Anolog to Digital Converter (A/D)
Digital to Anolog converter (D/A)

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Analog signals

- Analog output is typical of most transducers and sensors.
- Need to convert these analog signals into a digital representation so the microcontroller can use it.
- Some characteristics of analog signals.
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- Need to convert these analog signals into a digital representation so the microcontroller can use it.
- Some characteristics of analog signals.
  - Maximum and minimum voltages
  - Precise continuous signals
  - Rate of voltage change
  - Frequency if not a steady state signal

Analog-to-Digital Converters

- The ideal transfer function of a 3-bit ADC
- Full-scale (input voltage) range (FSR)
- Analog signal is continuous
- Digital – finite and discrete
  - In general n-bit converter
  - Total of 2^n output codes

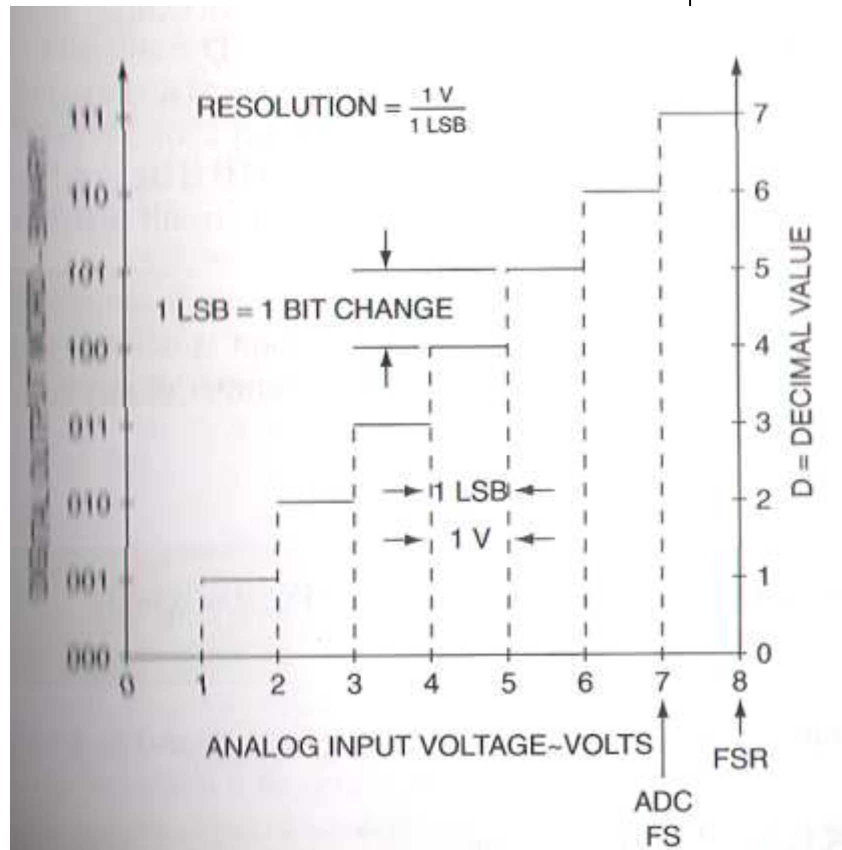
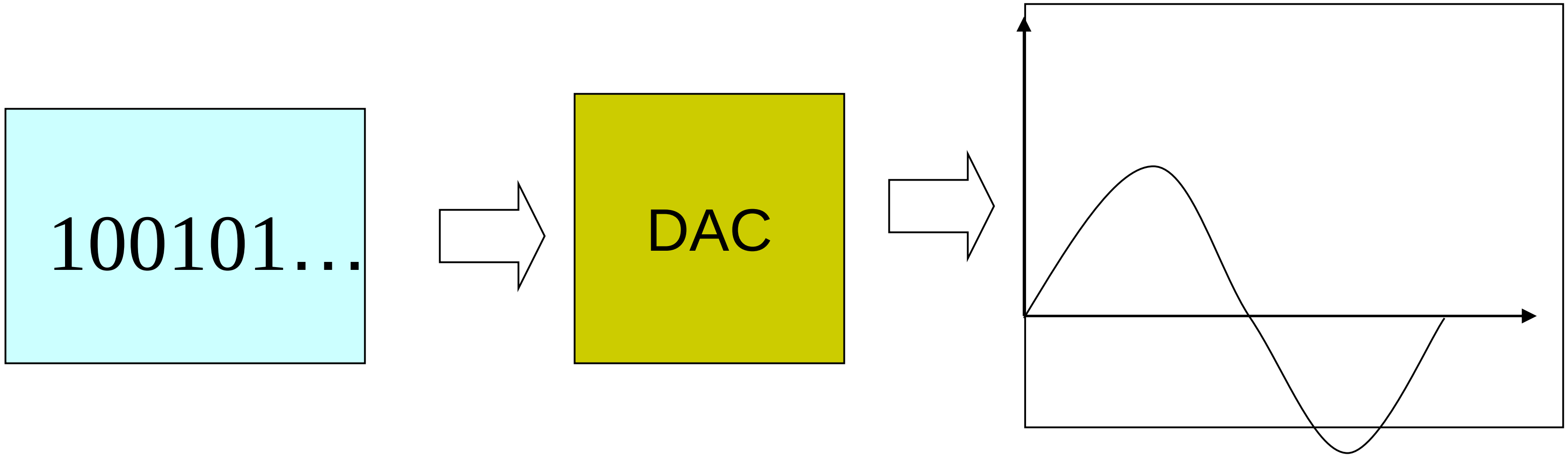


