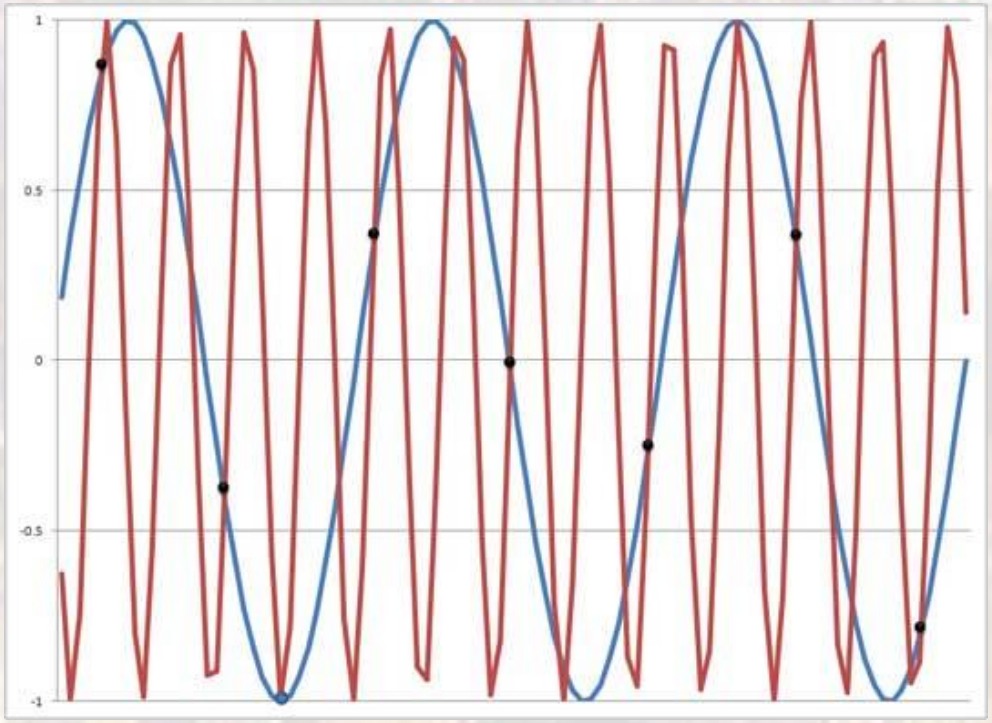
- Sampling
  - Sampling is a kind of MODULATION
  - Modulation systems are subject to Aliasing
  - Fin < fs/2
    - Fs: Nyquist rate

→ LPF the input
(anti-aliasing filter)



A/D

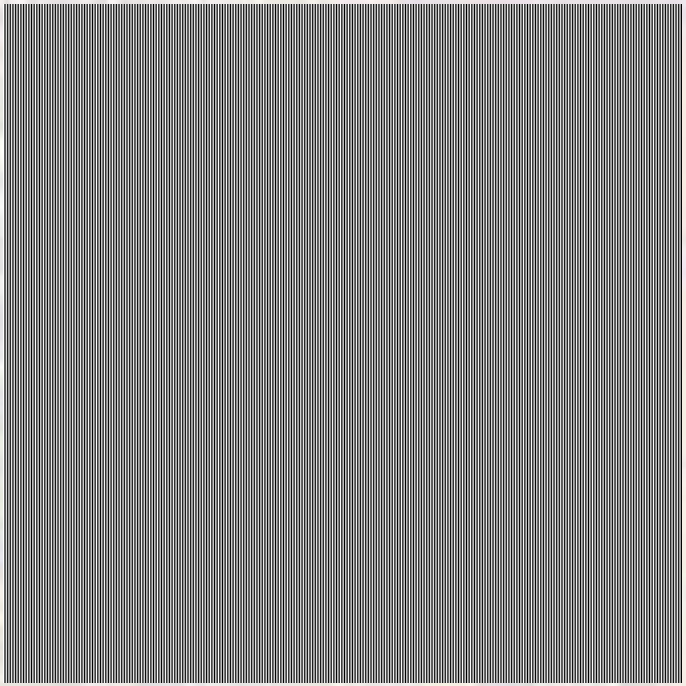
- Sampling
  - Example of analog aliasing

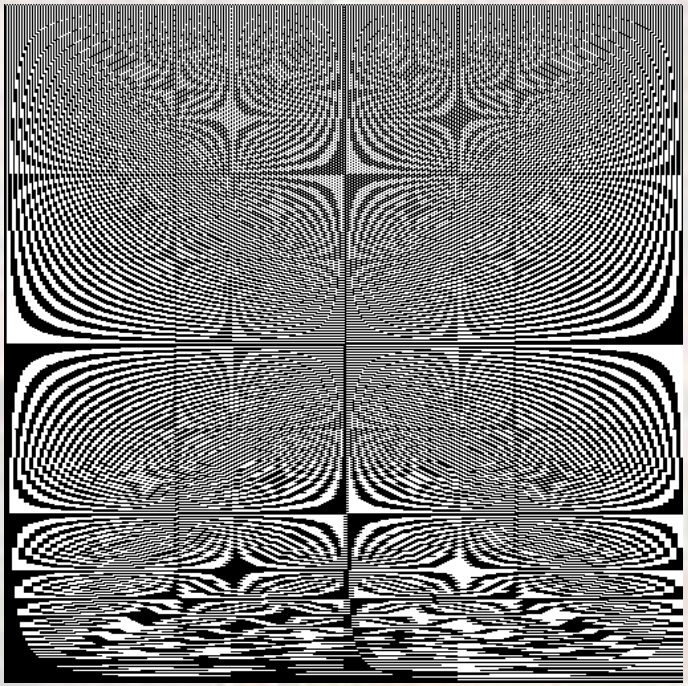


http://arstechnica.com/features/2007/11/audiofile-analog-to-digital-conversion/

A/D

- Sampling
  - Example of digital aliasing





http://www.cs.unm.edu/~brayer/vision/perception.html

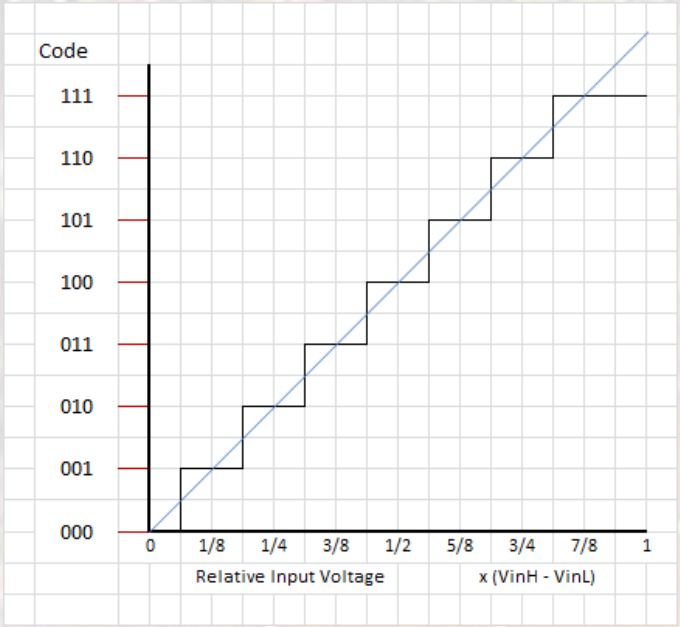
A/D

- Quantizing

  - In the A to D process we are converting an “infinite” resolution analog signal into a finite number of digital bits
  - Converters use reference voltages to set the range of allowed input voltages - Vref-H , Vref-L
  - Each binary step represents

