ECOR1044: Boolean Logic and ADC

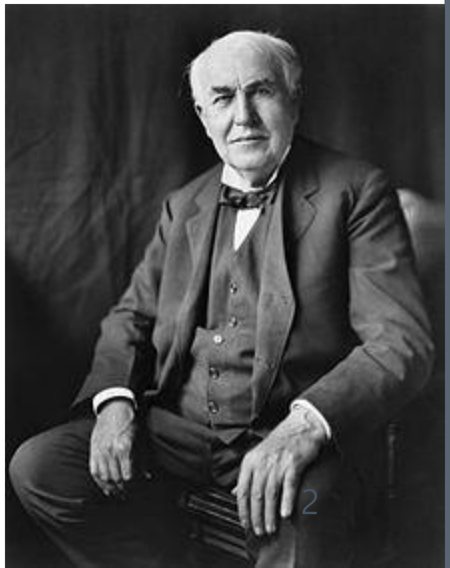
AC Power
Analog to Digital Conversion

History

- Edison was a prolific inventor holding more than 1000 US patents.
- His first patent was for the electric vote recorder, granted in 1869.
- Edison's major innovation was the establishment of an industrial research lab in 1876.

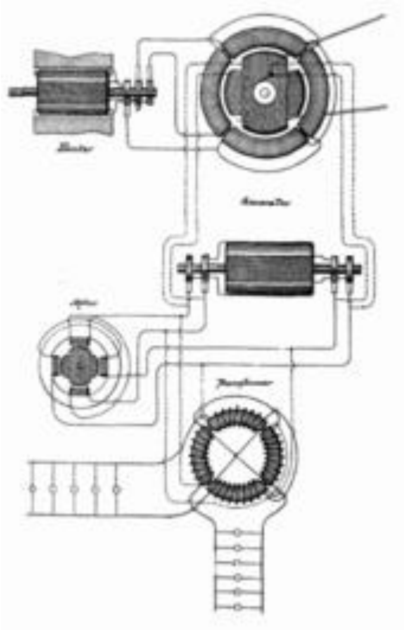
- After many experiments, the first successful light bulb was in 1879.
- This bulb lasted 13.5 hours.
- In 1880, first commercially practical incandescent light bulb and Edison Illuminating Company was founded to develop an electric "utility" to compete with the existing gas light utilities.

Thomas Edison
1847-1931



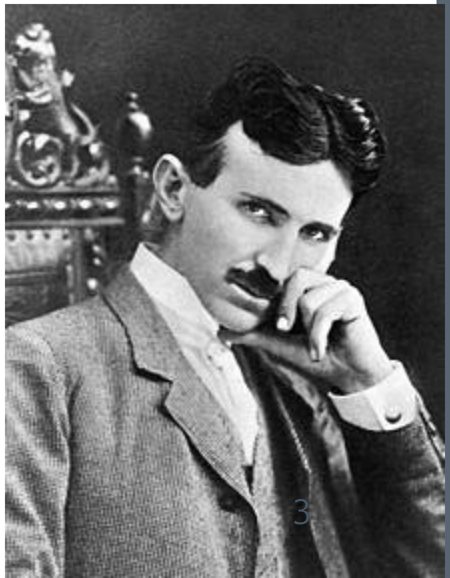
History

- Tesla was a Serbian-American inventor best known for AC power.
- In 1884, Tesla emigrated to United States to work for Edison.
- Tesla resigned after 6 months because of a $50K bonus.
- Soon after leaving the Edison company, Tesla started working on patenting an arc lighting system.



- Two investors financed the idea and after it was up and running in 1886, they formed a new utility company, leaving Tesla's company and the inventor penniless.
- In 1887, Tesla developed an induction motor that ran on alternating current.

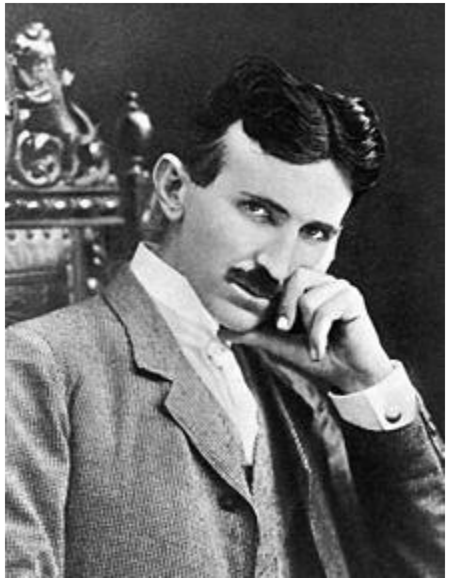
Nikola Tesla
1856-1943



History: War of Currents

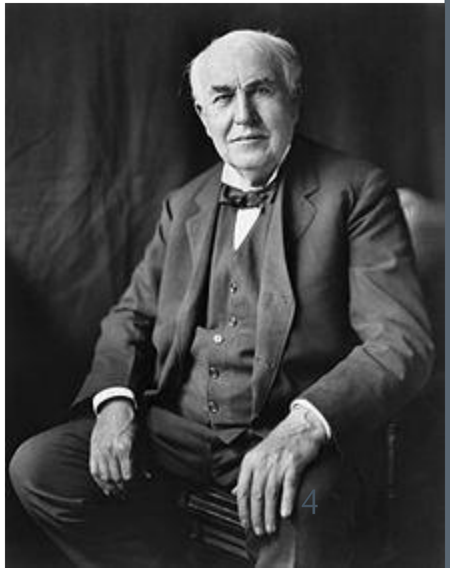
- In 1888, Tesla's AC patents were licensed.
- As Edison expanded his DC power delivery system, he received stiff competition from companies installing AC systems.
- DC supply was limited to about one mile distance from the plant.

Nikola Tesla
1856-1943



- With transformers (1885–1886), it became possible to transmit AC long distances over thinner and cheaper wires, and "step down" the voltage at the destination for users.
- Power electronics and semiconductor devices emerged in 1950s.

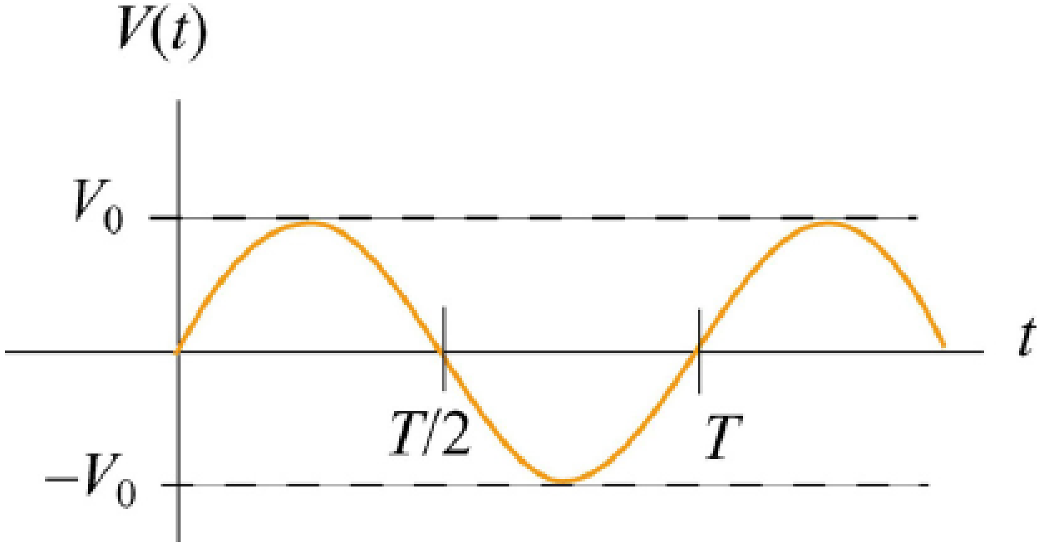
Thomas Edison
1847-1931



AC Sources

AC sources are periodic in time (same amplitude). The angular frequency is defined as,

$$\omega = 2\pi f$$



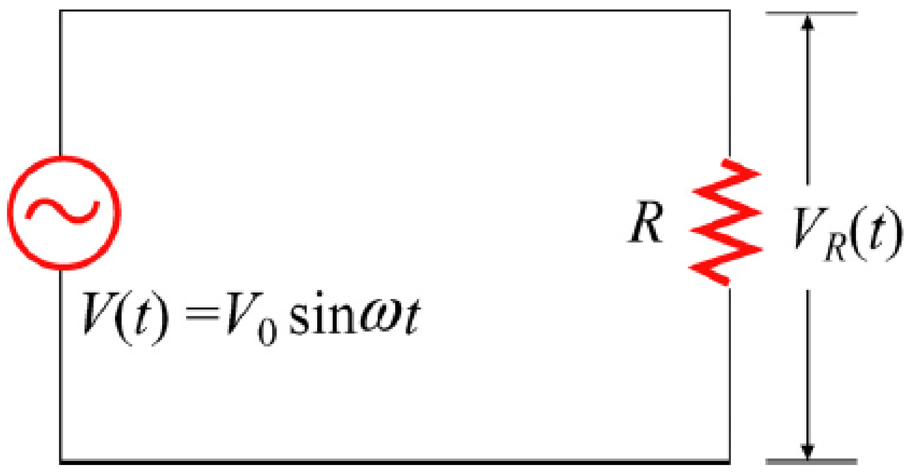
$$V(t) = V_0 \sin \omega t$$

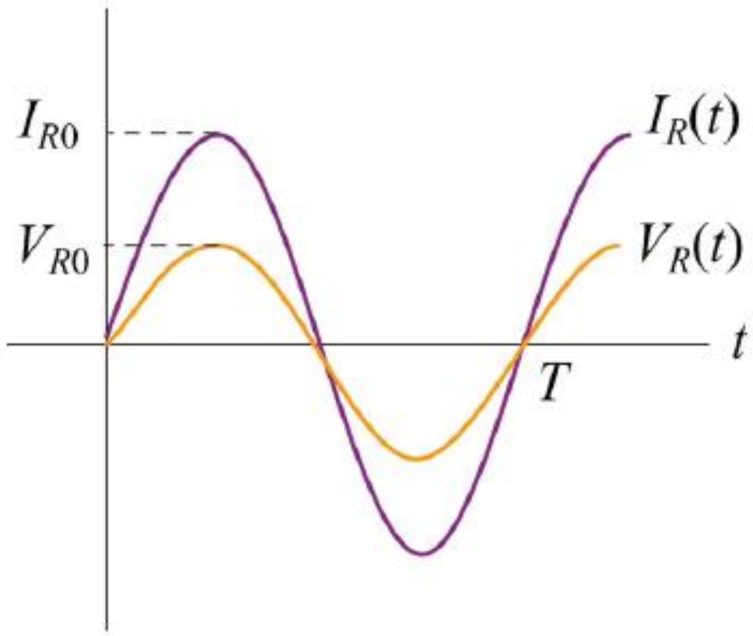
After an initial "transient time," an AC current will flow in the circuit as,

