Digital Electronics (303105220)

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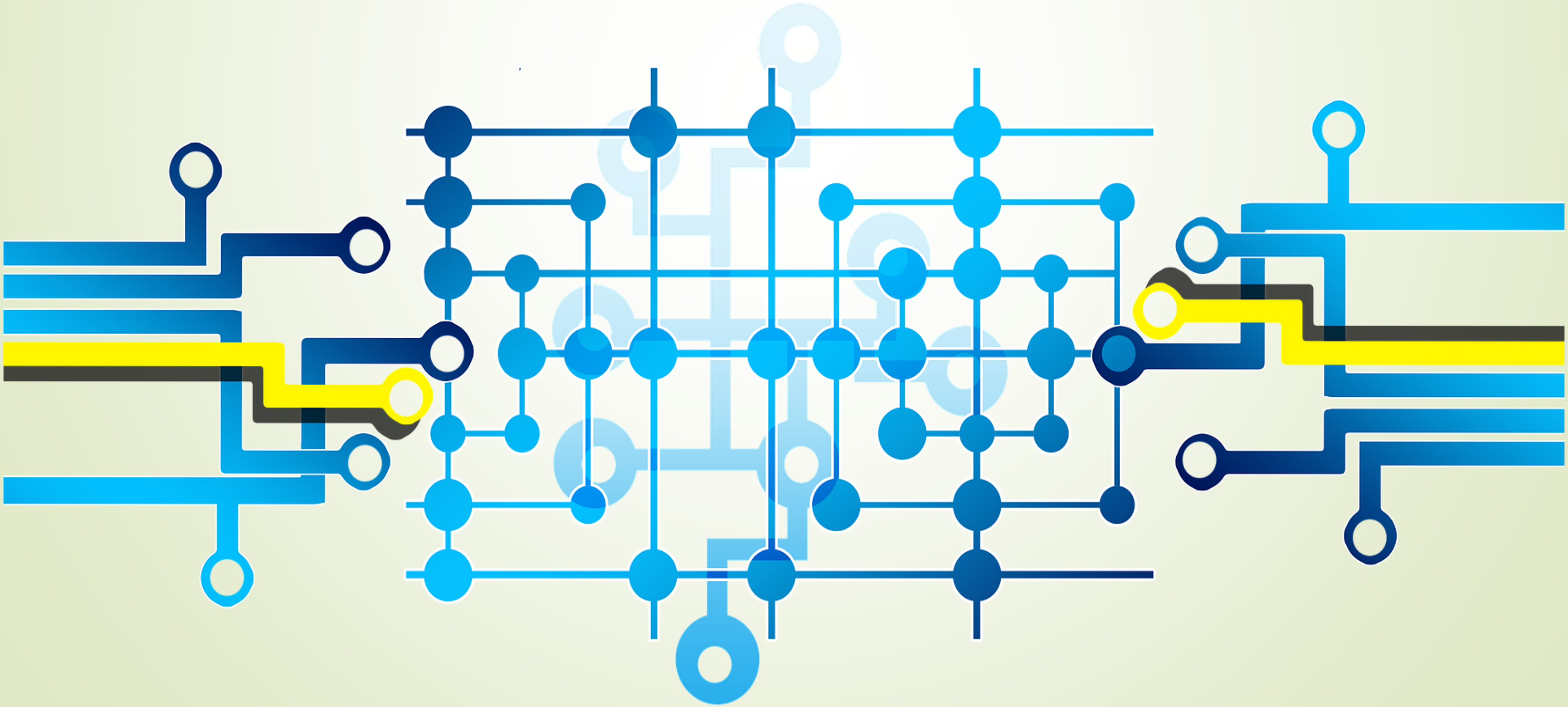


CHAPTER-5

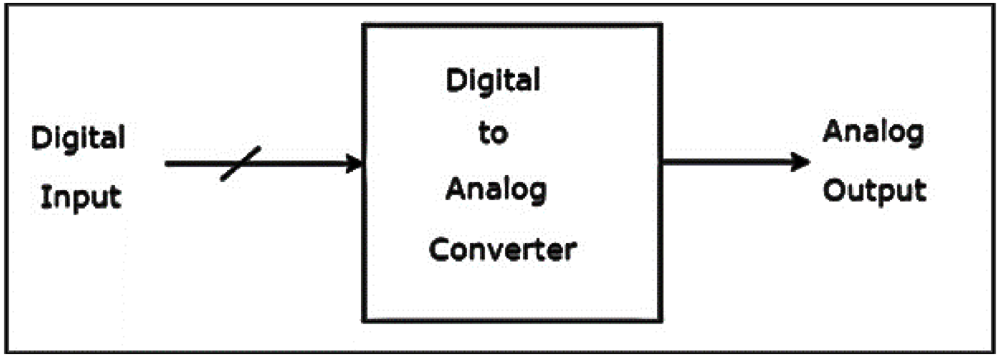
A/D and D/A Converters

Digital to analog converters: weighted resistor/converter, R-2R Ladder, examples of D to A converters IC's, Analog to Digital converters: successive approximation A/D converter, dual slope A/D converter , example of A/D Converter ICs

A/D and D/A Converters

A **Digital to Analog Converter (DAC)** converts a digital input signal (in parallel), into an analog output signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.

- A Digital to Analog Converter (DAC) consists of a number of binary inputs and a single output.
- In general, the **number of binary inputs** of a DAC will be a power of two.



$$\boxed{V_0 = K\,(2^{N-1}b_{N-1} + 2^{N-2}b_{N-2} + \cdots + 2^2 b_2 + 2^1 b_1 + b_0)}$$

K: Proportionality Factor

$$b_n = \begin{cases} 1, if\ n-th\ input\ bit\ is\ 1 \\ 0. if\ n-th\ input\ bit\ is\ 0 \end{cases}$$

A/D and D/A Converters

Q. Find the analog output voltage of a 4-bit DAC for all possible inputs. Assume K=1

Digital Input				Analog Output
b_3	b_2	b_1	b_0	V
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9

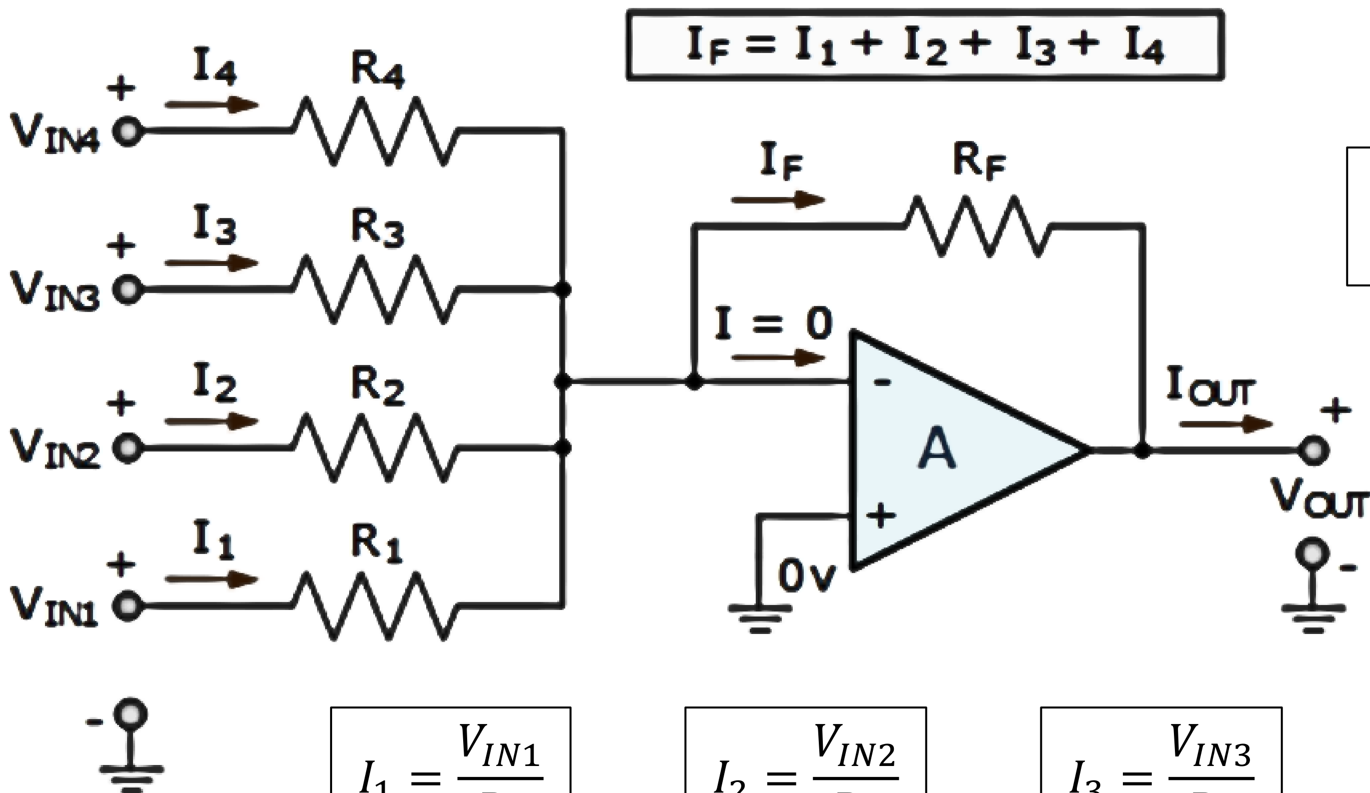
Digital Input				Analog Output
b_3	b_2	b_1	b_0	V
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

