Digital to Analog Converter

Last updated 5/5/2019

D/A

- Digital to Analog Converter
  - Converts a digital word to a fixed analog voltage level
  - Many applications
    - Electronic music
    - Audio conversion – cell phones
    - Video conversion – digital TV
    - Mechanical conversion – valve opening

D/A

- Digital to Analog Converter
  - Converts a digital word to a fixed analog voltage level
  - Many types of D/A converters
    - Resistor DAC
    - Current DAC
    - Switched Capacitor DAC
    - Delta-sigma DAC
    - Pulse width modulator

D/A

- Digital to Analog Converter Performance
  - Resolution
    - n-bit digital word can represent 2^n levels
    - 8-bit DAC → 256 levels
  - Frequency
    - Outputs are provided at a fixed rate – data rate
    - Desired output is limited by the Nyquist criteria
    - Signals can be re-constructed iff
      - data rate > 2 * Maximum signal frequency content
  - Accuracy
    - Linearity
    - Noise
    - Many others

D/A

- Digital to Analog Converter Performance
  - 4 bit DAC, 5v range
    - 5v / 2^4 → 0.3125v/step

Code	Output
0000	0.0v
0001	0.3125v
0010	0.625v
0011	0.9375v
…	
1101	4.0625v
1110	4.375v
1111	4.6875v

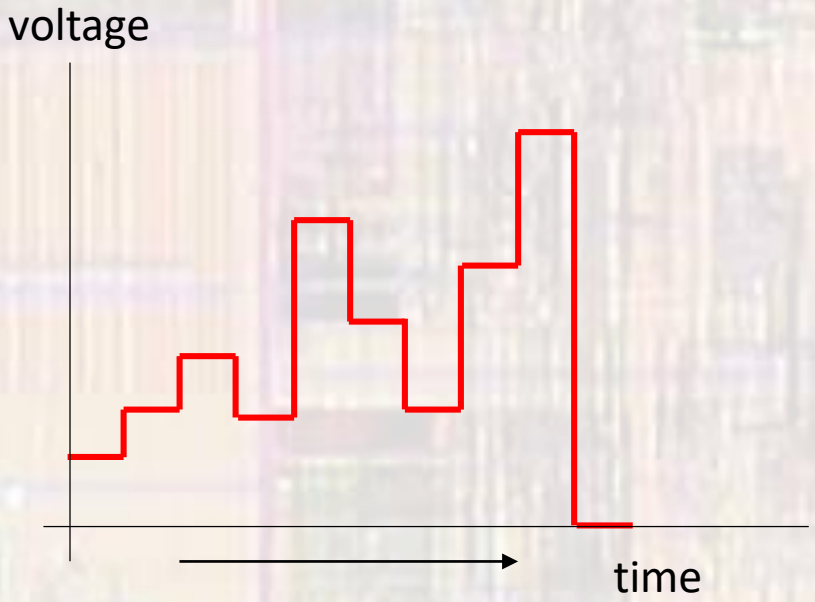
D/A

- Digital to Analog Converter Performance
  - 4 bit DAC, 5v range

Code

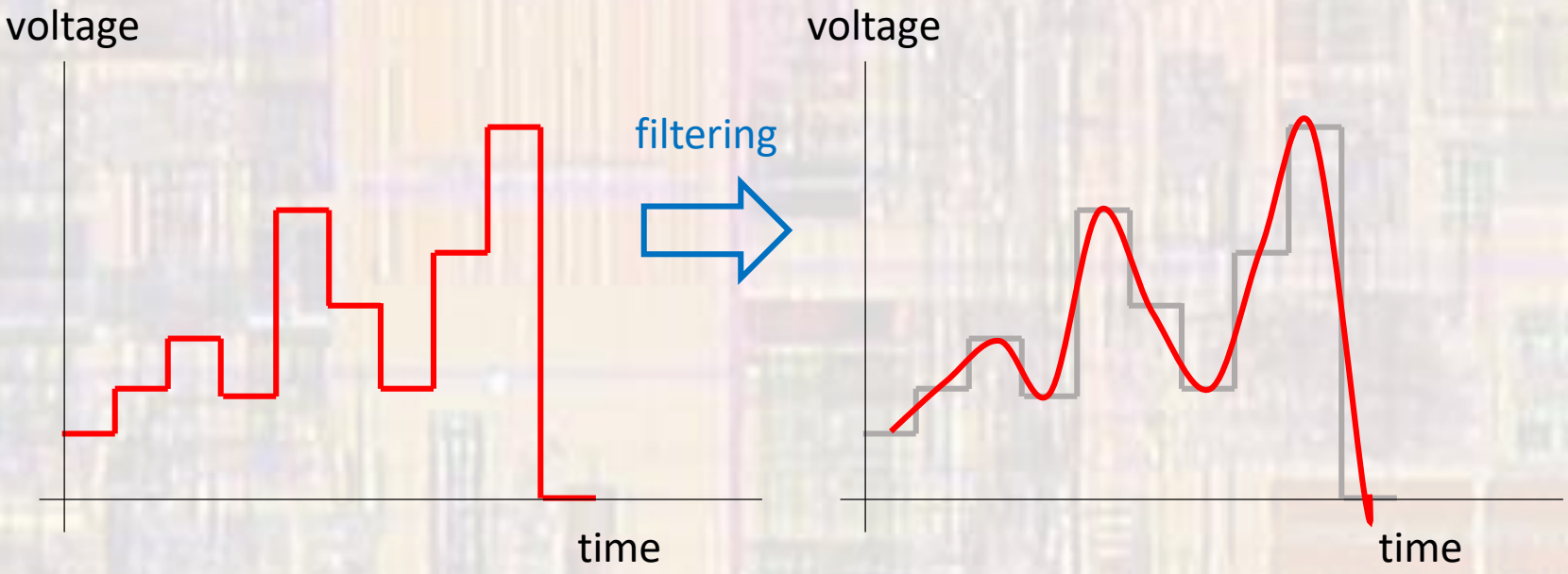
0010
0011
0100
0011
0111
0101
0011
0110
1001
0000

