KECE321 Communication Systems I

(Haykin Sec. 5.4 - Sec. 5.6)

Lecture #22, May 30, 2012

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Completing the Transition from Analog to Digital

- The advantages offered by digital pulse modulation
  - Performance
    - *Digital pulse modulation permits the use of regenerative repeaters, when placed along the transmission path at short enough distances, can practically eliminate the degrading effects of channel noise and signal distortion.*
  - Ruggedness
    - *A digital communication system can be designed to withstand the effects of channel noise and signal distortion*
  - Reliability
    - *Can be made highly reliable by exploiting powerful error-control coding techniques.*
  - Security
    - *Can be made highly secure by exploiting powerful encryption algorithms*
  - Efficiency
    - *Inherently more efficient than analog communication system in the tradeoff between transmission bandwidth and signal-to-noise ratio*
  - System integration
    - *To integrate digitized analog signals with digital computer data*

Quantization Process

- Amplitude quantization
  - The process of transforming the sample amplitude $m(nT_s)$ of a baseband signal $m(t)$ at time $t = nT_s$ into a discrete amplitude $\nu(nT_s)$ taken from a finite set of possible levels.

$$I_k : \{m_k < m \leq m_{k+1}\}, \qquad k = 1, 2, \ldots, L$$

  - Representation level (or Reconstruction level)
    - The amplitudes $\nu_k,\ k = 1, 2, 3, \ldots, L$
  - Quantum (or step-size)
    - The spacing between two adjacent representation levels

$$v = g(m)$$

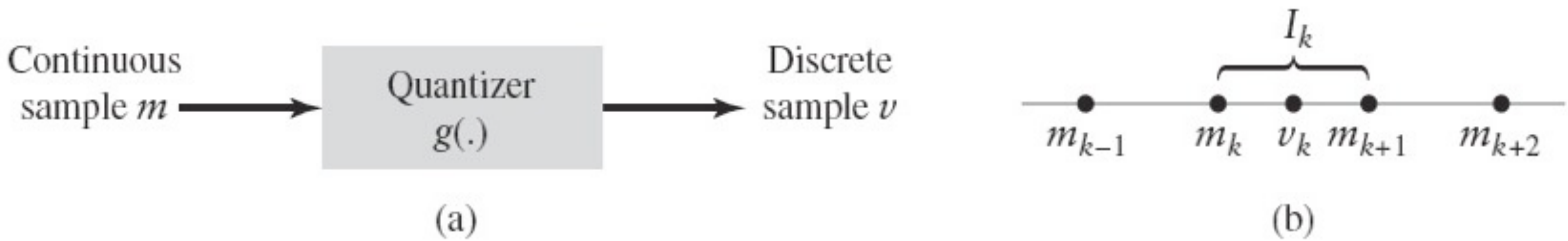


FIGURE 5.9 Description of a memoryless quantizer.

[Ref: Haykin & Moher, Textbook]