Common DACs:

- **Weighted Resistor DAC,** &
- **R-2R Ladder DAC**

A/D and D/A Converters

Weighted resistor type DAC: Weighted resistors are used along with a summing amplifier.



$$I_F = -\frac{V_{OUT}}{R_F}$$

$$I_1 = \frac{V_{IN1}}{R_1} \qquad I_2 = \frac{V_{IN2}}{R_2} \qquad I_3 = \frac{V_{IN3}}{R_3} \qquad I_4 = \frac{V_{IN4}}{R_4}$$

A/D and D/A Converters

$$I_F = -\frac{V_{OUT}}{R_F} = \frac{V_{IN1}}{R_1} + \frac{V_{IN2}}{R_2} + \frac{V_{IN3}}{R_3} + \frac{V_{IN4}}{R_4}$$

$$V_{OUT} = -\left(\frac{R_F.V_{IN1}}{R_1} + \frac{R_F.V_{IN2}}{R_2} + \frac{R_F.V_{IN3}}{R_3} + \frac{R_F.V_{IN4}}{R_4}\right)$$

$$R_F = \frac{R_1}{2^0} = \frac{R_2}{2^1} = \frac{R_3}{2^2} = \frac{R_4}{2^3}$$

Weighted resistors

$$V_{OUT} = -\left(\frac{V_{IN1}}{2^0} + \frac{V_{IN2}}{2^1} + \frac{V_{IN3}}{2^2} + \frac{V_{IN4}}{2^3}\right)$$

MSB

LSB

A/D and D/A Converters

A	B	C	D	V_{OUT}
0	0	0	0	0
0	0	0	1	-0.625
0	0	1	0	-1.25
0	0	1	1	-1.875
0	1	0	0	-2.5
0	1	0	1	-3.125
0	1	1	0	-3.75
0	1	1	1	-4.375
1	0	0	0	-5
1	0	0	1	-5.625
1	0	1	0	-6.25
1	0	1	1	-6.875
1	1	0	0	-7.5
1	1	0	1	-8.125
1	1	1	0	-8.75
1	1	1	1	-9.375

$$\boxed{V_{OUT} = -\left(\frac{V_A}{2^0} + \frac{V_B}{2^1} + \frac{V_C}{2^2} + \frac{V_D}{2^3}\right)}$$

MSB LSB

Resolution : $\frac{1}{2^n - 1}$

$V_A, V_B, V_C, V_D = +5V\,(logic\ 1), or\ 0V\ (logic\ 0)$

Step-size: -0.625 V

Resolution: $\frac{1}{15}$; 4-bit

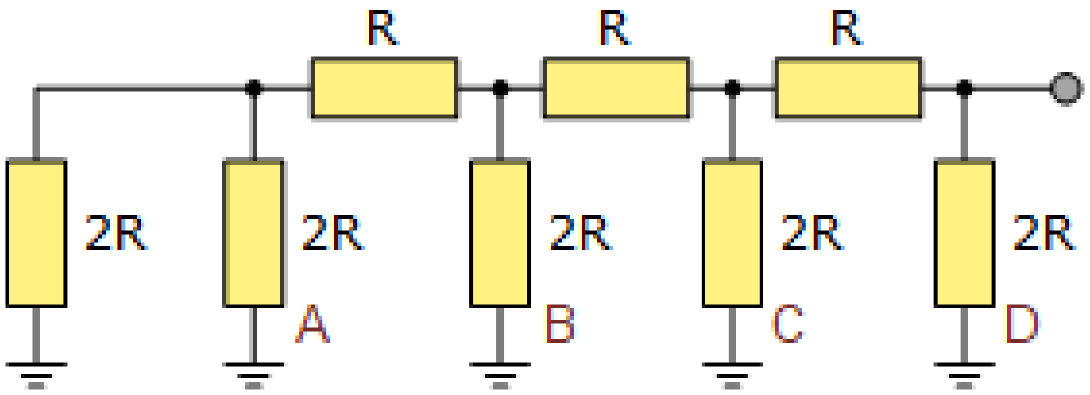
Drawbacks
- requires a very precise value of resistors.
- impractical for higher-order DACs
- The stability of the device is resistor-dependent

Advantages
- It has a simple assembly.
- It has a fast conversion speed.
- Simple conversion circuit

A/D and D/A Converters

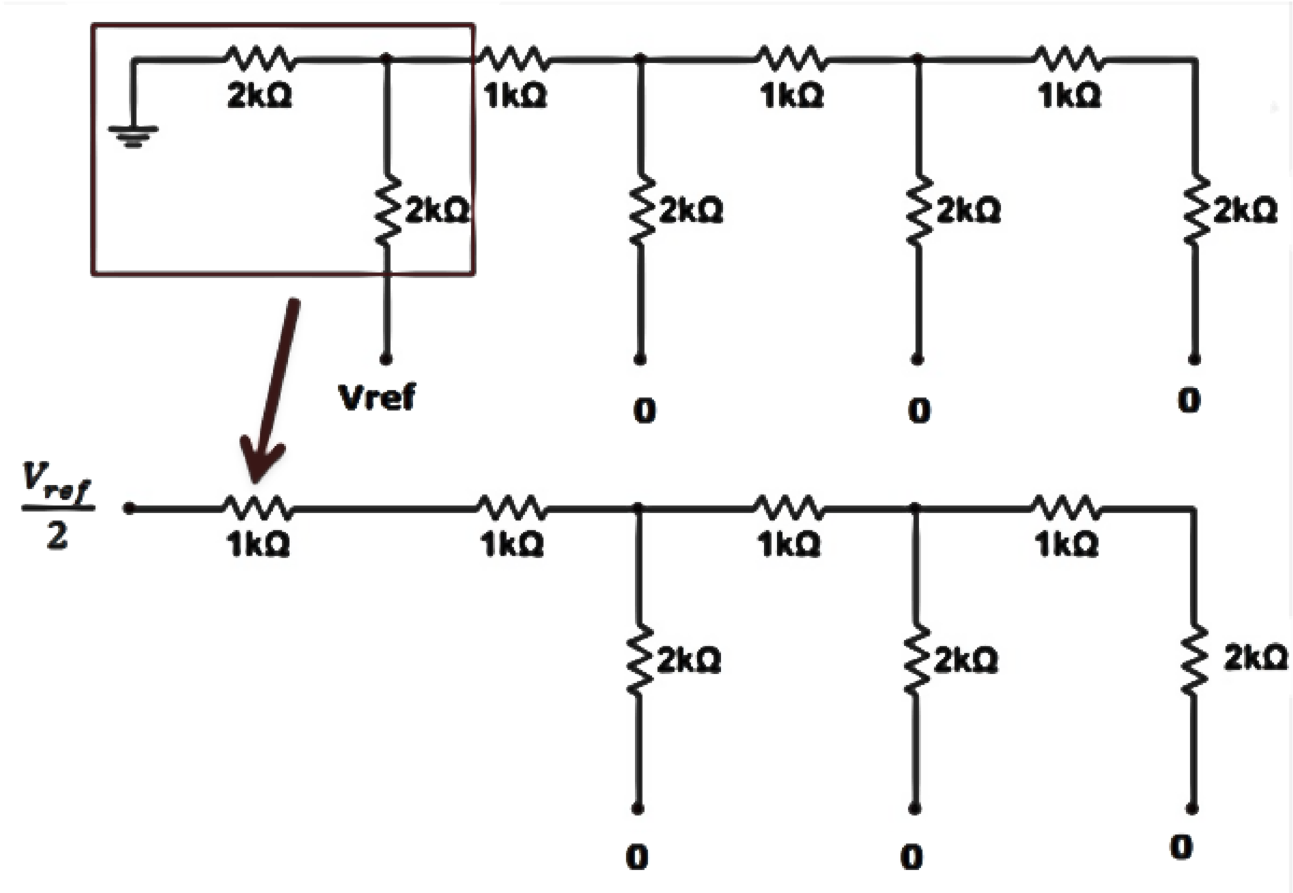
R-2R Ladder type DAC: It uses only two values of (precision) resistors to convert a digital binary number into an analog output signal proportional to the digital number's value.