Time



D/A

- Digital to Analog Converter Performance
  - Typically additional signal conditioning is required to ‘clean up’ the output



D/A

- Example

3.3V Vref
8 bit convertor

Code	Steps	Volts
0000 0000	0	0
0000 0001	1	0.013
0001 0000	16	0.206
0111 1111	127	1.637
1000 0000	128	1.650
1100 0000	192	2.475
1111 1111	255	3.287

3.3v / 2^8 steps
= 12.89mv/step

D/A

- R-2R DAC
  - Converts a digital word to a fixed voltage level
  - example: 4 bit code

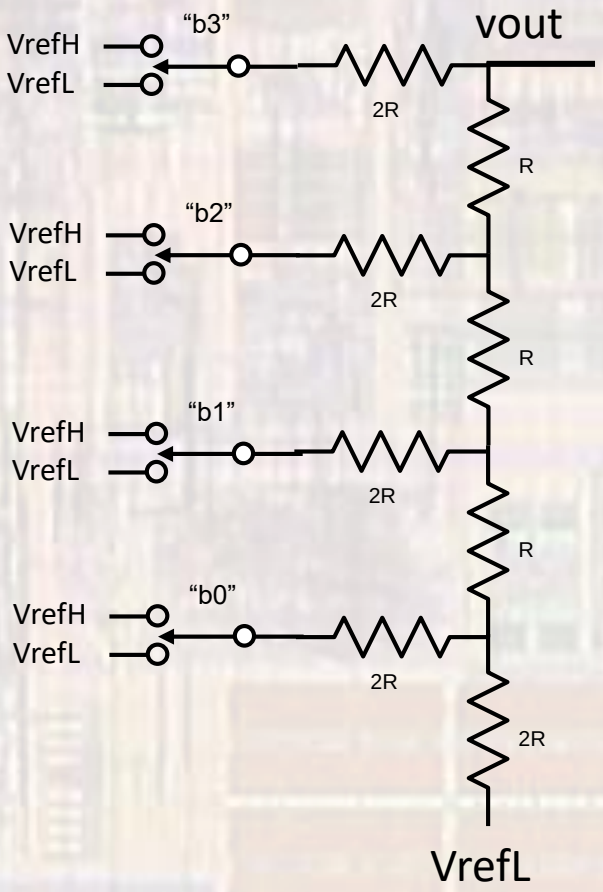
    0000 → Vout = VrefL

    1111→ Vout = VrefL+(VrefH-VrefL)$(\frac{15}{16})$

    b0 contributes 1/16
    b1 contributes 1/8
    b2 contributes ¼
    b3 contributes ½

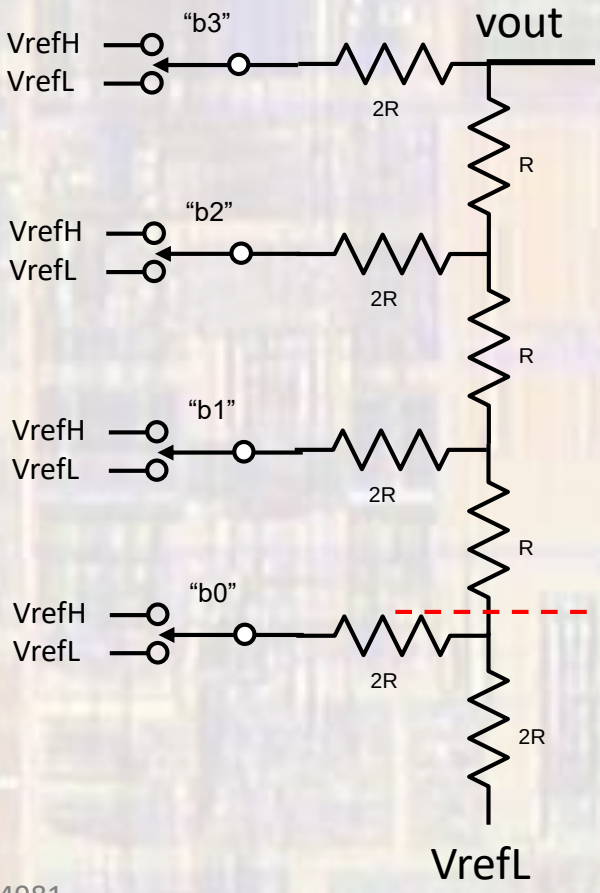
    0110 → Vout = VrefL+(VrefH-VrefL)$(\frac{1}{4}+\frac{1}{8})$

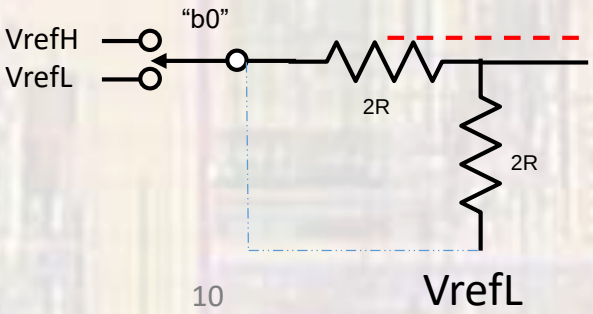
    1000 → Vout = VrefL+(VrefH-VrefL)$(\frac{1}{2})$

