DIGITAL-TO-ANALOG AND ANALOG-TO-DIGITAL CONVERTER

Topic Outcomes

- Discuss different type of data converter
- Implement ladder network and op-amps to DAC and ADC.

Introduction

Introduction

- Many voltages and currents in electronics vary continuously over some range of values.
- In digital circuitry the signals are at either one of two levels, representing the binary values of 1 or 0.
- An analog–digital converter (ADC) obtains a digital value representing an input analog voltage, whereas a digital–analog converter (DAC) changes a digital value back into an analog voltage.
- Ladder network is primarily used in DAC circuit. The used of operational-amplifier to different converter is also introduced.

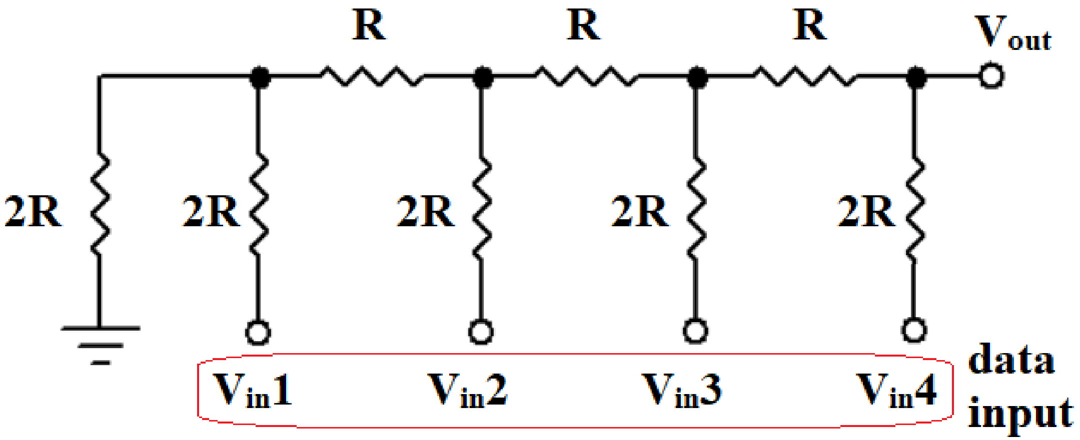
Digital-to-Analog Conveter (DAC)

Digital-to Analog-Converter

- A Digital-to Analog-Converter or DAC converts a digital input signal into its equivalent analog output signal. The digital input is represented by a combination of two conditions (binary code).
- The converter consists of multiple binary inputs and a single output. In general, the number of binary inputs of a DAC will be a power of two.

Ladder Network Conversion

- One way to achieve a digital-to-analog conversion is by the use of networks of resistors called ladder network. The network accepts binary inputs (typically $0V\ or\ Vref$) and provides an analog output proportional to the input.

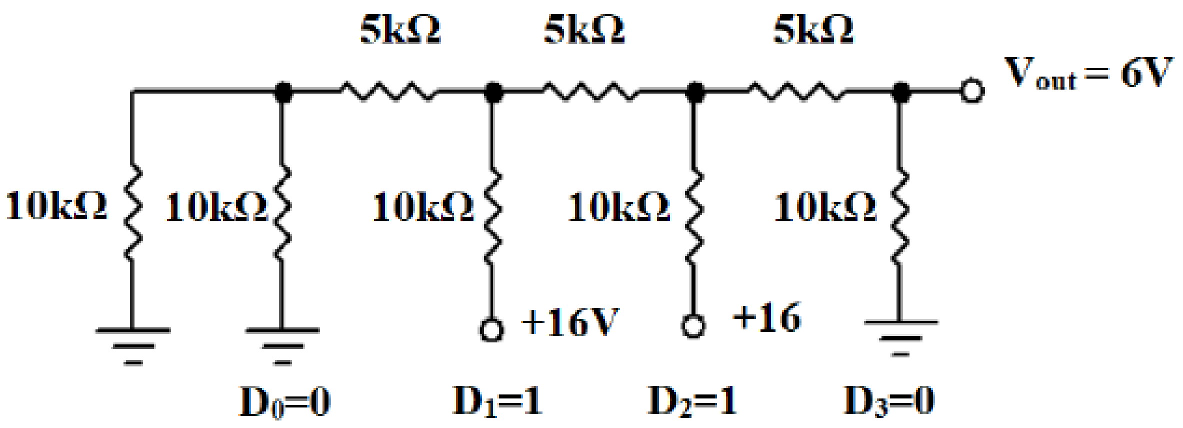


Four Stage Ladder Network Basic Circuit

$$V_{out} = \frac{(D_0 * 2^0) + (D_1 * 2^1) + (D_2 * 2^2) + (D_3 * 2^3)}{2^4} * V_{ref}$$

