RAMA UNIVERSITY

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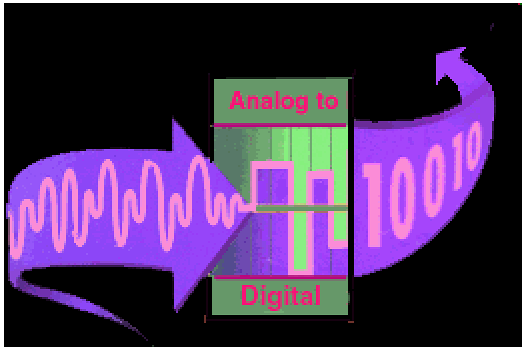
FACULTY OF ENGINEERING & TECHNOLOGY

Data Converters: Basic Concepts

- Analog signals are continuous, with infinite values in a given range.
- Digital signals have discrete values such as on/off or 0/1.
- Limitations of analog signals
  - Analog signals pick up noise as they are being amplified.
  - Analog signals are difficult to store.
  - Analog systems are more expensive in relation to digital systems.

- Advantages of digital systems (signals)
  - Noise can be reduced by converting analog signals in 0s and 1s.
  - Binary signals of 0s/1s can be easily stored in memory.
  - Technology for fabricating digital systems has become so advanced that they can be produced at low cost.
- The major limitation of a digital system is how accurately it represents the analog signals after conversion.



Embedded System

- A typical system that converts signals from analog to digital and back to analog includes:
  - A transducer that converts non-electrical signals into electrical signals
  - An A/D converter that converts analog signals into digital signals
  - A digital processor that processes digital data (signals)
  - A D/A converter that converts digital signals into equivalent analog signals
  - A transducer that converts electrical signals into real life non-electrical signals (sound, pressure, and video)

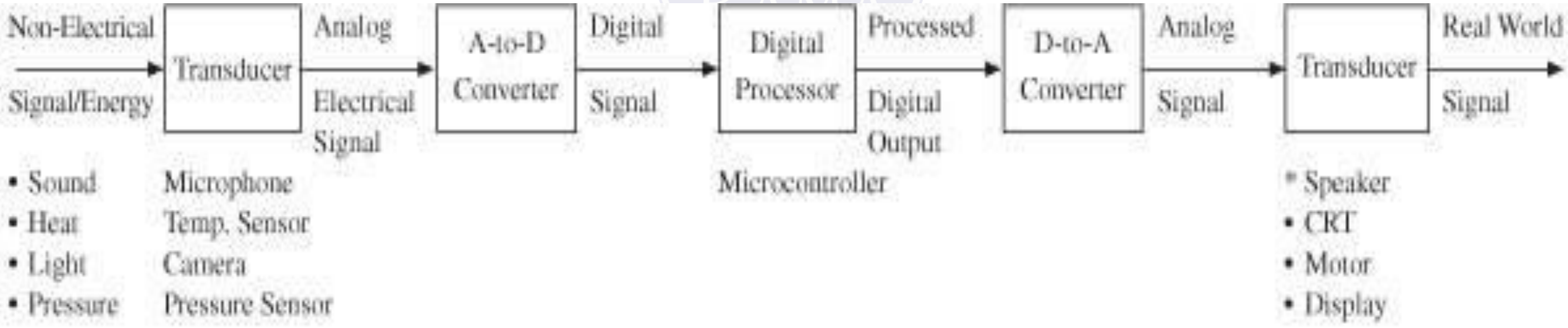
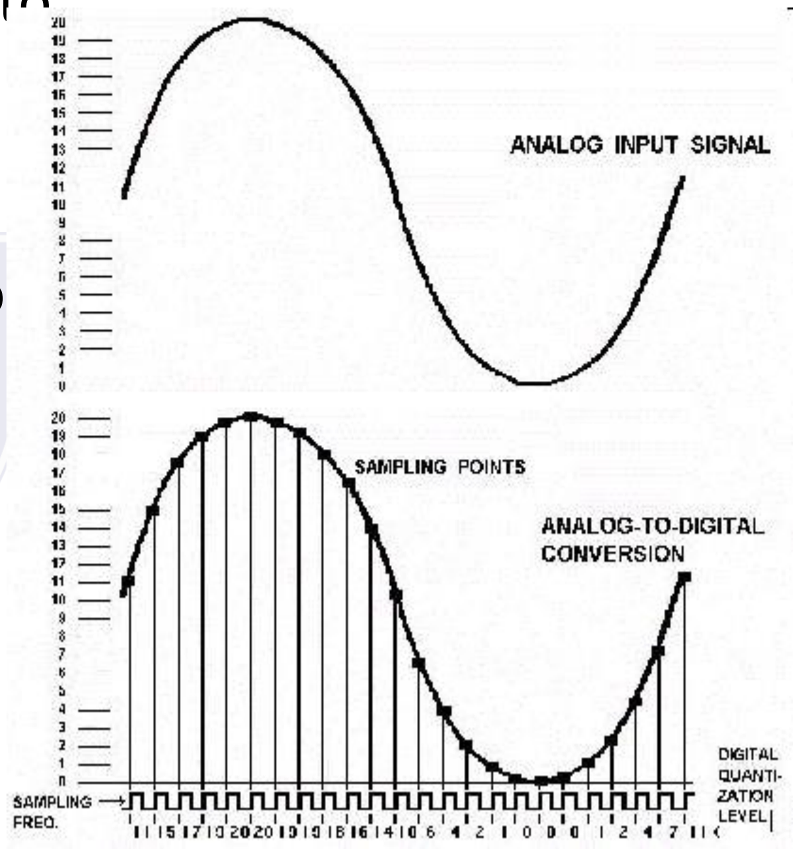