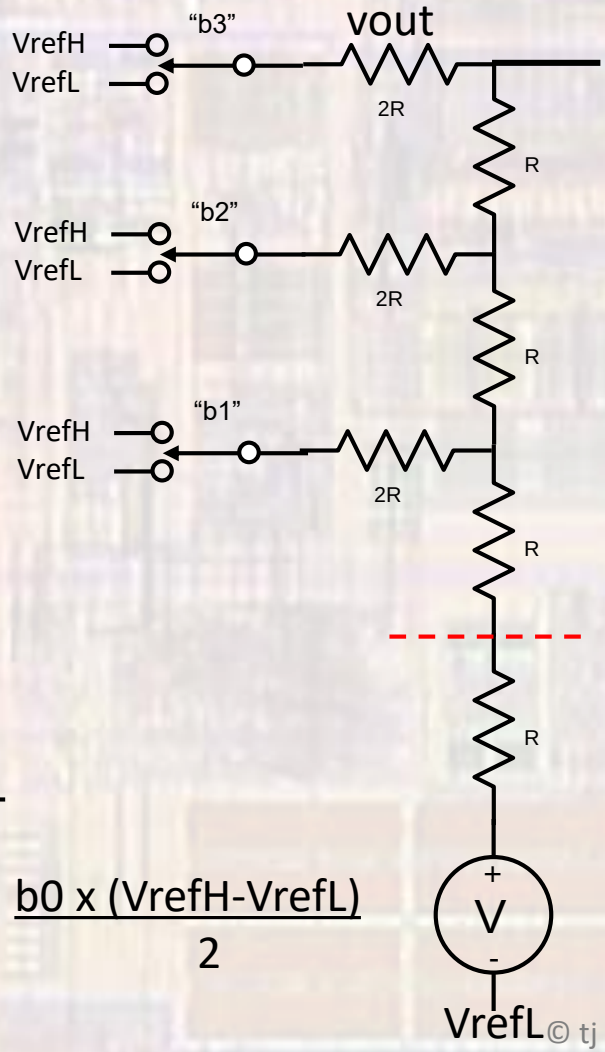


D/A

- R-2R DAC
  - Superposition and Thevenin Equivalents



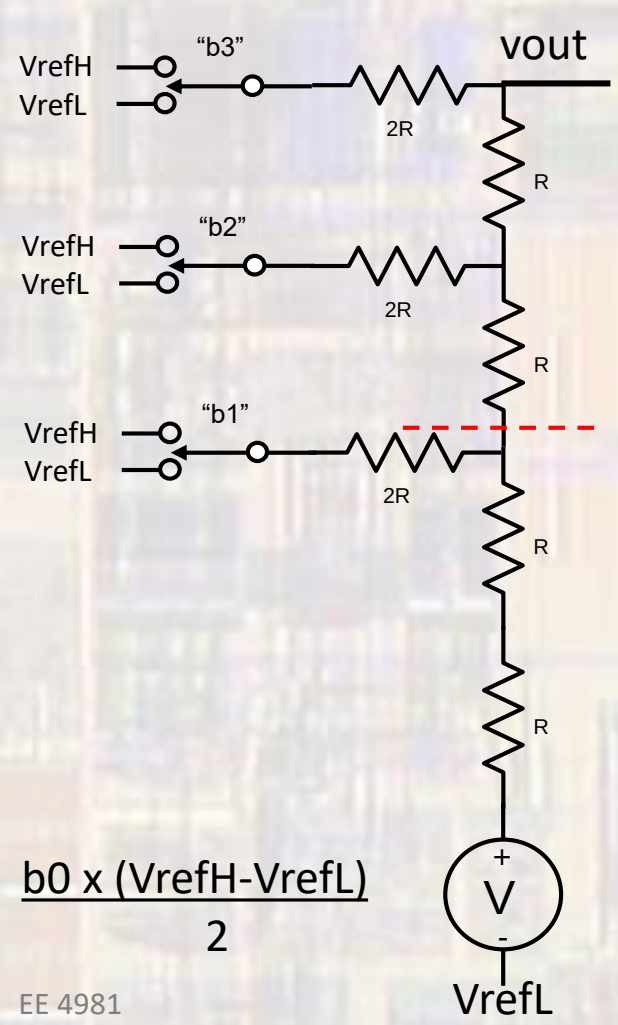




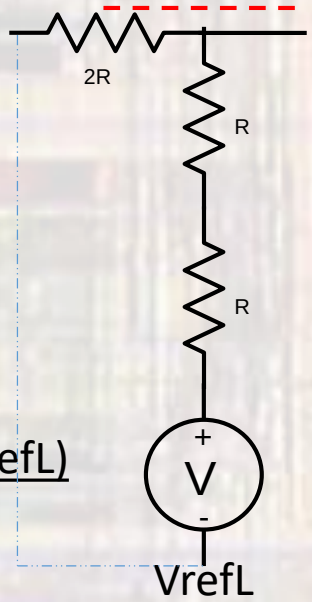
$$\frac{b0 \times (VrefH - VrefL)}{2}$$

D/A

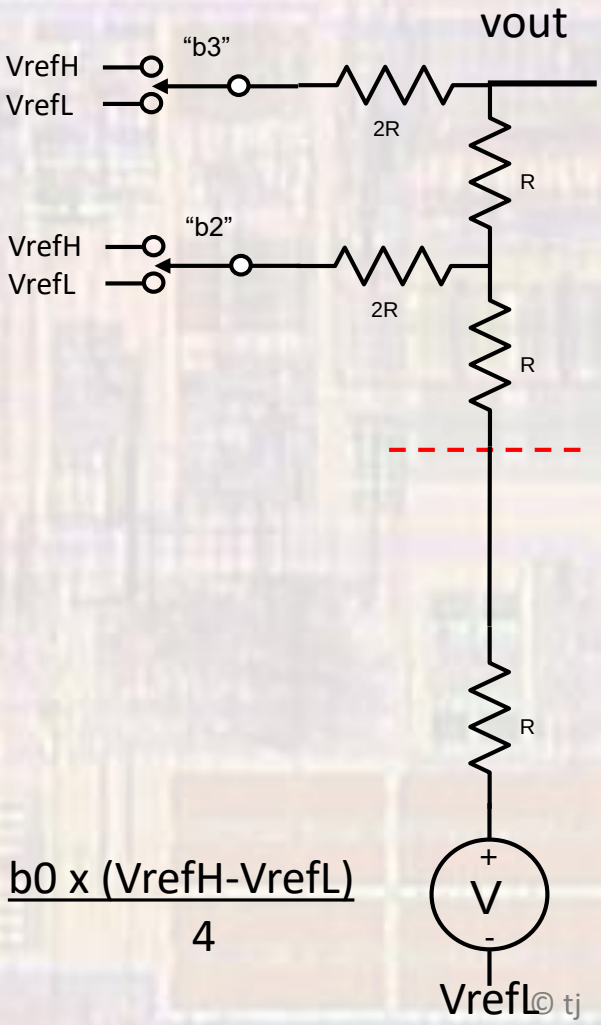
- R-2R DAC



$$\frac{b0 \times (VrefH - VrefL)}{2}$$



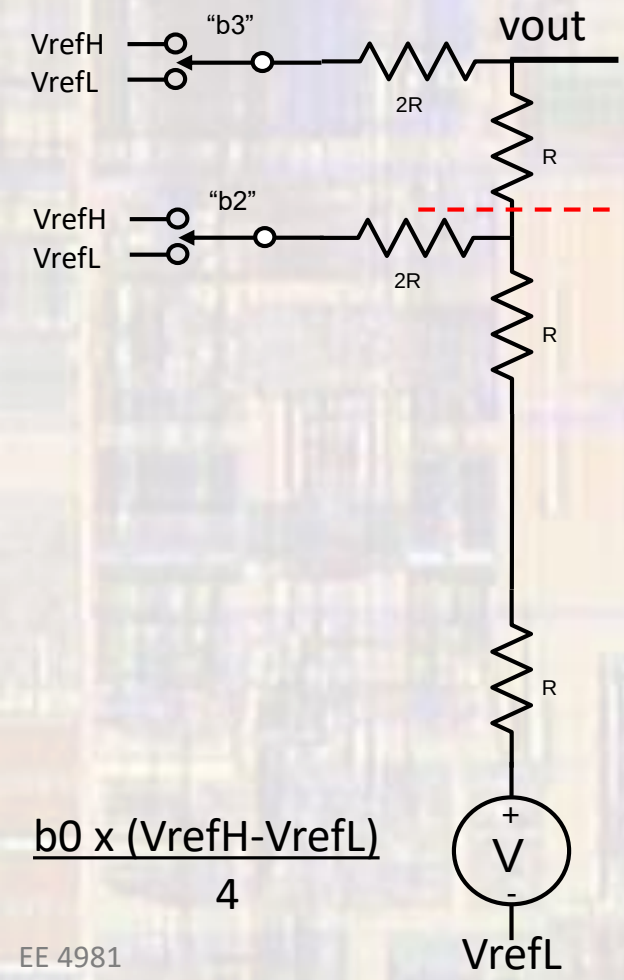