- ladder-like configuration
- Long strings of parallel and series-connected resistors acting as interconnected voltage dividers along their length,
- and whose output voltage depends only on the interaction of the input voltages with each other

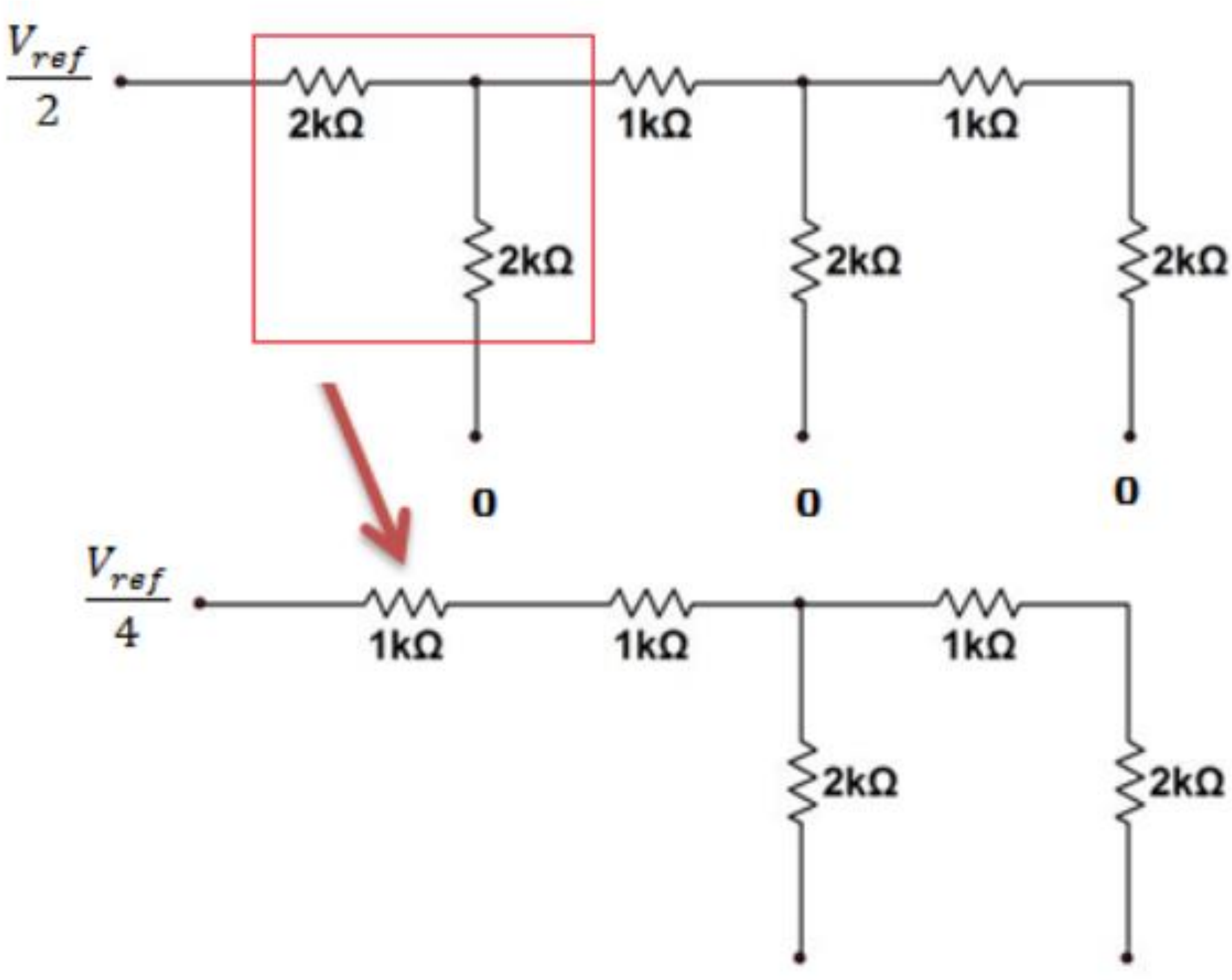


A/D and D/A Converters

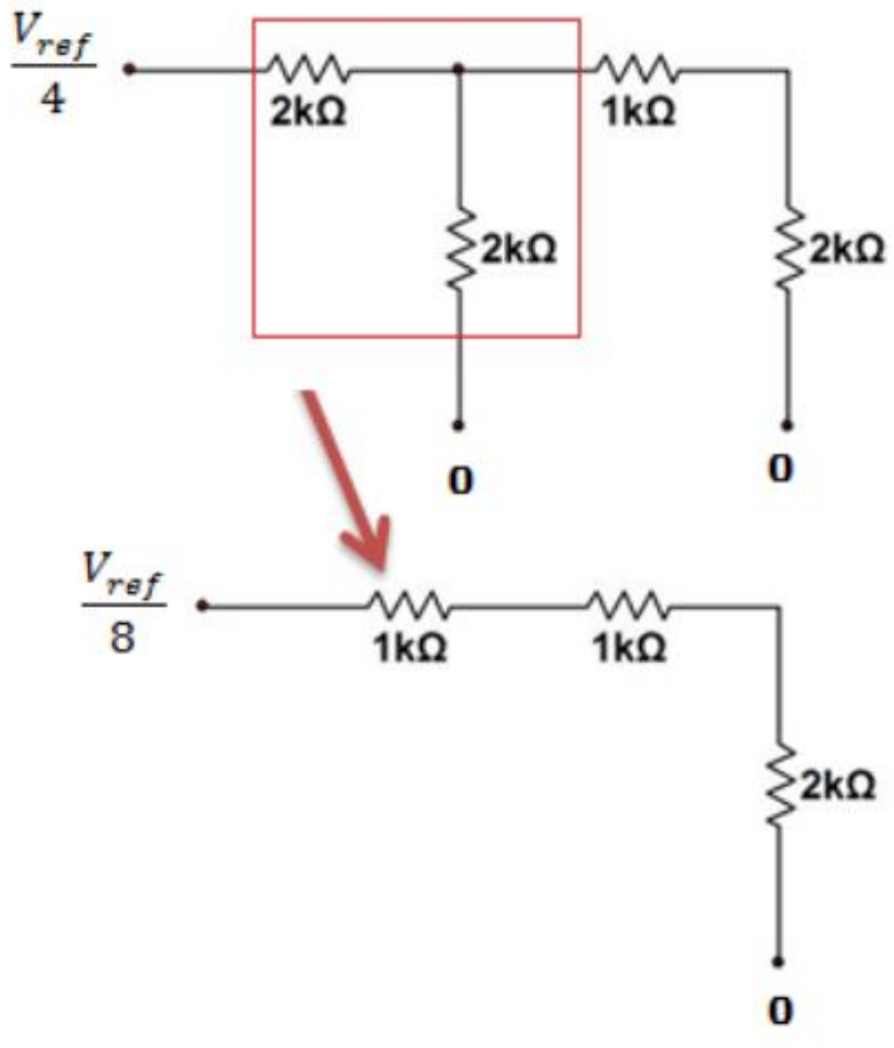
Let us consider the digital data $D_3D_2D_1D_0$= ABCD=1000 is applied to the DAC, then Thevenin's equivalent circuit reduction is shown below.



