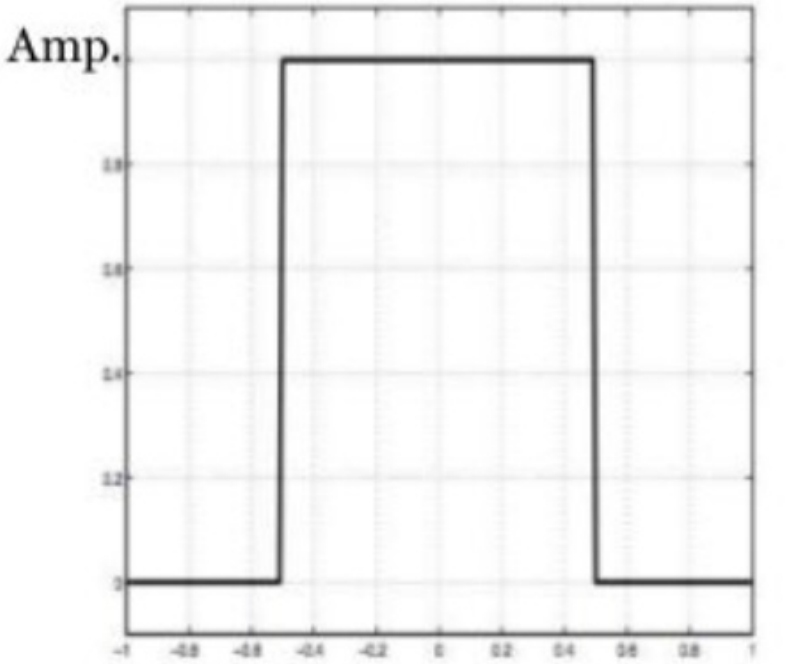
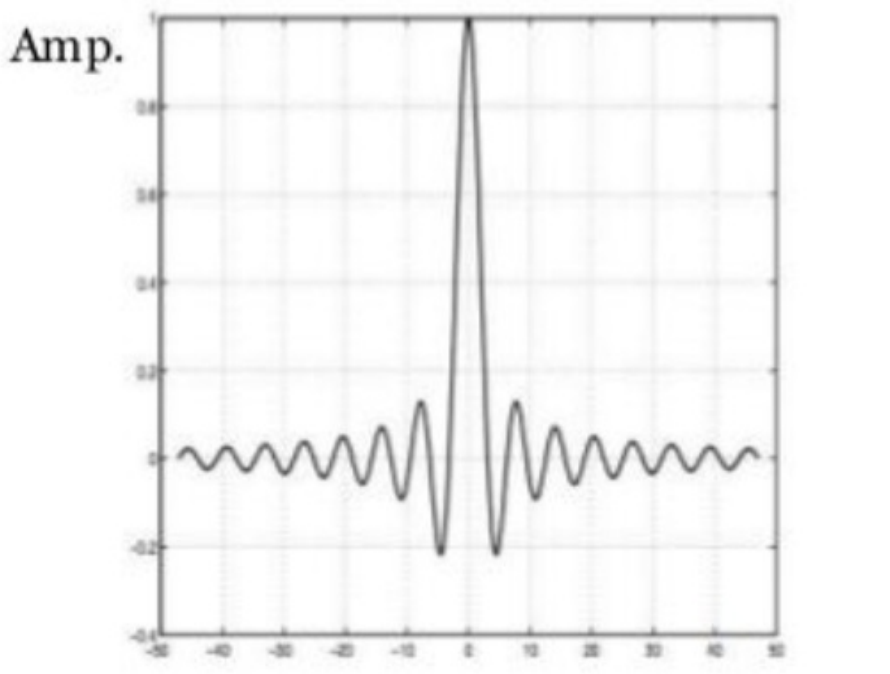
- A/D is the process of converting an analog signal to digital signal, in order to transmit it through a digital communication system.
- Electric Signals can be represented either in Time domain or frequency domain.
  - Time domain i.e $v(t) = 2\sin(2\pi 1000t + 45)$
  - We can get the value of that signal at any time (t) by substituting in the v(t) equation.