$$\frac{b0 \times (VrefH - VrefL)}{2}$$



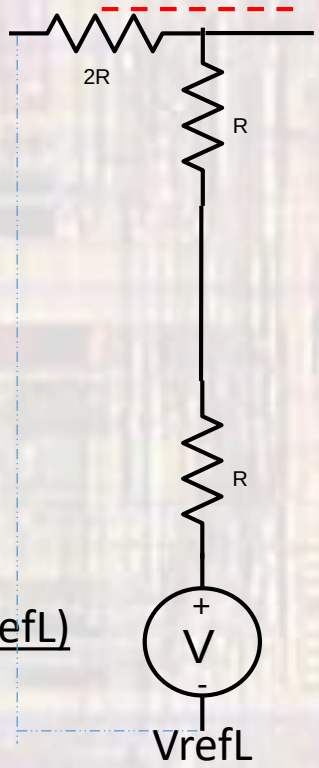
$$\frac{b0 \times (VrefH - VrefL)}{4}$$

D/A

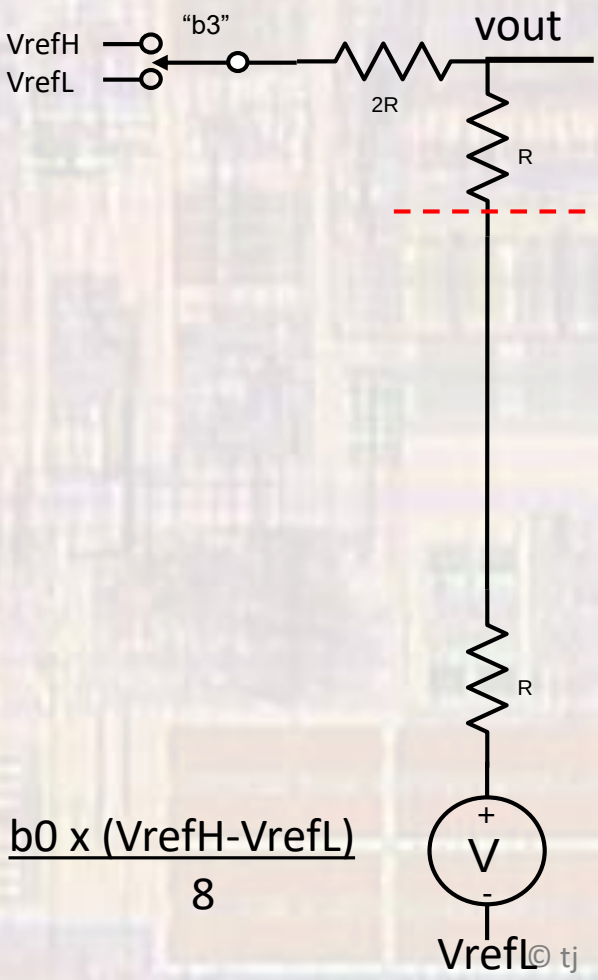
- R-2R DAC



$$\frac{b0 \times (VrefH - VrefL)}{4}$$



$$\frac{b0 \times (VrefH - VrefL)}{4}$$

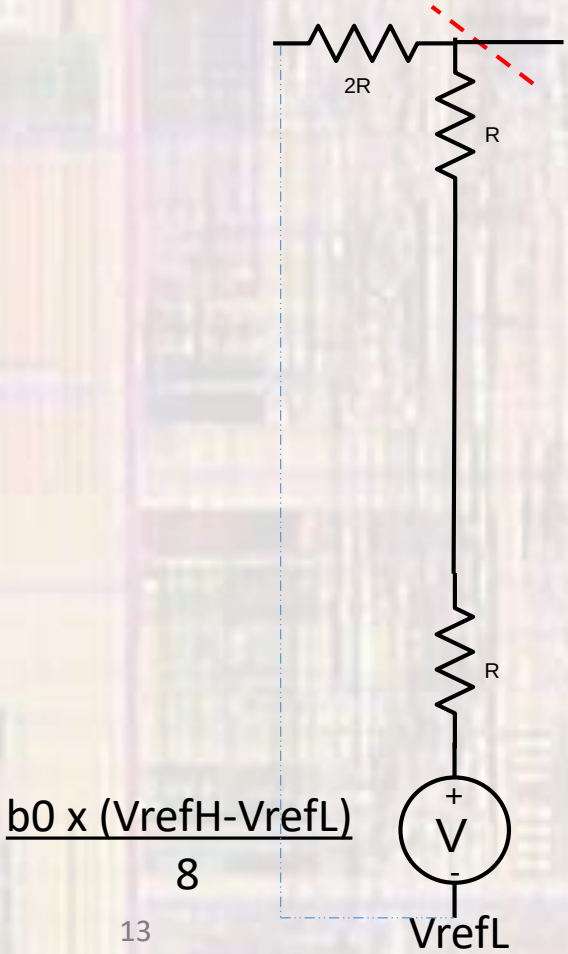


$$\frac{b0 \times (VrefH - VrefL)}{8}$$