FIGURE 12-1 Embedded Systems: A-to-D and D-to-A Signal Conversion

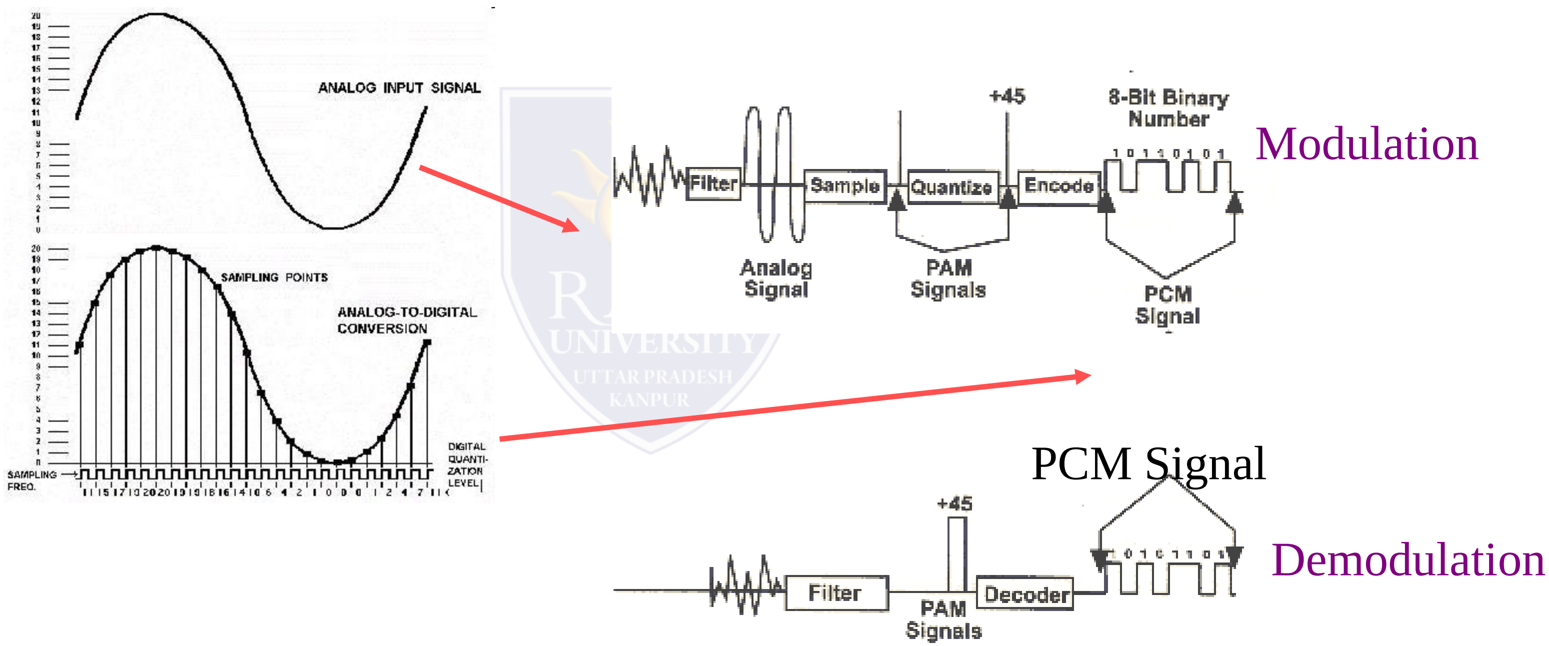
So, how does A/D Converter works?