Time Domain



Frequency Domain



Converting an Analog Signal to a Discrete Signal (A/D)

- Can be done through three basic steps:

1- Sampling

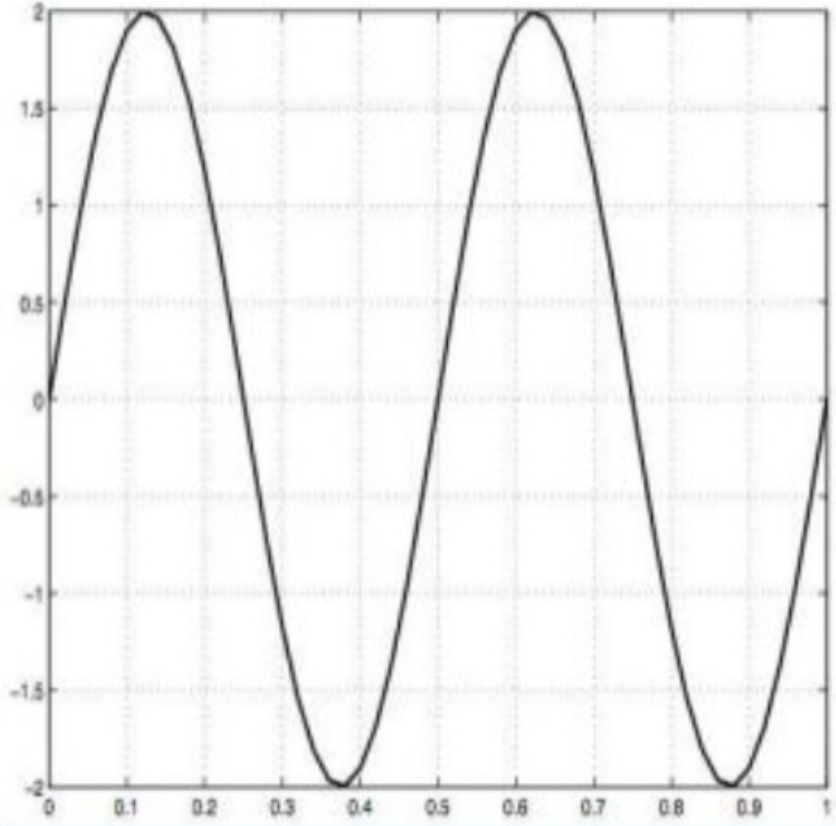
2- Quantization

3- Coding

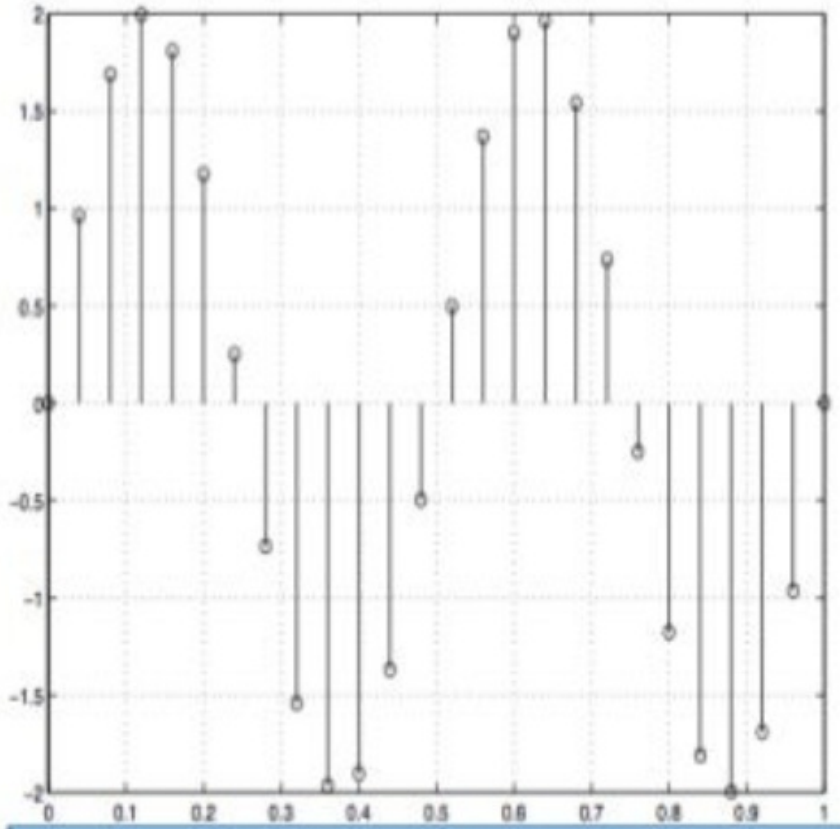
Sampling

- Process of converting the continuous time signal to a discrete time signal.
- Sampling is done by taking "Samples" at specific times spaced regularly.
  - V(t) is an analog signal
  - $V(nT_s)$ is the sampled signal
    - T_s = positive real number that represent the spacing of the sampling time
    - n = sample number integer

Sampling



Original Analog Signal
"Before Sampling"



Sampled Analog Signal
"After Sampling"

Sampling

- The closer the Ts value, the closer the sampled signal resemble the original signal.
- Note that we have lost some values of the original signal, the parts between each successive samples.

