Pulse Code Modulation (PCM)

CDEEP
IIT Bombay

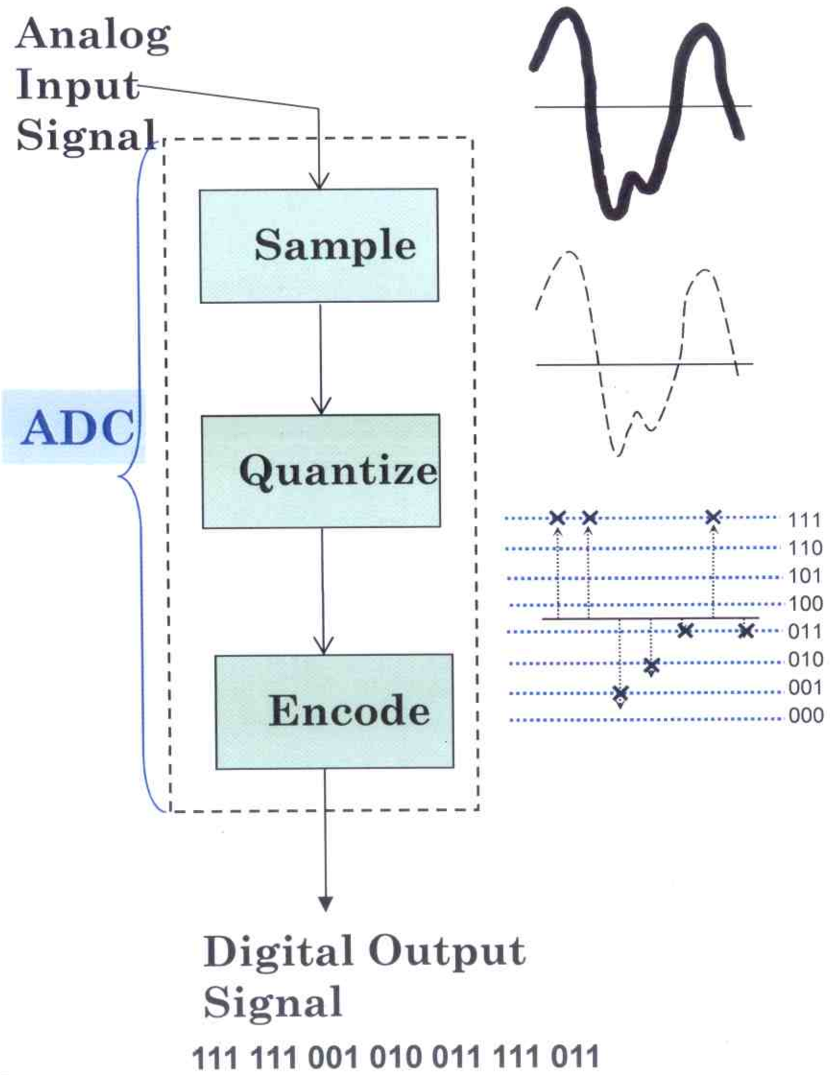
➢DEFINITION:

Pulse code modulation (PCM) is essentially analog-to-digital conversion of a special type where the information contained in the instantaneous samples of an analog signal is represented by digital words in a *serial bit stream.*

ADVANTAGES OF PCM

- Relatively inexpensive digital circuitry may be used extensively
- PCM signals derived from all types of analog sources may be merged with data signals and transmitted over a common high-speed digital communication system
- In long-distance digital telephone systems requiring repeaters, a clean PCM waveform can be regenerated at the output of each repeater, where the input consists of a noisy PCM waveform
- The noise performance of a digital system can be superior to that of an analog system
- The probability of error for the system output can be reduced even further by the use of appropriate coding techniques

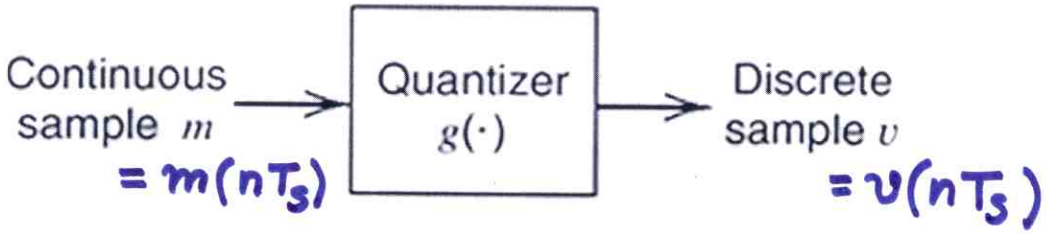
ANALOG TO DIGITAL CONVERSION



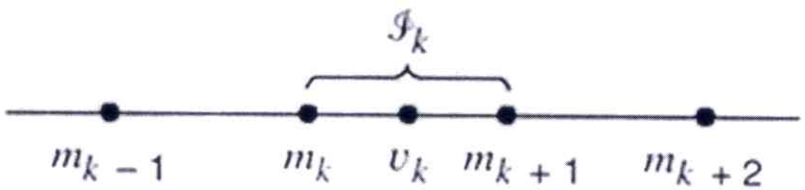
- The *Analog-to-digital Converter* (ADC) performs three functions:
  - **Sampling**
    - Makes the signal discrete in time.
    - If the analog input has a bandwidth of W Hz, then the ***minimum sample frequency*** such that the signal can be reconstructed without distortion.
  - **Quantization**
    - Makes the signal discrete in amplitude.
    - Round off to one of q discrete levels.
  - **Encode**
    - Maps the quantized values to digital words that are ν bits long.
- **If the (Nyquist) *Sampling Theorem* is satisfied, then only quantization introduces distortion to the system.**