A/D Converter

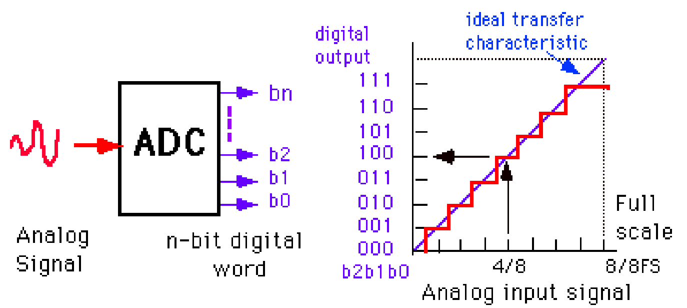
- In order to change an analog signal to digital, the input analog signal is sampled at a high rate of speed.
- The amplitude at each of those sampled moments is converted into number equivalent – this is called quantization.
- These numbers are simply the combinations of the 0s and 1s used in computer language – this called encoding.



A/D Conversion – Pulse Code Modulation/Demodulation



Analog-to-Digital



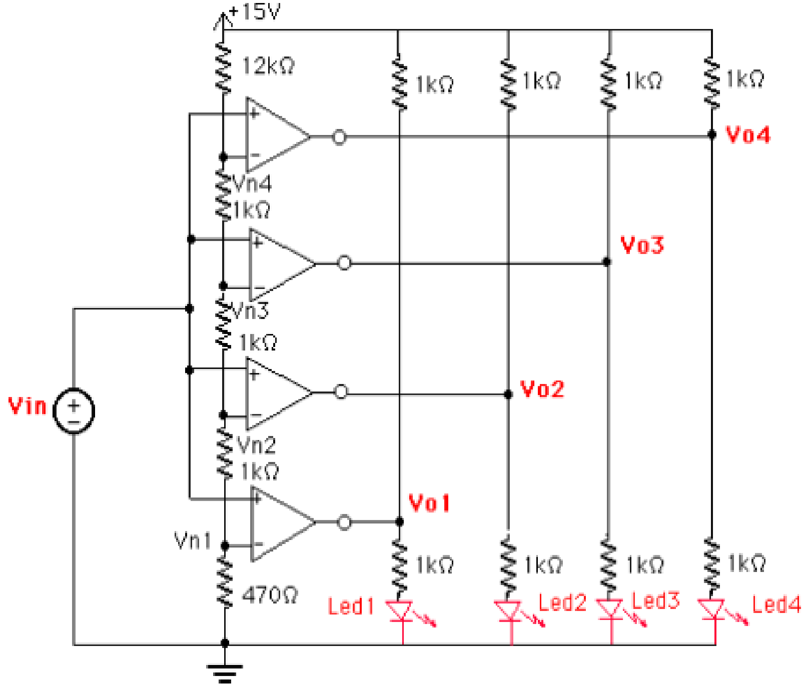
- A simple hypothetical A/D converter circuit with one analog input signal and three digital output lines with eight possible binary combinations: 000 to 111
  - Shows the graph of digital output for FS V analog input
- The following points can be summarized in the above process:
  - Maximum value this quantization process reaches is **7/8** V for a 1 V analog signal; includes 1/8 V an inherent error
  - 1/8 V (an inherent error) is also equal to the value of the Least Significant Bit (LSB) = 001.
  - Resolution of a converter is defined in terms of the number of discrete values it can produce; also expressed in the number of bits used for conversion or as $1/2^n$ where n =number of bits
  - The value of the most significant bit (MSB) -100- is equal to ½ the voltage of the full-scale value of 1 V.
  - The value of the largest digital number 111 is equal to full-scale value minus the value of the LSB.
  - The quantization error can be reduced or the resolution can be improved by increasing the number of bits used for the conversion

A/D Conversion - Types

- Can be classified in four groups:
  - Integrator:
    - Charges a capacitor for a given amount of time using the analog signal.
    - It discharges back to zero with a known voltage and the counter provides the value of the unknown signal.
    - Provides slow conversion but low noise.
    - Often used in monitoring devices (e.g., voltmeters)
  - Flash: uses multiple comparators in parallel.
    - The known signal is connected to one side of the comparator and the analog signal to be converted to the other side of the comparator.
    - The output of the comparators provides the digital value.
    - This is a high-speed, high cost converter.