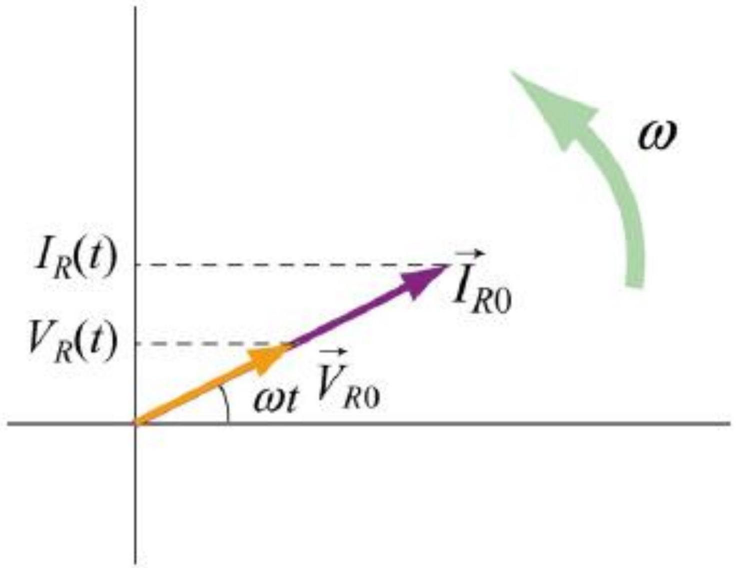
$$I(t) = I_0 \sin(\omega t - \phi)$$

Resistive load

$$\phi = 0$$



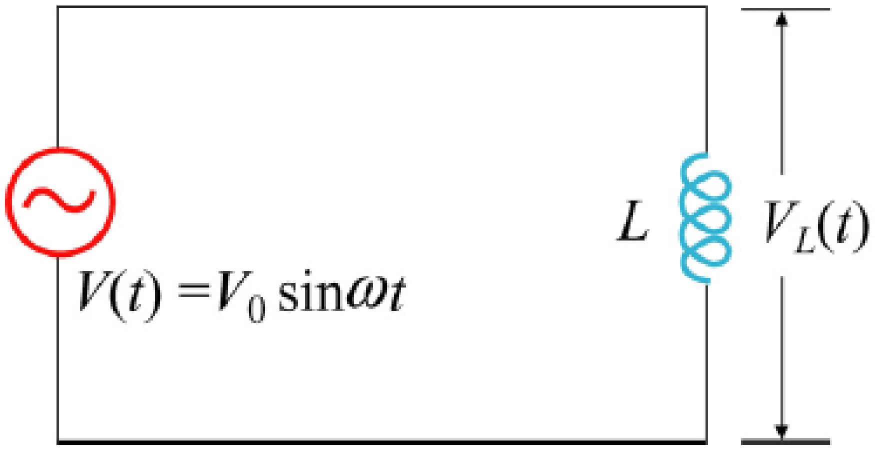


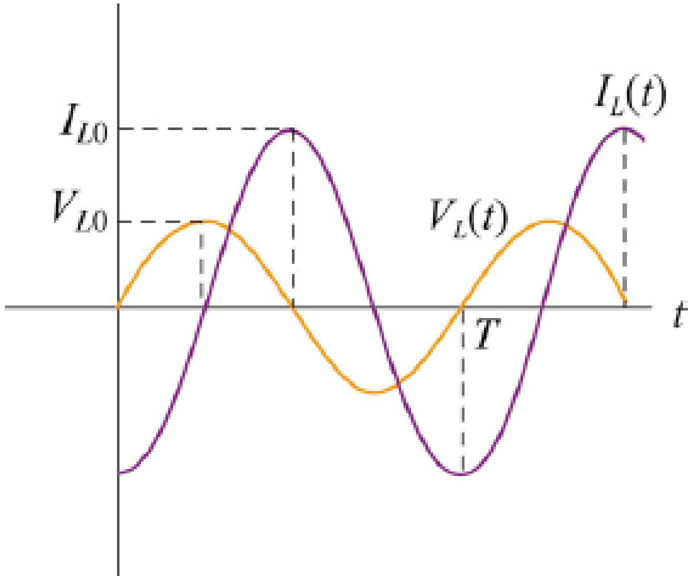


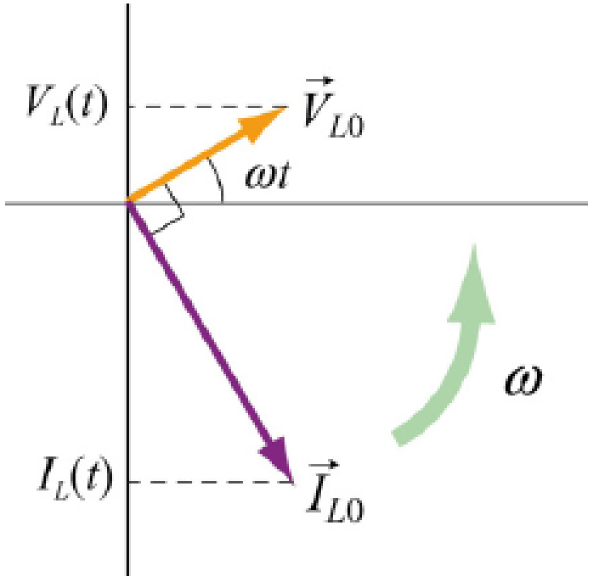
The current lags voltage by $\pi / 2$ in a purely inductive circuit

Inductive load

$$\phi = +\frac{\pi}{2}$$

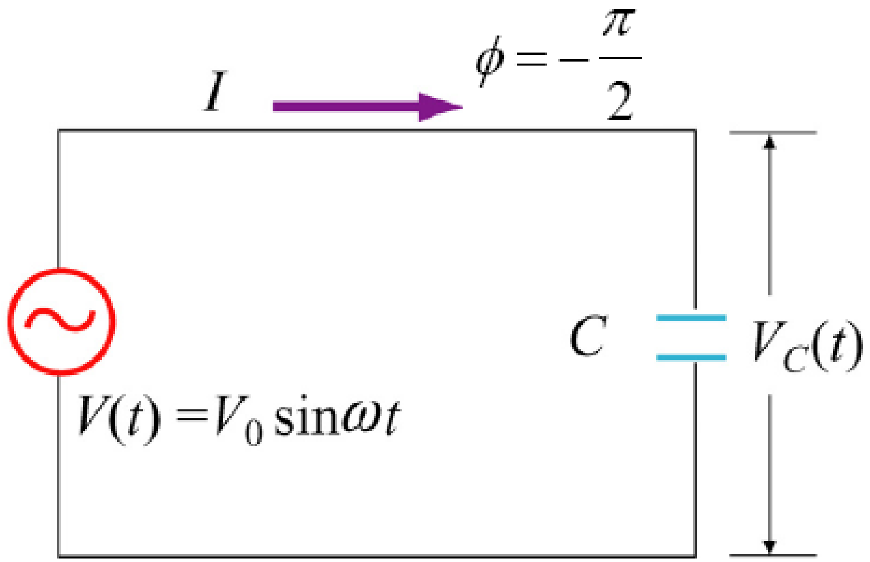


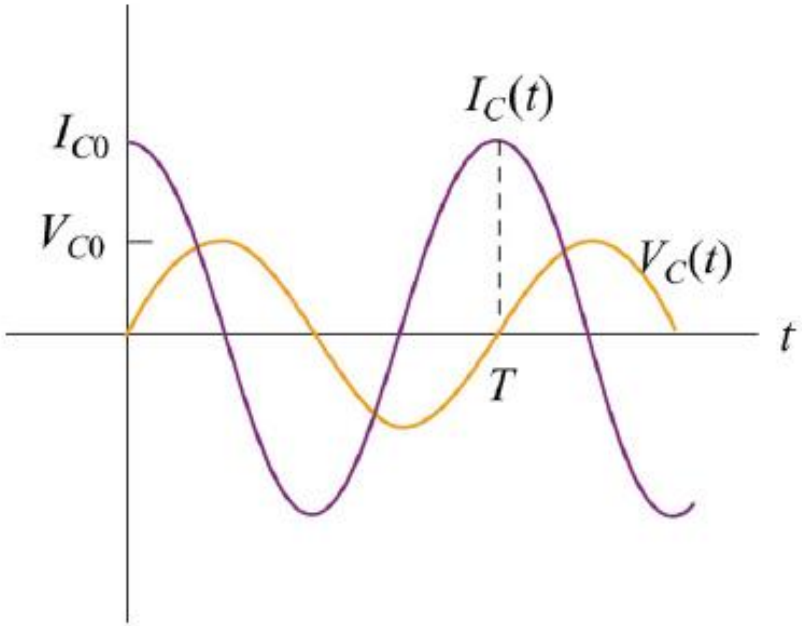


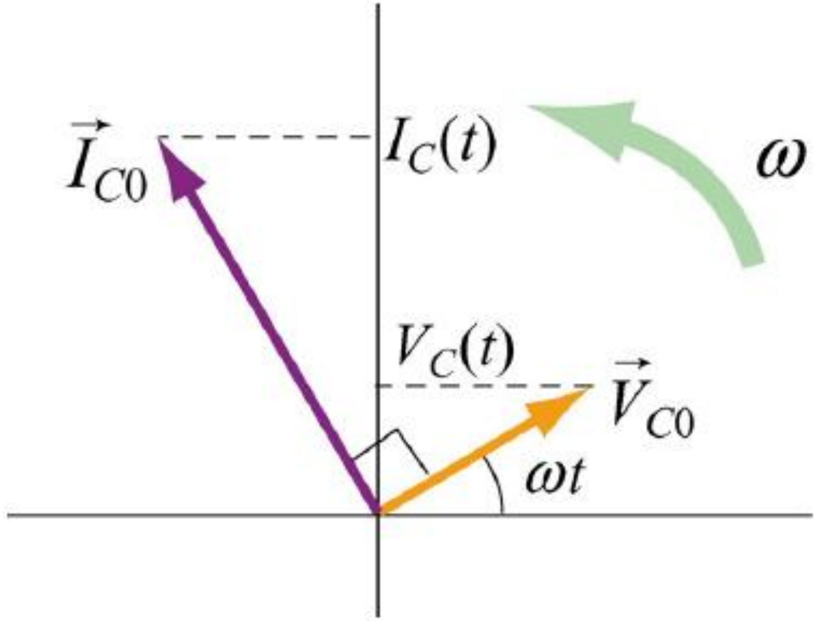


The current leads the voltage by $\pi/2$ in a capacitive circuit

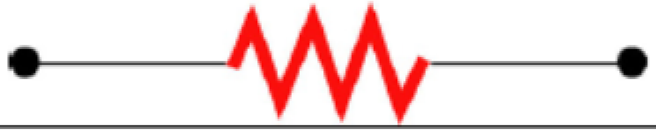
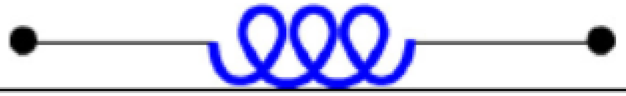
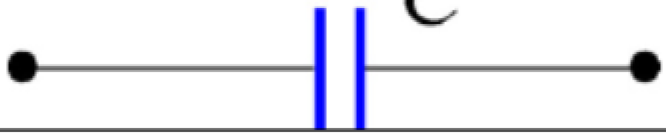
Capacitive load







Summary

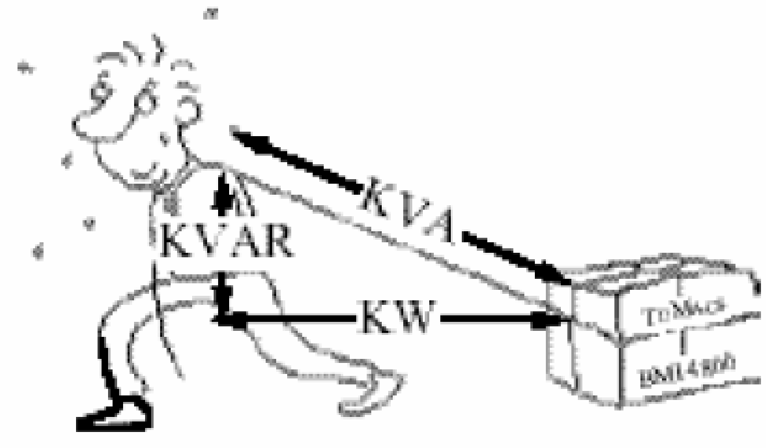
Circuit Elements	Phase angle ϕ
R 	0
L 	$\pi / 2$ current lags voltage by $90°$
C 	$-\pi / 2$ current leads voltage by $90°$

Power (Active, Reactive, Apparent)

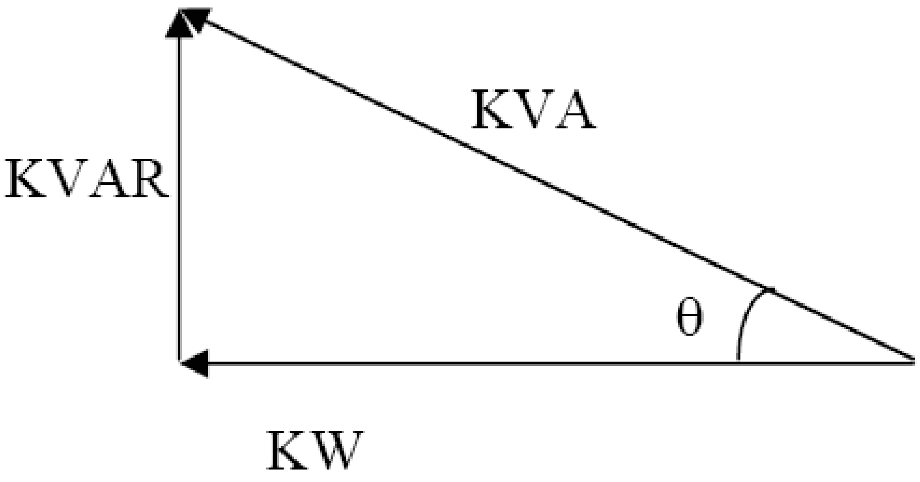
- Active Power (KW) is the power that actually powers the equipment and performs useful work.

- Reactive Power (KVAR) is the power that a magnetic equipment (transformer, motor, relay) needs to produce the magnetizing flux.

- Apparent Power (KVA) is the “vector summation” of KW and KVAR.