    $(V_{ref\text{-}H} - V_{ref\text{-}L}) / 2^n$ for an n bit conversion

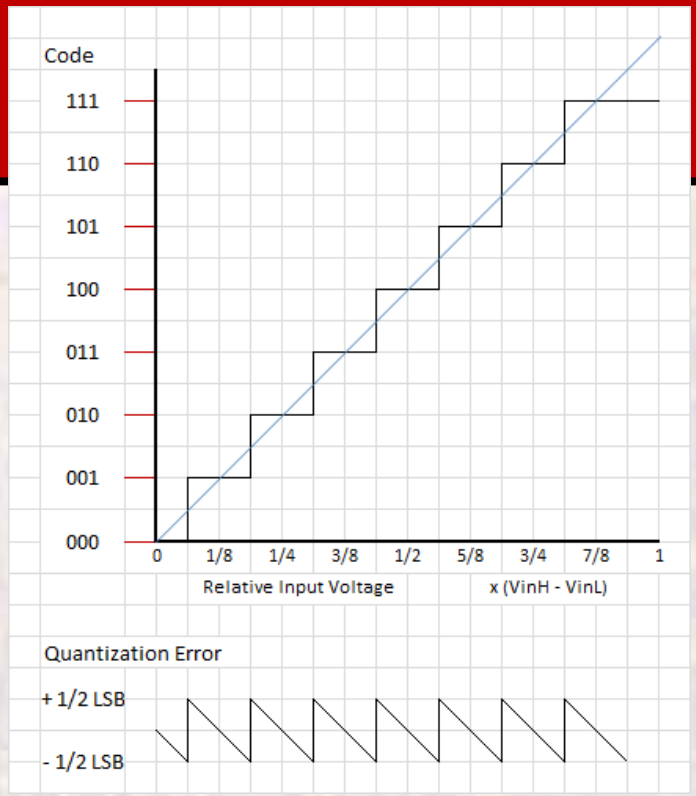
  - e.g. 0V – 1V input converted to 3 bit digital value
    - each binary step represents 0.125V
    - since 000 typically represents 0.0V, 111 represents 0.875V



A/D

- Quantizing
  - Quantization error looks like noise on the signal (Quantization Noise)
  - Dynamic Range is a measure of signal to noise ratio. (SNR in dB)
  - For an AtoD the Dynamic Range is the measure of signal to Quantizing Noise ratio (SQNR)
  - SQNR = $20 \log_{10}(2^n/(1/2 - (-1/2))$

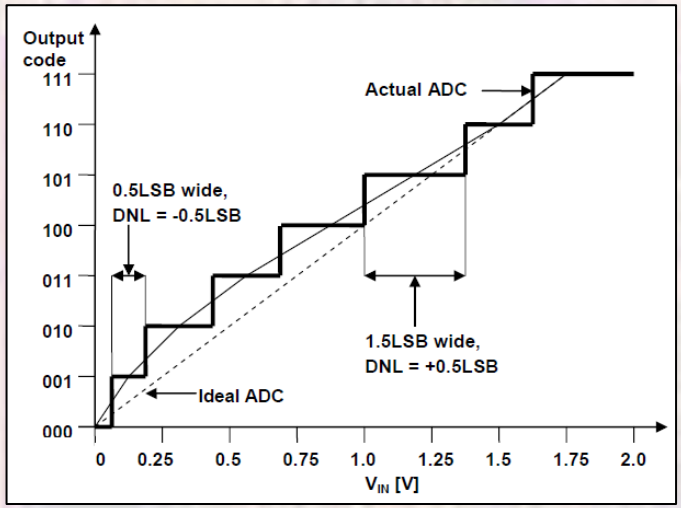
    $= 20 \log_{10} 2^n$
    - 8bit → 48dB
    - 10bit → 60dB



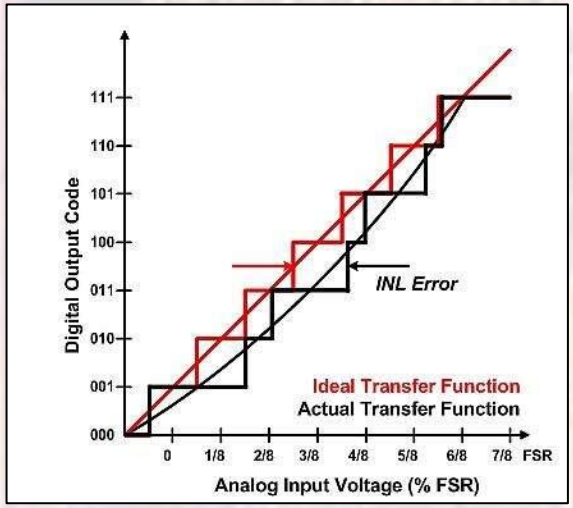
n	steps	Step Size rel to Vref-H - Vref-L	SQNR (dB)
1	2	0.5	6
2	4	0.25	12
3	8	0.125	18
4	16	0.0625	24
5	32	0.03125	30
6	64	0.015625	36
7	128	0.0078125	42
8	256	0.00390625	48
9	512	0.001953125	54
10	1024	0.000976563	60
11	2048	0.000488281	66
12	4096	0.000244141	72

A/D

- Other errors
  - Differential non-linearity



  - Integral non-linearity



A/D

- A/D Conversion Example
- 10 bit converter with VrefH=3.0V, VrefL=0.0V
- If the input is 2V, what is the output code