Ladder Network Conversion

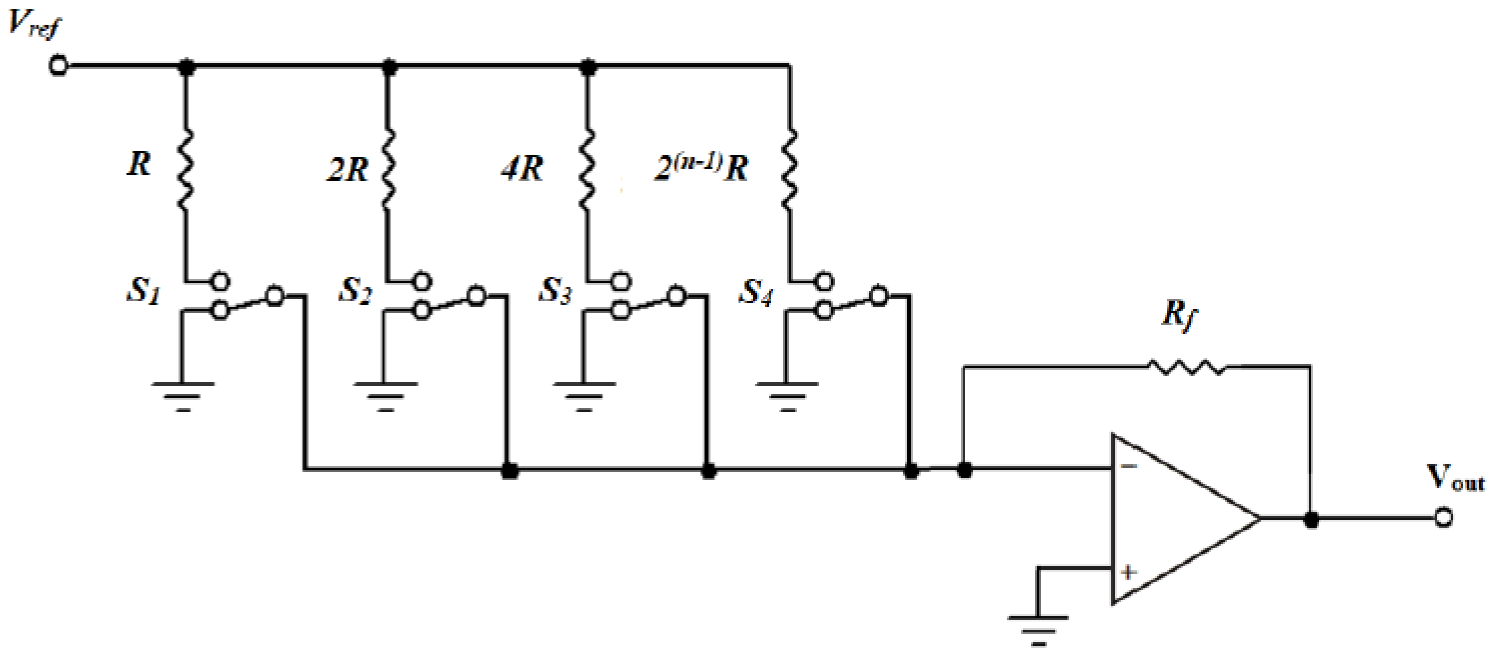
- Below shows an example of ladder network circuit that convert a digital input of 0110 to 6V analog output voltage.



$$V_{out} = \frac{(0 * 2^0) + (1 * 2^1) + (1 * 2^2) + (0 * 2^3)}{2^4} * 16 = 6\,V$$

Binary-Weighted Resistor DAC

- A weighted resistor DAC produces an analog voltage output that is equal to the digital input by means of binary weighted resistors in the inverting adder circuit.



Binary-Weighted Resistor DAC

The Binary-weighted Resistor DAC is composed of four major components

1. Switches equivalent to the number of binary input.
2. Weighted resistor ladder network (value of resistance are inversely proportional to thenumerical significance of each binary input equivalent).
3. Reference voltage
4. Summing amplifier that produce an analog signal that proportion to the digital input

Binary-Weighted Resistor DAC

Using the Millman's theorem, we can analyze the behavior of the circuit. Millman's theorem states that

"the voltage appearing at any node in a resistive network is equal to the summation of the current entering the node (assuming the node voltage is zero) divided by the summation of the conductance connected to the node".