QUANTIZATION - UNIFORM

Quantization Process



(a) (Memoryless)

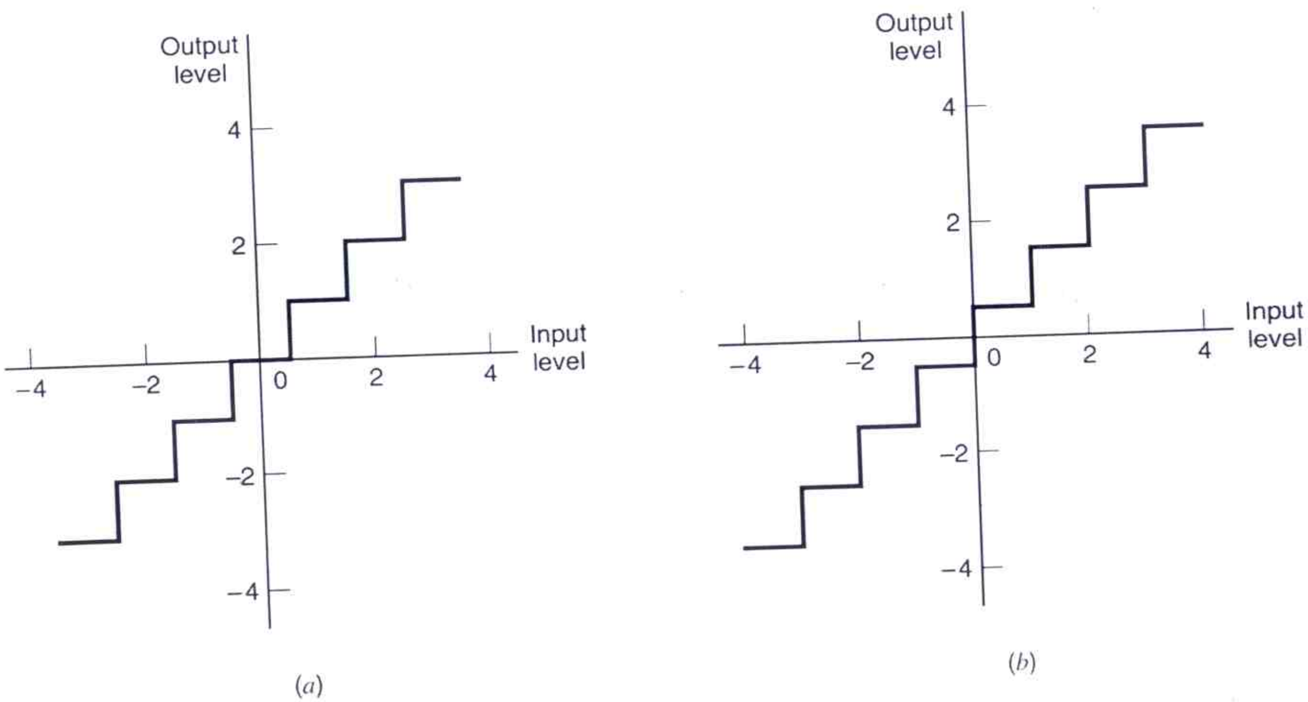


(b)