A/D Conversion

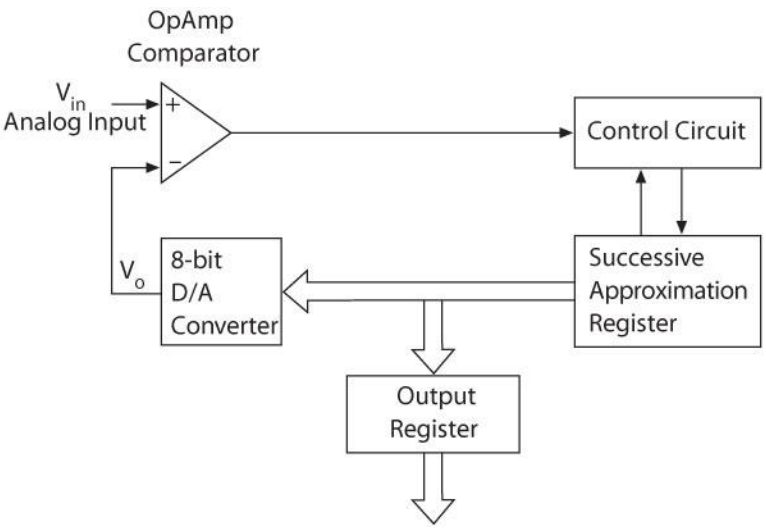
- Flash Converter
  - The circuit consists of 4 comparators whose inverting inputs are connected to a voltage divider.
  - A comparator is basically an operational amplifier used without feedback.
  - The outputs of the comparators correspond to a digital word.
  - When the input rises above Vn1 , the first comparator will switch to a high output voltage causing the LED to light up, indicating a (0001).
  - For larger input voltages the output of other comparators will switch high as well. For large input voltages (above Vn3) all comparators will be high corresponding to (1111) digital output.



A/D Conversion

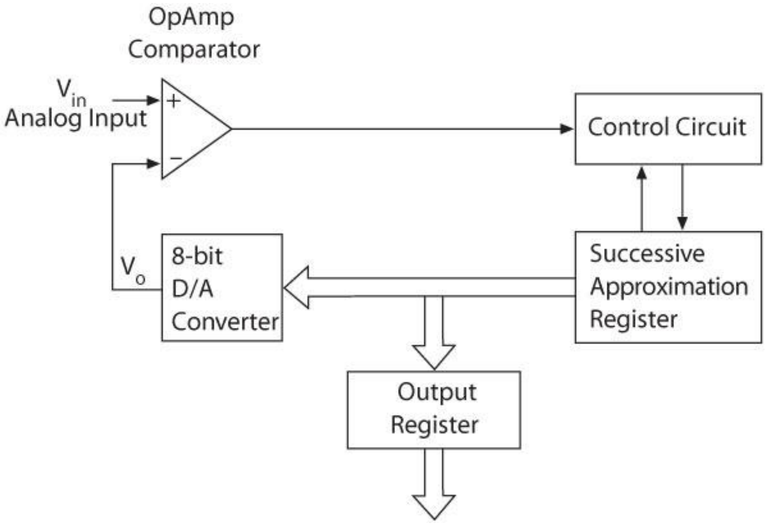
– Successive approximation: Includes a D/A (digital to analog) converter and a comparator. An internal analog signal is generated by turning on successive bits in the D/A converter.

– Counter: Similar to a successive approximation converter except that the internal analog signal is generated by a counter starting at zero and feeding it to the D/A converter.



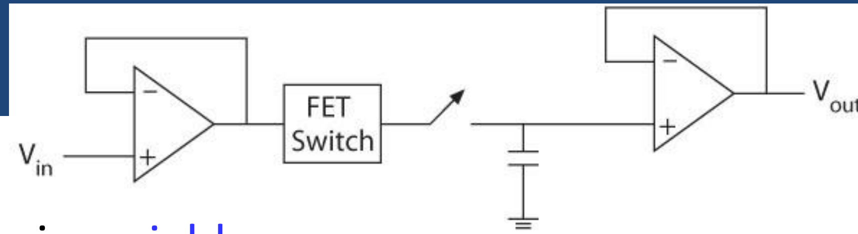
Successive Approximation A/D Converter Circuit

- The SAR (successive approximation register) begins by turning on the MSB Bit7.
- V_o of the D/A converter is compared with the analog input voltage V_{in} in the comparator.
- If analog voltage is less than the digital voltage, Bit7 is turned off and Bit6 is turned on.
- If analog voltage is greater than the digital voltage, Bit7 is kept on and Bit6 is turned on.
- The process of turning bit on/off is continued until Bit0.
- Now the 8-bit input to the D/A converter represents the digital equivalent of the analog signal V_{in}.