Therefore we can write the equation for output mathematically

$$\frac{V_{out}}{R_f} = \frac{V_{ref}S_1}{2^0 R} + \frac{V_{ref}S_2}{2^1 R} + \frac{V_{ref}S_3}{2^2 R} + \cdots + \frac{V_{ref}S_n}{2^{n-1} R}$$

$$V_{out} = \frac{V_{ref}R_f}{R}\left(\frac{S_1}{2^0} + \frac{S_2}{2^1} + \frac{S_3}{2^2} + \cdots + \frac{S_n}{2^{n-1}}\right)$$

$$V_{ref} = 1\,, Ground = 0$$

Binary-Weighted Resistor DAC

Advantages

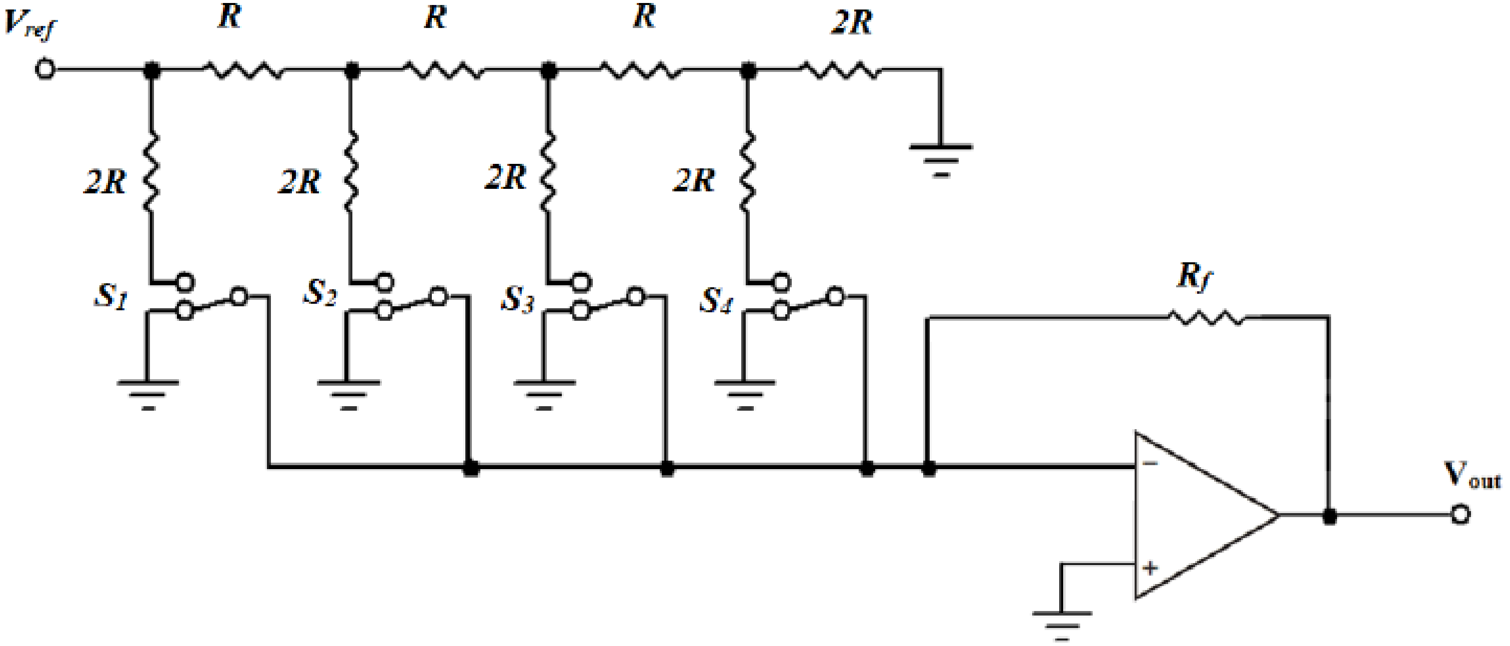
- Single resistor is used per binary input representation

Disadvantages

- Resistors for network application have a wide range of values and it is difficult to design more accurate resistors. When the number of input is large, the resistance of the least weighted bit is also large which may be comparable to the Zin of the op-amp that may leadto erroneous results.
- The temperature coefficients of all resistors is very hard to match

R-2R Ladder Network

- We see that in weighted resistor DAC requires a wide range of resistance value as our binary input increases. With R-2R ladder network shown below, overcome the disadvantages of a binary weighted resistor in equivalent to additional resistor for each bit.