VrefH-VrefL = 3V range

10 bit converter step size = range/2^{10} = 2.9297mV/step

2V / 2.9297mV/step = 682 steps from VrefL

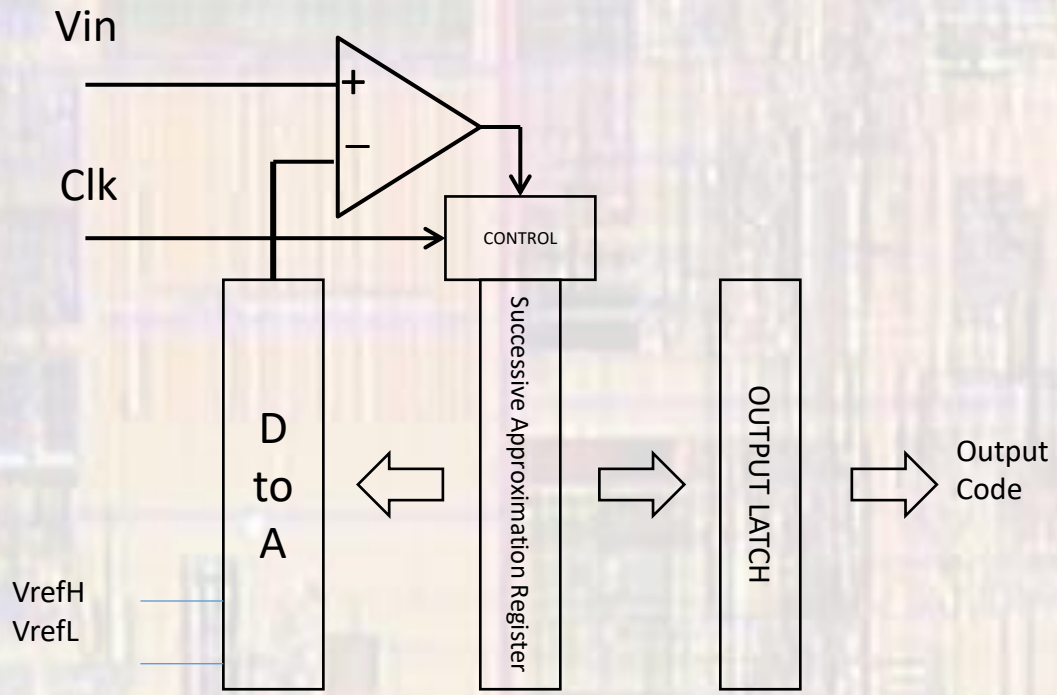
10 1010 1010

A/D

- Successive Approximation A to D
  - Uses an iterative process to determine the correct digital value for the analog input
  - Requires
    - Input (sample and held)
    - A register to hold the current estimate of the digital value
    - D to A converter to convert the digital estimate back to analog
    - A comparator to determine if the estimate is above or below the actual input value
    - Control logic to run the process
  - Uses a binary search to find the nearest code value to the input value

A/D

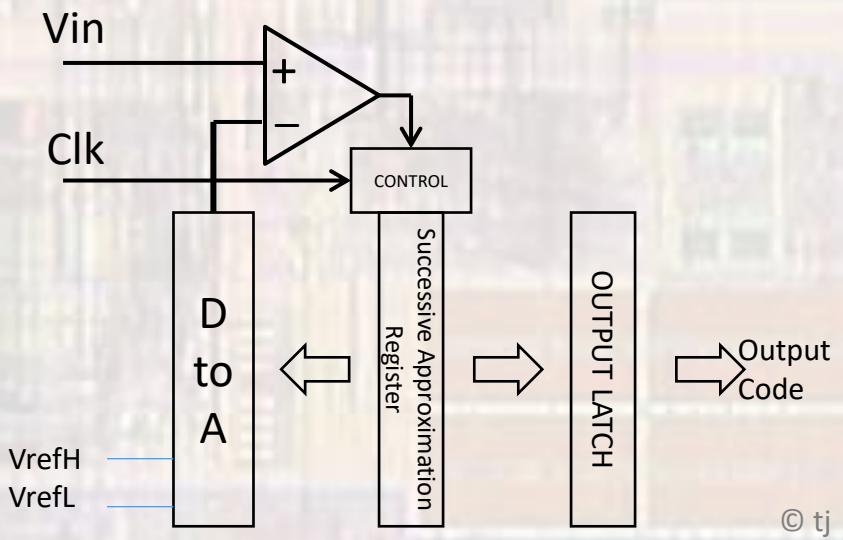
- Successive Approximation A to D



A/D

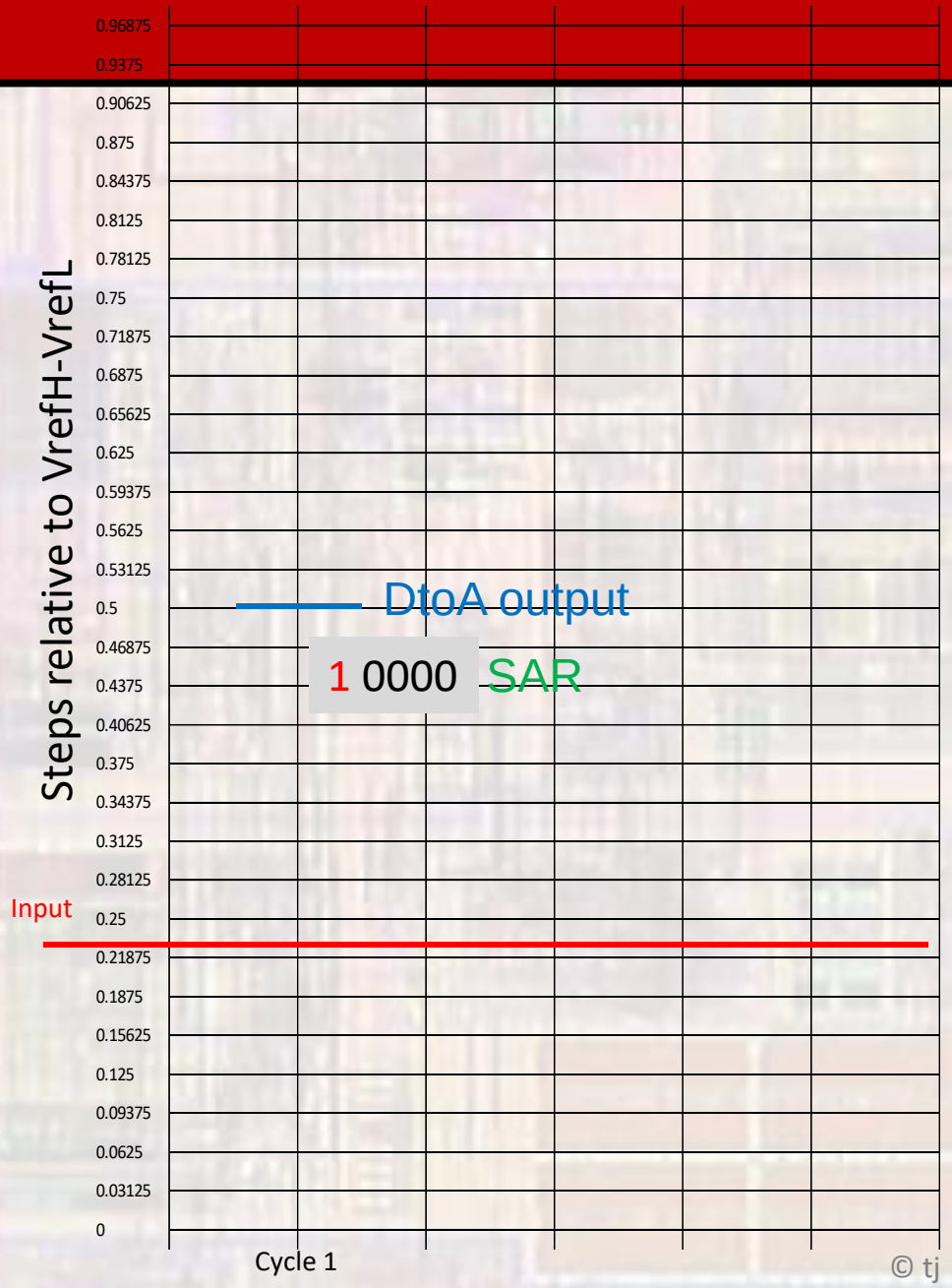
- Successive Approximation A to D

- The control logic resets the SAR before each conversion
- The control logic then sets the msb
  - The DtoA converts this to ½ the reference voltage
  - The comparator tests to see if the input is above or below this value
    - if above, the 1 in the msb stays
    - if below, the msb is reset to zero
- The control logic then sets the msb-1 bit
  - The DtoA converts this to the appropriate voltage level
  - The comparator tests to see if the input is above or below this value
    - if above, the 1 stays
    - if below, the msb-1 bit is reset to 0
- The control logic then sets the msb-n bit
  - The DtoA converts this to voltage
  - The comparator tests to see if the input is above or below this value
    - if above, the 1 stays
    - if below, the msb-n bit is reset to 0