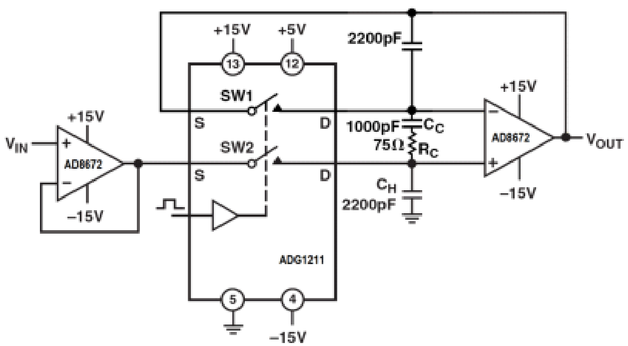


Bit 7 is set: b7=1
If Va < Vd → b7=0; b6=1
If Va > Vd → b7=1; b6=1
…..
If Va < Vd → b7=0; …b0=1
If Va > Vd → b7=1; … b0=1
Done

Sample and Hold Circuit



- If the input voltage to an A/D converter is variable, the digital output is likely to be unreliable and unstable. Therefore, the varying voltage source is connected to the ADC through a sample and hold circuit.
- Basic Operation:
  - When the switch is connected, it samples the input voltage.



- When the switch is open, it holds the sampled voltage by charging the capacitor.
- Acquisition time: time to charge the capacitor after the switch is open and settle the output.
- Conversion time: total time needed from the start of a conversion (turning on the MSB in the SAR) until the end of the conversion (turning on/off Bit0 in the SAR)
  - TAD: conversion time per bit.

A/D Examples

- Example 1
  - Assumes the input analog voltage is changing between 0-5 V.
  - Using a 3-bit A/D converter draw the output as the input signal ramps from 0 to 5V.
  - Calculate the resolution.
  - What is the maximum possible voltage out? (this is called the full-scale output)
  - If the output is 1000 0000, what is the input?
- Example 2
  - Assumes the input analog voltage is changing between -5 to 5 V; using a 10-bit A/D converter.
  - Calculate the number of quantization levels.
  - Calculate the voltage resolution.

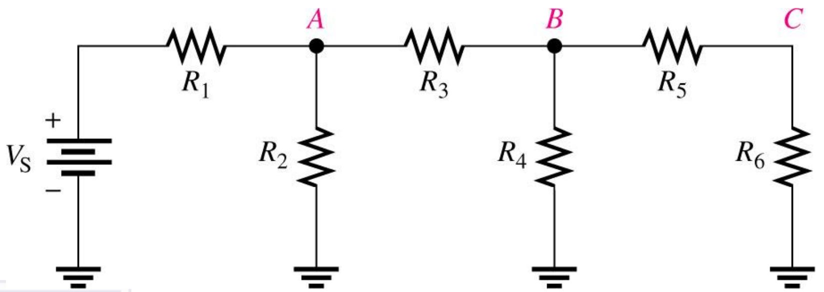
- Example 1
  - Assumes the input analog voltage is changing between 0-5 V.
  - Using a 3-bit A/D converter draw the output as the input signal ramps from 0 to 5V.
  - Calculate the resolution. 1 / 2^8 = 19.53 mV
  - What is the maximum possible voltage out? (this is called the full-scale output) 5- Resolution
  - If the output is 1000 0000, what is the input? MaxVolt / 2 = 2.5
- Example 2
  - Assumes the input analog voltage is changing between -5 to 5 V; using a 10-bit A/D converter.
  - Calculate the number of quantization levels. 2^10
  - Calculate the voltage resolution. 5-(-5)/1024=9.76 mV