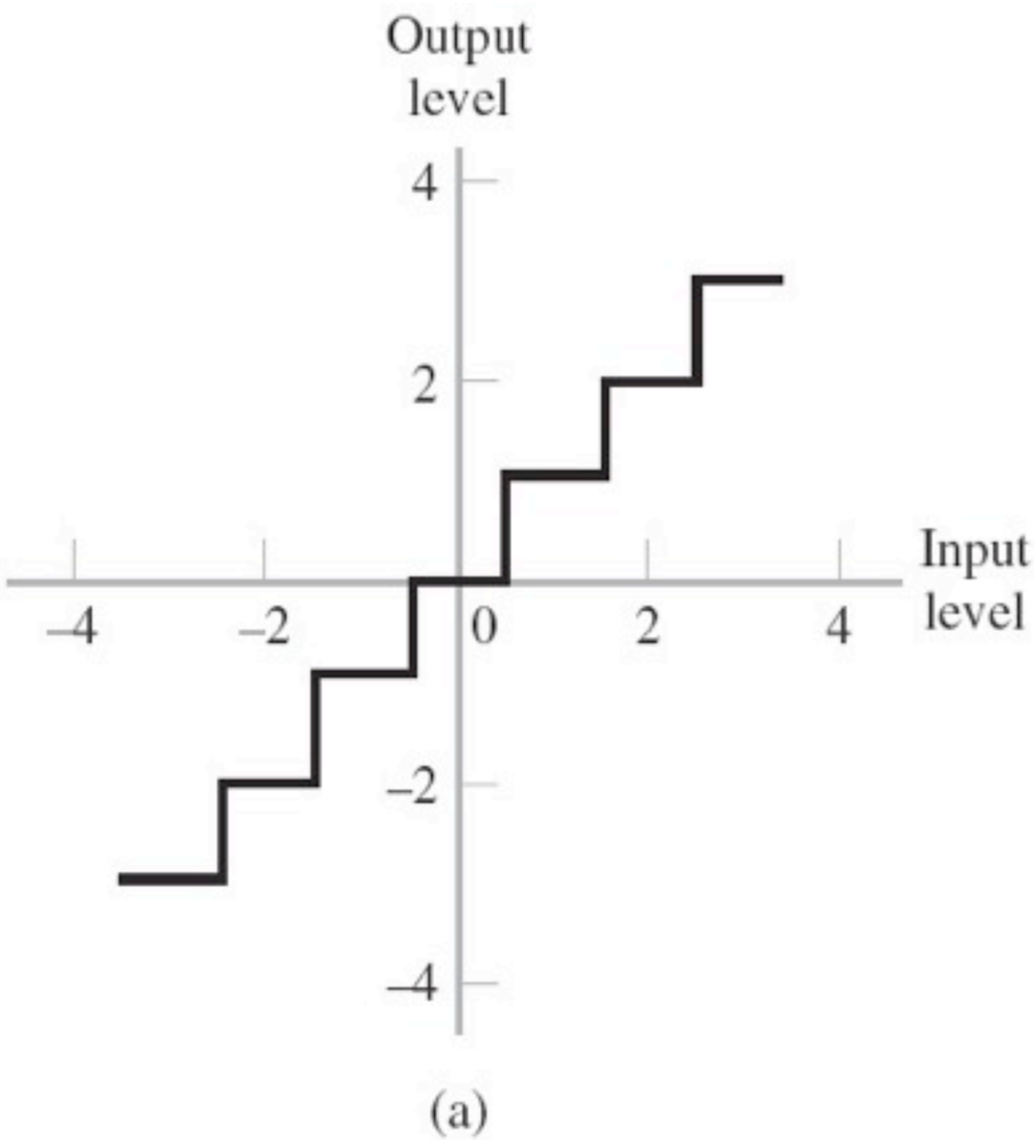


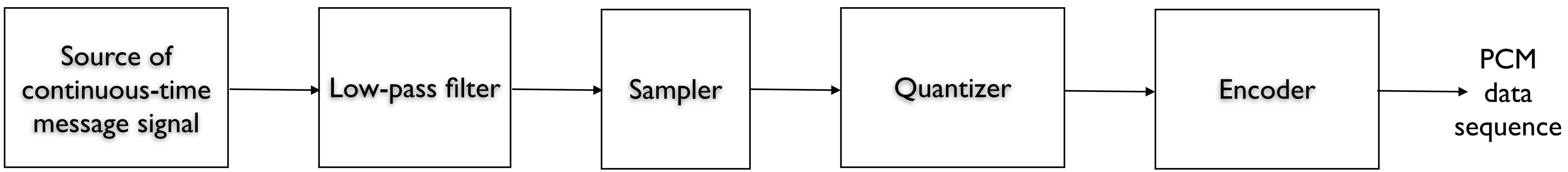
FIGURE 5.10 Two types of quantization: (*a*) midtread and (*b*) midrise.

[Ref: Haykin & Moher, Textbook]

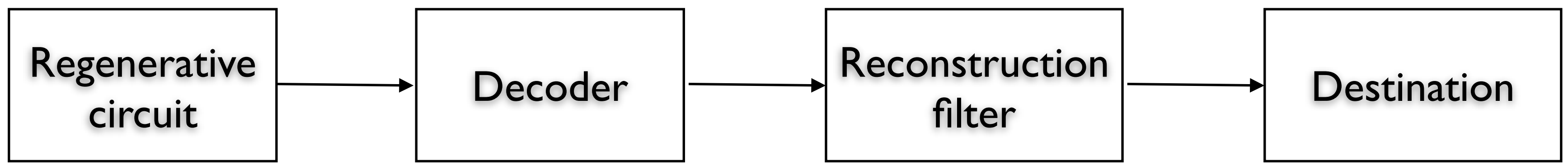
Pulse-Code Modulation (PCM)

- PCM is the most basic form of digital pulse modulation.
- In PCM, a message signal is represented by a sequence of coded pulses, which is accomplished by representing the signal in discrete form in both time and amplitude.
- The basic operations performed in the transmitter of a PCM system
  - Sampling
  - Quantization
  - Encoding