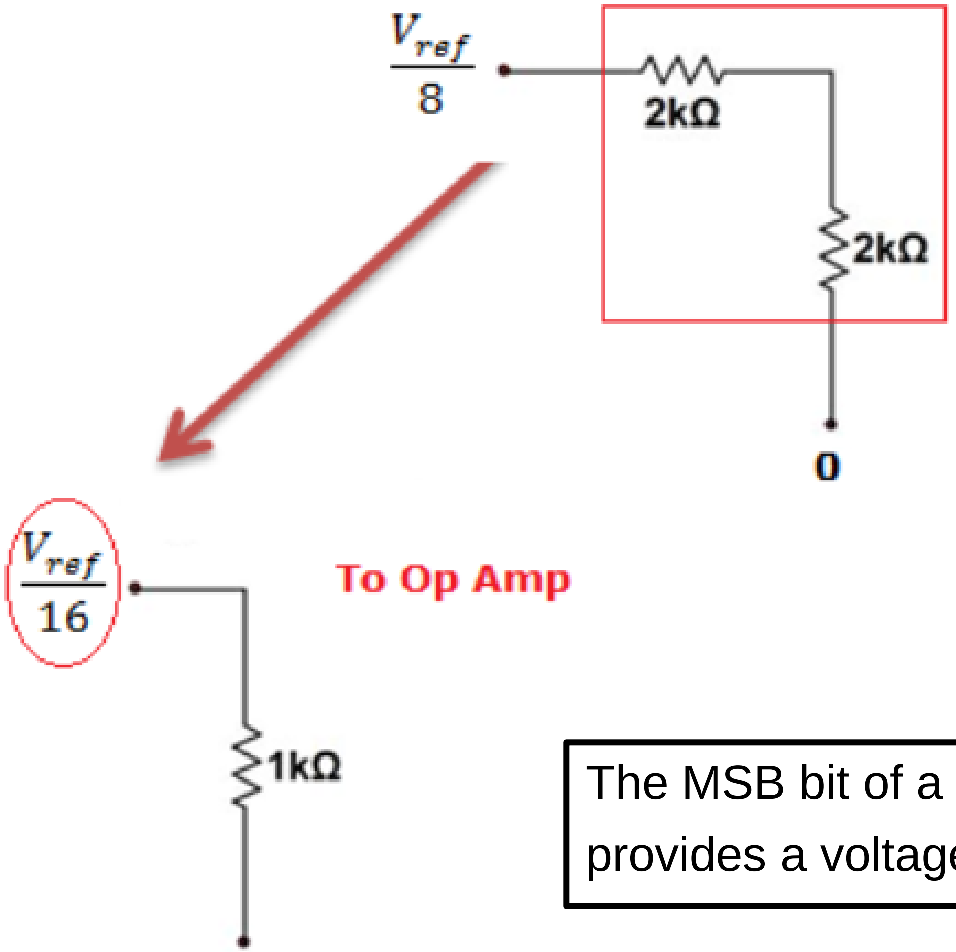
A/D and D/A Converters



A/D and D/A Converters



A/D and D/A Converters



The MSB bit of a 4-digit number provides a voltage $\frac{V_{ref}}{2^4}$

A/D and D/A Converters

The MSB (4th) bit of a 4-digit number provides a voltage $\frac{V_{ref}}{2^4}$

$$V_{out,\,A} = \frac{V_A}{2^4}$$

The (MSB-1) (3rd bit of a 4-digit number provides a voltage $\frac{V_{ref}}{2^3}$

$$V_{out,\,B} = \frac{V_B}{2^3}$$

The (MSB-2) (2nd bit of a 4-digit number provides a voltage $\frac{V_{ref}}{2^2}$