FIGURE 7.1 The ideal transfer function of a simple 3-bit analog-to-digital converter.

What is a D/A ?

- A digital to analog converter (D/A) converts a digital signal to an analog voltage or current output.



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Types of D/A

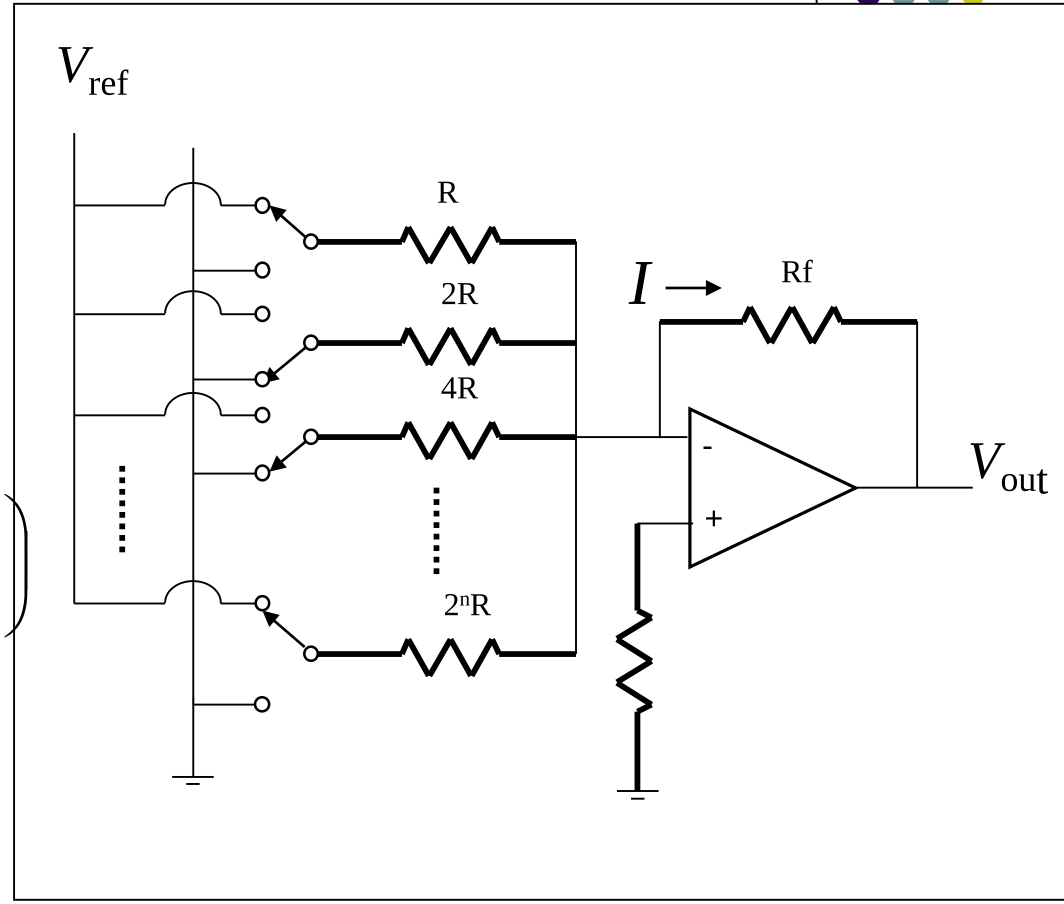
- Many types of D/A available.
- Usually switches, resistors, and op-amps used to implement conversion
- Two Types:
  - Binary Weighted Resistor
  - R-2R Ladder