Scalar

CDEEP
IIT Bombay

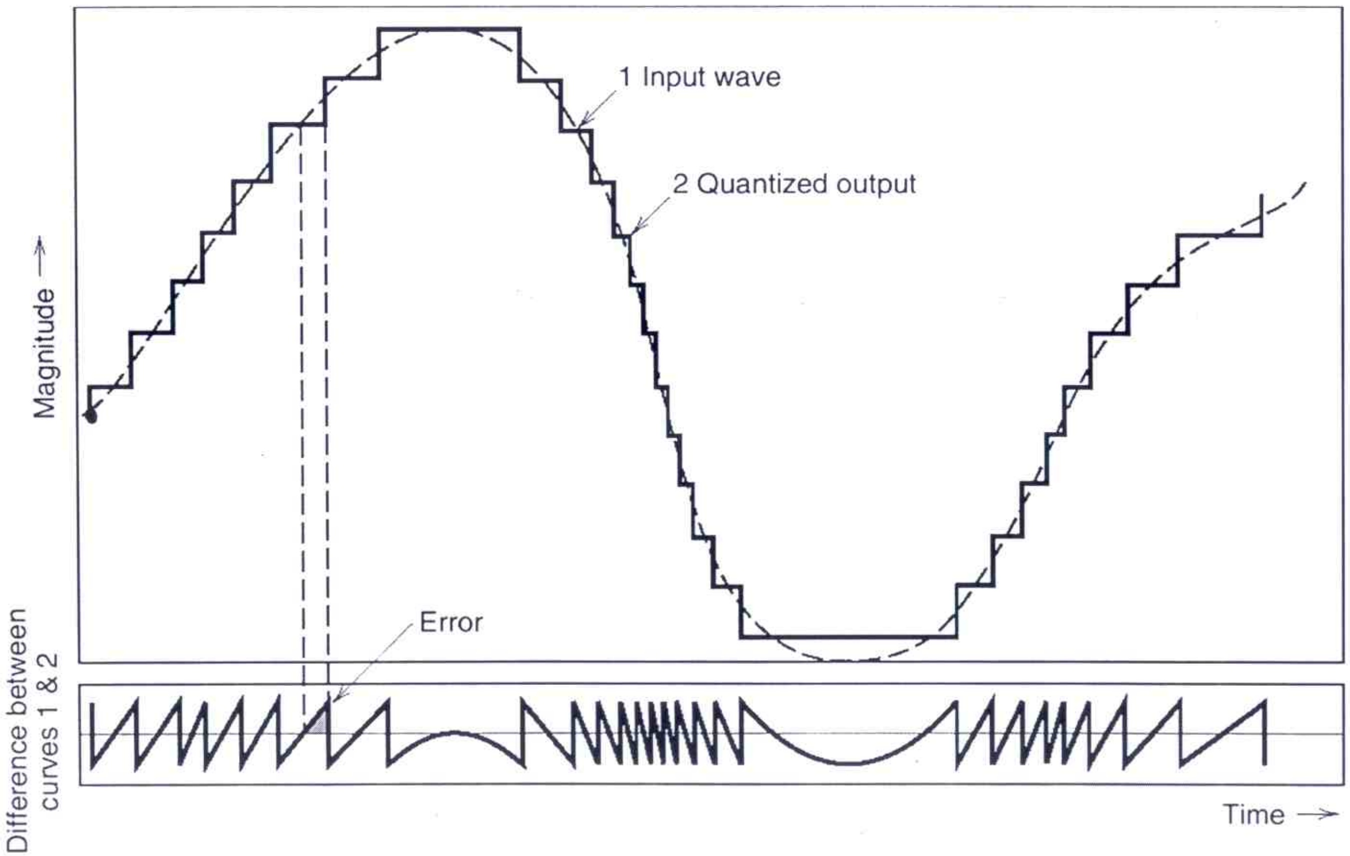
EE 308 L ___ / Slide 8



Two types of quantization: (*a*) midtread and (*b*) midrise

Quantization Noise

(Illustration of the quantization process)



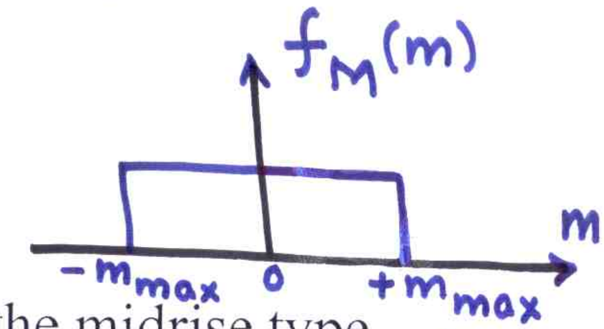
CDEEP
IIT Bombay

EE 308 L___ / Slide 9

Let the quantization error be denoted by the random variable Q of sample value q

$$q = m - v$$

$$Q = M - V, \ (E[M] = 0)$$



Assuming a uniform quantizer of the midrise type

$$\left\{ \begin{array}{l} E[M] = 0 \\ \overline{V} = \overline{g(M)} = 0 \\ (\because g(\cdot) \text{ is symmetric}) \\ \therefore E[Q] = 0 \end{array} \right\}$$

the step-size is $\Delta = \dfrac{2m_{\max}}{L}$

$-m_{\max} < m < m_{\max}$, L: total number of levels

$$f_Q(q) = \begin{cases} \dfrac{1}{\Delta}, & -\dfrac{\Delta}{2} < q \le \dfrac{\Delta}{2} \\ 0, & \text{otherwise} \end{cases}$$

$$\sigma_Q^2 = E[Q^2] = \int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} q^2 f_Q(q)\,dq = \frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} q^2\,dq$$

$$= \frac{\Delta^2}{12}$$

CDEEP
IIT Bombay

When the quatized sample is expressed in binary form,

$$L = 2^R$$

where R is the number of bits per sample

$$R = \log_2 L$$

$$\Delta = \frac{2m_{\max}}{2^R}$$

$$\sigma_Q^2 = \frac{1}{3} m_{\max}^2 2^{-2R}$$

Let P denote the average power of $m(t)$

$$\Rightarrow (SNR)_o = \frac{P}{\sigma_Q^2}$$

$$= \left(\frac{3P}{m_{\max}^2}\right) 2^{2R}$$

(Expressed in dB gives 6dB improvement per bit)

$(SNR)_o$ increases exponentially with increasing R (bandwidth).