A/D

- A to D Convertor
  - 1V, 5 bit example
  - Test to see if input is > or < midpoint
    - if < , clear msb
    - if >, set msb



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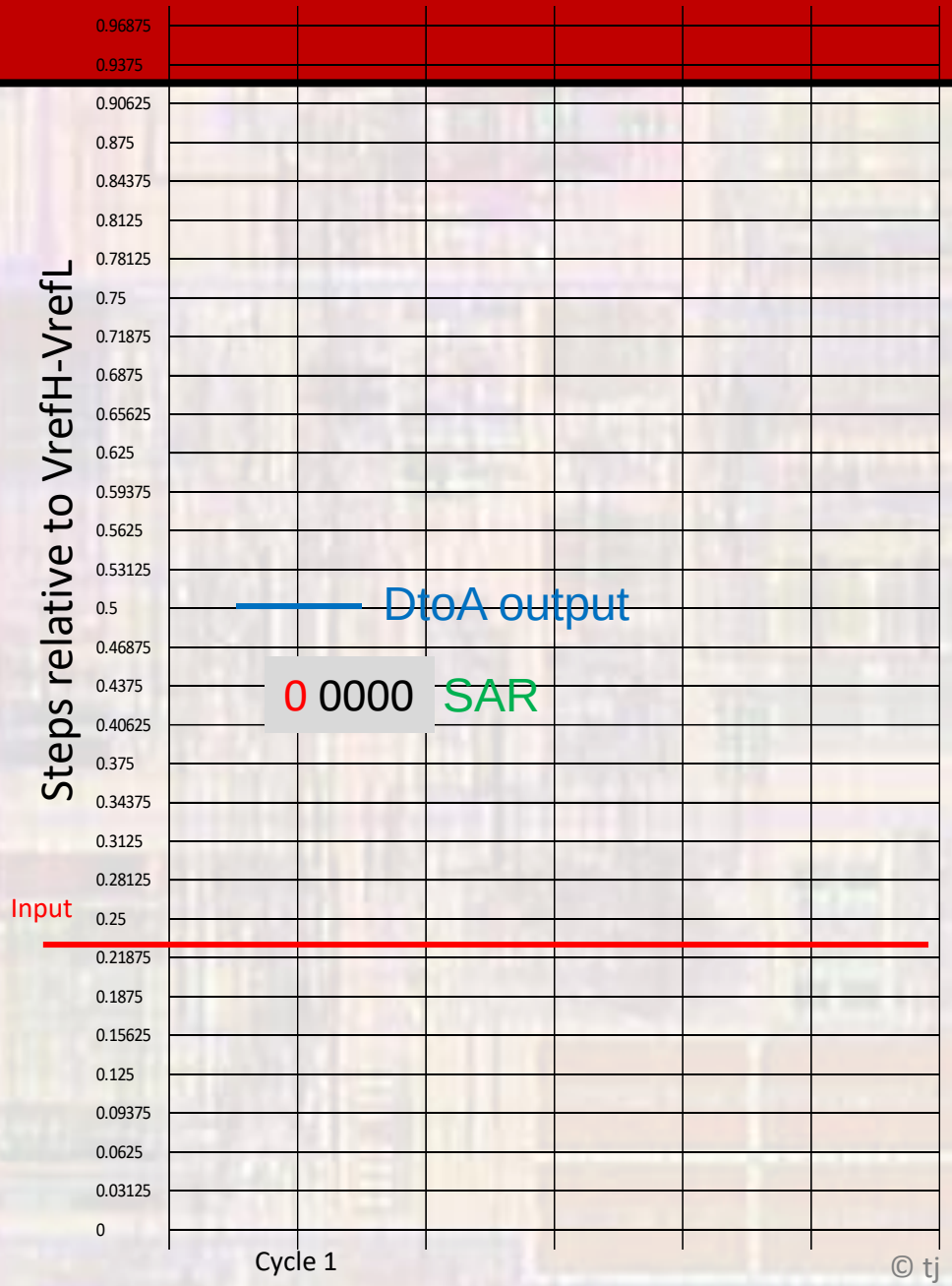
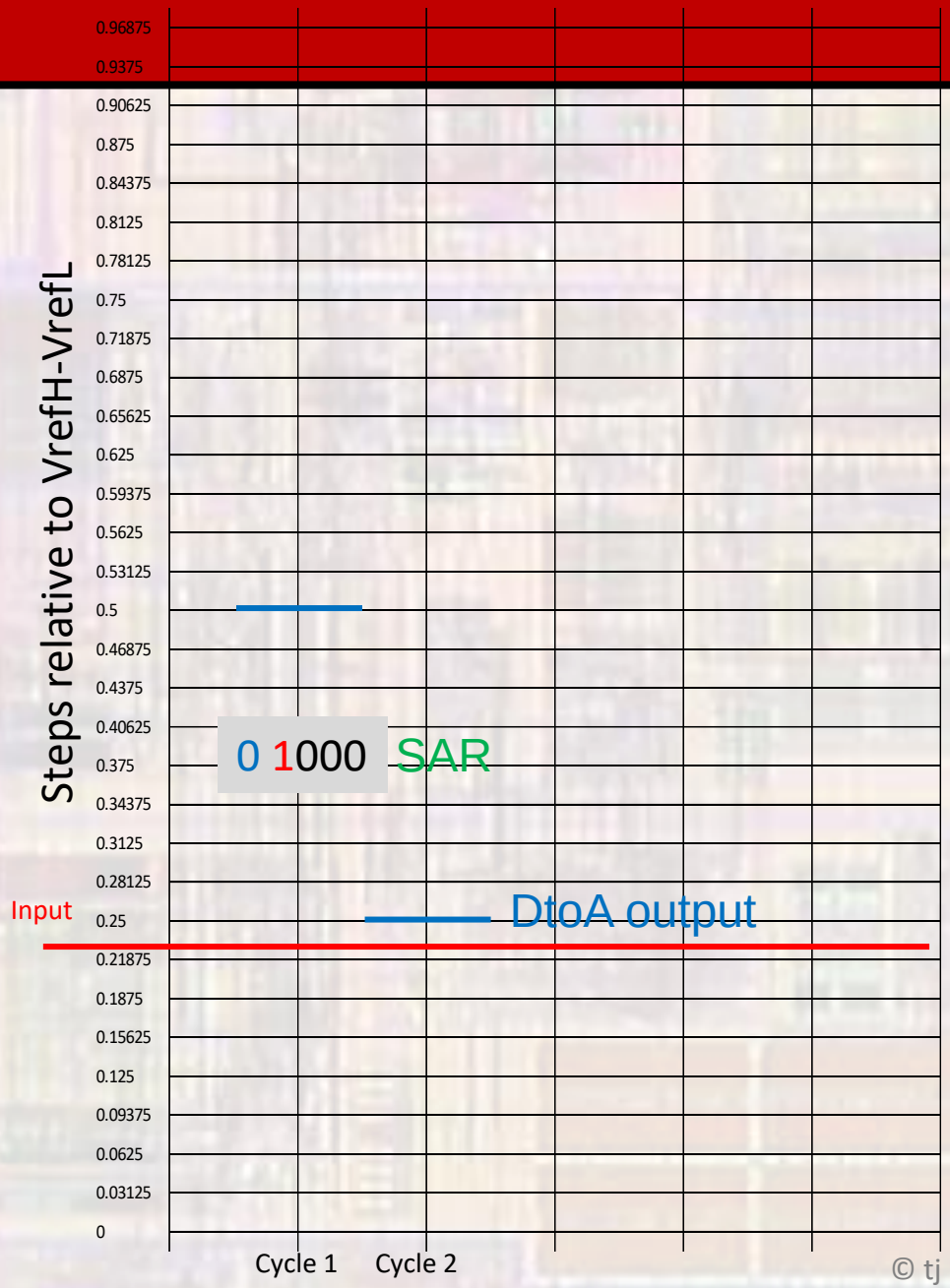