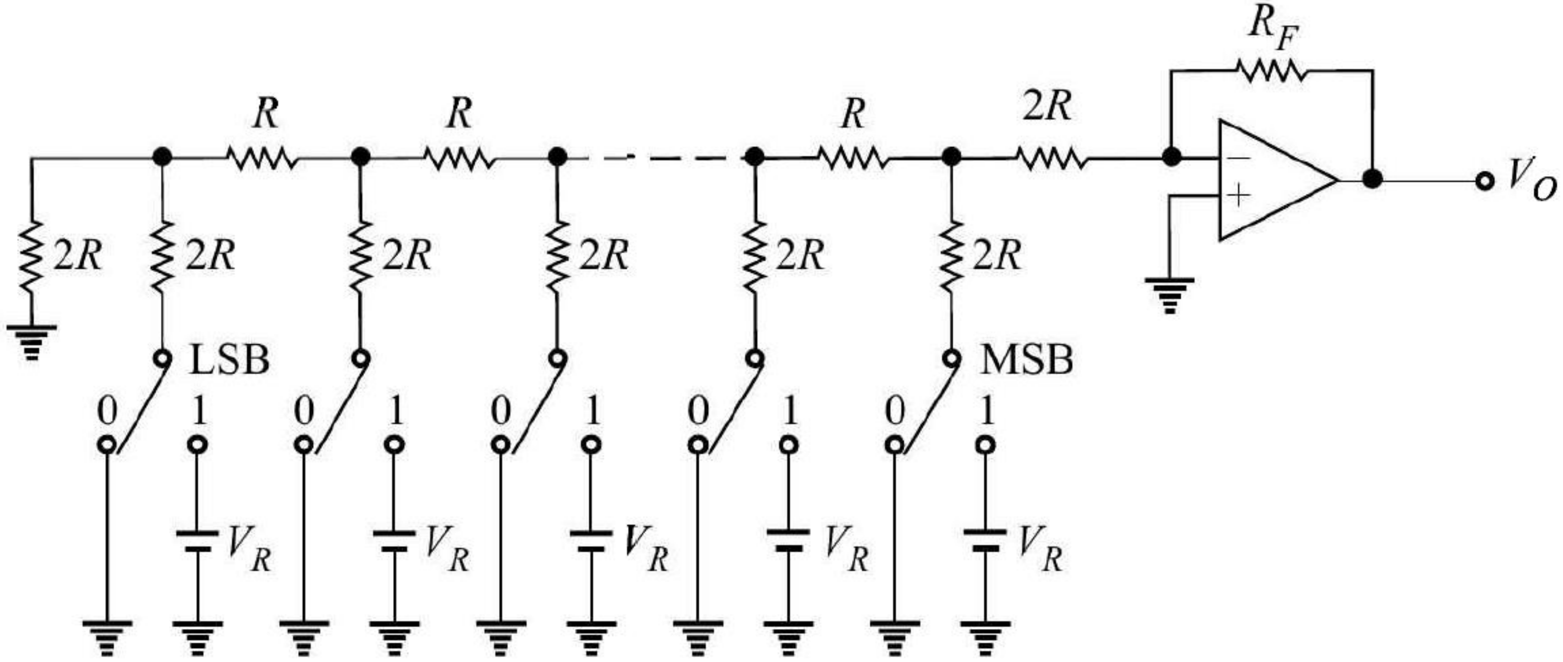
$$V_{out,\,C} = \frac{V_C}{2^2}$$

The LSB (1st bit of a 4-digit number provides a voltage $\frac{V_{ref}}{2^1}$

$$V_{out,\,D} = \frac{V_D}{2^1}$$

$$V_{out} = \frac{1}{16}(V_A + 2V_B + 4V_C + 8V_D)$$

A/D and D/A Converters

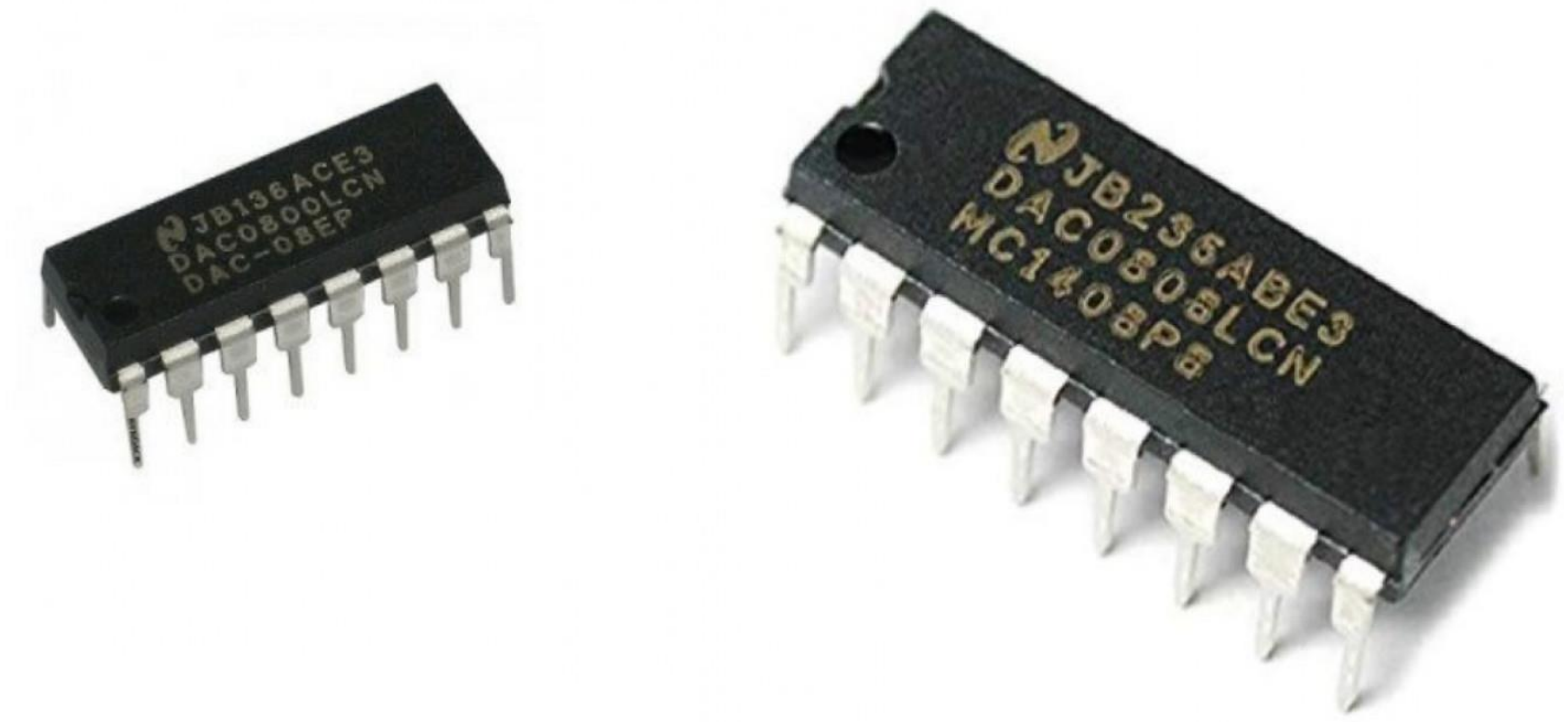


A 5-bit R-2R ladder type DAC

A/D and D/A Converters

Examples of D to A converters IC's

1. **DAC0800**: monolithic 8-bit high-speed current-output DAC
2. **DAC0808:** 8-bit monolithic DAC featuring a full-scale output



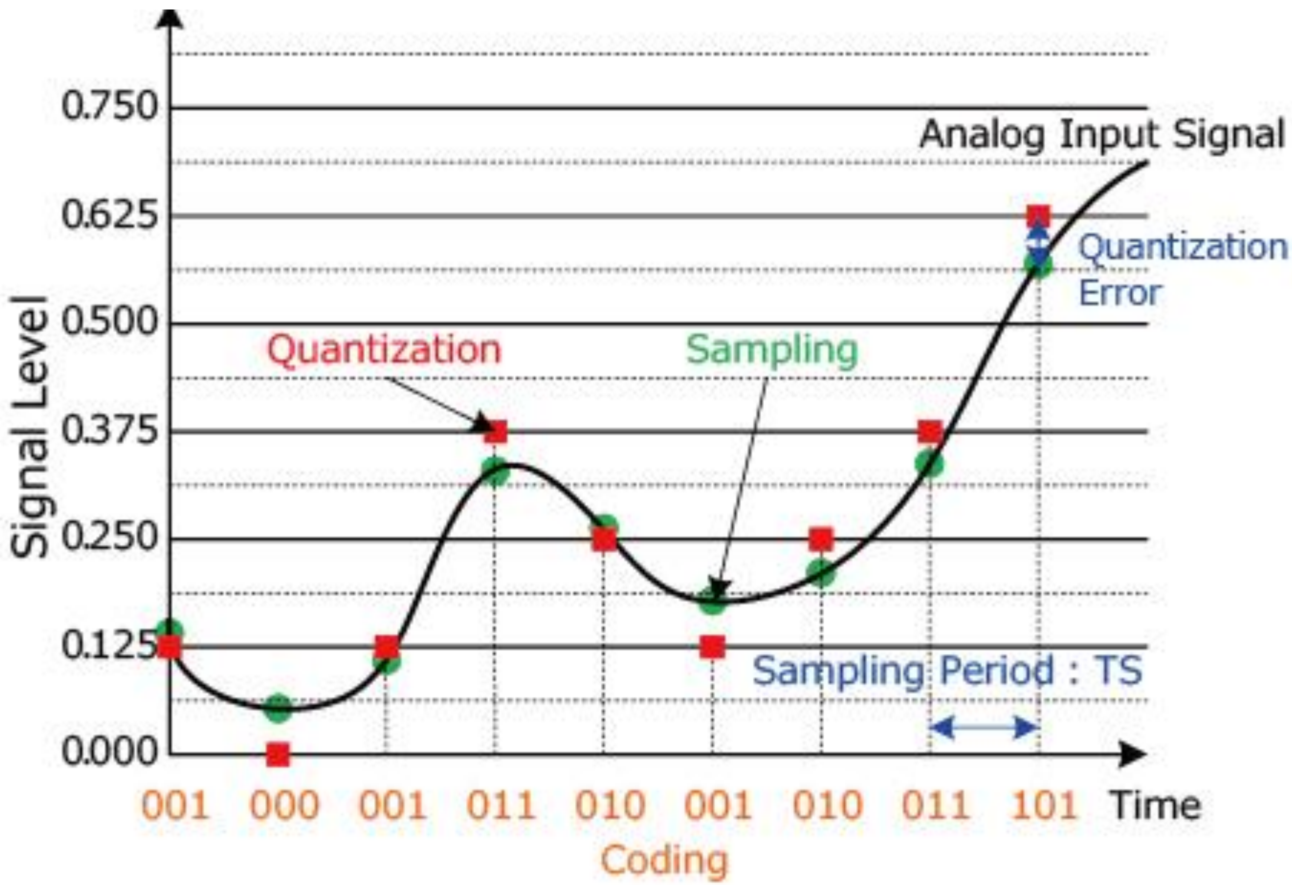
A/D and D/A Converters

Comparison of DAC's:

S. No.	Parameter	Weighted Resistor DAC	R-2R Ladder DAC
1	Simplicity	Simple	Slightly complicated
2	Range of resistor values	A wide range is required	Resistors of only two values are required
3	Number of resistor per bit	One	Two
4	Ease of expansion	Not easy to expand for more bits	Easy to expand

A/D and D/A Converters

An **A/D converter** is a device that **converts analog signals** (usually voltage) obtained from environmental (physical) phenomena **into digital format**. Conversion involves a series of steps, including **sampling, quantization, and coding**.