- **Can we recover these values? And How?**
- **Can we go back from the discrete signal to the original continuous signal?**

Quantization

- Quantization is a process of approximating a continuous range of values, very large set of possible discrete values, by a relatively small range of values, small set of discrete values.

- Continuous range → infinte set of values

- Discrete range → finite set of values

Sampling Theorem

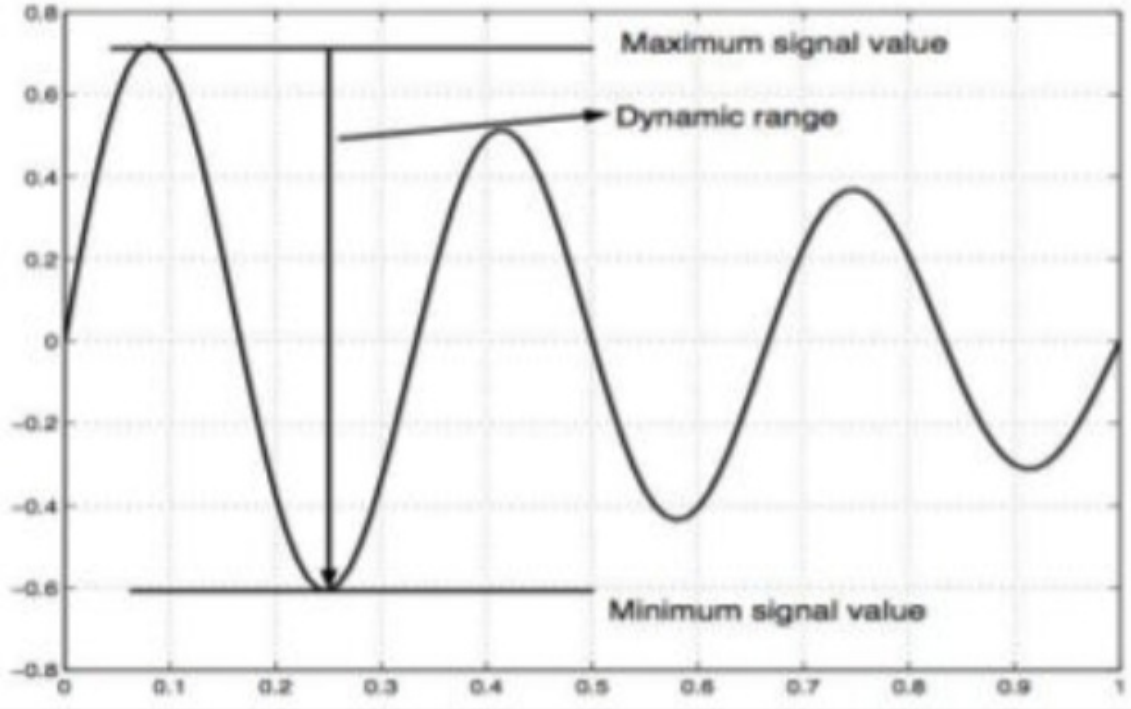
- A bandlimited signal having no spectral components above f_{max} (Hz), can be determined uniquely by values sampled at uniform intervals of Ts seconds, where

- An analog signal can be reconstructed from a sampled signal without any loss of information if and only if it is:
  - Band limited signal
  - The sampling frequency is at least twice the signal bandwidth

$$Ts \leq \frac{1}{2f_{\max}}$$

Quantization

- **Dynamic range of a signal**
  - The difference between the highest to lowest value the signal can takes.