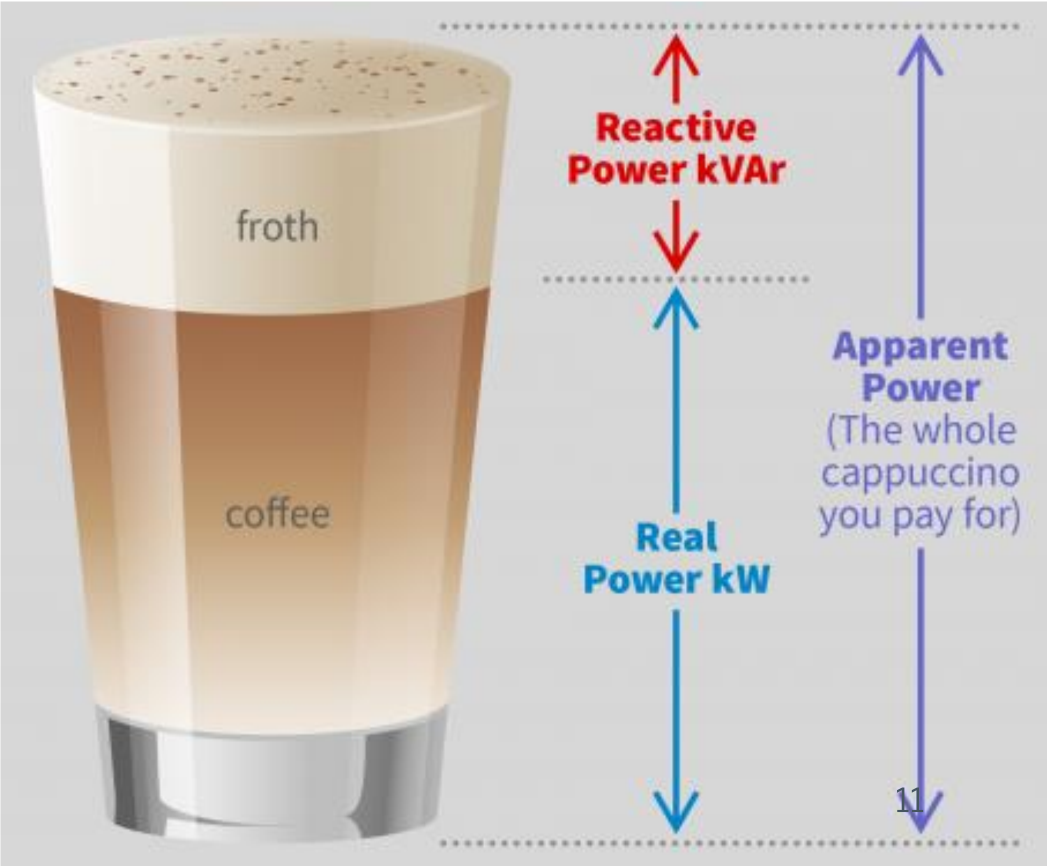


Power Factor



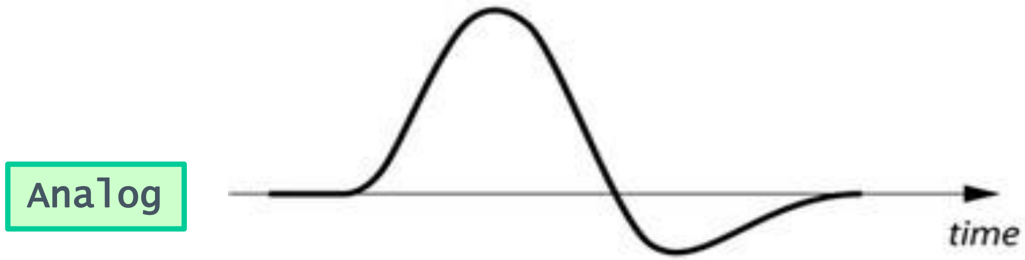
$$P.F. = \frac{KW}{KVA} = \cos\theta$$

P.F. should be close to unity

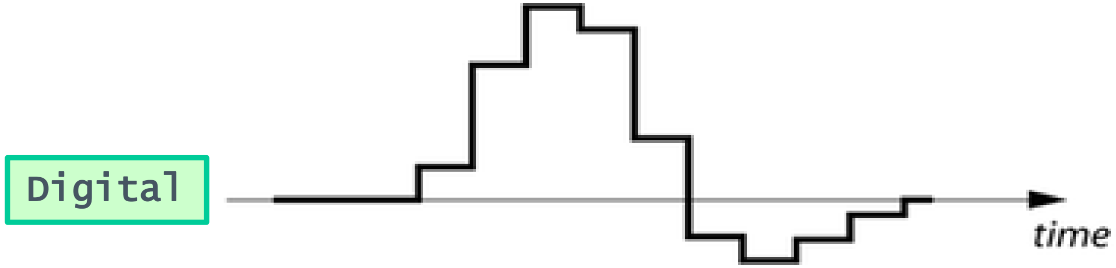


Analog versus Digital Signals

- As mentioned earlier analog signals have an infinite number of increments, therefore when we plot a voltage signal for example we get a smooth curve:



- As digital signals have a limited number of values, we instead see something similar to the following:



Analog to Digital Converter (ADC)

- ✓ An **Analog-to-Digital Converter (ADC)** is an essential device to convert **continuous analog signals to discrete digital values**.
- ✓ ADCs allow digital systems, such as microcontrollers and computers, to process **real-world analog data** like temperature, voltage, or pressure, which are inherently analog in nature.
- ✓ **Signal Conversion:**

  ADCs convert an analog input (e.g., voltage) into a corresponding digital output. This is done by **sampling** the analog signal at regular intervals and quantizing the sampled values into a finite set of digital codes.
- ✓ **Digitization Process:**

  The analog signal is divided into discrete steps based on the resolution of the ADC. The **more bits the ADC** has, the **finer the resolution**, allowing for a more accurate representation of the original signal.

Key Parameters of ADCs

- **Resolution**: The resolution of an ADC is determined by the number of bits it uses to represent the digital output. Common resolutions include **8-bit, 10-bit, 12-bit, or 16-bit**. Higher resolution provides greater precision.

- **Sampling Rate**: This refers to how **frequently** the ADC samples the analog signal, usually measured in **samples per second (SPS)**.

- **Input Range**: The input voltage range of the ADC defines the **minimum** and **maximum** voltages that the ADC can measure. **Any voltage outside this range may result in incorrect conversion**.

Challenges of ADCs

- **Noise Sensitivity**: ADCs are **sensitive to noise**, which can degrade the accuracy of the conversion. Proper shielding, filtering, and careful design can minimize this effect.

- **Power Consumption**: Some types of ADCs, especially **high-speed** variants like flash ADCs, consume **considerable power**, making them unsuitable for low-power or portable applications.

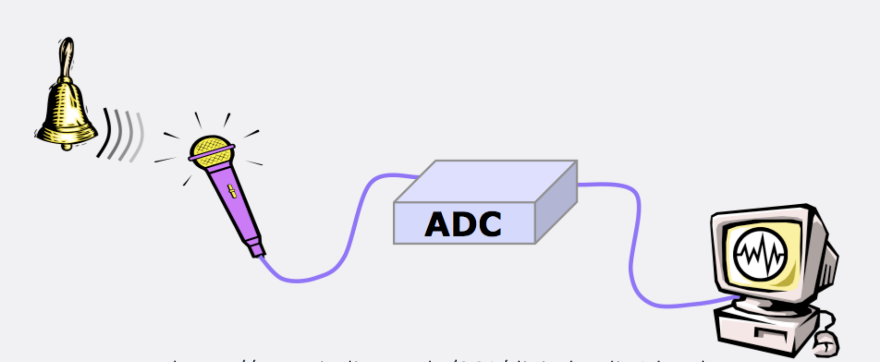
- **Trade-off Between Speed and Accuracy**: High-precision ADCs may operate at slower speeds and **high-speed ADCs may have less precision**. So, Designers must choose the appropriate ADC type and configuration based on the application's needs.

Applications of ADCs

- **Sensors:** ADCs are used to convert analog sensor data (**e.g., from temperature, pressure, or light sensors**) into digital form for further processing by microcontrollers or computers.
- **Data Acquisition Systems:** ADCs are a core component in systems that **gather and process data** from the physical world, such as in environmental monitoring, industrial automation, and biomedical devices.
- **Communication Systems:** ADCs are used in digital signal processing (DSP) for converting analog signals, **such as audio and radio waves**, into digital form for encoding, transmission, or analysis.
- **Control Systems:** In control applications, ADCs help digitize real-time sensor data, which is then used by **digital controllers** (e.g., PID controllers) to regulate actuators and systems.

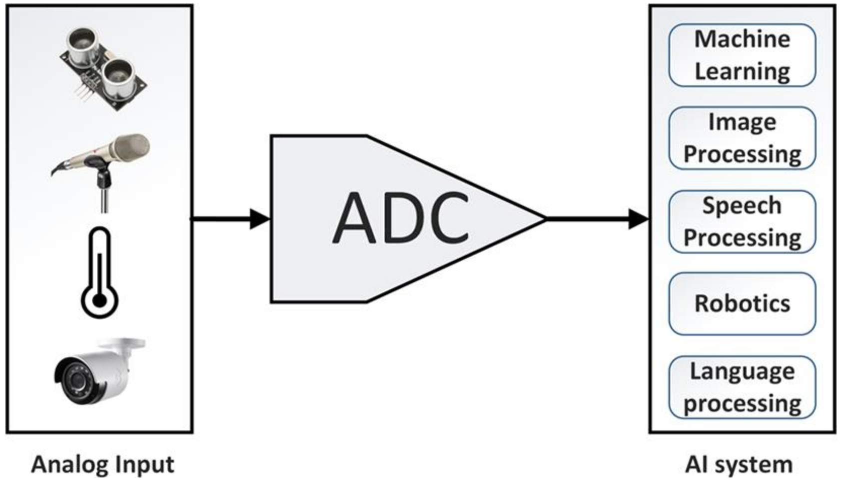
Applications of ADCs

- **Audio and Music:** Converting sound waves into digital form (e.g., MP3 encoding).



https://cecm.indiana.edu/361/digitalaudio1.html

- **Sensors**: Temperature, pressure, and light sensors convert analog signals for microcontroller use.



https://www.researchgate.net/figure/Typical-diagram-of-AI-system-with-sensors-ADC-and-processing_fig1_337630402

ADCs Working Principle

- **Sampling:** The continuous analog signal is sampled at discrete intervals (sample rate). The **higher** the sample rate, the more **accurate** the representation.

- **Encoding/Quantizing:** The sampled signal is **approximated** to the nearest value within a defined range.

Key Parameters:

- **Sampling Rate:** Determines how often the signal is measured.
- **Resolution:** The number of bits used to represent each sample.

ADCs: Old vs. New Models

Resolution

- **Old model:**

✓ Typically, 8-bit or 10-bit resolution.

✓ Limited precision, sufficient for simpler applications like early audio systems or low-end microcontrollers.

- **New model:**

✓ ADCs now have **12-bit, 16-bit, 18-bit**, and even **24-bit** resolution.

✓ **Higher resolution** provides greater precision, enabling use in applications requiring detailed measurements like medical imaging.

ADCs: Old vs. New Models

Conversion Speed

- **Old model:**

✓ Conversion speeds were relatively **slow**, typically in the range of **kilosamples per second (kSps)**.

✓ Used in applications where speed was **not critical**, such as temperature sensing or low-frequency signals.

- **New model:**

✓ Modern ADCs are much **faster**, capable of reaching speeds in the **megahertz (MHz)** and even **gigahertz (GHz)** range.

✓ Fast enough for high-speed data acquisition in communication systems, **radar, or video applications**.

ADCs: Old vs. New Models

Power Consumption

- **Old model:**

✓ They are **less power-efficient** due to older transistor technology.

✓ Power consumption was a concern in portable and **battery-powered applications**.