Binary Weighted Resistor

- Utilizes a summing op-amp circuit
- Weighted resistors are used to distinguish each bit from the most significant to the least significant
- Transistors are used to switch between V_{ref} and ground (bit high or low)

Binary Weighted Resistor

- Assume Ideal Op-amp
- No current into op-amp
- Virtual ground at inverting input
- $V_{out} = -IR_f$



If $R_f = R/2$

$$V_{out} = -IR_f = -\left(\frac{V_1}{2} + \frac{V_2}{4} + \frac{V_3}{8} + \cdots \frac{V_n}{2^n}\right)$$

For example, a 4-Bit converter yields

$$V_{out} = -V_{ref}\left(b_3 \frac{1}{2} + b_2 \frac{1}{4} + b_1 \frac{1}{8} + b_0 \frac{1}{16}\right)$$

Where b_3 corresponds to Bit-3, b_2 to Bit-2, etc.

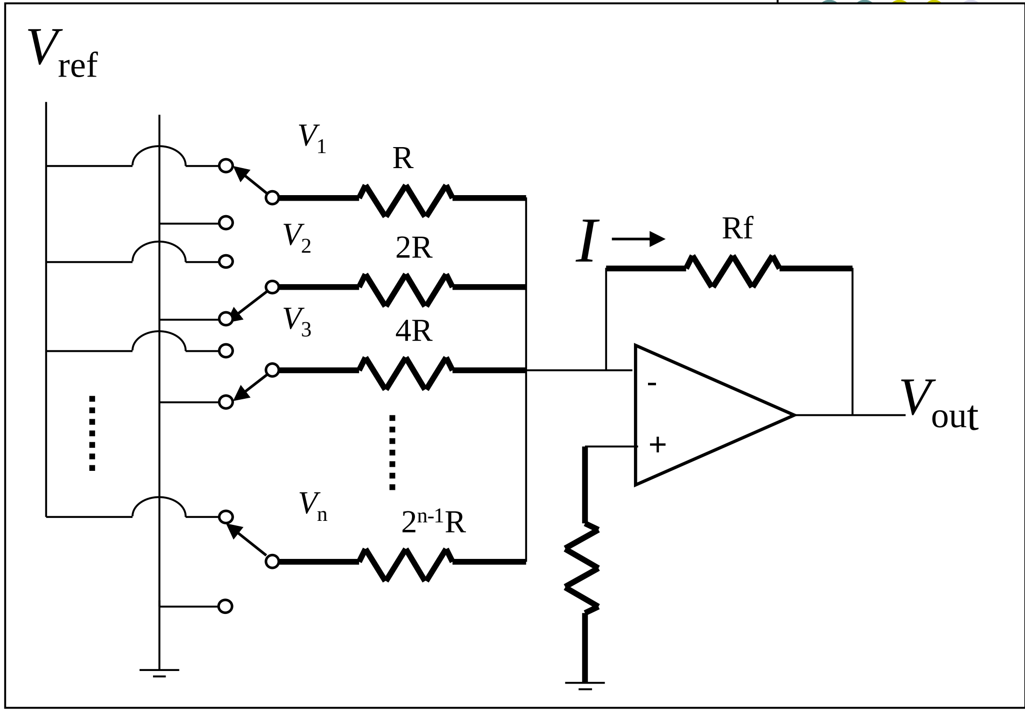
Binary Weighted Resistor

Voltages V_1 through V_n are either V_{ref} if corresponding bit is high or ground if corresponding bit is low