- Block diagram of the transmitter

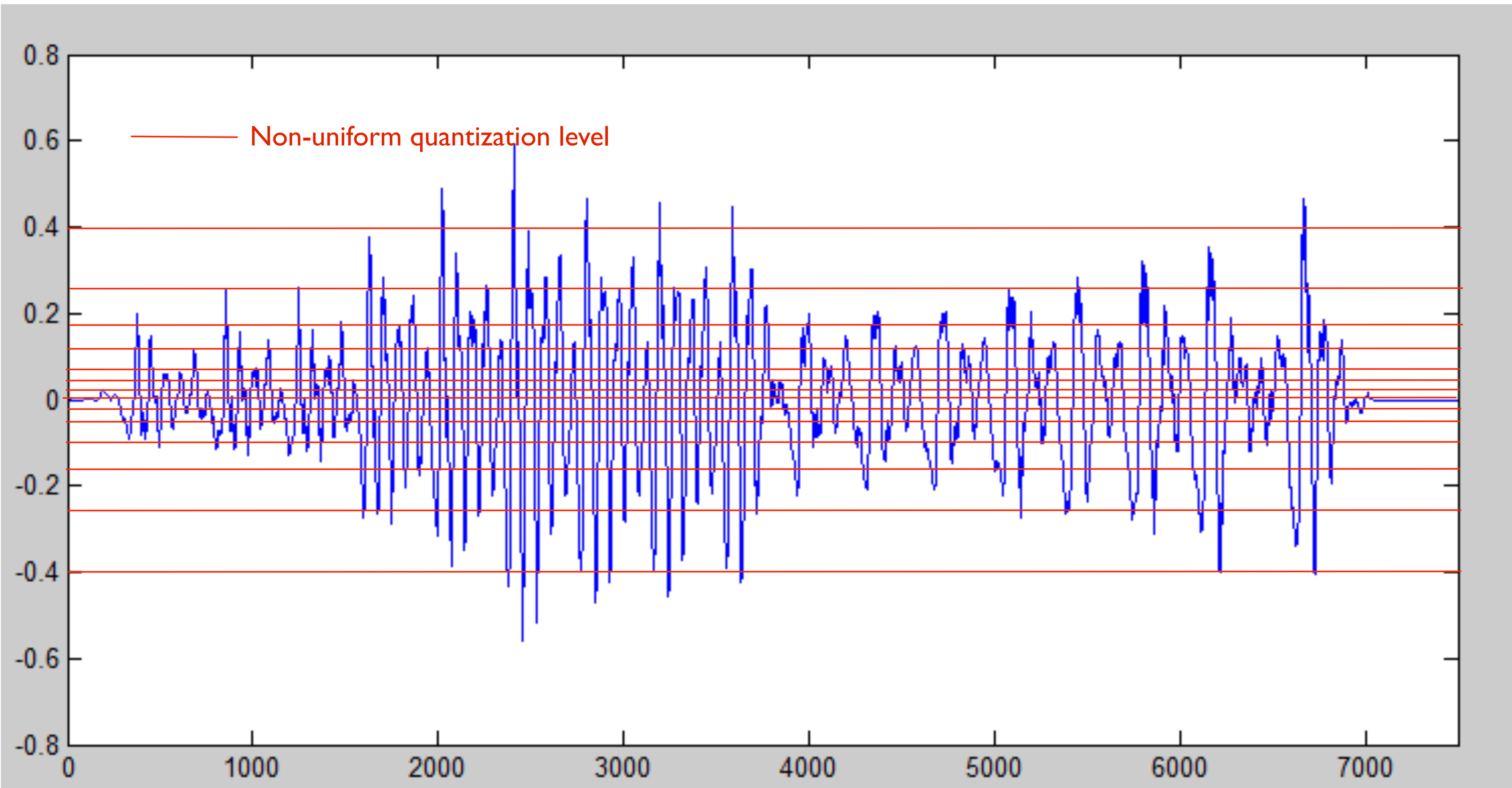


- Block diagram of the receiver



- Operations in the transmitter
  - Sampling
    - The incoming message signal is sampled with a train of rectangular pulses.
    - The reduction of the continuously varying message signal to a limited number of discrete values per second
  - Nonuniform quantization
    - Different step size per each level is used.
    - Frequent level of the signal has small step size while infrequent level has relatively large step size.