- **New model:**

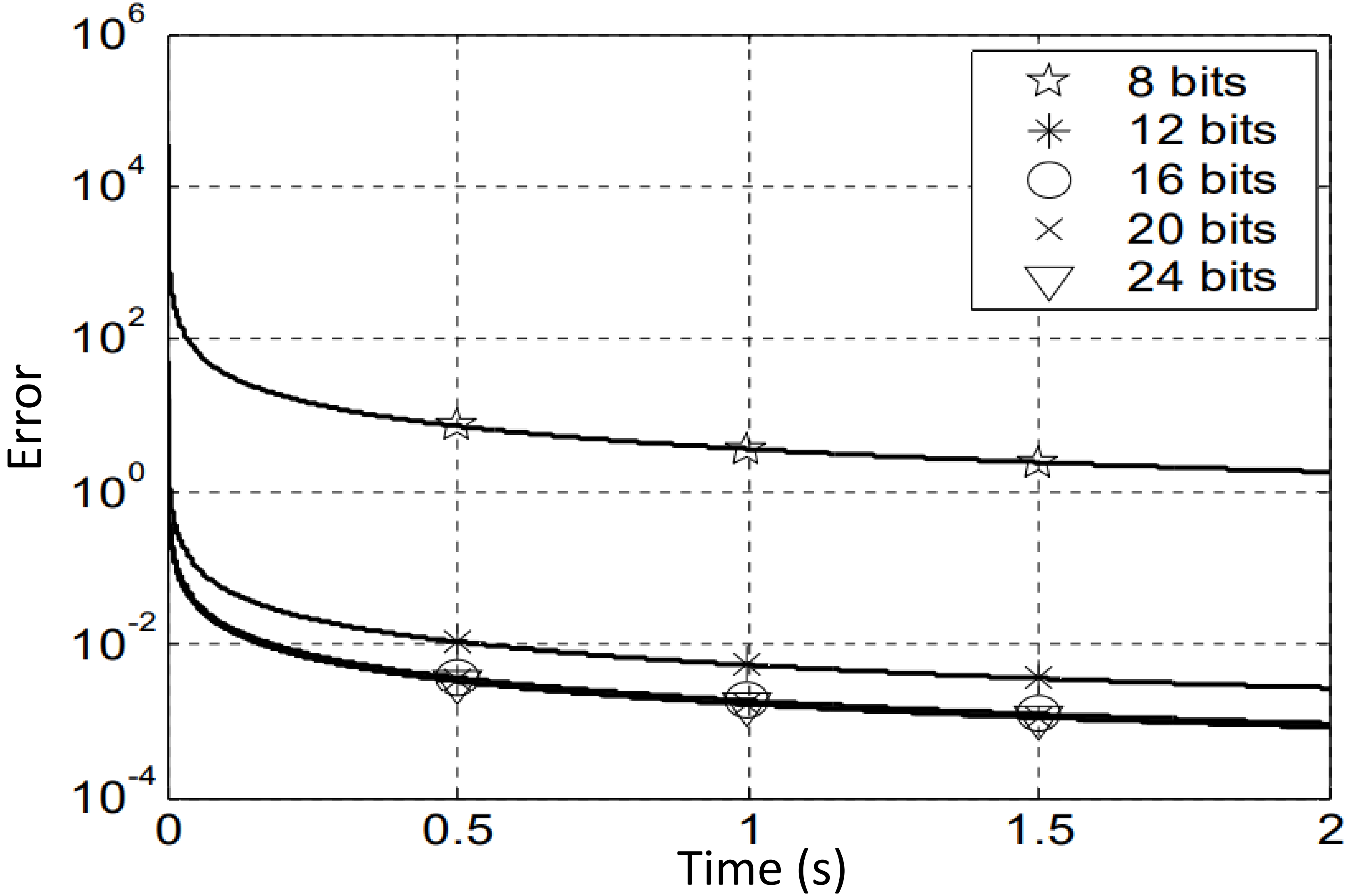
✓ Modern ADCs are much **more power-efficient**, due to improvements in semiconductor technology.

✓ **Low-power ADCs** are now available for portable and embedded systems, consuming significantly less power, making them ideal for **IoT and mobile devices**.

Choosing the Right ADC

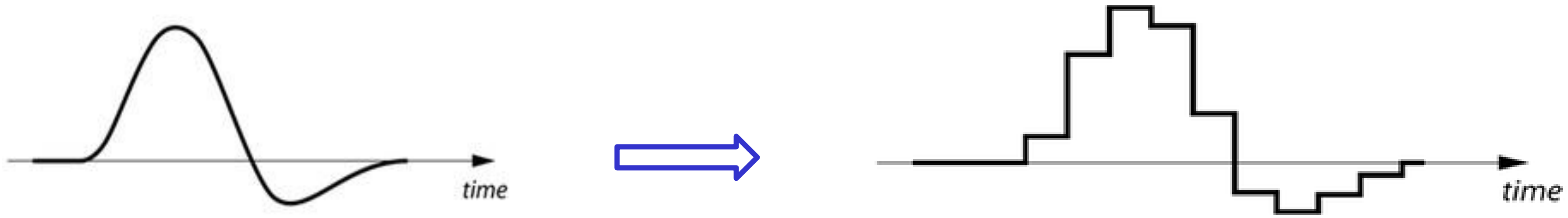
- **Resolution**: How **precise** do your measurements need to be?
- **Sampling Rate**: How **fast** does the signal change, and how often do you need to sample it?
- **Power Consumption**: Important for battery-powered systems.
- **Cost**: Higher performance ADCs are generally more expensive.

Resolutions of ADCs

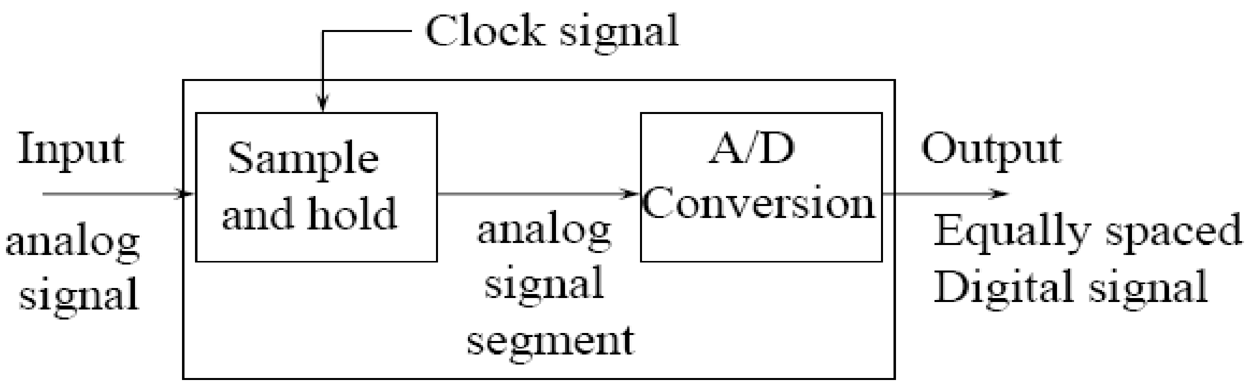


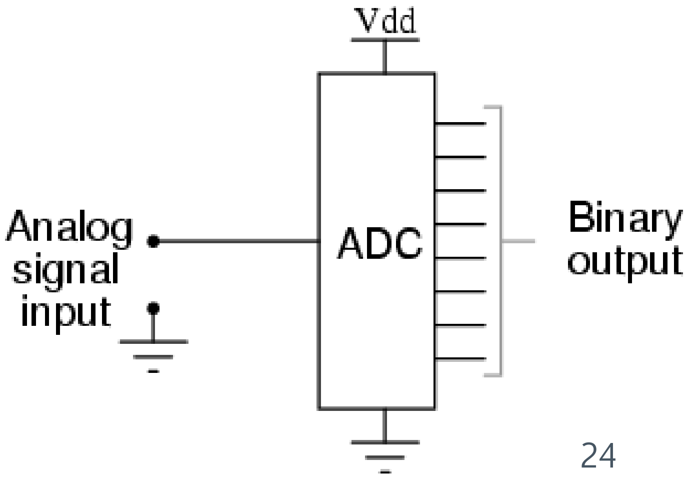
Analog to Digital Converter

- If we start with the analog signal, how do we convert it to the digital 'equivalent'?



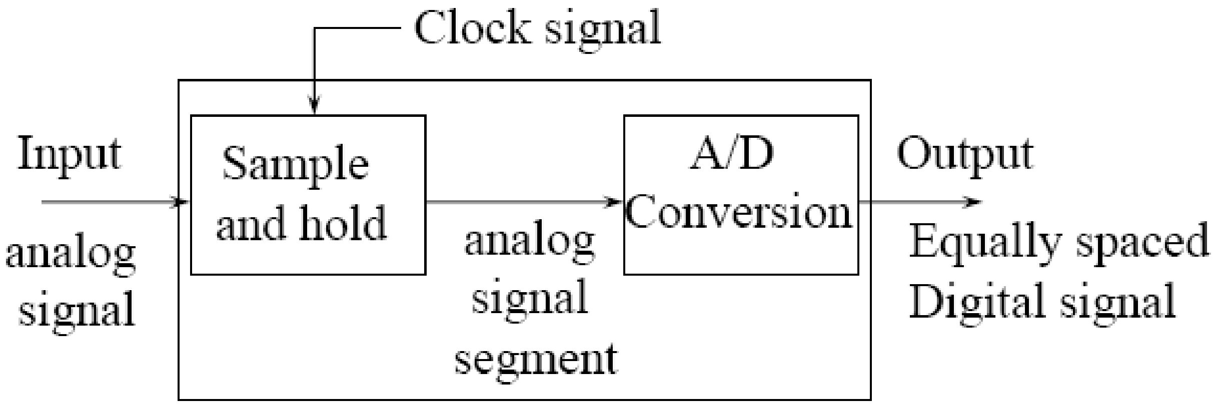
- We use a 'sample and hold' system

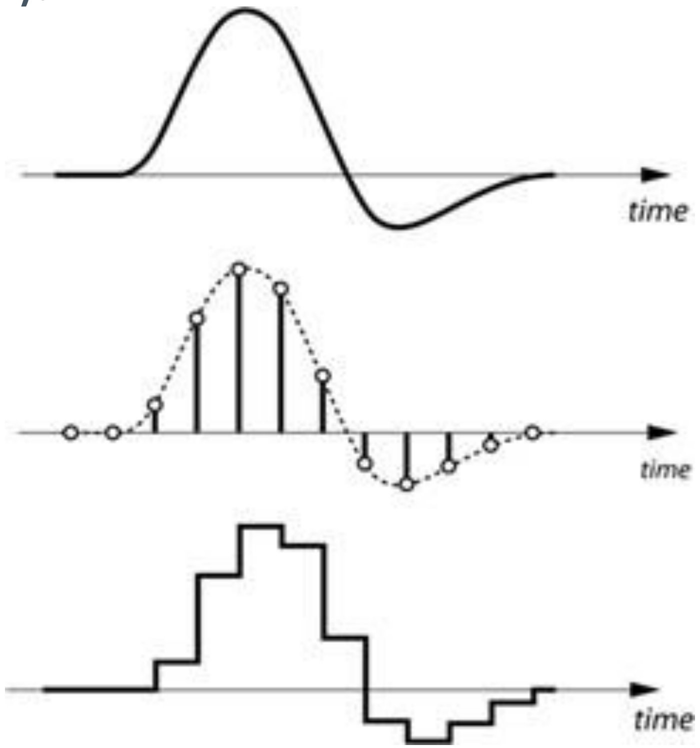




What does the ADC do?

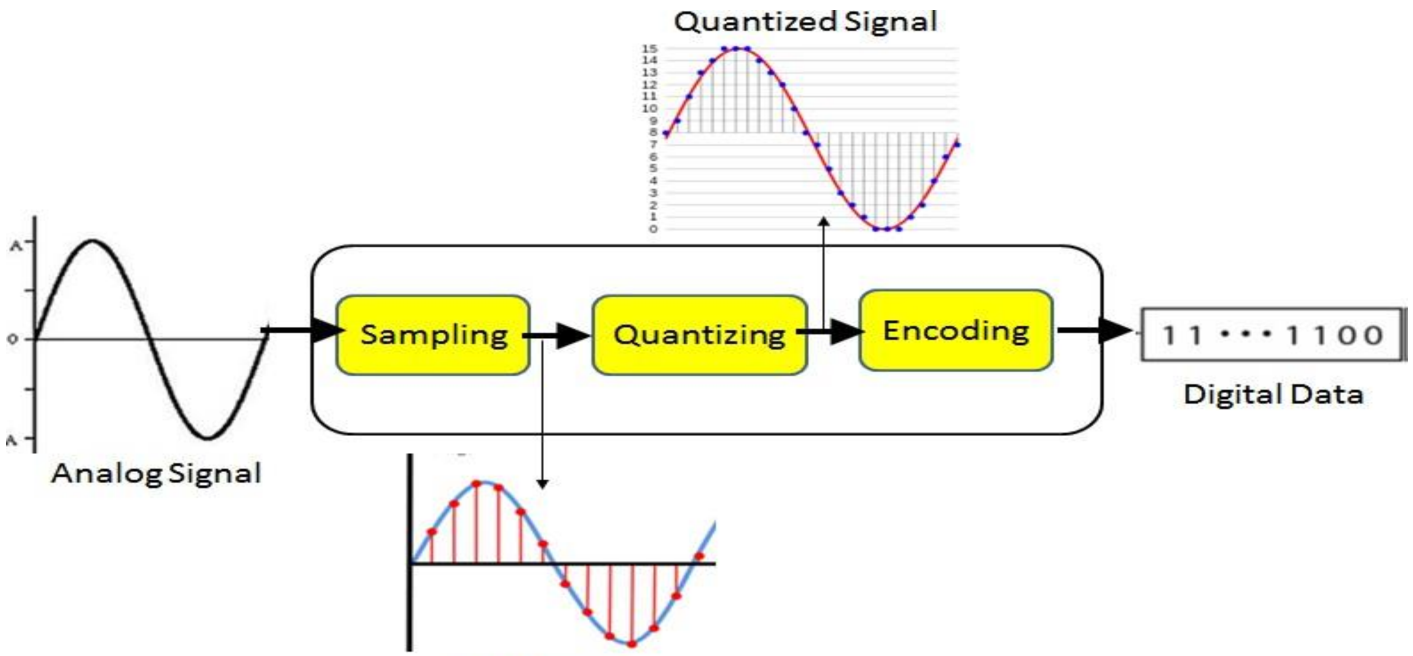
- Converts **analog** signals into **binary** words.
- These binary words can be in different length **2, 4, 8, 10-bit**.
- The more bits the binary number has, the higher the resolution of the analog to digital converter (ADC , A/D, or A to D).