V_1 is most significant bit

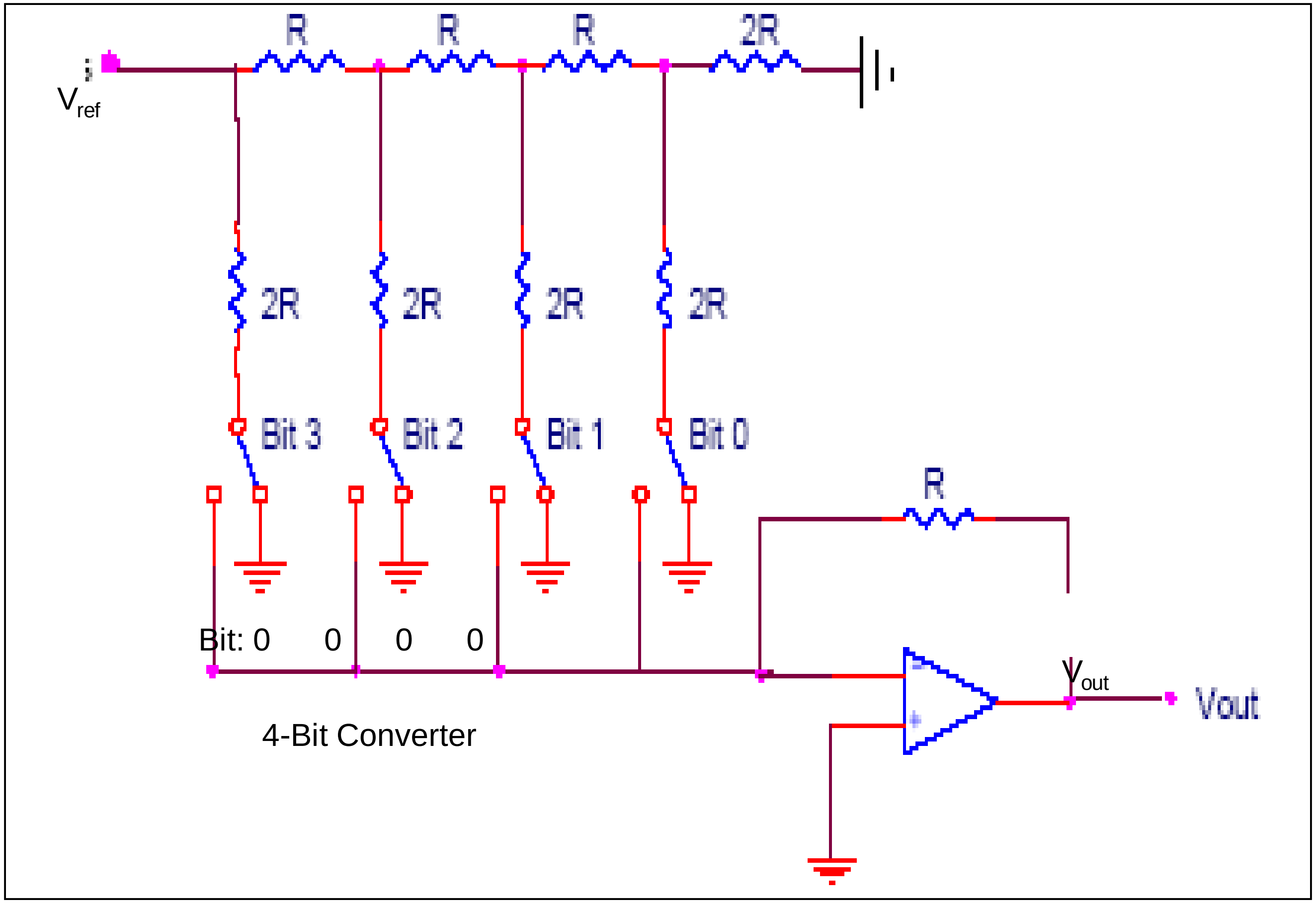
V_n is least significant bit

$$V_{out} = -IR_f = -R_f\left(\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \cdots \frac{V_n}{2^{n-1}R}\right)$$



- Advantages
  - Simple Construction/Analysis
  - Fast Conversion
- Disadvantages
  - Requires large range of resistors (2000:1 for 12-bit DAC) with necessary high precision for low resistors
  - Requires low switch resistances in transistors
  - Can be expensive. Therefore, usually limited to 8-bit resolution.