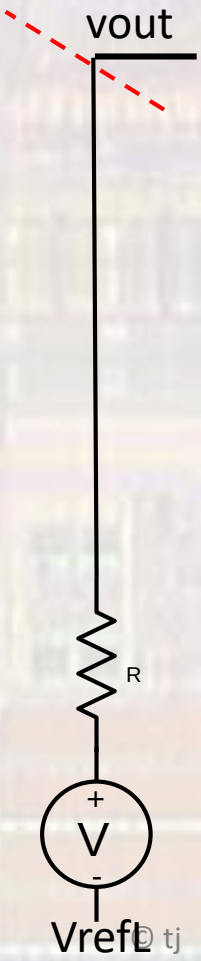
D/A

- R-2R DAC

$$\frac{b0 \times (VrefH - VrefL)}{8}$$



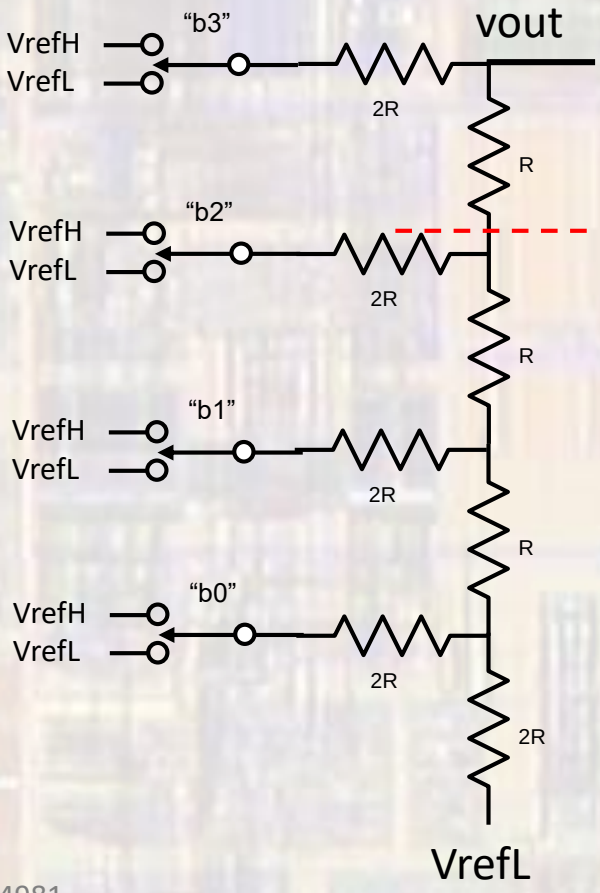
$$\frac{b0 \times (VrefH - VrefL)}{8}$$

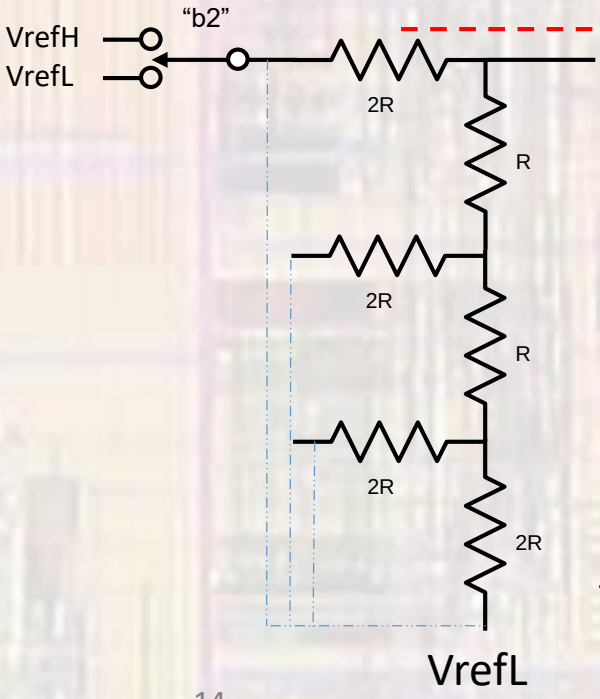


$$\frac{b0 \times (VrefH - VrefL)}{16}$$

D/A

- R-2R DAC
  - b2 analysis

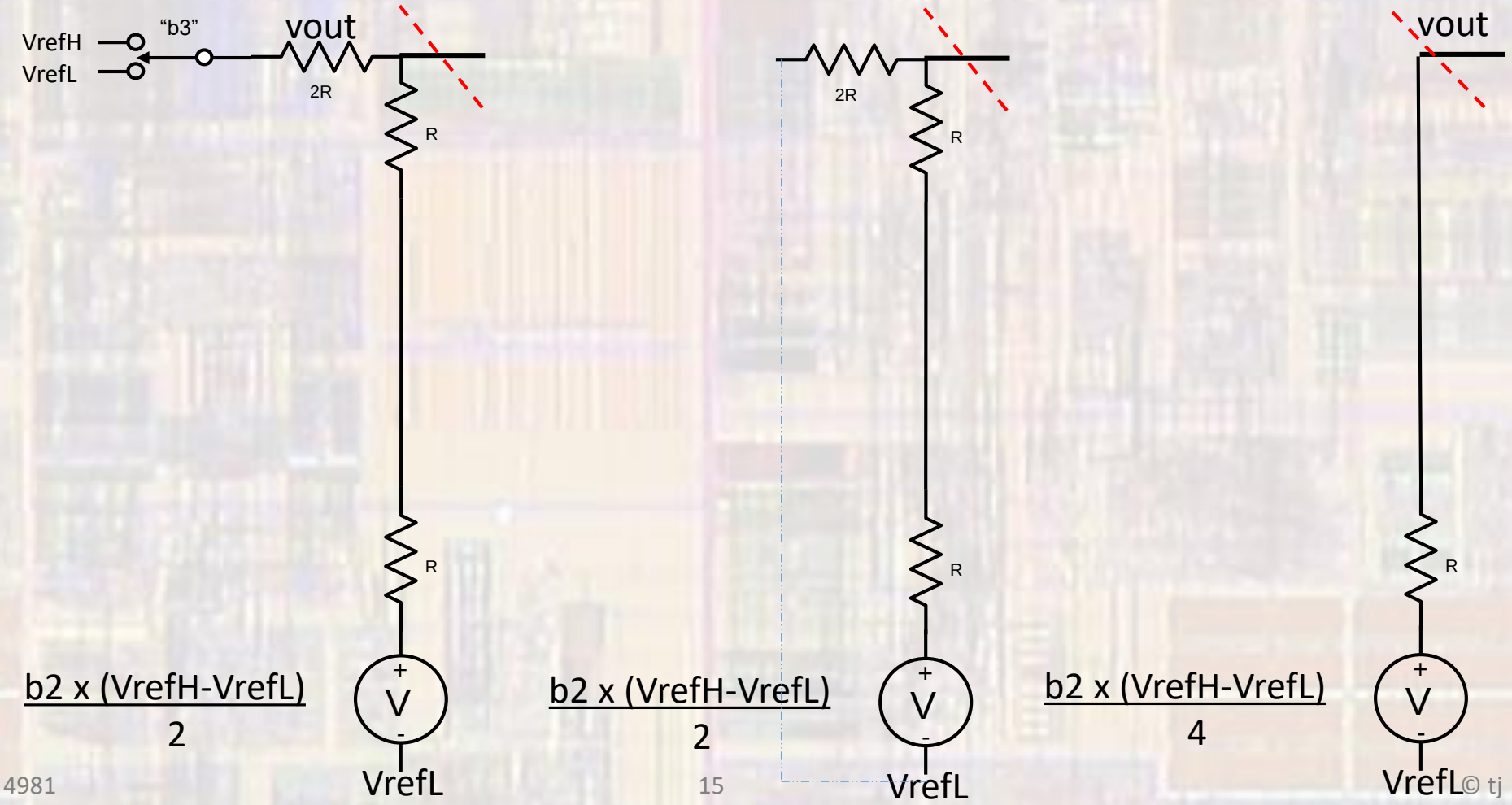




$$\frac{b2 \times (VrefH - VrefL)}{2}$$