A/D

- A to D Converter
- Test to see if input is
  > or < new “midpoint”
  - if < , clear bit
  - if >, set bit



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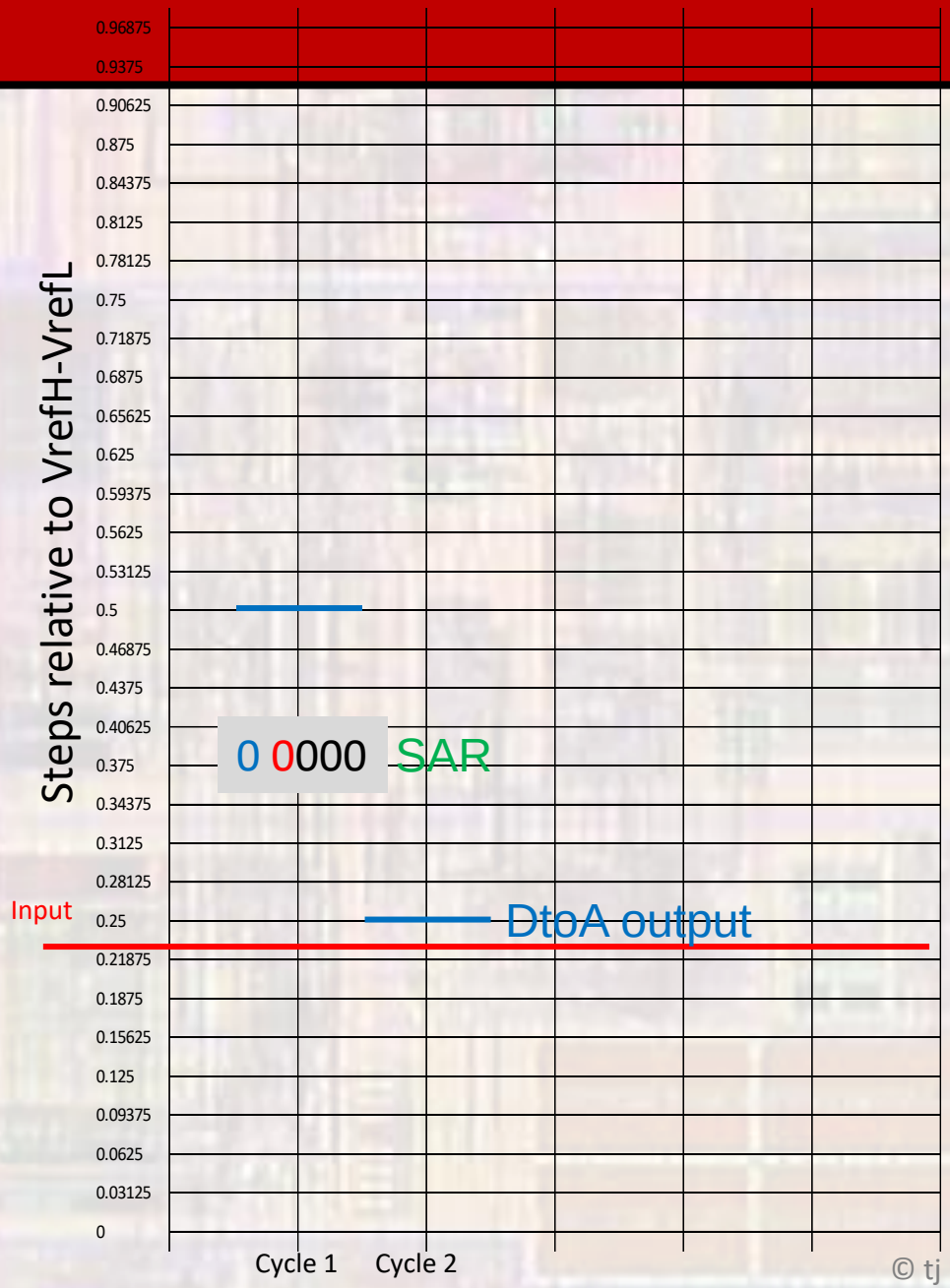

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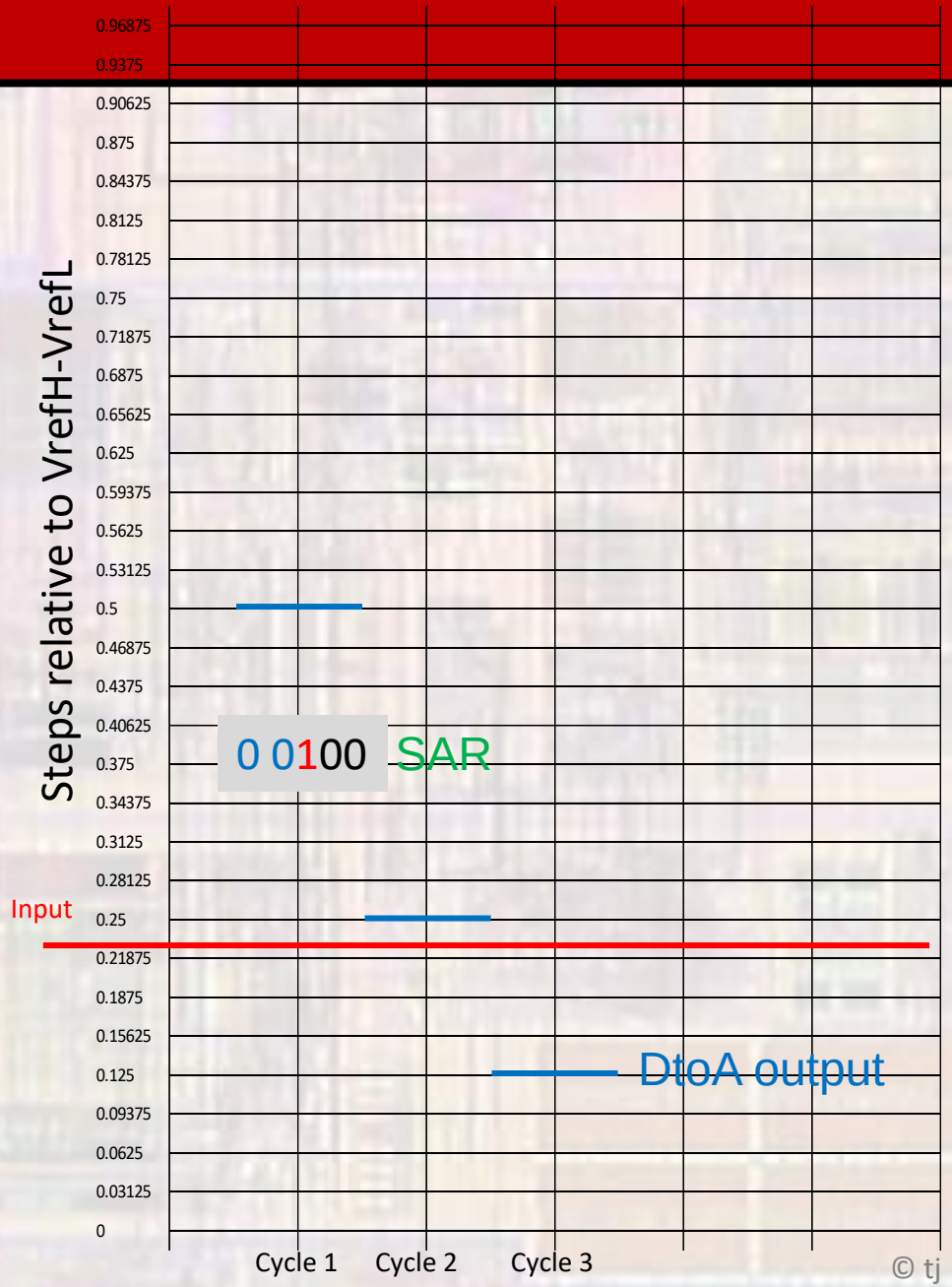