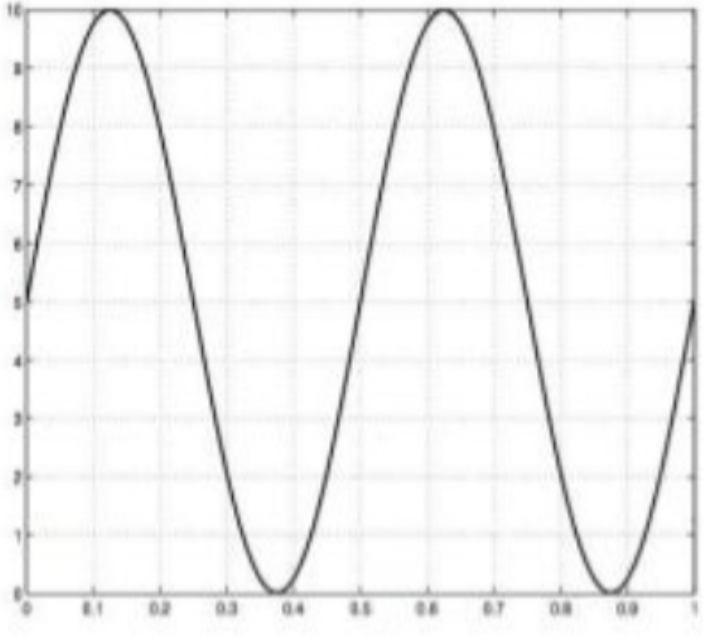


Quantization

- In the Quantization process, the dynamic range of a signal is divided into L amplitude levels denoted by m_k, where $k = 1, 2, 3, .. L$
- L is an integer power of 2
  - $L = 2^k$
  - K is the number of bits needed to represent the amplitude level.
- For example:
  - If we divide the dynamic range into 8 levels,
    - $L = 8 = 2^3$
  - We need 3 bits to represent each level.

Quantization

- Example:
  - Suppose we have an analog signal with the values between [0, 10]. If we divide the signal into four levels. We have
    - m1 → [0, 2.5]
    - m2 → [2.5, 5]
    - m3 → [5 , 7.5]
    - m4 → [7.5, 10]