R-2R Ladder

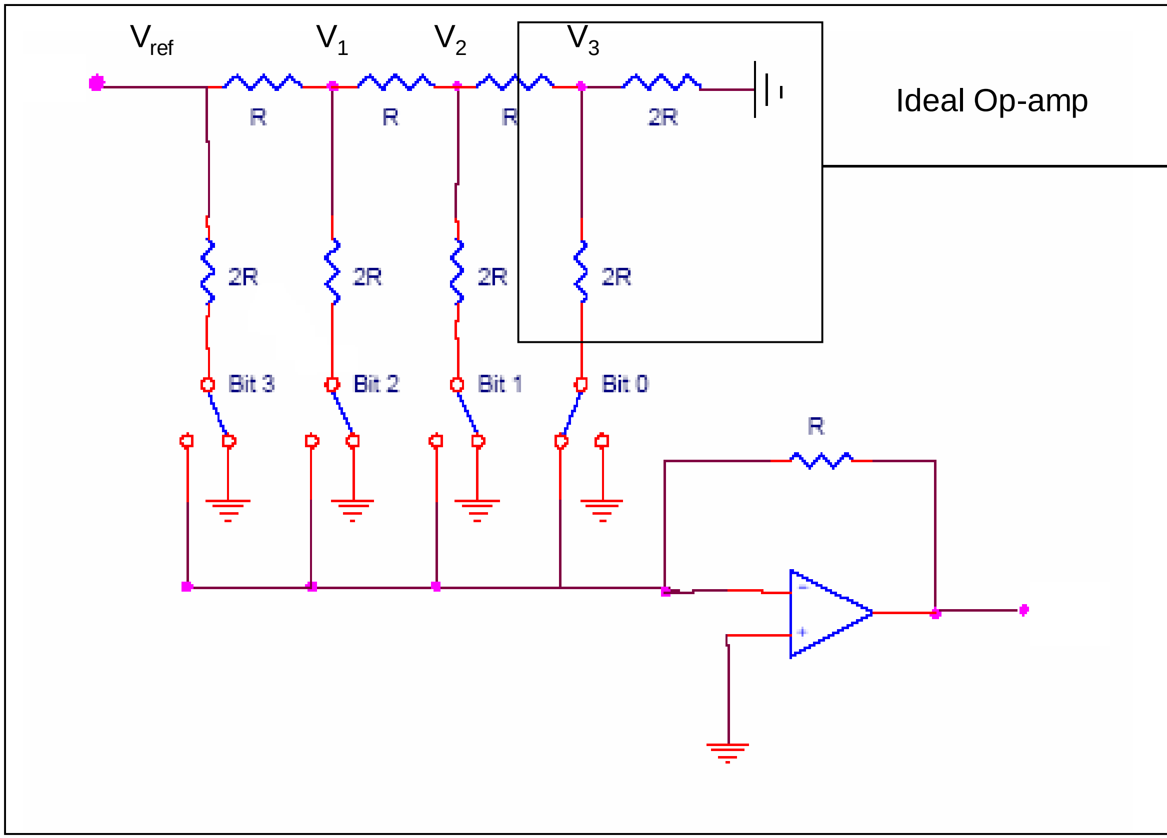


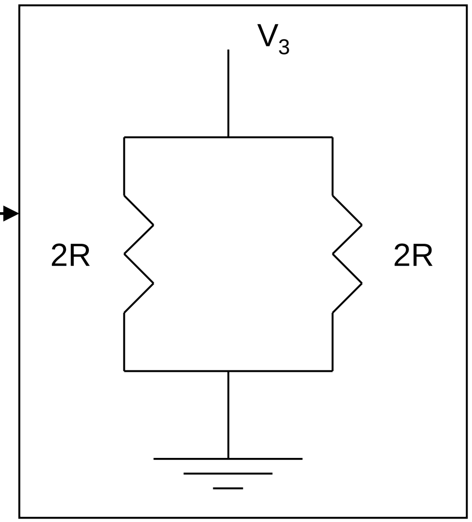
Each bit corresponds to a switch:

If the bit is high, the corresponding switch is connected to the inverting input of the op-amp.