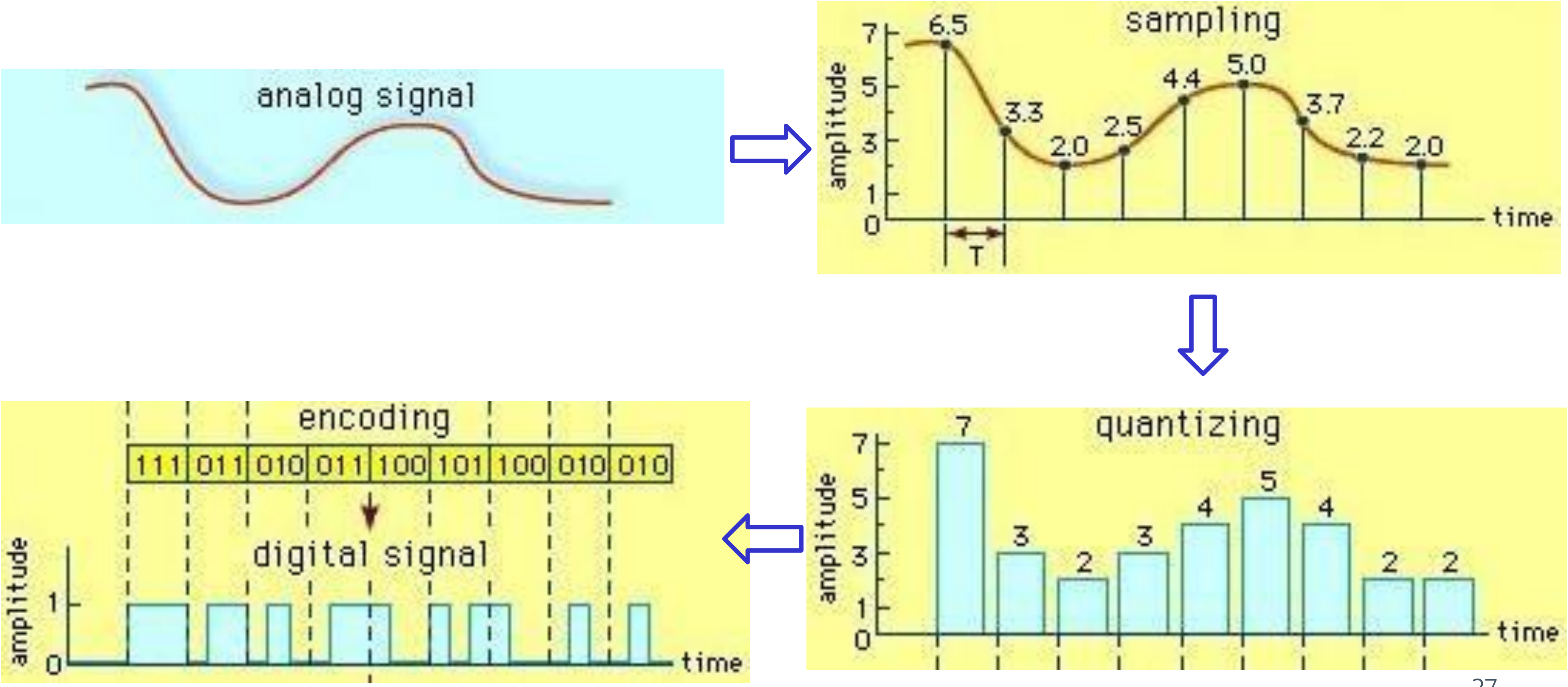
Analog to Digital Conversion - 3 Steps

- A 3-Step Process
  - **Sampling** – Conversion of a continuous signal to a discrete-time (DT) signal
  - **Quantizing** – Conversion of a DT signal to discrete amplitude signal
  - **Encoding** – Conversion of a discrete signal to binary word



Analog to Digital Conversion

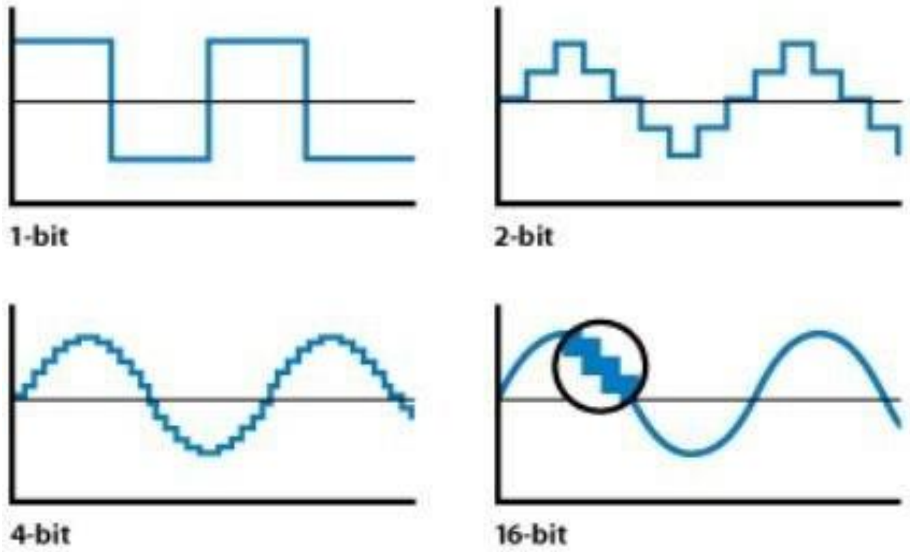
- Exp. 1: Convert a time varying signal of 0-7V to a digital using a 3-bit ADC.



Quantization Details

- Resolution/Quantization **Step-Size** (Q)
  - The smallest voltage that can be encoded digitally, in other words the voltage represented by the least significant bit.
  - It describes the general performance of an ADC, how finely it can convert signals.
  - The quantization step size (Q) can be calculated as follows:

$$Q = \frac{V_{MAX} - V_{MIN}}{N_{STATES}}$$



Quantization Details

- Exp. 2:

- You have a 0-10V signal. Separate the voltage range such that it fits into a 3-bit number.
- Reminder: $2^n = 2^3 = 8$ different values can be represented in binary using 3 bits.

- **First**, we assign discrete values to range of analog voltage values using resolution (also known as quantization step-size)

$$Q = \frac{V_{MAX} - V_{MIN}}{N_{STATES}}$$

$$Q = \frac{10V - 0V}{8\ states} = 1.25\ \frac{V}{State}$$

Output States	Discrete Voltage Ranges (V)
0	0.00≤V≤1.25
1	1.25<V≤2.50
2	2.50<V≤3.75
3	3.75<V≤5.00
4	5.00<V≤6.25
5	6.25<V≤7.50
6	7.50<V≤8.75
7	8.75<V≤10.0

Quantization Details

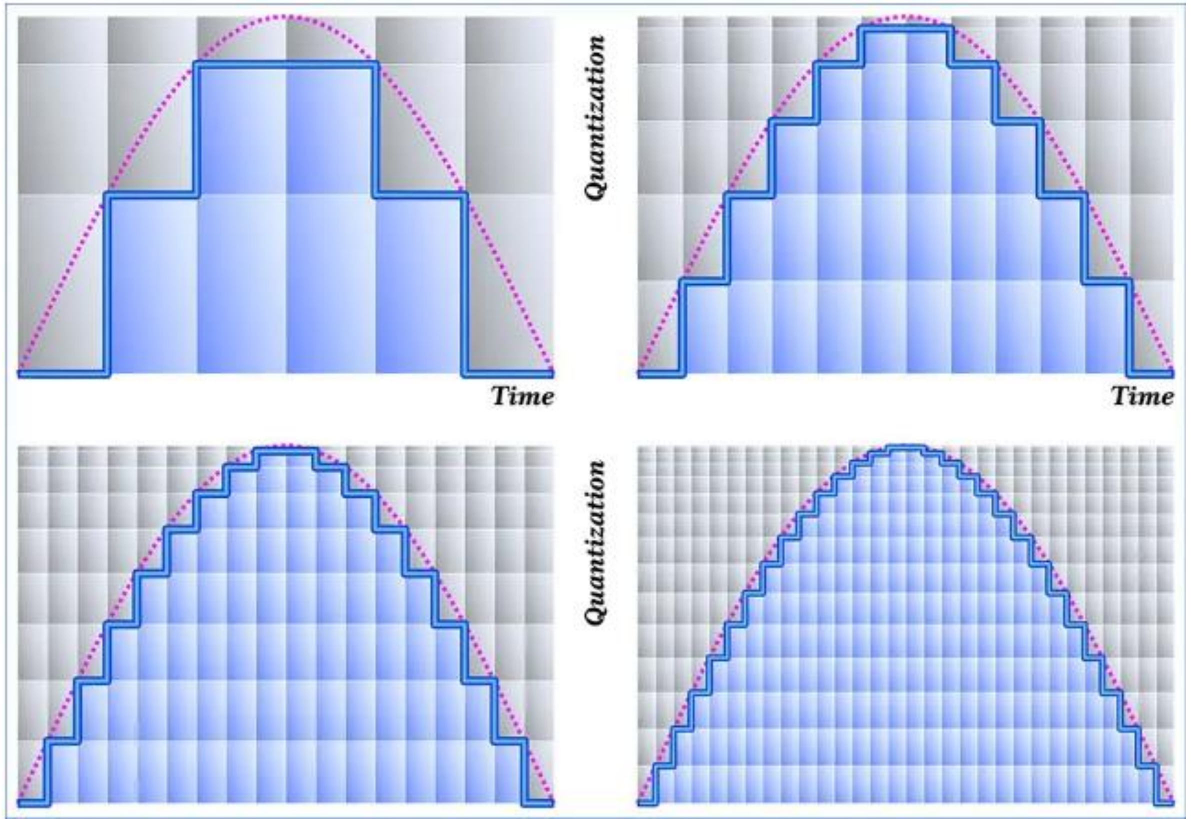
- Exp. 2: Now we set each of these states to a binary equivalent

Output States	Discrete Voltage Ranges (V)
0	$0.00 \leq V \leq 1.25$
1	$1.25 < V \leq 2.50$
2	$2.50 < V \leq 3.75$
3	$3.75 < V \leq 5.00$
4	$5.00 < V \leq 6.25$
5	$6.25 < V \leq 7.50$
6	$7.50 < V \leq 8.75$
7	$8.75 < V \leq 10.0$

Output States	Output Binary Equivalent
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Accuracy of A/D Conversion

- There are two ways to best improve accuracy of A/D conversion:
  - Increasing the **resolution**.
  - Increasing the **sampling rate**.