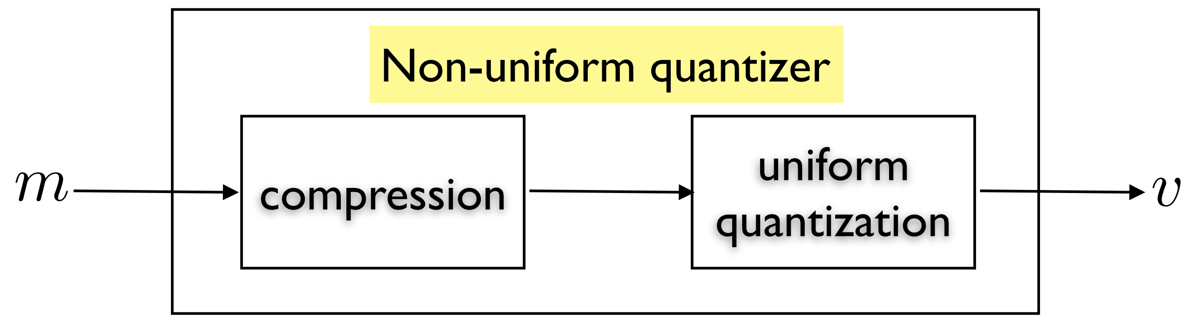
Typical voice signal



- Nonuniform quantizer
  - The use of a nonuniform quantizer is equivalent to passing the message signal through a compressor and then applying the compressed signal to a uniform quantizer.
  - Compression law

- μ - *law*

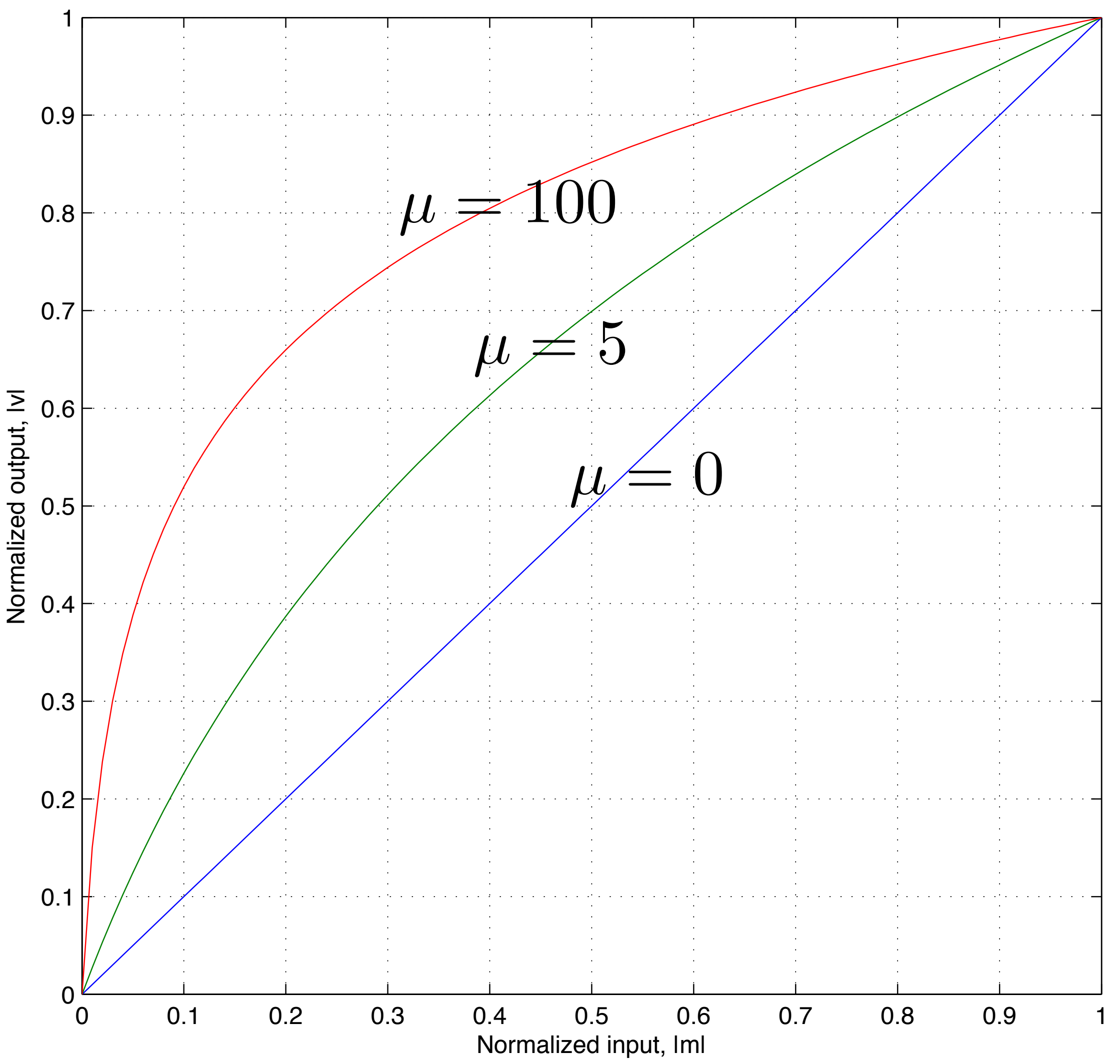
$$|v| = \frac{\ln(1+\mu|m|)}{\ln(1+\mu)}$$