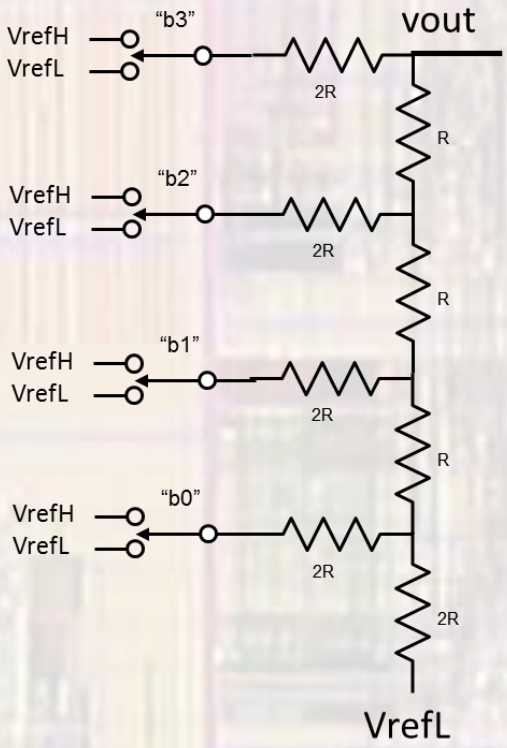
D/A

- R-2R DAC


VrefH
VrefL
"b3"
vout
2R
R
R
+
V
-
VrefL
b2 x (VrefH-VrefL)
2
2R
R
R
+
V
-
VrefL
b2 x (VrefH-VrefL)
2
vout
R
R
+
V
-
VrefL
b2 x (VrefH-VrefL)
4

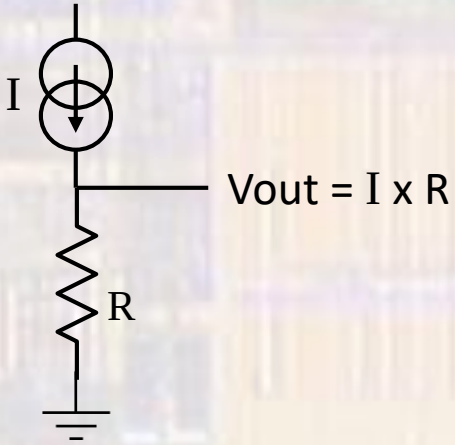
D/A

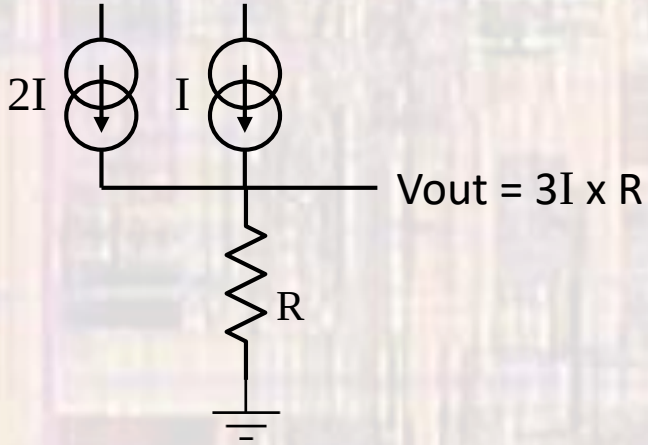
- R-2R DAC
  - Vout = ((b0)/16 + (b1)/8 + (b2)/4 + (b3)/2)(VrefH-VrefL) + VrefL