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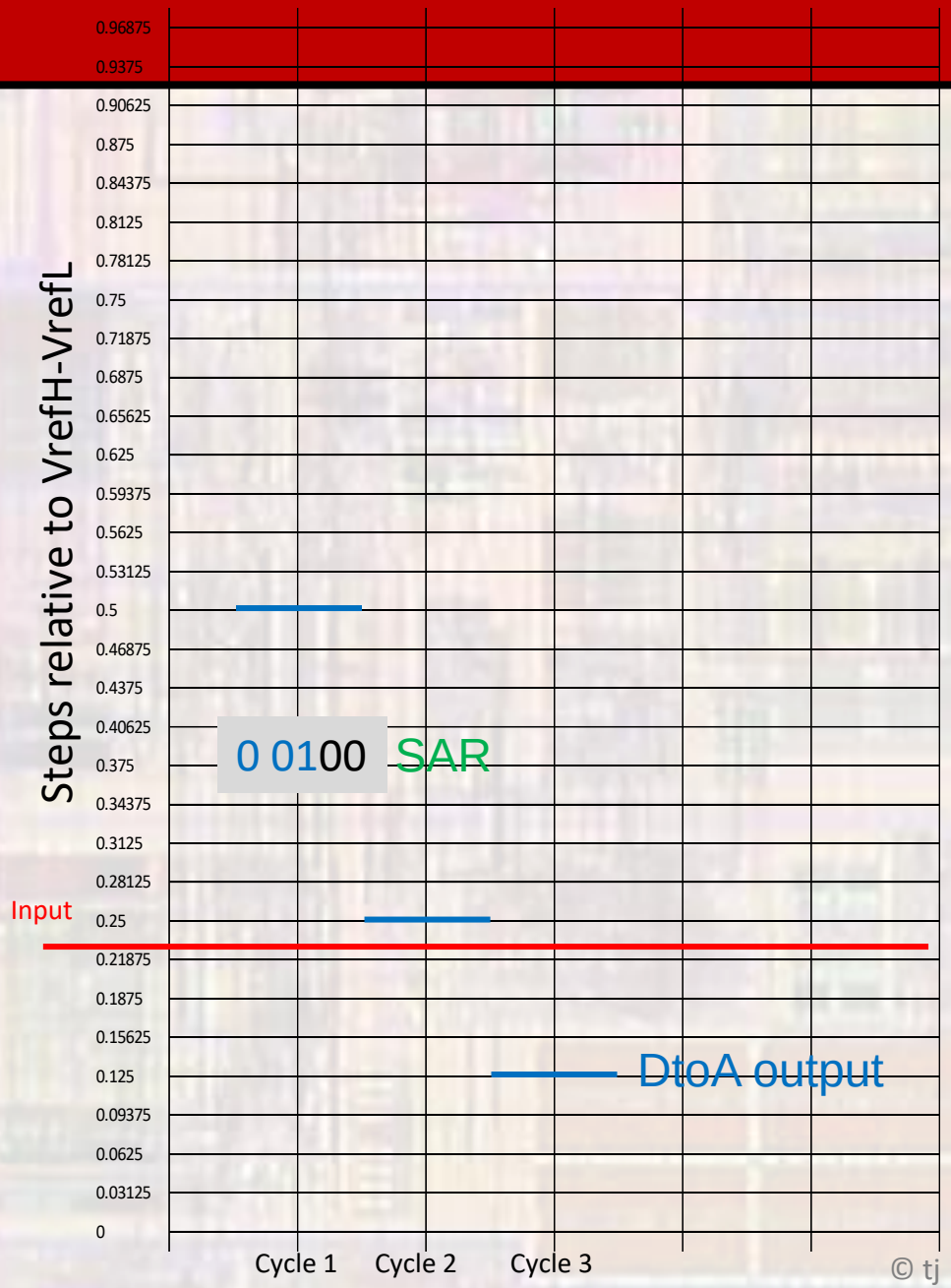

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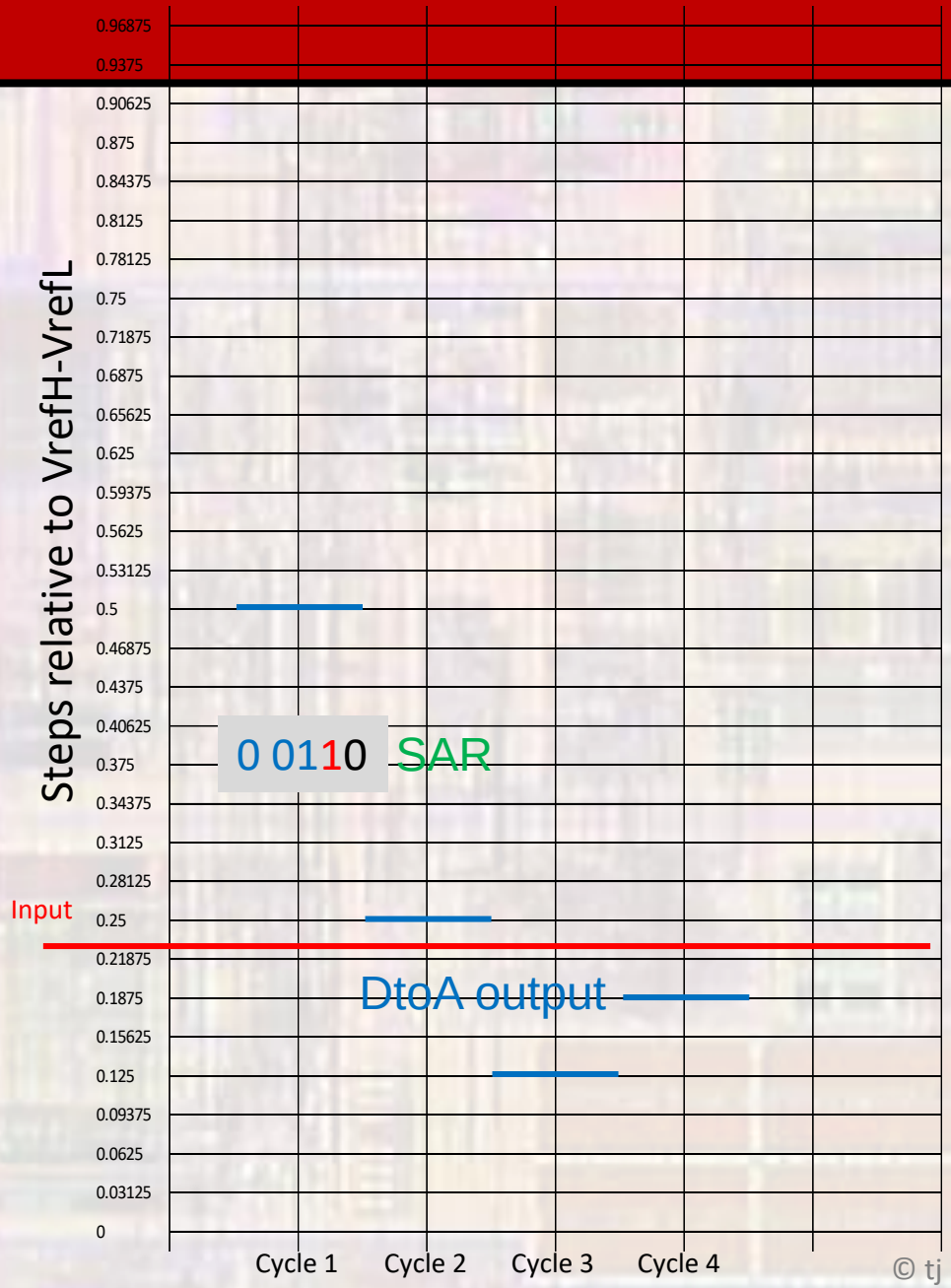