Converting a Voltage to Binary

- What is the binary value of a voltage given the number of bits and voltage range?
  - We can use our quantization step-size to convert:

$$\boldsymbol{ADC\ reading = \frac{1}{Q} \times (V_A - V_{min})}$$

$$\boldsymbol{Q = \frac{V_{MAX} - V_{MIN}}{N_{STATES}}}$$

$$\boxed{\boldsymbol{ADC\ reading = \frac{N_{States}}{voltage\ range} \times (V_A - V_{min})}}$$

Converting a Voltage to Binary

- Exp. 4: For a range of 0-5V, and a 10-bit resolution, what is the binary value for 3.65V?

$$\boldsymbol{ADC\ reading = \frac{Number\ of\ states}{voltage\ range} \times (V_A - V_{min})}$$

$$\boldsymbol{X = \frac{2^{10}\ states}{5V}(3.65\ V) = 747.52}$$

747 ÷ 2 = 373 with 1 remainder
373 ÷ 2 = 186 with 1 remainder
186 ÷ 2 = 93 with 0 remainder
93 ÷ 2 = 46 with 1 remainder
46 ÷ 2 = 23 with 0 remainder
23 ÷ 2 = 11 with 1 remainder
11 ÷ 2 = 5 with 1 remainder
5 ÷ 2 = 2 with 1 remainder
2 ÷ 2 = 1 with 0 remainder
1 ÷ 2 = 0 with 1 remainder

$747_{10} = 1011101011_2$

Converting a Voltage to Binary

- Exp. 5: For a range of (-5V) to 5V, and a 10-bit resolution, what is the binary value for 3.65V?

$$\boldsymbol{ADC\,reading = \frac{Number\ of\ states}{voltage\ range} \times (V_A - V_{min})}$$

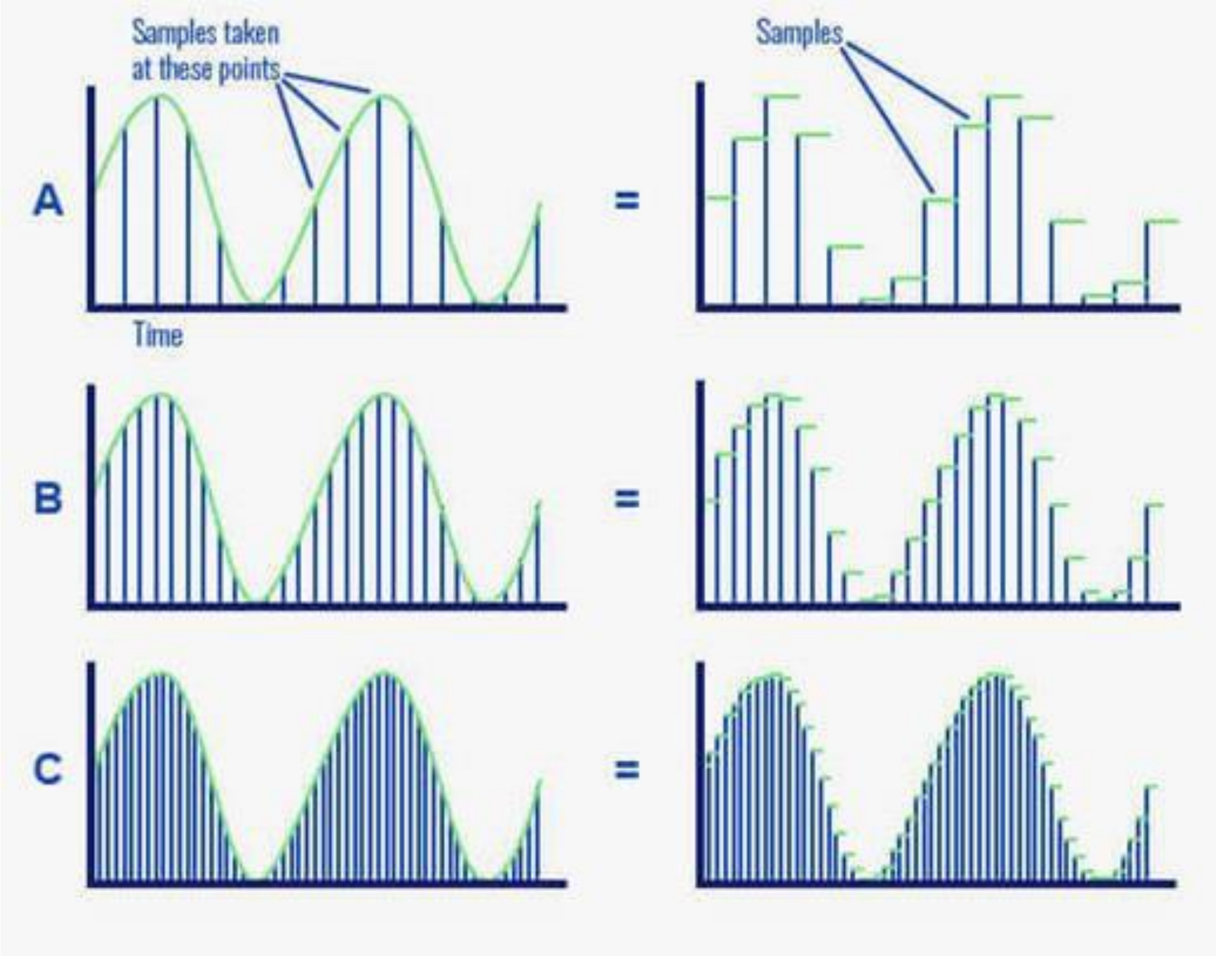
$$\boldsymbol{X = \frac{2^{10}\ states}{10V}\big(3.65\,V - (-5V)\big) = 885.76}$$

885 ÷ 2 = 442 with 1 remainder
442 ÷ 2 = 221 with 0 remainder
221 ÷ 2 = 110 with 1 remainder
110 ÷ 2 = 55 with 0 remainder
55 ÷ 2 = 27 with 1 remainder
27 ÷ 2 = 13 with 1 remainder
13 ÷ 2 = 6 with 1 remainder
6 ÷ 2 = 3 with 0 remainder
3 ÷ 2 = 1 with 1 remainder
1 ÷ 2 = 0 with 1 remainder

$885_{10} = 1101110101_2$

Sampling Rate or frequency

- This is the frequency at which ADC samples the analog signal. Frequent sampling leads to higher accuracy.

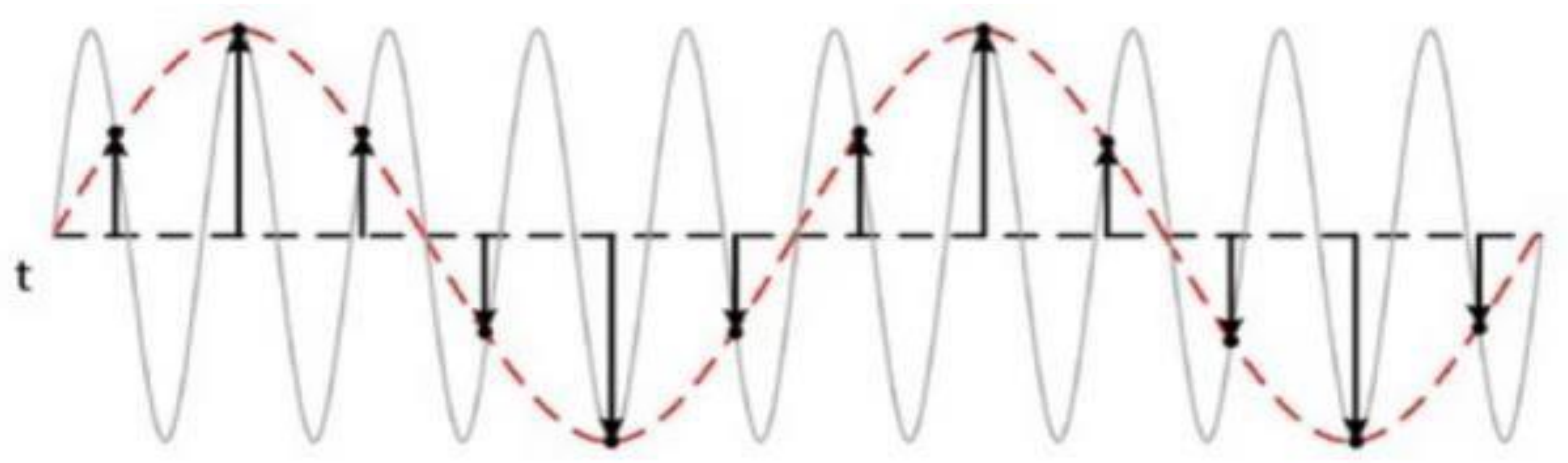


Limitation: Aliasing

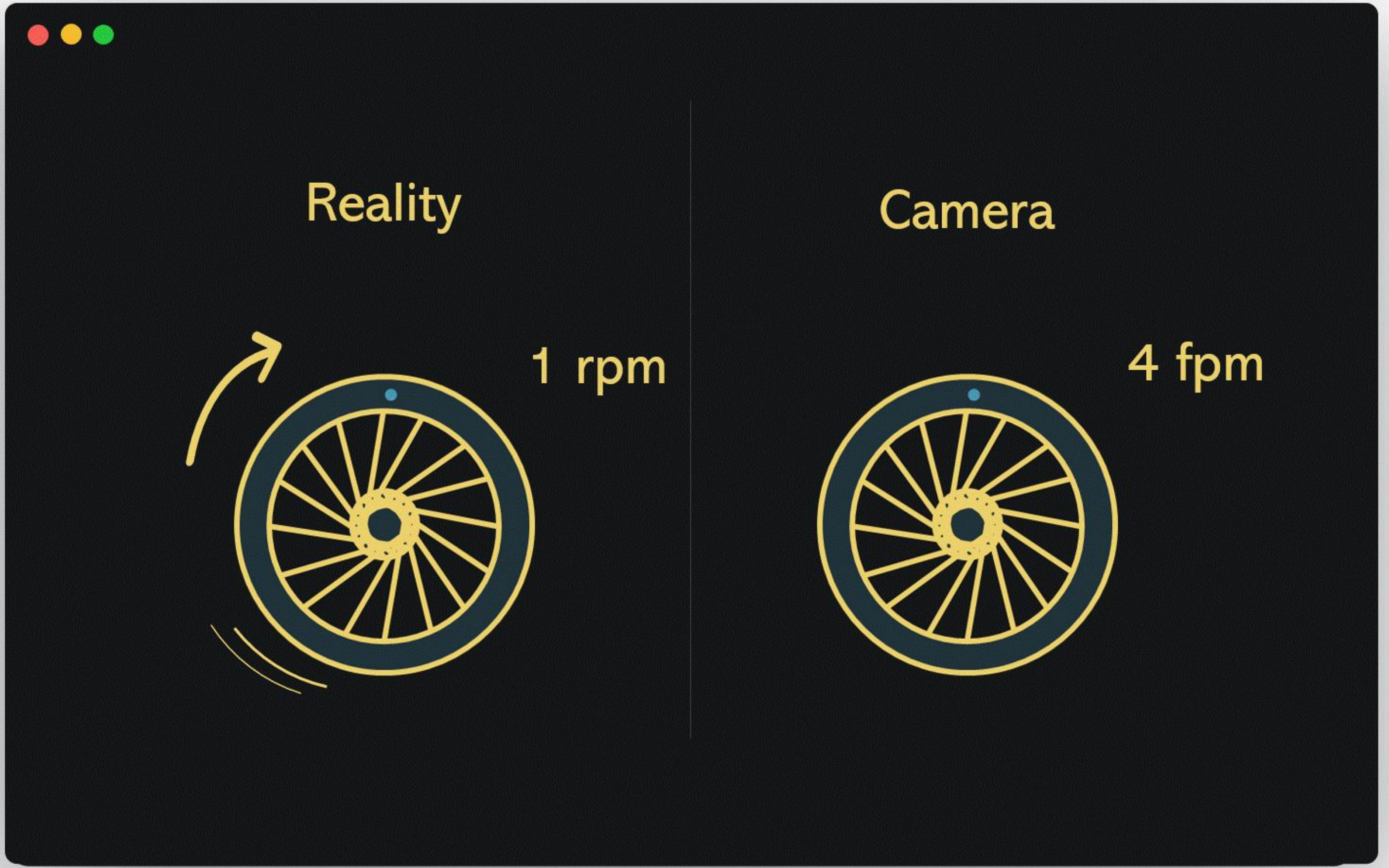
- Effect that causes different signals to become indistinguishable when sampled.
- Occurs when the input signal is changing much faster than the sample rate.