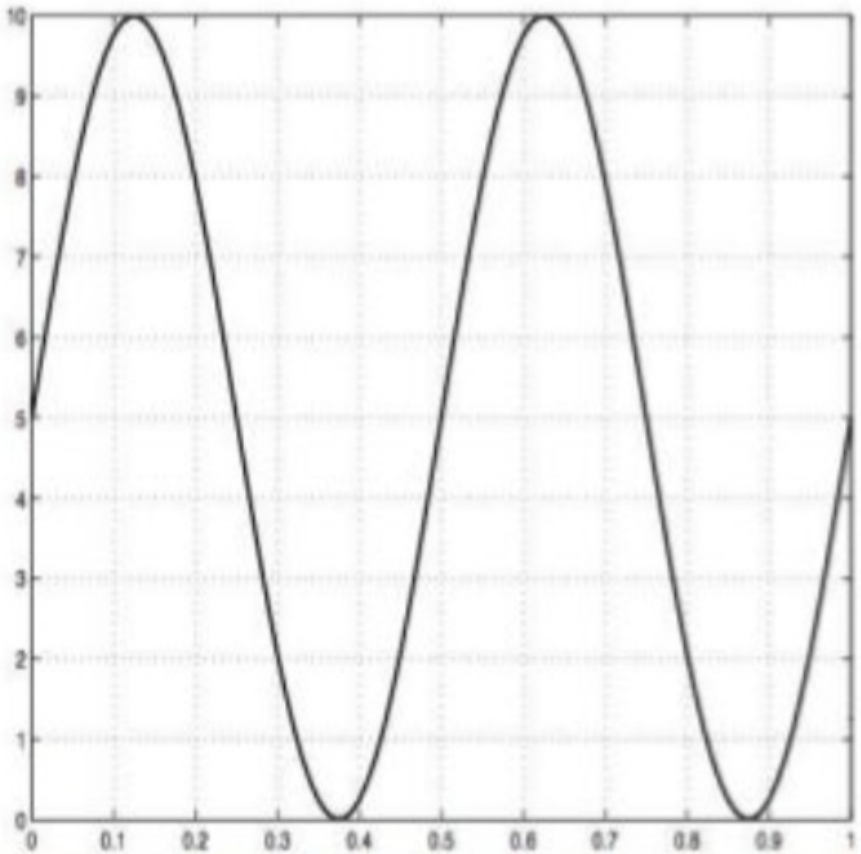


Quantization

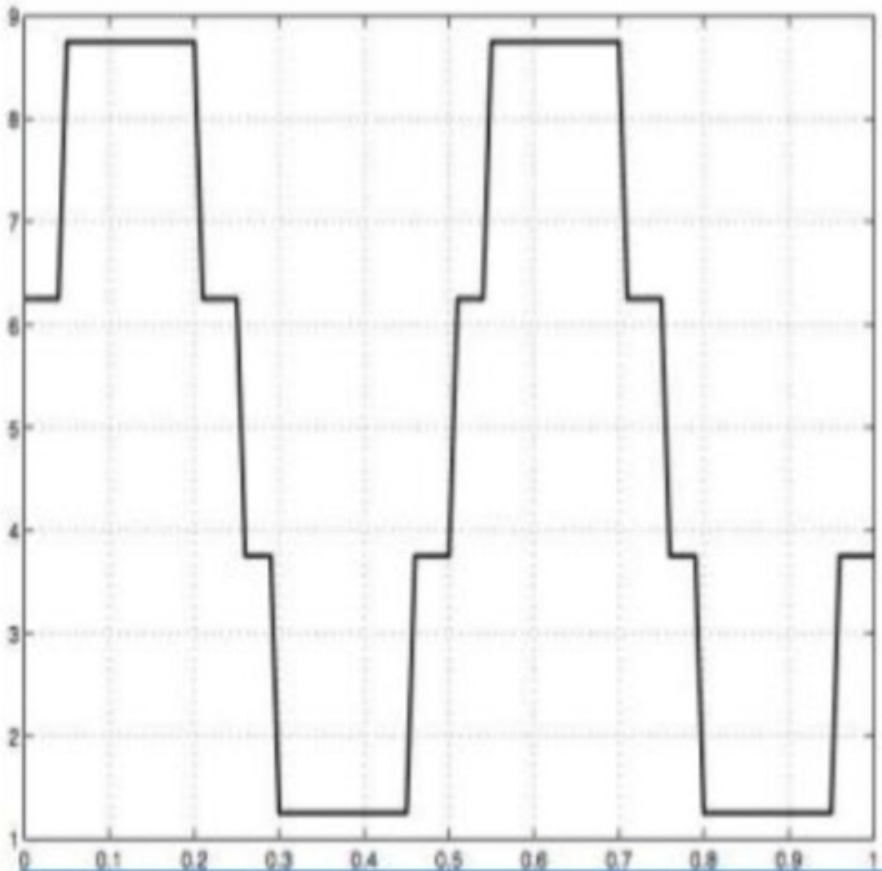
- For every level, we assign a value for the signal if it falls within the same level.

$$Q[\,v(t)\,] = \begin{cases} M1 = 1.25 & \text{if the signal in } m1 \\ M2 = 3.75 & \text{if the signal in } m2 \\ M3 = 6.25 & \text{if the signal in } m3 \\ M4 = 8.75 & \text{if the signal in } m4 \end{cases}$$