D/A

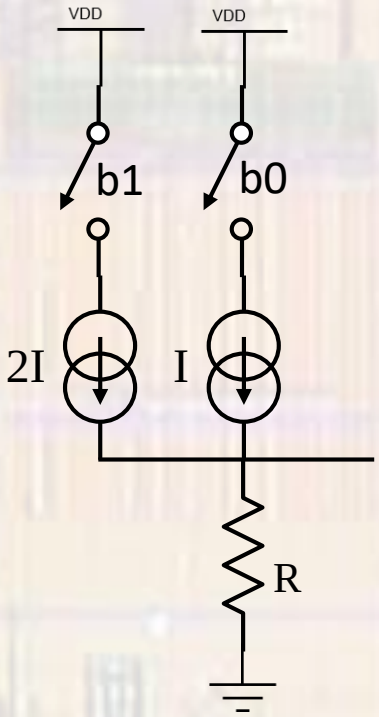
- Current DAC





D/A

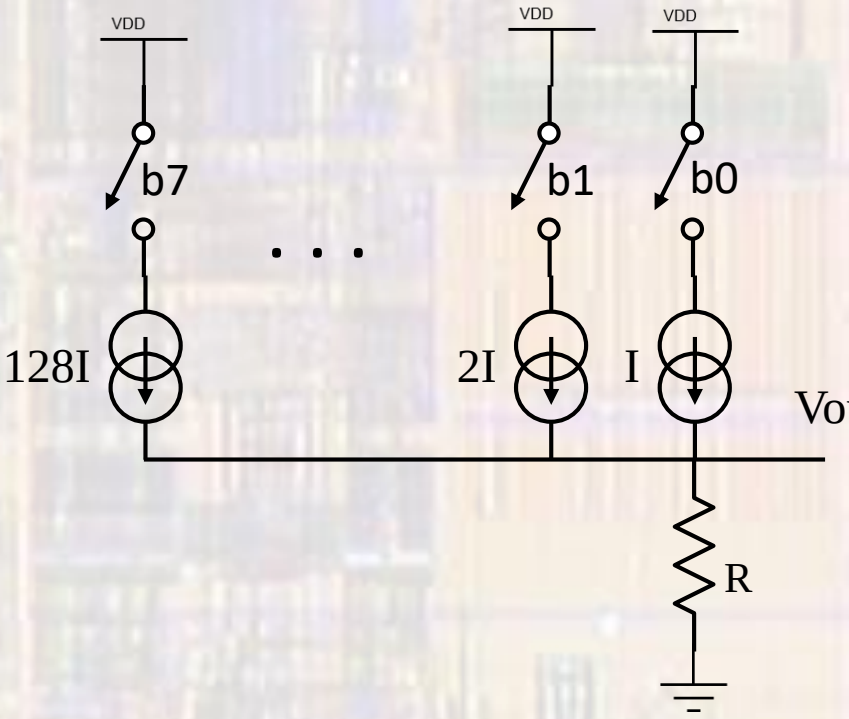
- Current DAC



$$V_{out} = (b0 \times I + b1 \times 2I) \times R$$

D/A

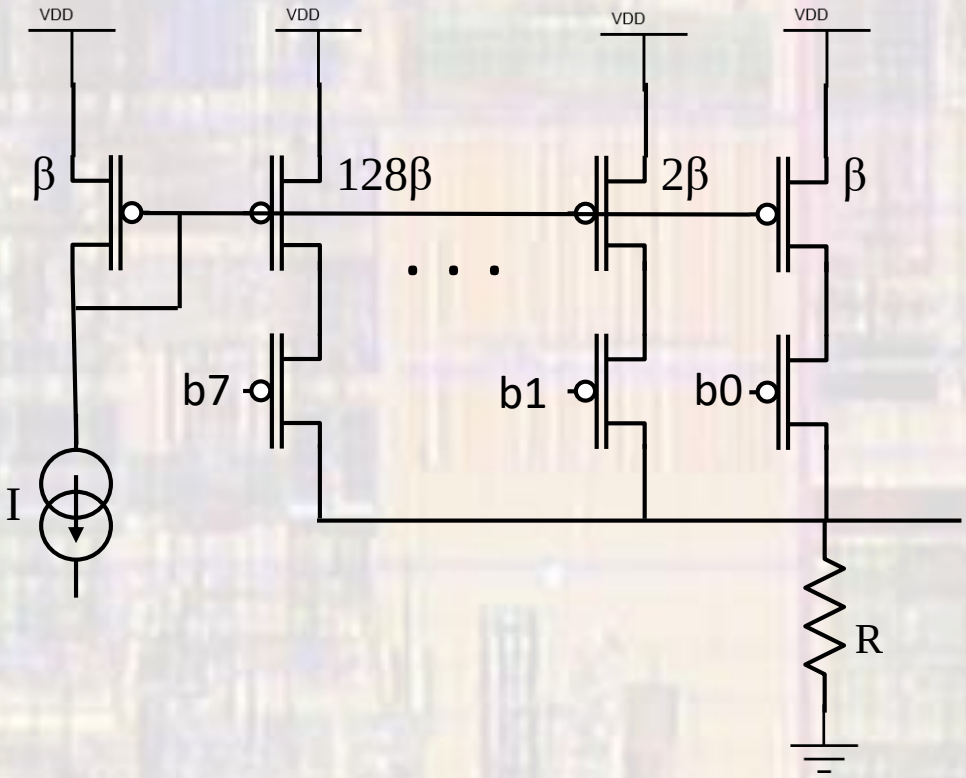
- Current DAC



$$Vout = (b0xI + b1x2I + b2x4I + b3x8I + b4x16I + b5x32I + b6x64I + b7x128I) \times R$$