Nyquist Rule:

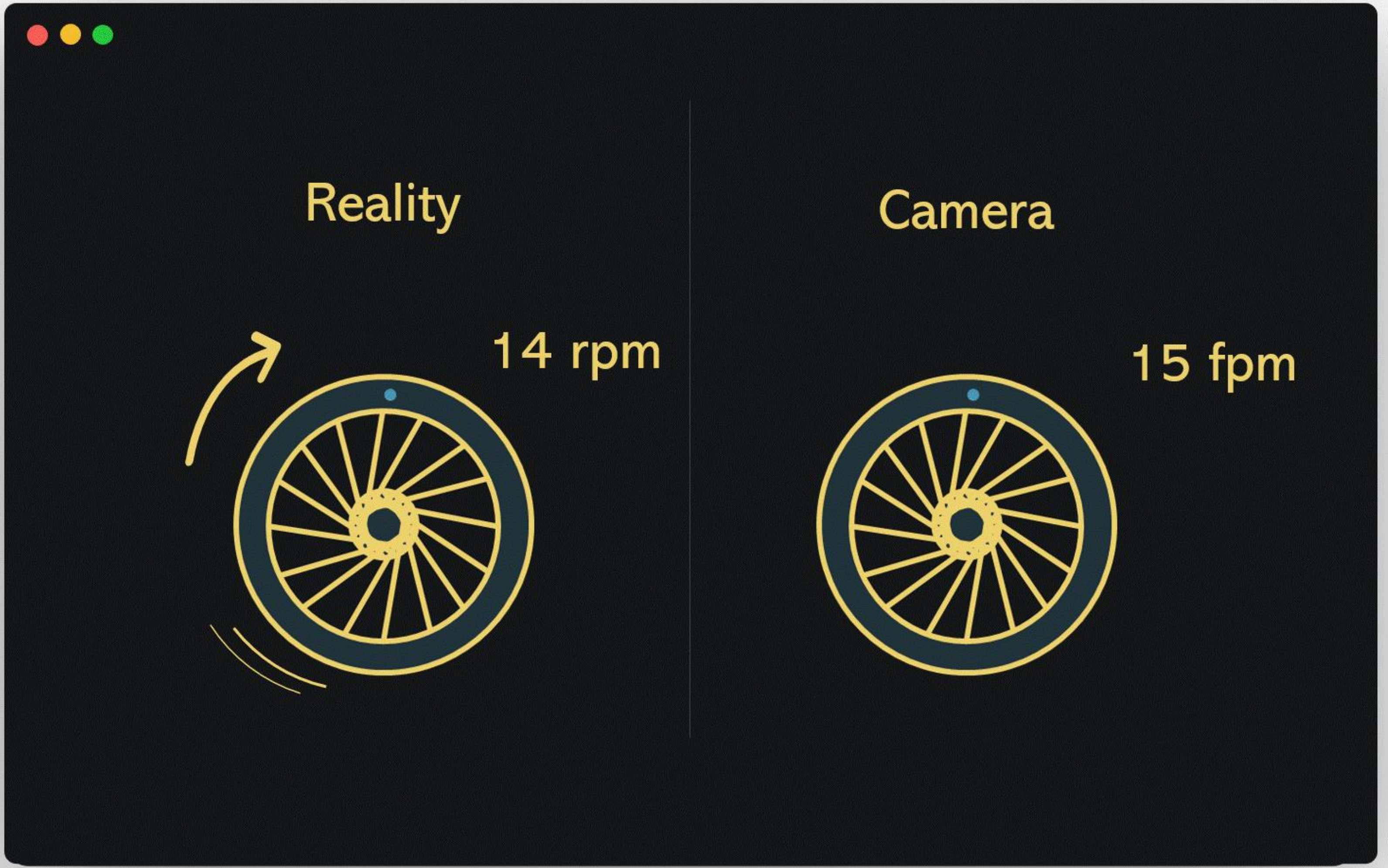
- Use a sampling frequency at **least twice** as high as the maximum frequency in the signal to avoid aliasing.



Limitation: Aliasing



Limitation: Aliasing



Minimum Sampling Frequency

- Exp. 3: If I want to convert a 500 kHz analog signal into a digital signal, what is the minimum sampling frequency to avoid aliasing?

For a 500 kHz signal, the minimum sampling frequency (f_s) can be calculated as:

$$f_s \geq 2 \times f_{max}$$

Where f_{max} is the maximum frequency of the analog signal.

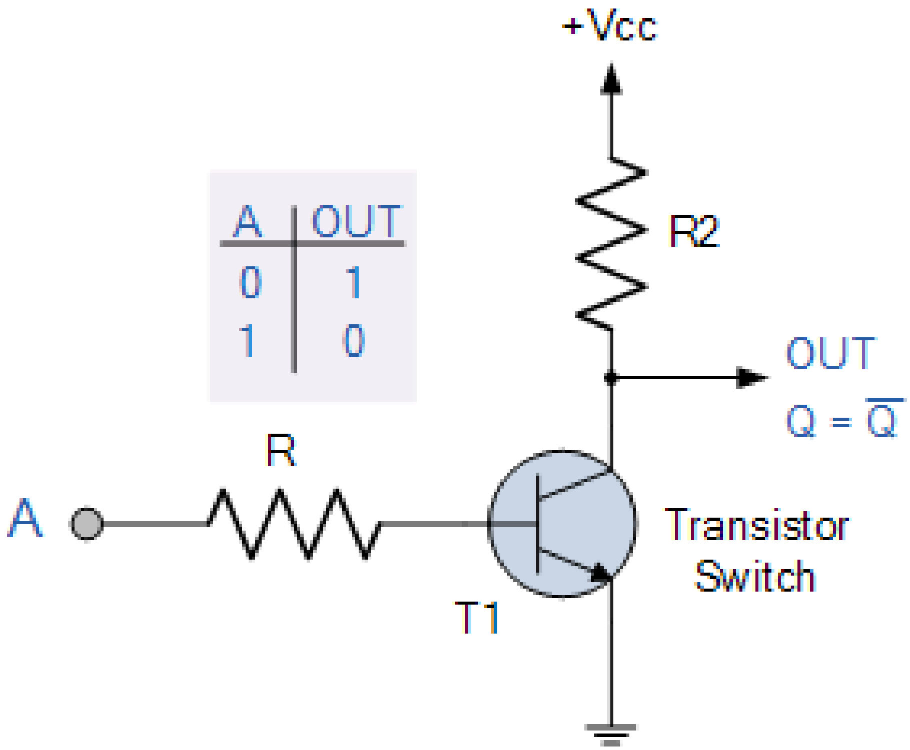
Substituting in the values:

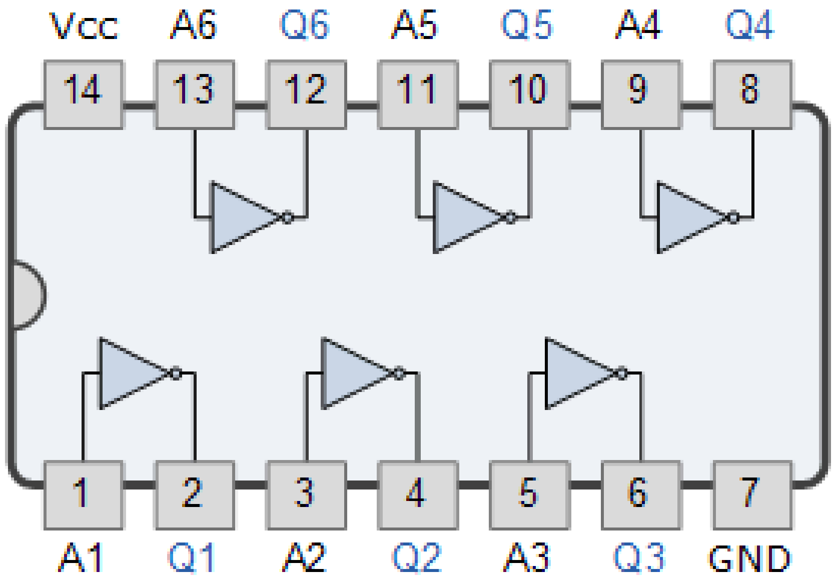
$$f_s \geq 2 \times 500\ \text{kHz} = 1000\ \text{kHz} = 1\ \text{MHz}$$

$\boldsymbol{Ans: 1000\ kHz\ or\ 1\ MHz}$

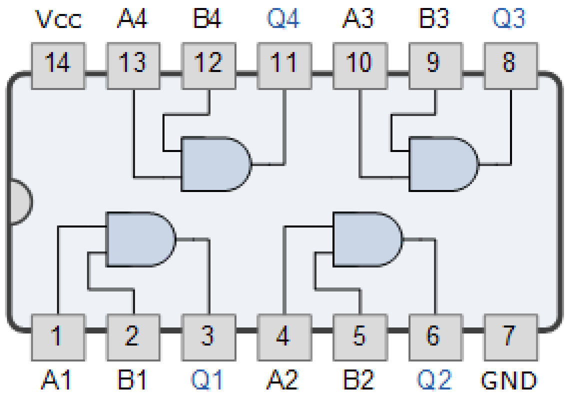
Logic Gates

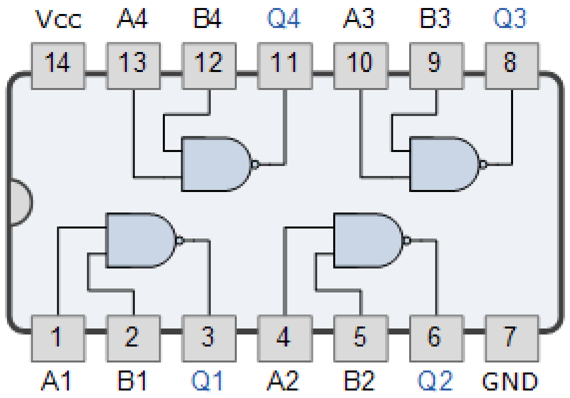
- Gates use Complementary Metal-Oxide-Semiconductor (CMOS) transistors.



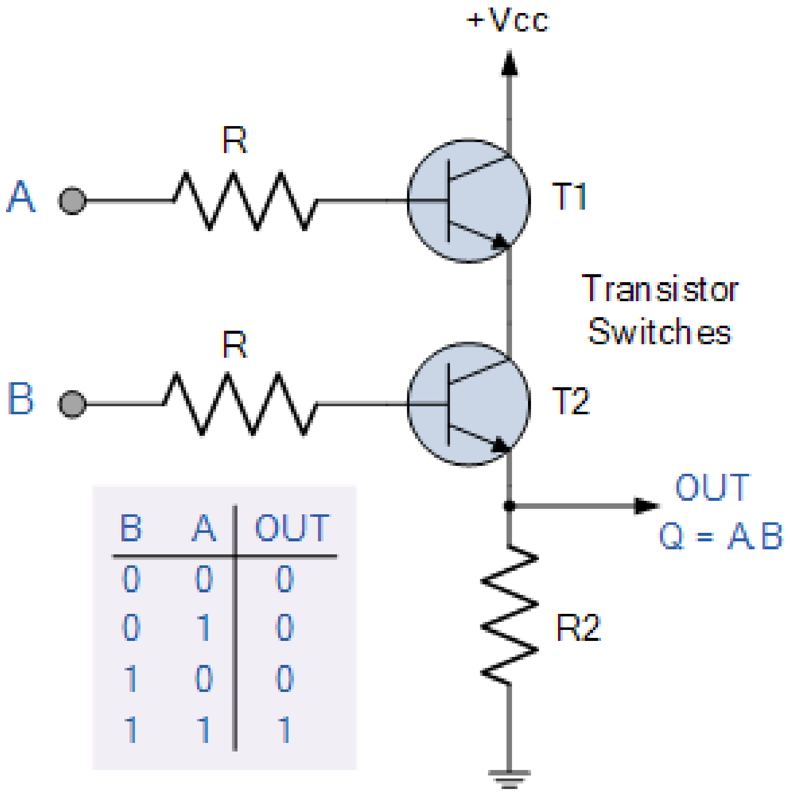


Logic Gates

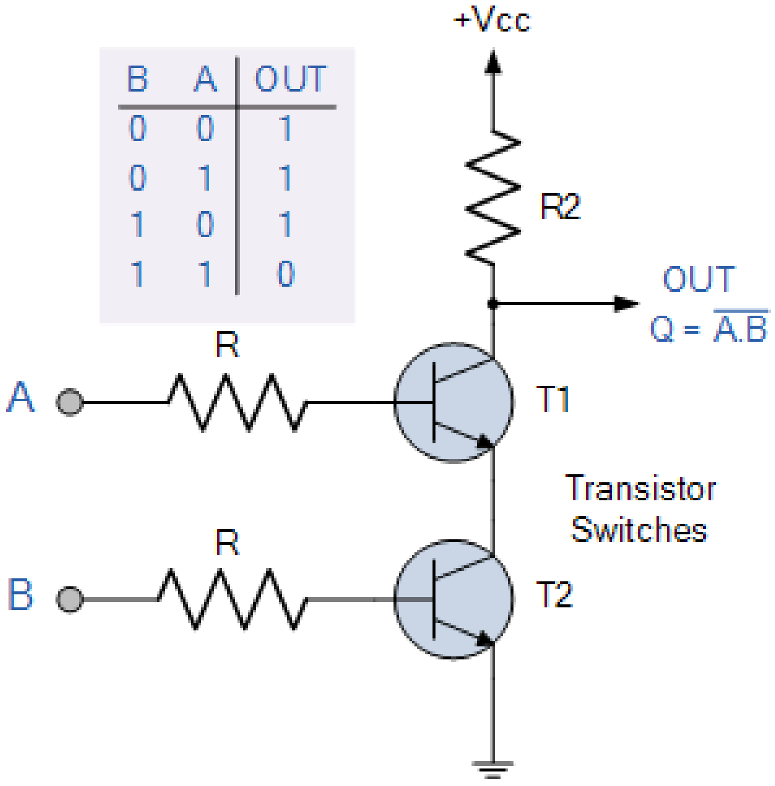




- Gates use Complementary Metal-Oxide-Semiconductor (CMOS) transistors.