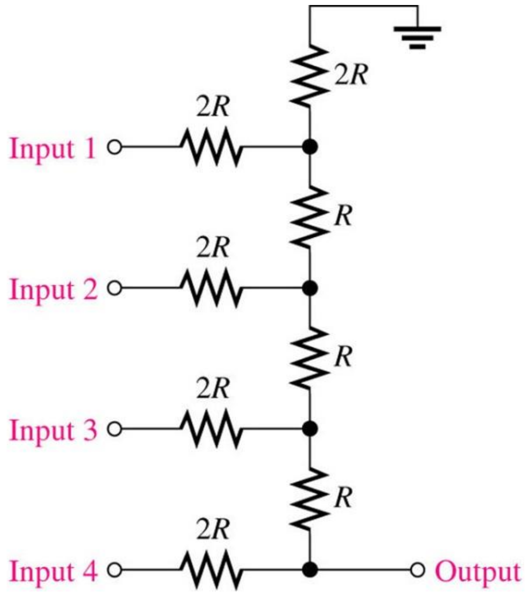
Digital to Analog (D/A, DAC, or D-to-A) Conversion

- Converting discrete signals into discrete analog values that represent the magnitude of the input signal compared to a standard or reference voltage
  - The output of the DAC is discrete analog steps.
  - By increasing the resolution (number of bits), the step size is reduced, and the output approximates a continuous analog signal.

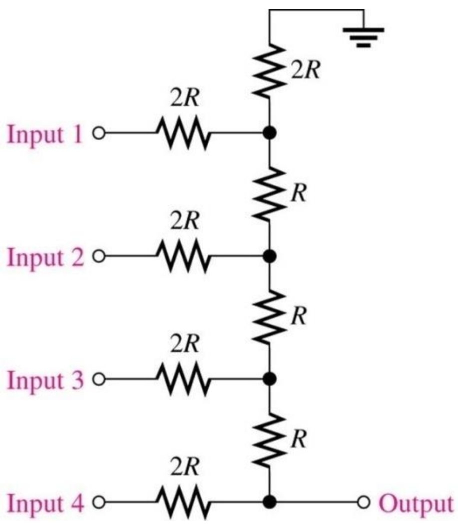
Analysis of a Ladder Network

- A resistive ladder network is a special type of series-parallel circuit.
- One form of ladder network is commonly used to scale down voltages to certain weighted values for digital-to-analog conversion
  - Called R/2R Ladder Network
- To find total resistance of a ladder network, start at the point farthest from the source and reduce the resistance in steps.