Quantization

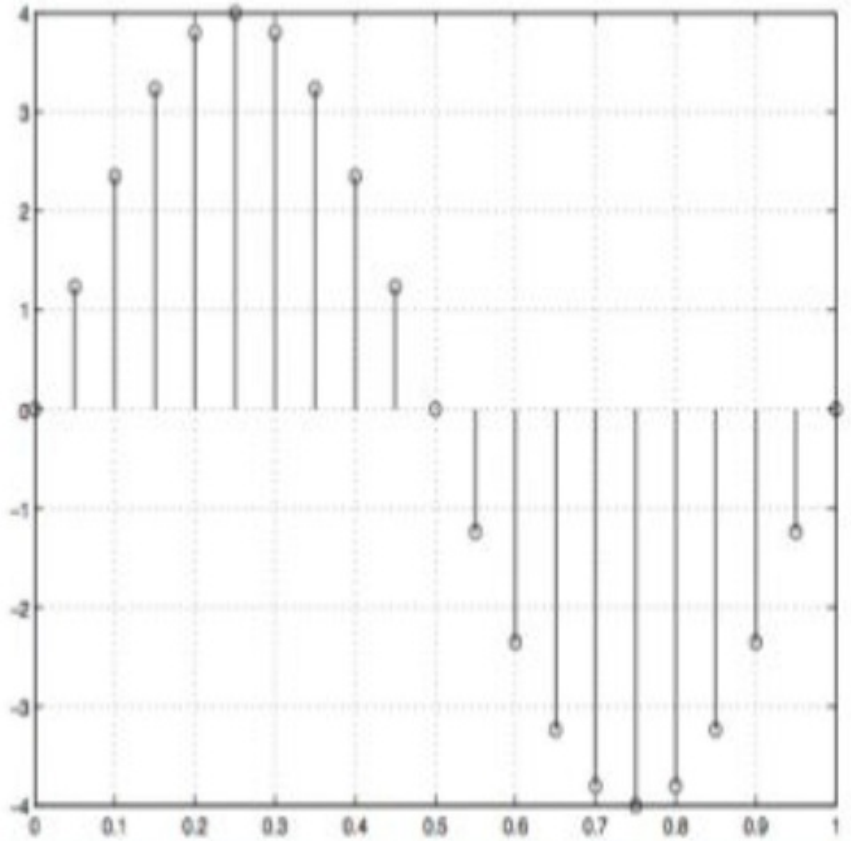


Original Analog Signal
"Before Quantization"

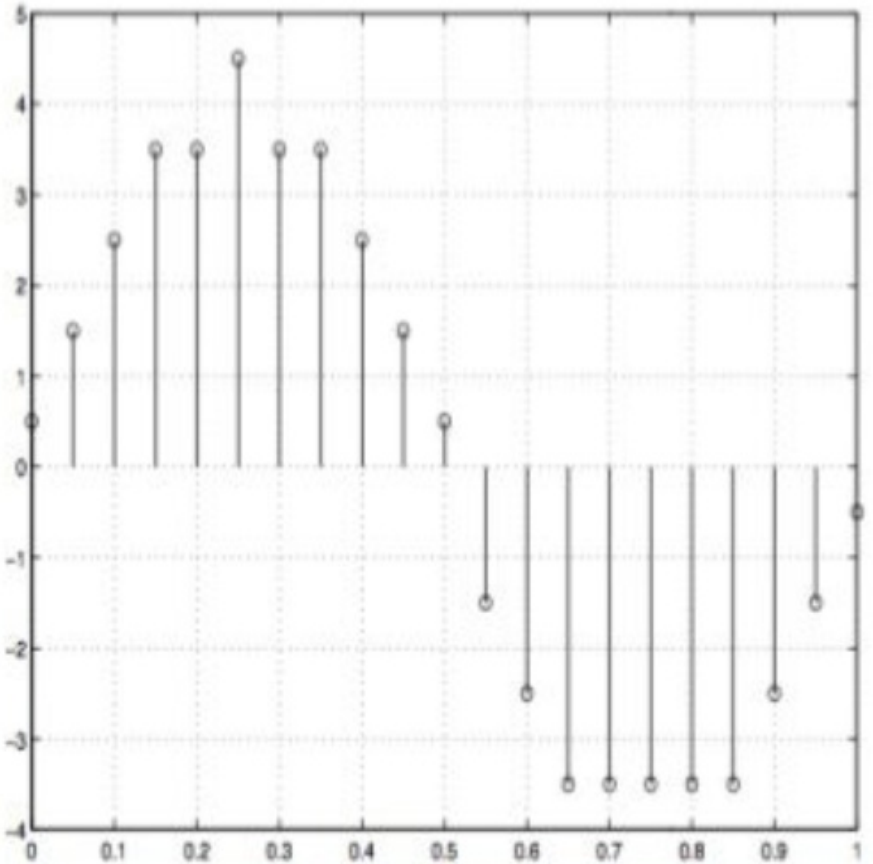


Quantized Analog Signal
"After Quantization"

Quantization



Original Discrete Signal
"Before Quantization"



Quantized Discrete Signal
"After Quantization"

Quantization

- The more quantization levels we take the smaller the error between the original and quantized signal.
- Quantization step

$$\Delta = \frac{Dynamic\ \ Range}{No.\ of\ \ Quantization\ \ levels} = \frac{S_{\max} - S_{\min}}{L}$$

- The smaller the Δ the smaller the error.

Coding

- Assigning a binary code to each quantization level.
- For example, if we have quantized a signal into 16 levels, the coding process is done as the following:

Step	Code	Step	Code	Step	Code	Step	Code
0	0000	4	0100	8	1000	12	1100
1	0001	5	0101	9	1001	13	1101
2	0010	6	0110	10	1010	14	1110
3	0011	7	0111	11	1011	15	1111

Coding

- The binary codes are represented as pulses
  - Pulse means 1
  - No pulse means 0

- After coding process, the signal is ready to be transmitted through the channel. And Therefore, completing the A/D conversion of an analog signal.