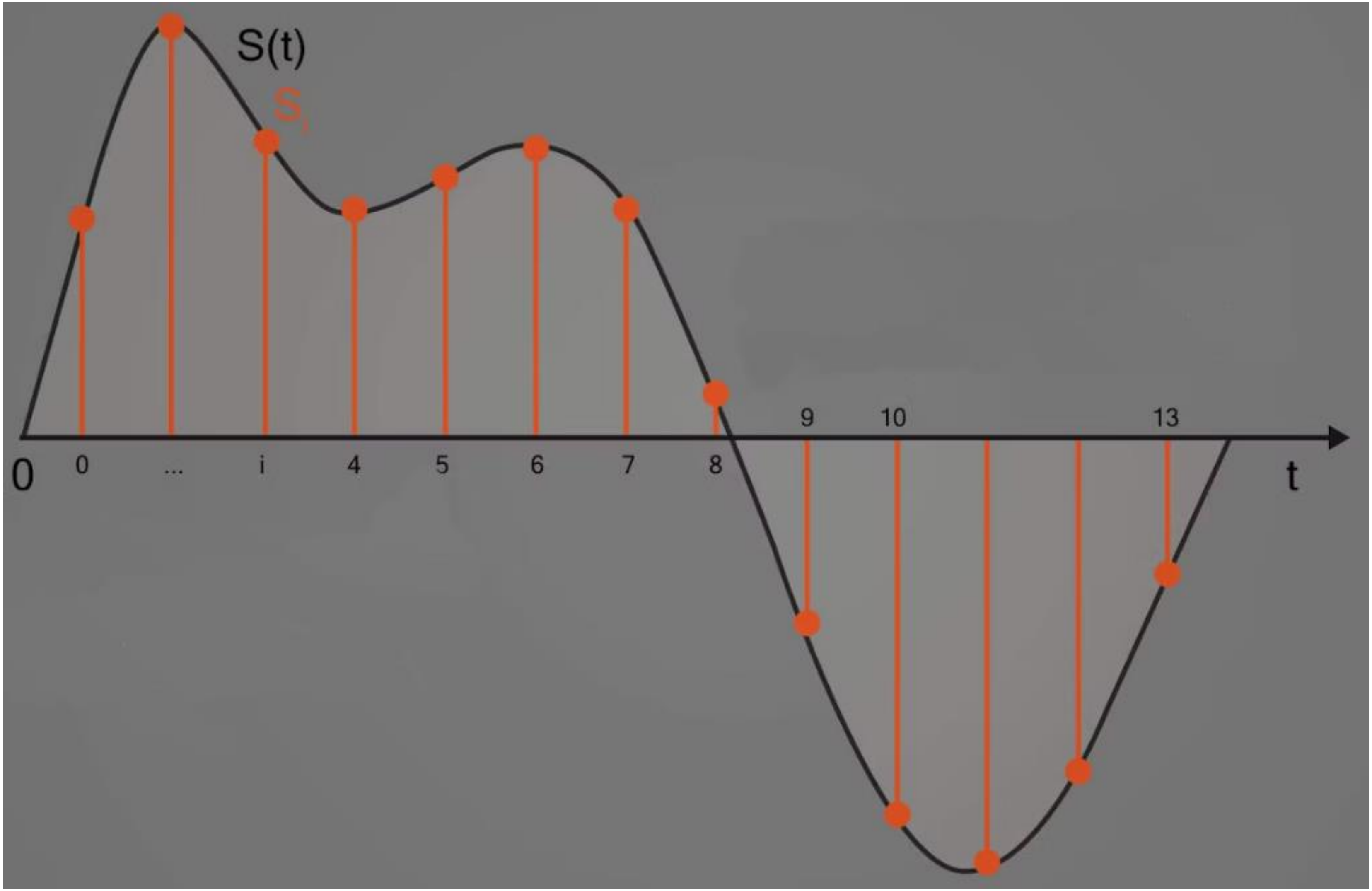
A/D and D/A Converters

There are **two types** of ADCs:
Direct type ADCs, and **Indirect type ADC.**

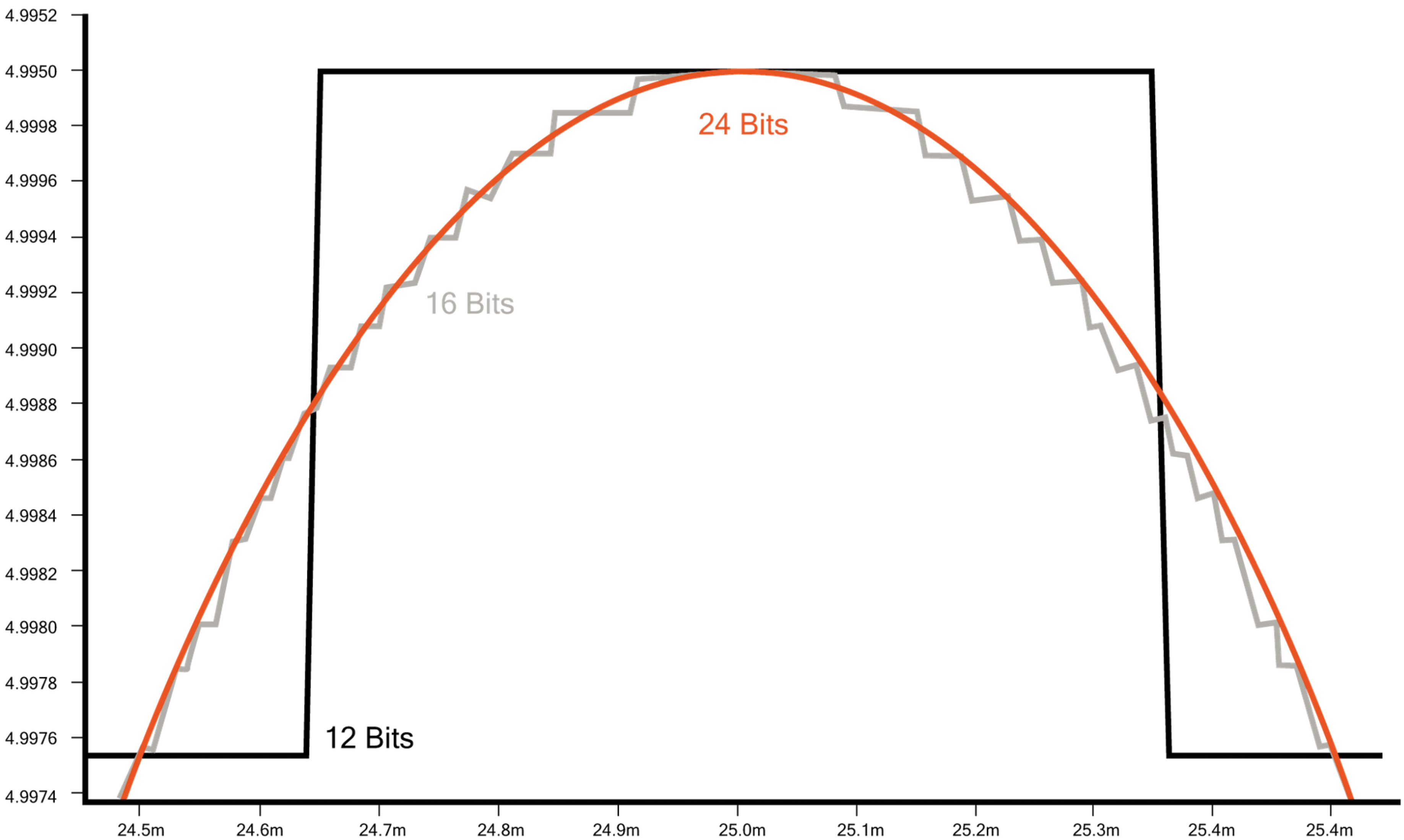
The following are examples of Direct type ADCs –
- Counter-type ADC
- **Successive Approximation ADC**
- Flash-type ADC