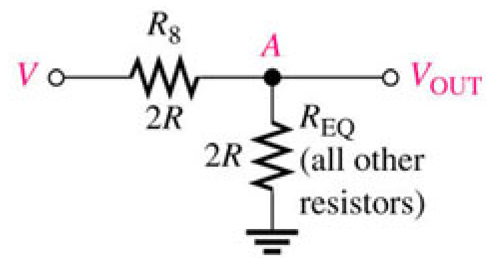




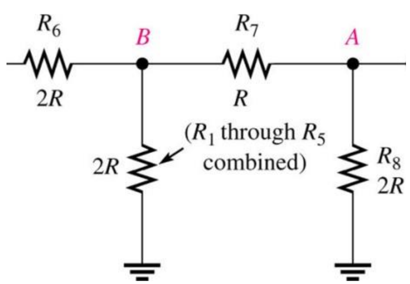
The R/R2 Ladder Network



Only Input 4 is HIGH

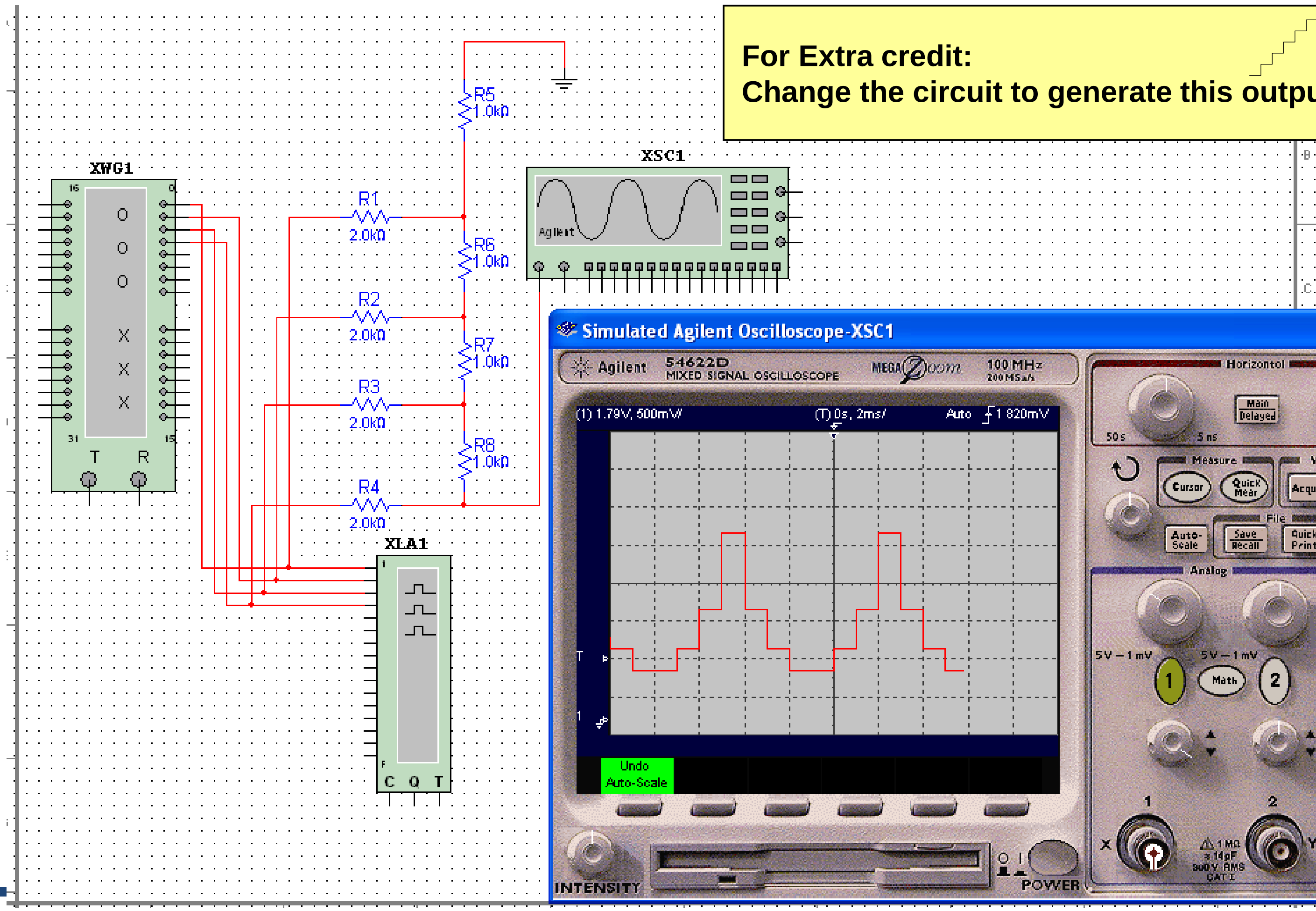


Only Input 3 is HIGH

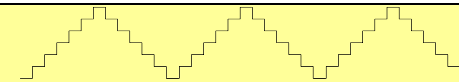


Used for Digital-to-analog converter!

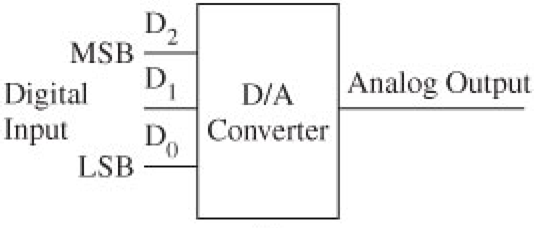
Examining Digital-to-Analog Conversion



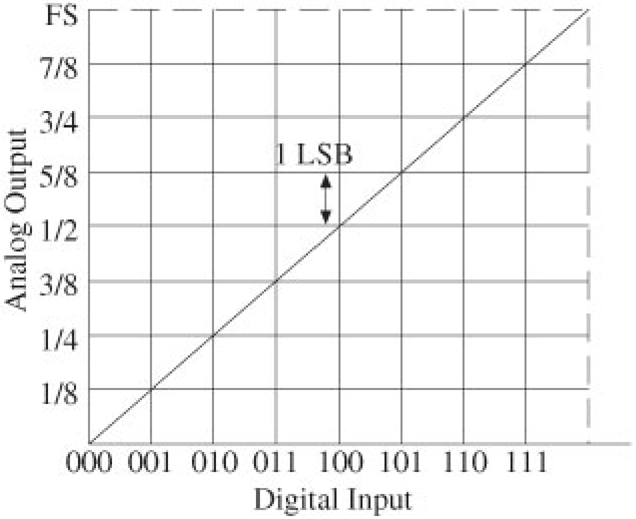
For Extra credit:
Change the circuit to generate this output:



- The resolution of a DAC is defined in terms of bits—the same way as in ADC.
- The values of LSB, MSB, and full-scale voltages calculated the same way as in the ADC.
- The largest input signal 111 is equivalent of 7/8 of the full-scale analog value.