R-2R Ladder Network

- The switch represents the binary input with $S1$ is the most weighted bit and $S4$ is the least weighted bit.
- The operation of R-2R Ladder Network used superposition theorem to determine the analog output equivalent to combinations of binary input.

$$V_{out} = V_{ref} 2^{-n} (S_{n-1} 2^{n-1} + S_{n-2} 2^{n-2} + \cdots + S_1 2^1 + S_0 2^0)$$

- Thus the output of R-2R ladder DAC is proportion to the sum of the weights represented by switches to the ratio in the ladder network.

R-2R Ladder Network

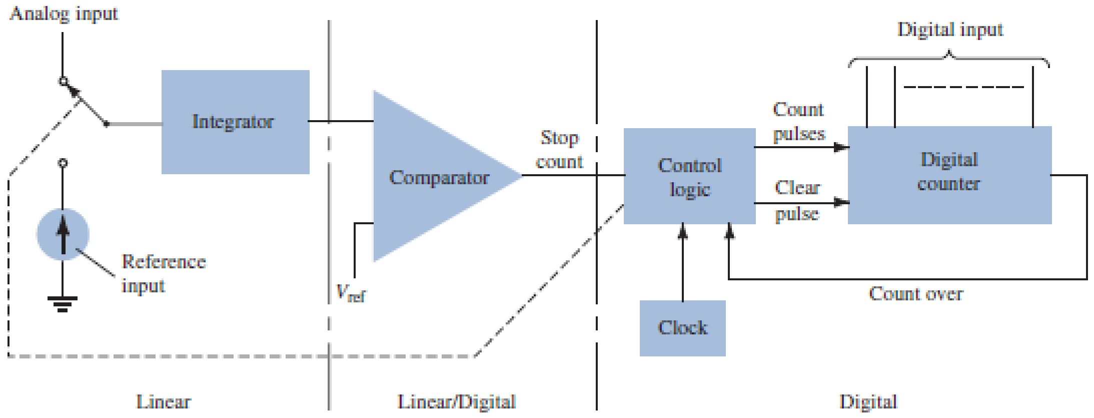
Advantages

- Only 2 values resistor are used
- R-2R are available to monolithic chips
- An addition of R-2R network if we want to add digital input

Analog to Digital Converter (ADC)

Dual-Slope Conversion

- The dual-slope method is a popular way to convert an analog voltage into a digital value.
- The analog voltage is applied through an electronic switch to an integrator or ramp-generator circuit.
- The integrator produces a linear ramp voltage by charging a capacitor with a constant current.
- The digital output is obtained from a counter operated during both positive and negative slope intervals of the integrator.



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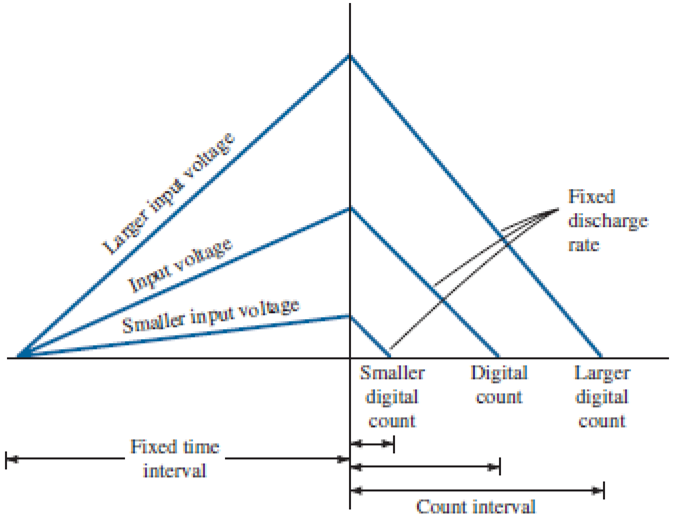

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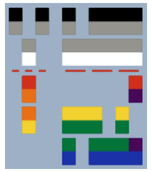
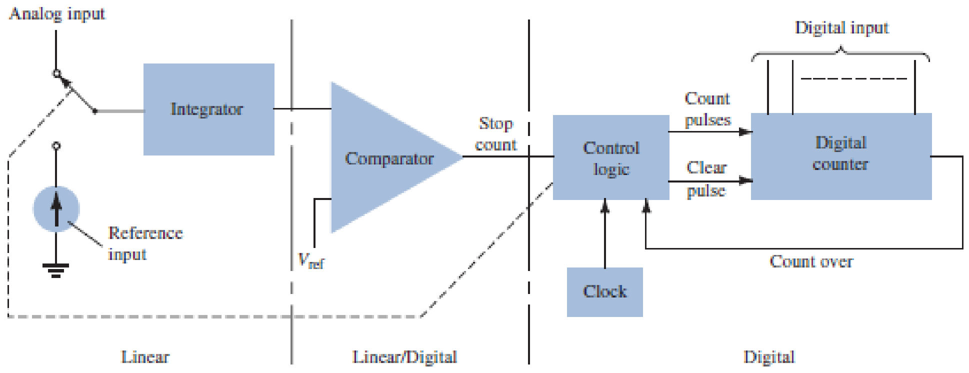