If the bit is low, the corresponding switch is connected to ground.

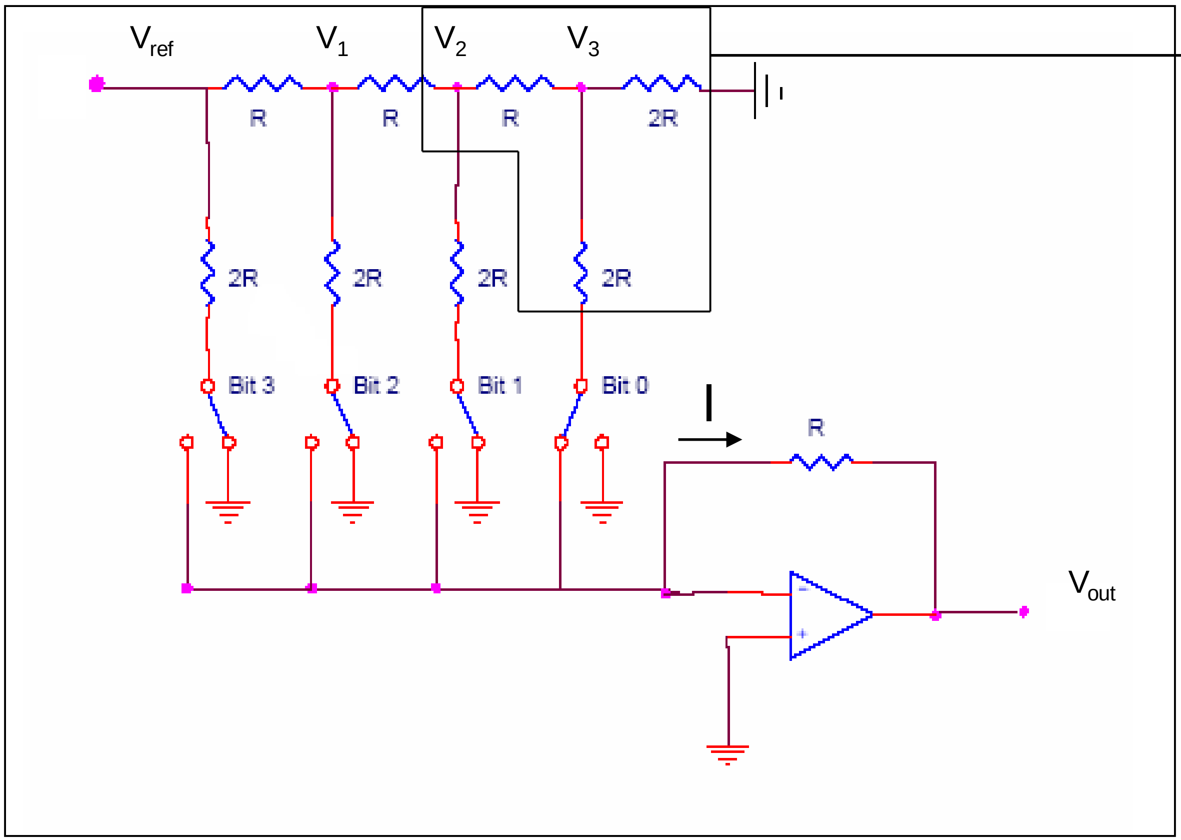
R-2R Ladder

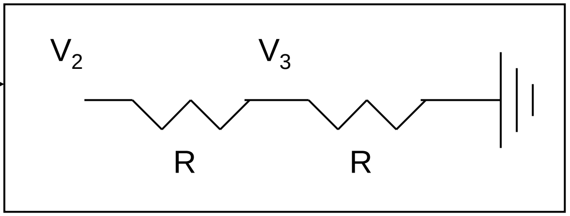




$$R_{eq} = \frac{(2R)(2R)}{(2R+2R)} = R$$

R-2R Ladder





$$V_3 = \left(\frac{R}{R+R}\right)V_2 = \frac{1}{2}V_2$$

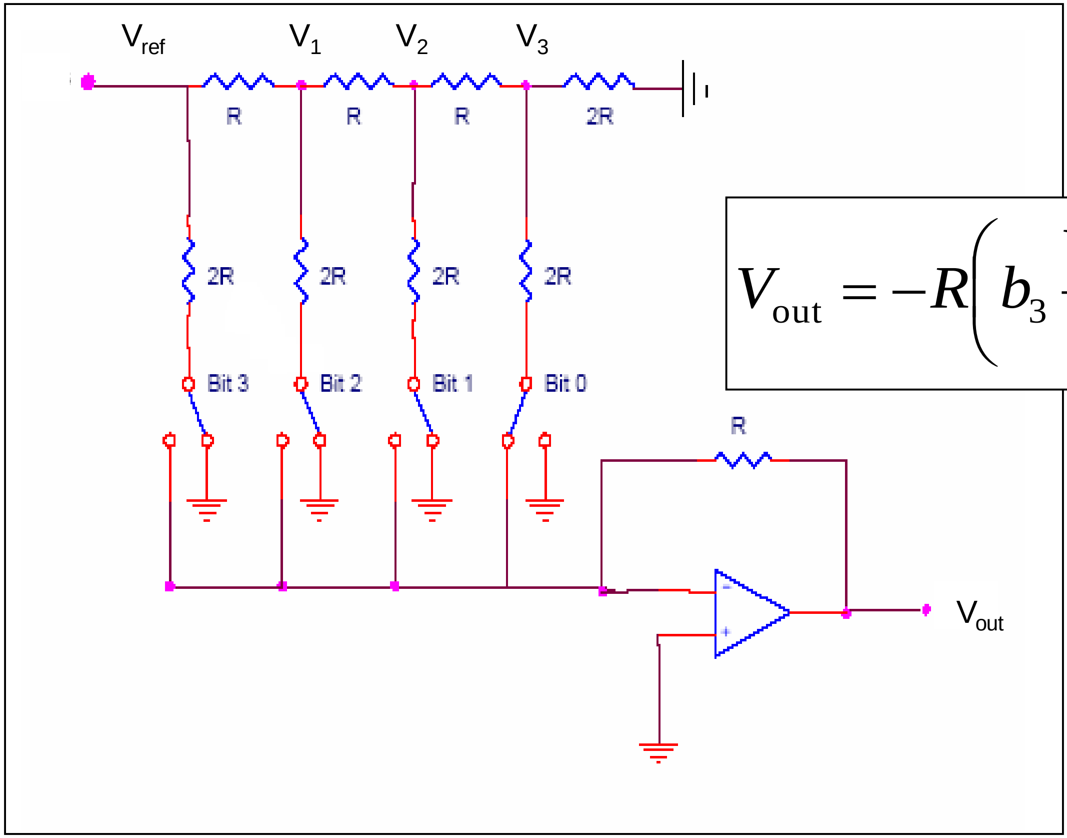
Likewise,

$$V_2 = \frac{1}{2}V_1$$

$$V_1 = \frac{1}{2}V_{\text{ref}}$$

$$V_{\text{out}} = -IR$$

R-2R Ladder



Results:

$$V_3 = \frac{1}{8} V_{\text{ref}}, \; V_2 = \frac{1}{4} V_{\text{ref}}, \; V_1 = \frac{1}{2} V_{\text{ref}}$$

$$V_{\text{out}} = -R\left(b_3 \frac{V_{\text{ref}}}{2R} + b_2 \frac{V_{\text{ref}}}{4R} + b_1 \frac{V_{\text{ref}}}{8R} + b_0 \frac{V_{\text{ref}}}{16R} \right)$$

Where b_3 corresponds to bit 3,
b_2 to bit 2, etc.

If bit n is set, b_n=1

If bit n is clear, b_n=0

R-2R Ladder

For a 4-Bit R-2R Ladder

$$V_{out} = -V_{ref}\left(b_3\frac{1}{2} + b_2\frac{1}{4} + b_1\frac{1}{8} + b_0\frac{1}{16}\right)$$

For general n-Bit R-2R Ladder or Binary Weighted Resister DAC

$$V_{out} = -V_{ref}\sum_{i=1}^{n} b_{n-i}\frac{1}{2^i}$$

- Advantages
  - Only two resistor values (R and 2R)
  - Does not require high precision resistors
- Disadvantage
  - Lower conversion speed than binary weighted DAC