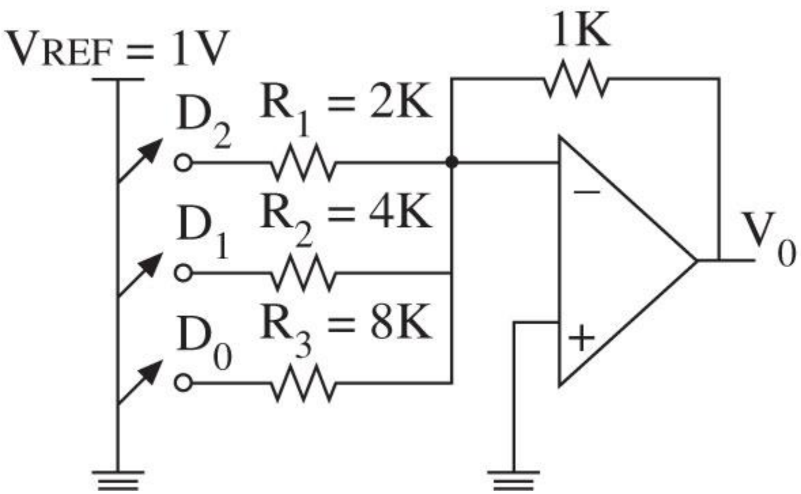
(a)

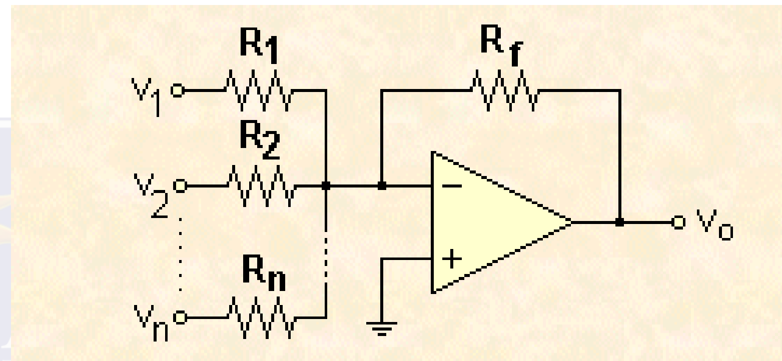


- Can be designed using an operational amplifier and appropriate combination of resistors
- Resistors connected to data bits are in binary weighted proportion, and each is twice the value of the previous one.
- Each input signal can be connected to the op amp by turning on its switch to the reference voltage that represents logic 1.
  - If the switch is off, the input signal is logic 0.

D/A Converter Circuits

- 3-bit D/A Converter Circuit





The transfer function of the summing amplifier :

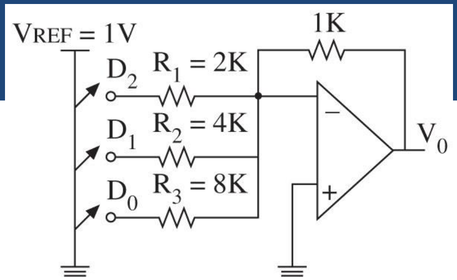
vo = -(v1/R1 + v2/R2 + … + vn/Rn)Rf

Thus if all input resistors are equal, the output is a scaled sum of all inputs.

If they are different, the output is a weighted linear sum of all inputs.

Summing amplifier

- R/2R Ladder Network for D/A Converter



- If the reference voltage is 1 V, and if all switches are connected, the output current can be calculated as follows:

$$I_o = I_T = I_1 + I_2 + I_3 = \frac{V_{REF}}{R_1} + \frac{V_{REF}}{R_2} + \frac{V_{REF}}{R_3} = \frac{V_{REF}}{1k}\left(\frac{1}{2} + \frac{1}{4} + \frac{1}{8}\right) = 0.875 mA$$

- Output voltage

$$V_O = -R_f I_T = -(1k) \times (0.875 mA) = -0.875 V = \left| \frac{7}{8} V \right|$$

D/A Converters as Integrated Circuits

- D/A converters are available commercially as integrated circuits
- Can be classified in three categories.
  - Current output, voltage output, and multiplying type
    - Current output DAC provides the current I_O as output signal
    - Voltage output D/A converts I_O into voltage internally by using an op amp and provides the voltage as output signal
    - In multiplying DAC, the output is product of the input voltage and the reference source V_{REF}.
  - Conceptually, all three types are similar