Dual-Slope Conversion

- The method of conversion involves a fixed time interval, usually the full count range of the counter.
- The analog voltage connected to the integrator raises the voltage at the comparator input to some positive level.
- At the end of the fixed time interval, the voltage from the integrator is greater for the larger input voltage.
- The count is set to zero and the electronic switch connects the integrator to a reference or fixed input voltage.
- The integrator output (or capacitor input) then decreases at a fixed rate.
- The counter advances during this time.
- The integrator's output decreases at a fixed rate until it drops below the comparator reference voltage.
- The control logic receives a signal (the comparator output) to stop the count.
- The digital value stored in the counter is then the digital output of the converter.
- Using the same clock and integrator for positive and negative slope intervals compensates for clock frequency drift and integrator accuracy limitations.
- The reference input value and clock rate can be set to scale the counter output as desired.
- The counter can be a binary, BCD, or other form of digital counter, depending on the requirements of the application.



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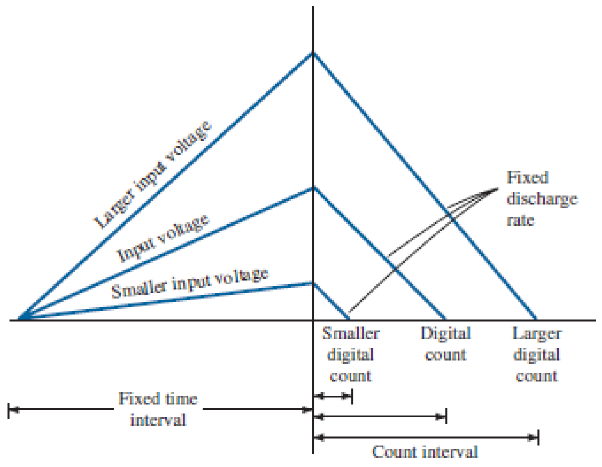

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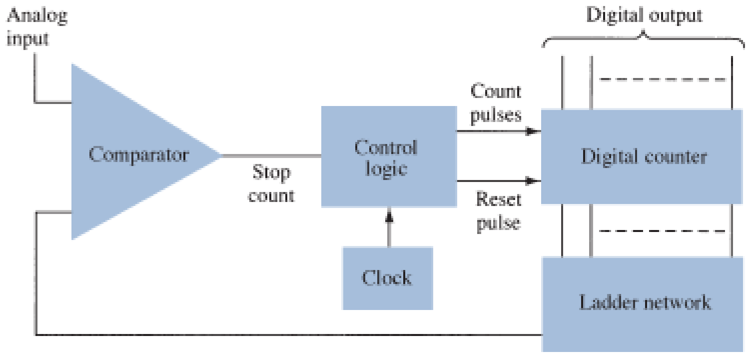
Ladder-Network Conversion

- Analog-to-digital conversion using ladder network, counter, and comparator circuits
- A ladder network driven by a digital counter outputs a staircase voltage that increases incrementally with each count step.
- A comparator circuit compares the staircase voltage with the analog input voltage and provides a signal to stop the count when the staircase voltage exceeds the input voltage.
- The counter value at that time is the digital output.
- Conversion resolution depends on the number of count bits used, and the voltage change stepped by the staircase signal.
- The clock rate of the counter affects the time required to carry out a conversion.
- A slower clock rate would result in fewer conversions per second, while using fewer count stages would result in more conversions per second with less conversion resolution.
- Conversion accuracy depends on the accuracy of the comparator.



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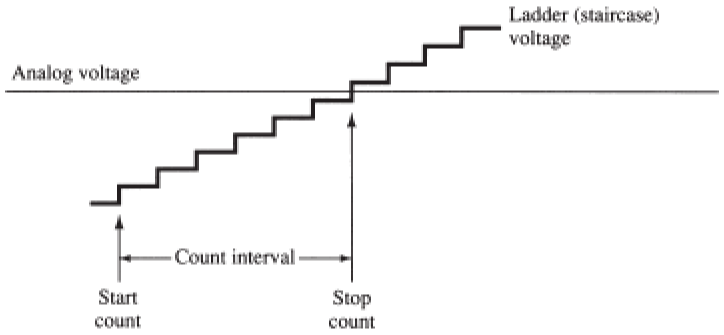

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