D/A

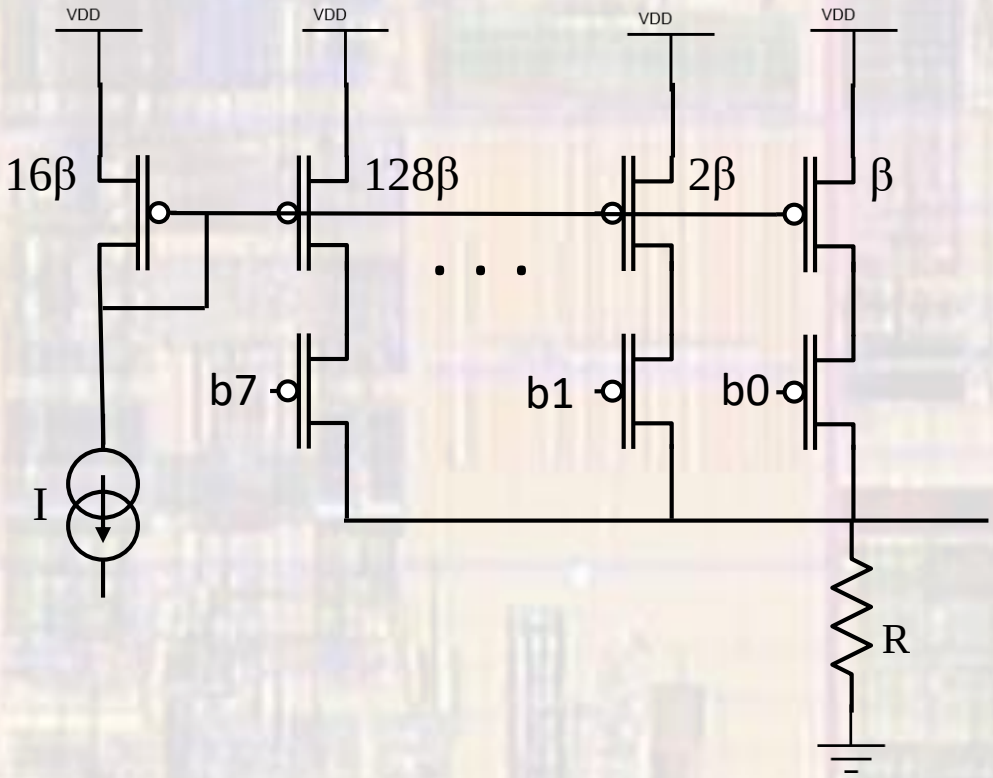
- Current DAC
  - MOS implementation



$$Vout = (b0xI + b1x2I + b2x4I + b3x8I + b4x16I + b5x32I + b6x64I + b7x128I) \times R$$

D/A

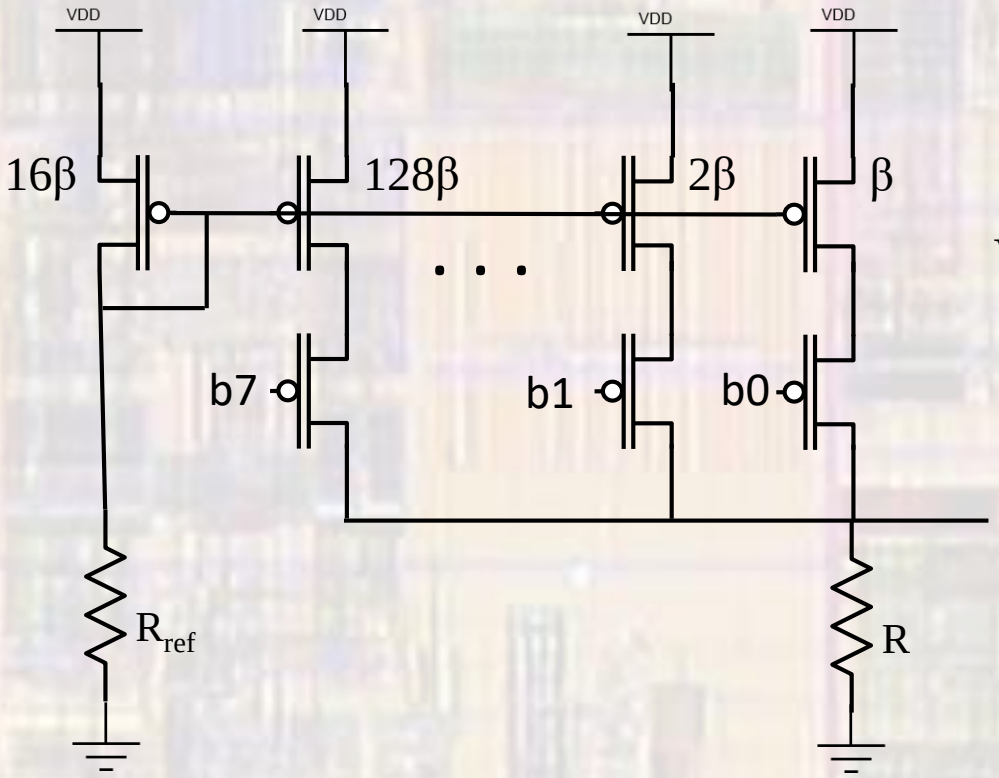
- Current DAC
  - Reduce the range relative to the current source



$$Vout = (b0xI + b1x2I + b2x4I + b3x8I + b4x16I + b5x32I + b6x64I + b7x128I) \times R$$

D/A

- Current DAC
  - Reduce absolute resistor tolerance → ratio of Rs



$$Vout = (b0xI + b1x2I + b2x4I + b3x8I + b4x16I + b5x32I + b6x64I + b7x128I) \times R$$

D/A

- Current DAC
  - Reduce absolute resistor tolerance → ratio of Rs