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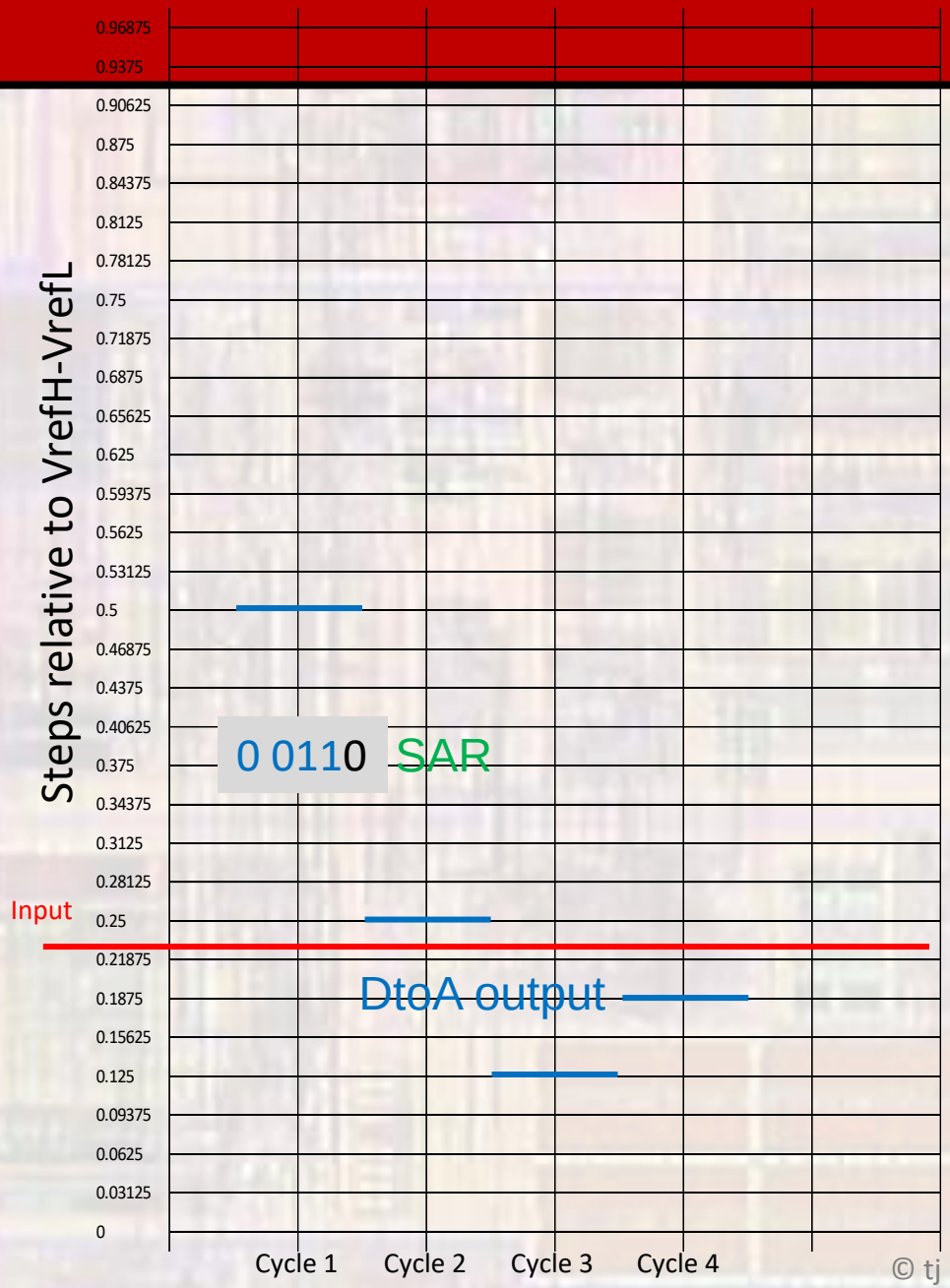