Indirect type ADC. It first converts the analog input into a linear function of time (or frequency) and then produces the digital (binary) output.
Dual slope ADC is the best **example** of an Indirect type ADC.

A/D and D/A Converters

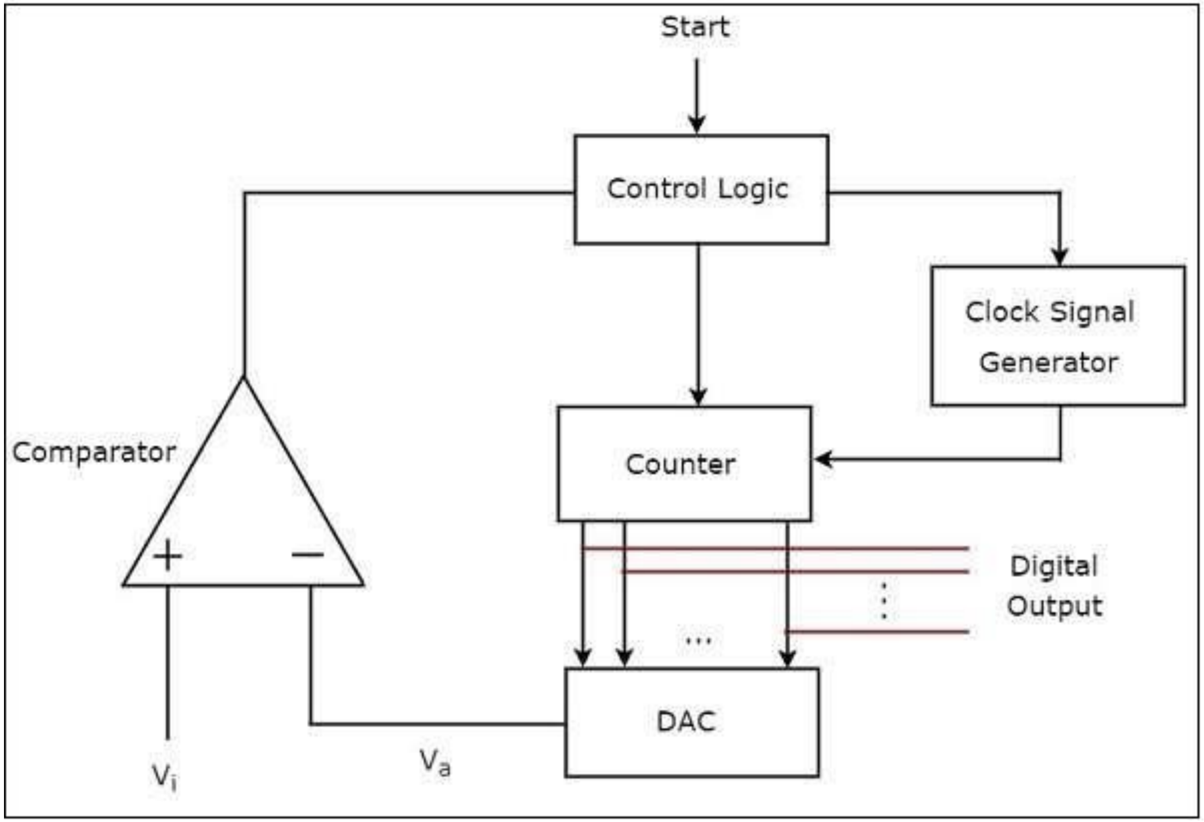


A/D and D/A Converters



A/D and D/A Converters

A **counter-type ADC** produces a digital output, which is approximately equal to the analog input by using counter operation internally.



A/D and D/A Converters

Counter-type ADC:

- The control logic resets the counter and enables the clock signal generator in order to send the clock pulses to the counter, when it received the start commanding signal.
- The counter gets incremented by one for every clock pulse and its value will be in binary (digital) format. This output of the counter is applied as an input of DAC.
- DAC converts the received binary (digital) input, which is the output of the counter, into an analog output. The comparator compares this analog value V_a with the external analog input value V_i
- The output of comparator will be '1' as long as V_i is greater than V_a. The operations mentioned in the above two steps will be continued as long as the control logic receives '1' from the output of the comparator.
- The output of the comparator will be '0' when V_i is less than or equal to V_a . So, the control logic receives '0' from the output of the comparator. Then, the control logic disables the clock signal generator so that it doesn't send any clock pulse to the counter.

At this instant, the output of the counter will be displayed as the digital output. It is almost equivalent to the corresponding external analog input value V_i

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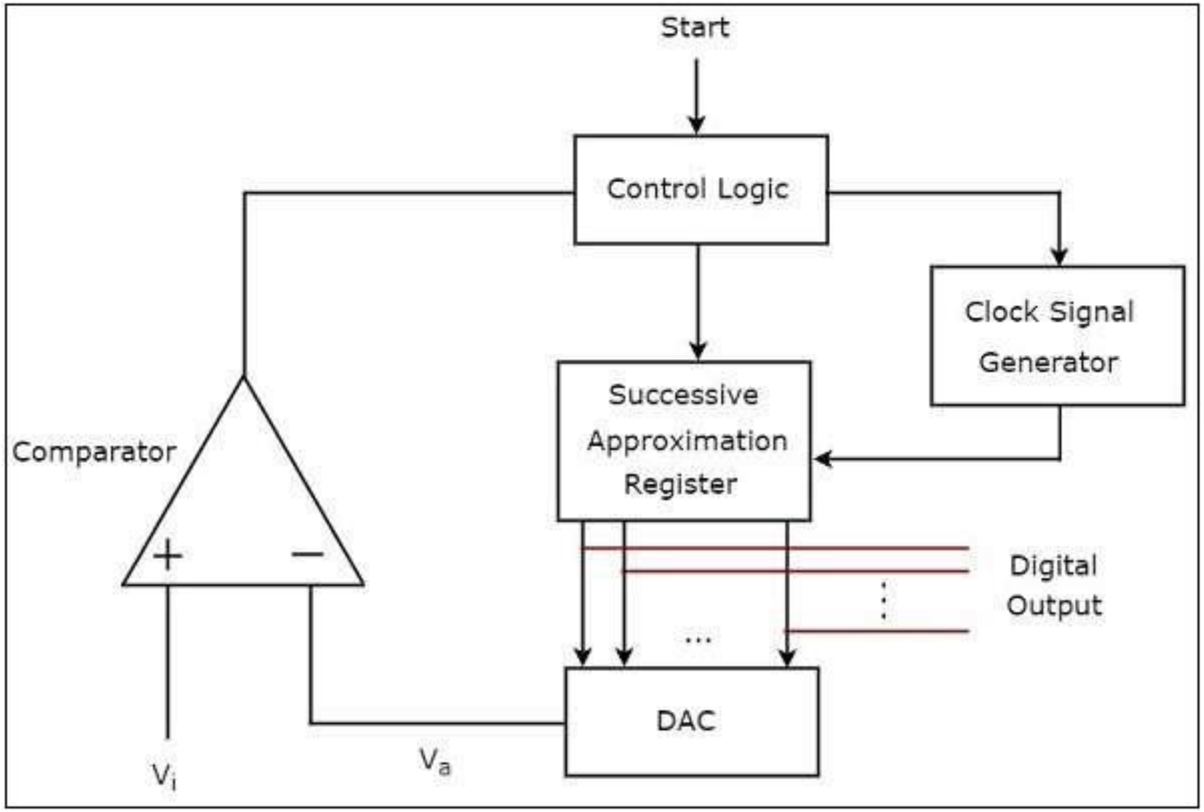
A/D and D/A Converters

Successive Approximation (SAR) ADC: The typical SAR ADC uses a sample-and-hold circuit. The DAC creates an analog reference voltage equal to the digital code output of the sample and hold circuit.