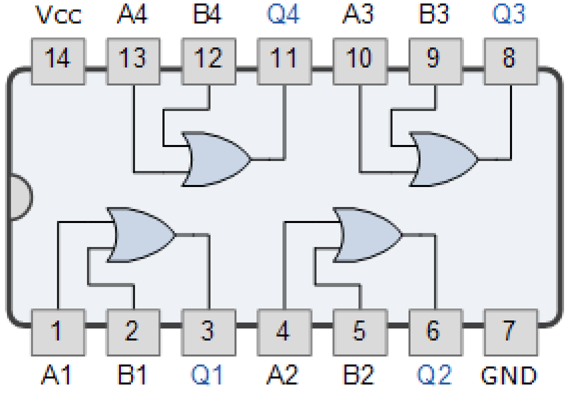


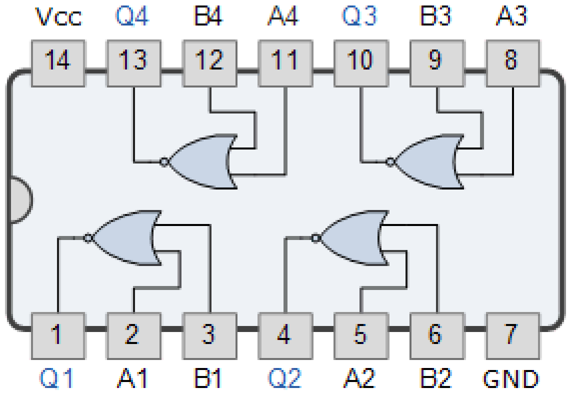
B	A	OUT
0	0	0
0	1	0
1	0	0
1	1	1



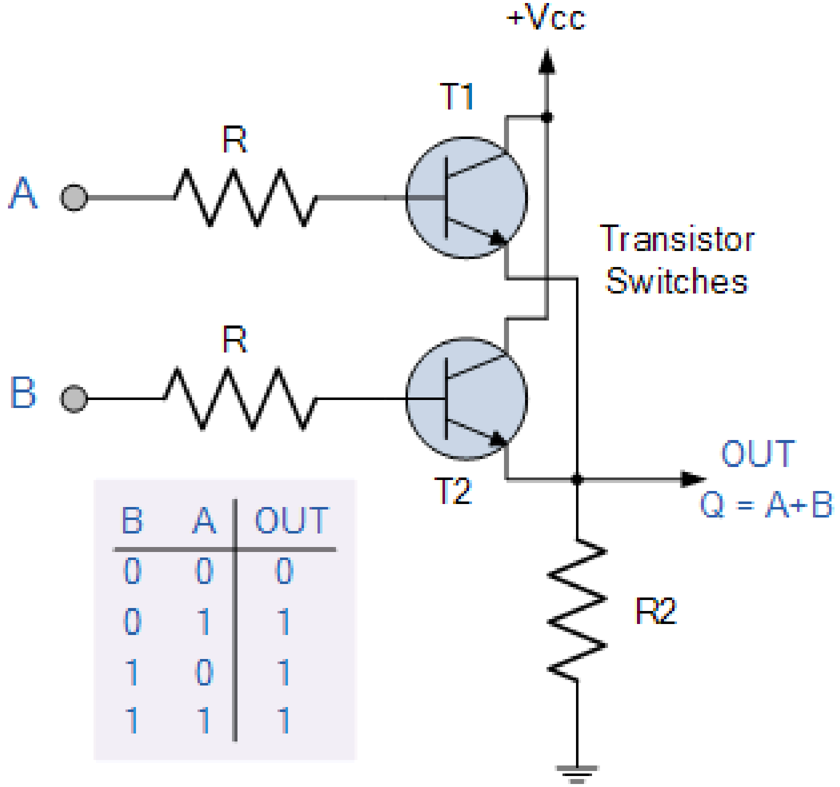
B	A	OUT
0	0	1
0	1	1
1	0	1
1	1	0

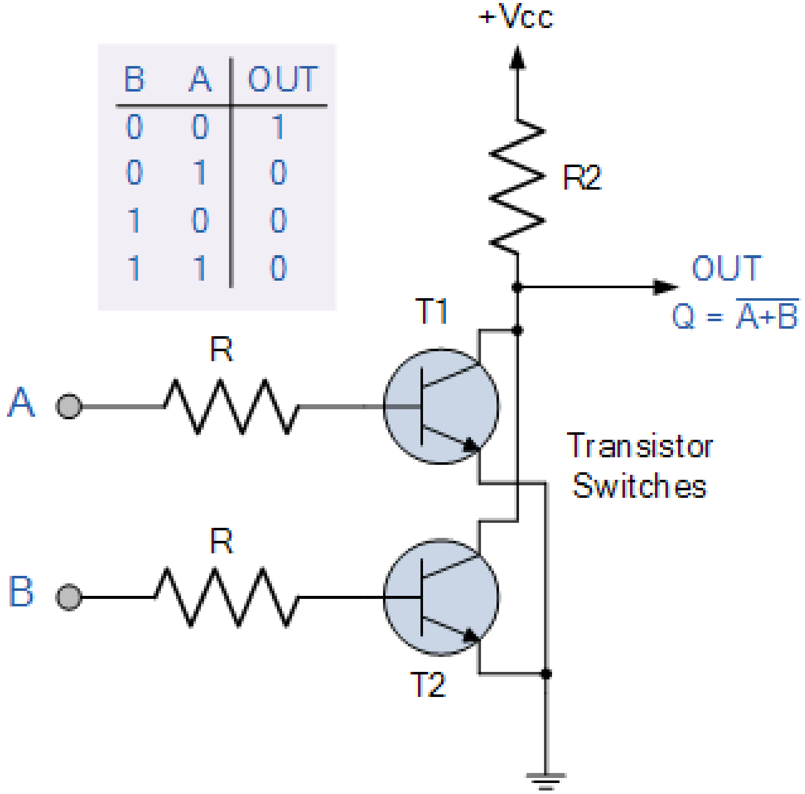
Logic Gates



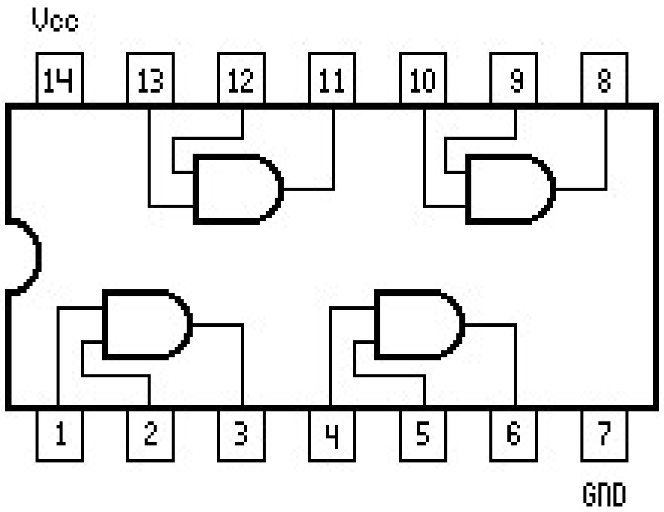


- Gates use Complementary Metal-Oxide-Semiconductor (CMOS) transistors.

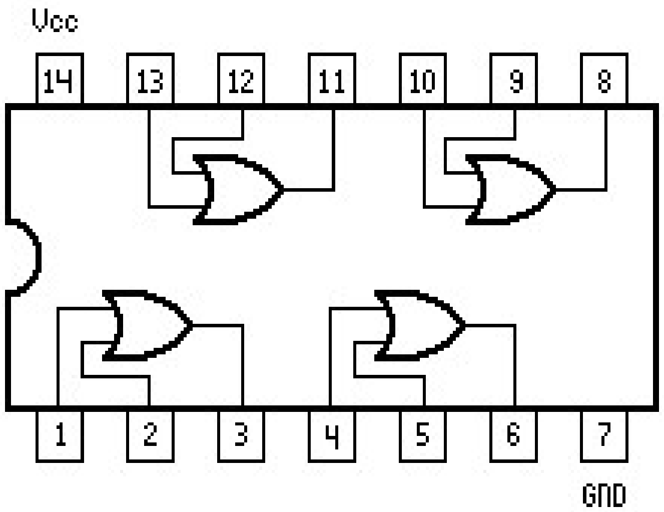




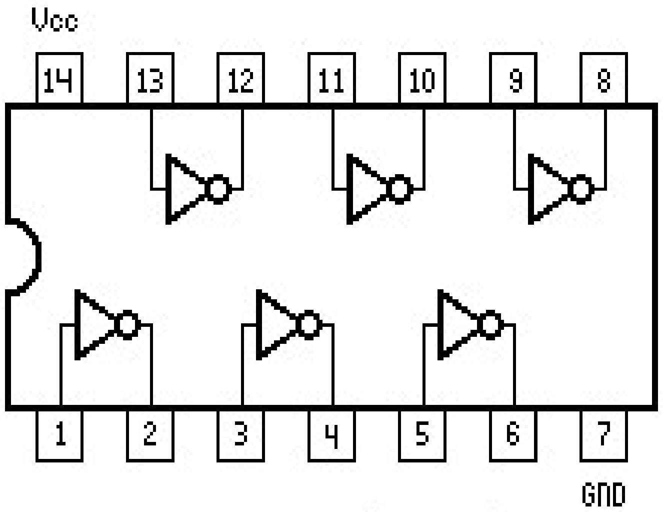
Identification of Integrated Circuits (ICs)



7408 (AND)



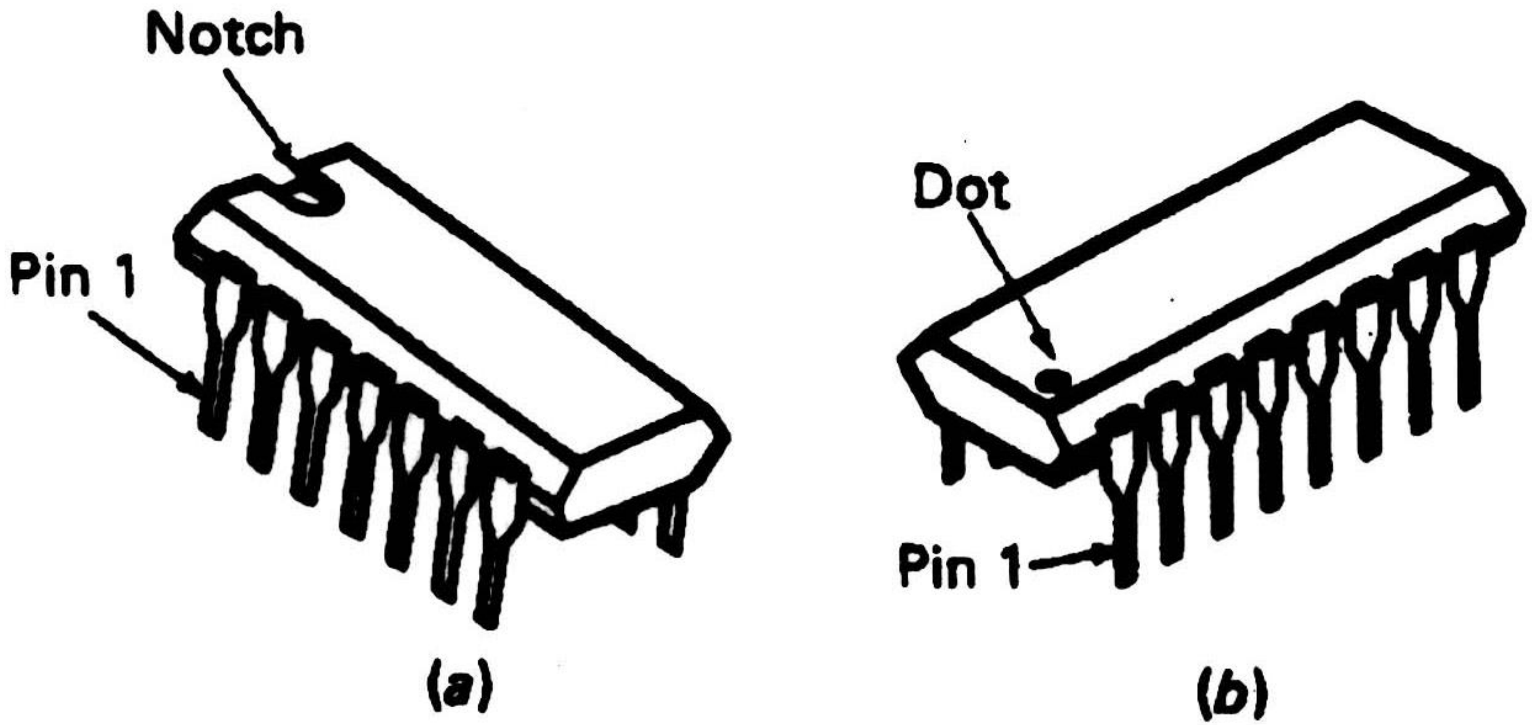
7432 (OR)



7404 (NOT)

Integrated Circuits (ICs)

- Used for implementation of combinational logic circuits
    - Use TTL (Transistor-Transistor Logic) Family.



Questions?