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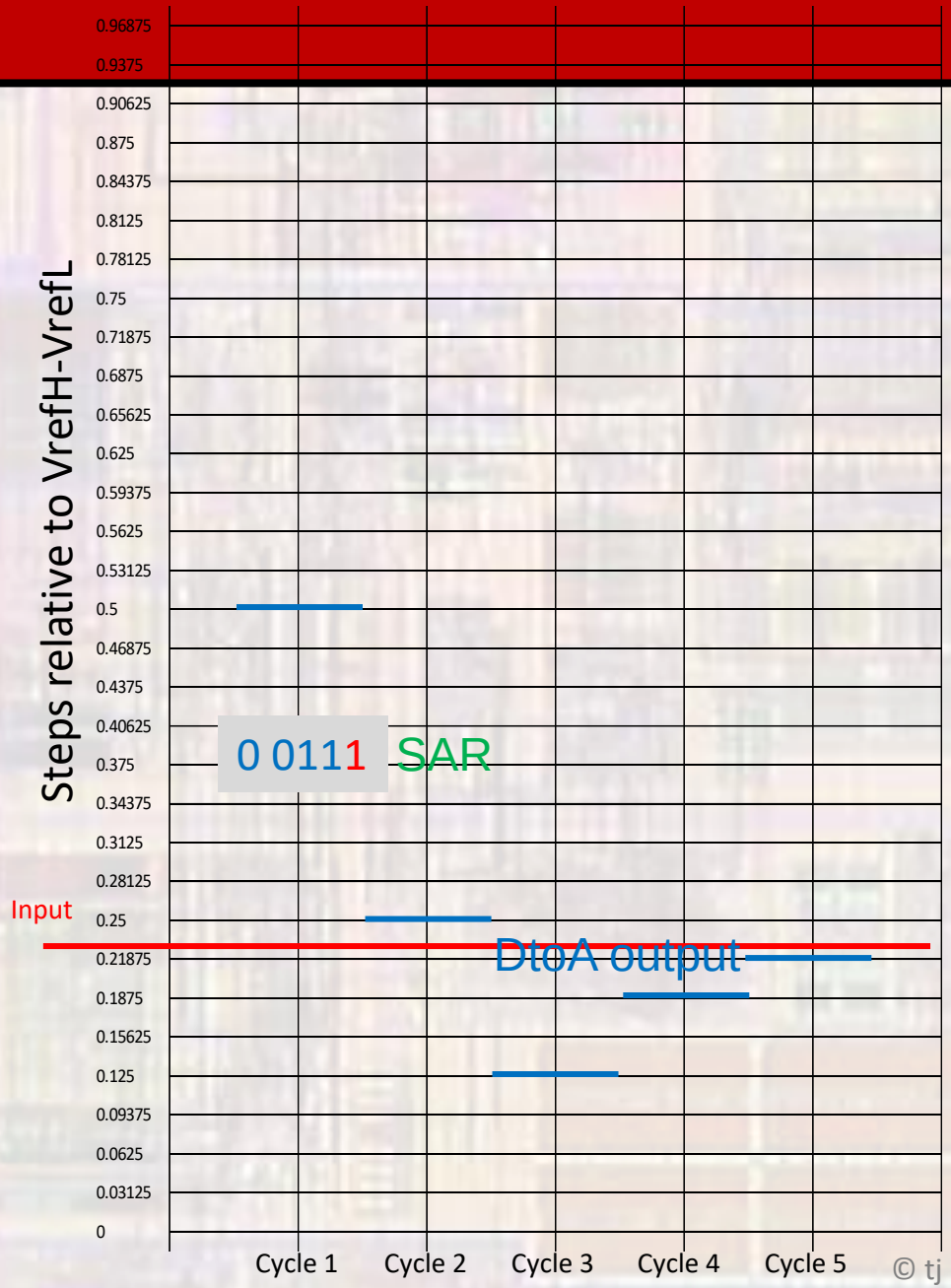

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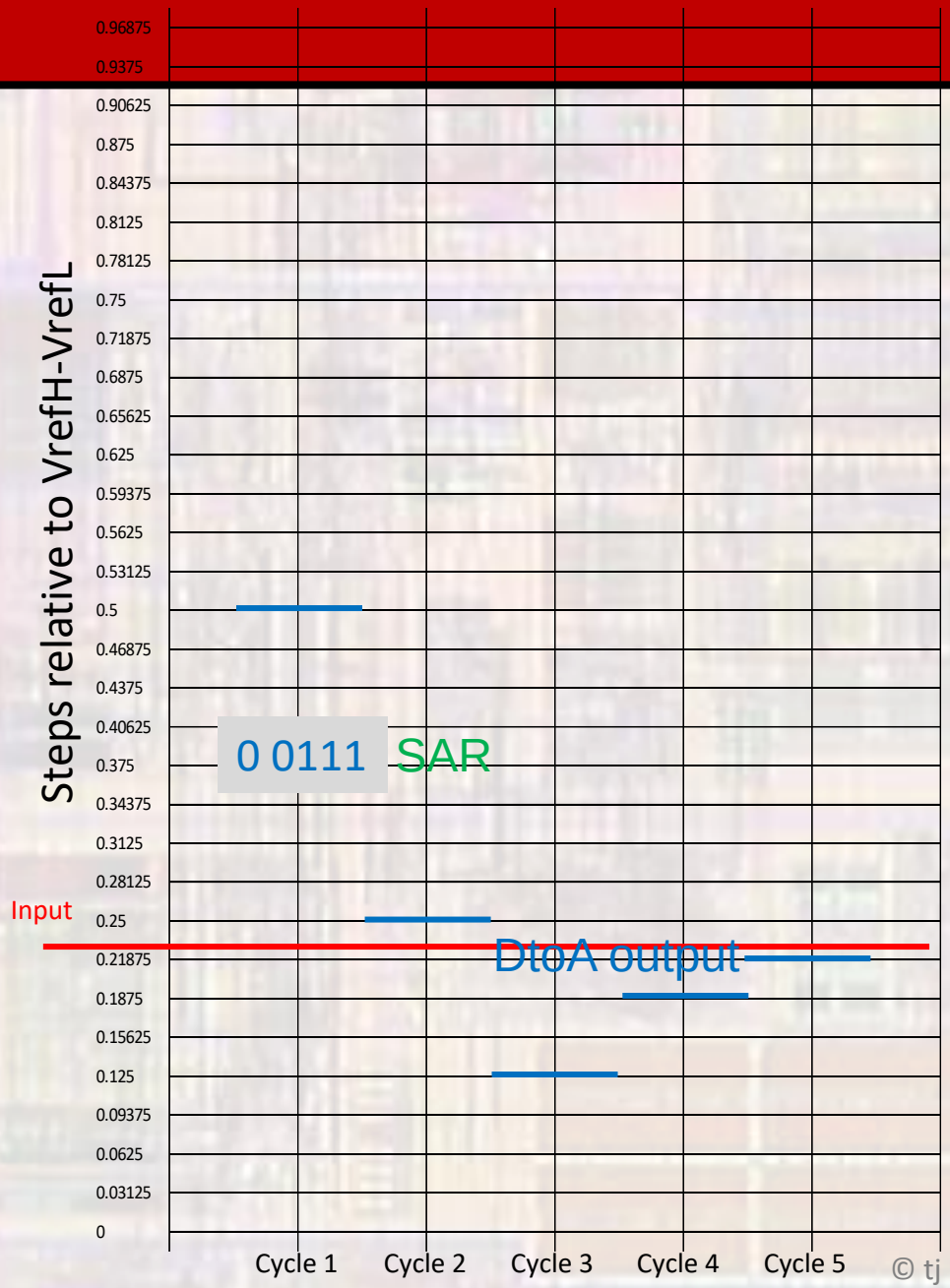

A/D

- Example 1

Nbits: 4
VrefH: 3v
VrefL: 0v

D/A Code HEX	D/A Output Voltage
0	0.000
1	0.188
4	0.750
6	1.125
8	1.500
C	2.250
E	2.625
F	2.813

A/D

- Example2

Nbits: 4
VrefH: 3v
VrefL: 0v

Input Voltage	Output Code
	Hex
0	0
0.3	1
0.9	4
1.47	7
1.53	8
2.4	C
2.85	F
3.3	F

A/D

- Example3

Nbits: 4
VrefH: 3v
VrefL: 0v

Input Voltage	Output Code Hex	D/A Output Voltage	Error Voltage	Error Bits
0	0	0.000	0.000	0.000
0.3	1	0.188	0.113	0.600
0.9	4	0.750	0.150	0.800
1.47	7	1.313	0.158	0.840
1.53	8	1.500	0.030	0.160
2.4	C	2.250	0.150	0.800
2.85	F	2.813	0.038	0.200
3.3	F	2.813	0.488	2.600

A/D

- Add other types

Nbits:	4
VrefH:	3v
VrefL:	0v