Both of these are fed into a comparator which sends the result of the comparison to the SAR.

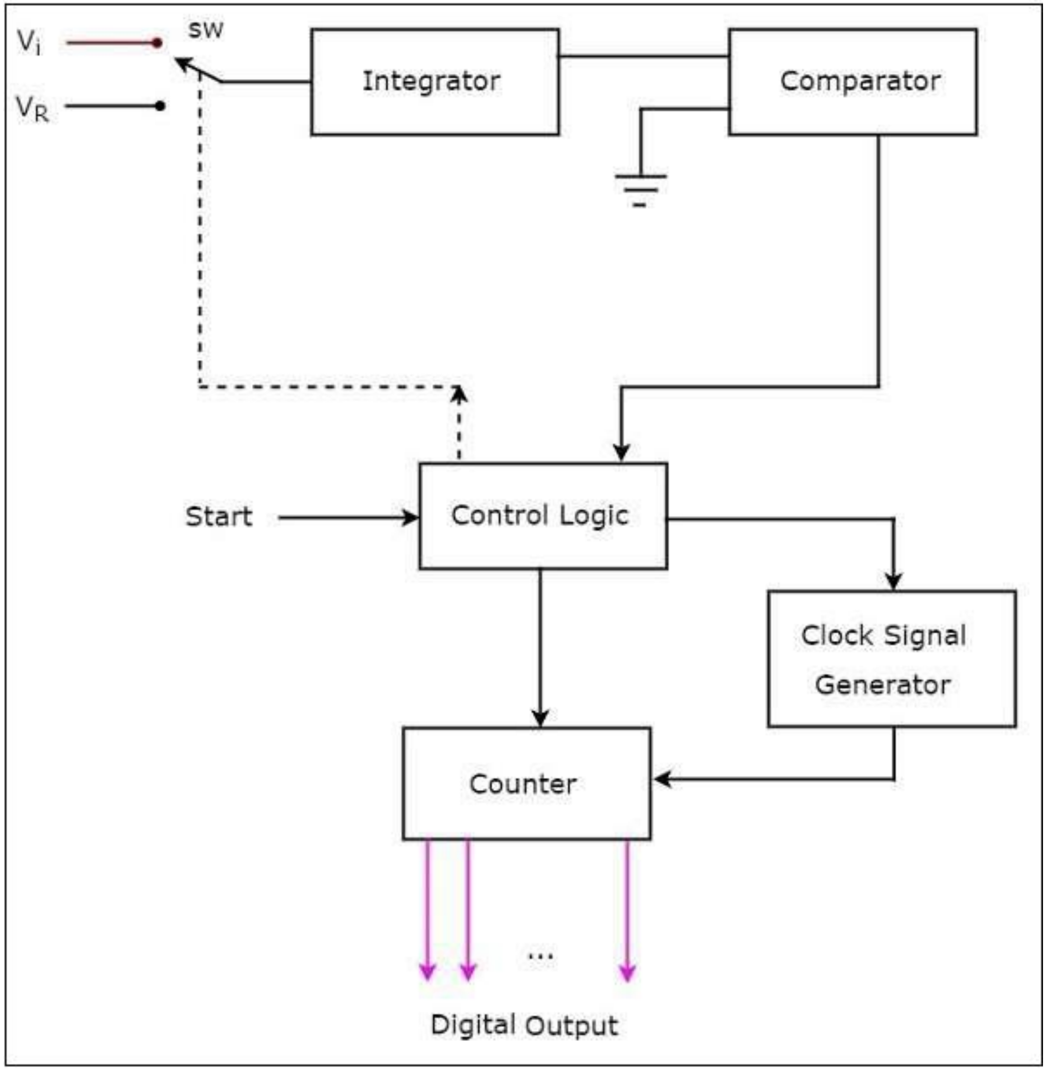
This process continues for “n” successive times, with “n” being the bit resolution of the ADC itself until the closest value to the actual signal is found.



Successive Approximation (SAR) ADC

A/D and D/A Converters

Dual Slope ADC



A/D and D/A Converters

The working of a **dual-slope ADC** is the following −

- The control logic resets the counter and enables the clock signal generator in order to send the clock pulses to the counter when it receives the commanding signal.
- Control logic pushes the switch SW to connect to the external analog input voltage V_i, when it is received the start commanding signal. This input voltage is applied to an integrator.
- The output of the integrator is connected to one of the two inputs of the comparator and the other input of the comparator is connected to the ground.
- Comparator compares the output of the integrator with zero volts (ground) and produces an output, which is applied to the control logic.
- The counter gets incremented by one for every clock pulse and its value will be in binary (digital) format. It produces an overflow signal to the control logic when it is incremented after reaching the maximum count value. At this instant, all the bits of the counter will be having zeros only.
- Now, the control logic pushes the switch SW to connect to the negative reference voltage $-V_{ref}$. This negative reference voltage is applied to an integrator. It removes the charge stored in the capacitor until it becomes zero. At this instant, both the inputs of a comparator are having zero volts. So, the comparator sends a signal to the control logic. Now, the control logic disables the clock signal generator and retains (holds) the counter value.

The counter value is proportional to the external analog input voltage. At this instant, the output of the counter will be displayed as the digital output. It is almost equivalent to the corresponding external analog input value V_i.

The dual-slope ADC is used in applications where accuracy is more important while converting analog input into its equivalent digital (binary) data.

A/D and D/A Converters

Examples of ADC ICs:

- The **ADC0804** are CMOS 8-Bit, successive approximation A/D converters.
- The **ADC0808** data acquisition component is a monolithic CMOS device with an 8-bit analog-to-digital converter, 8-channel multiplexer, and microprocessor-compatible control logic. The 8-bit A/D converter uses successive approximation as the conversion technique.
- The **ADC0809** data acquisition component is a monolithic CMOS device with an 8-bit analog-to-digital converter, 8-channel multiplexer, and microprocessor-compatible control logic. The 8-bit A/D converter uses successive approximation as the conversion technique.
- The **CA3161** is a monolithic integrated circuit that performs the BCD to seven-segment decoding function and features constant current segment drivers.

A/D and D/A Converters

Comparison of A/D Convertors:

ADC type	Pros	Cons	Max resolution	Max sample rate	Main applications
Successive Approximation (SAR)	**Good speed/resolution ratio**	**No inherent anti-aliasing protection**	**18 bits**	**10 MHz**	**Data Acquisition**
Delta-sigma (ΔΣ)	High dynamic performance, inherent anti-aliasing protection	Hysteresis on unnatural signals	32 bits	1 MHz	Data Acquisition, Noise & Vibration, Audio
Dual Slope	**Accurate, inexpensive**	**Low speed**	**20 bits**	**100 Hz**	**Voltmeters**
Pipelined	Very fast	Limited resolution	16 bits	1 GHz	Oscilloscopes
Flash	Fastest	Low bit resolution	12 bits	10 GHz	Oscilloscopes