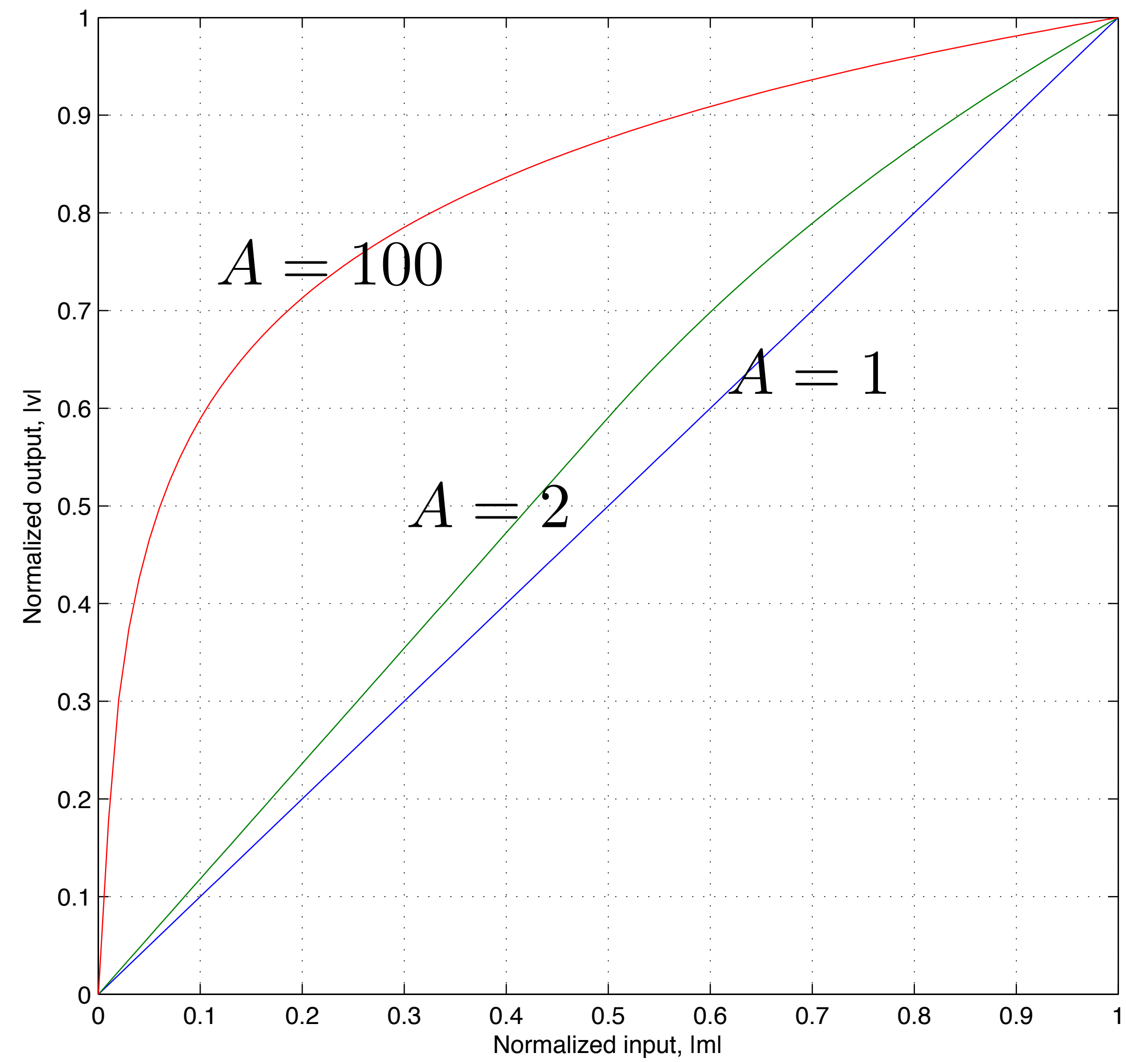


- A - *law*

$$|v| = \begin{cases} \frac{A|m|}{1+\ln A}, & 0 \le |m| \le \frac{1}{A} \\ \frac{1+\ln(A|m|)}{1+\ln A}, & \frac{1}{A} \le |m| \le 1 \end{cases}$$

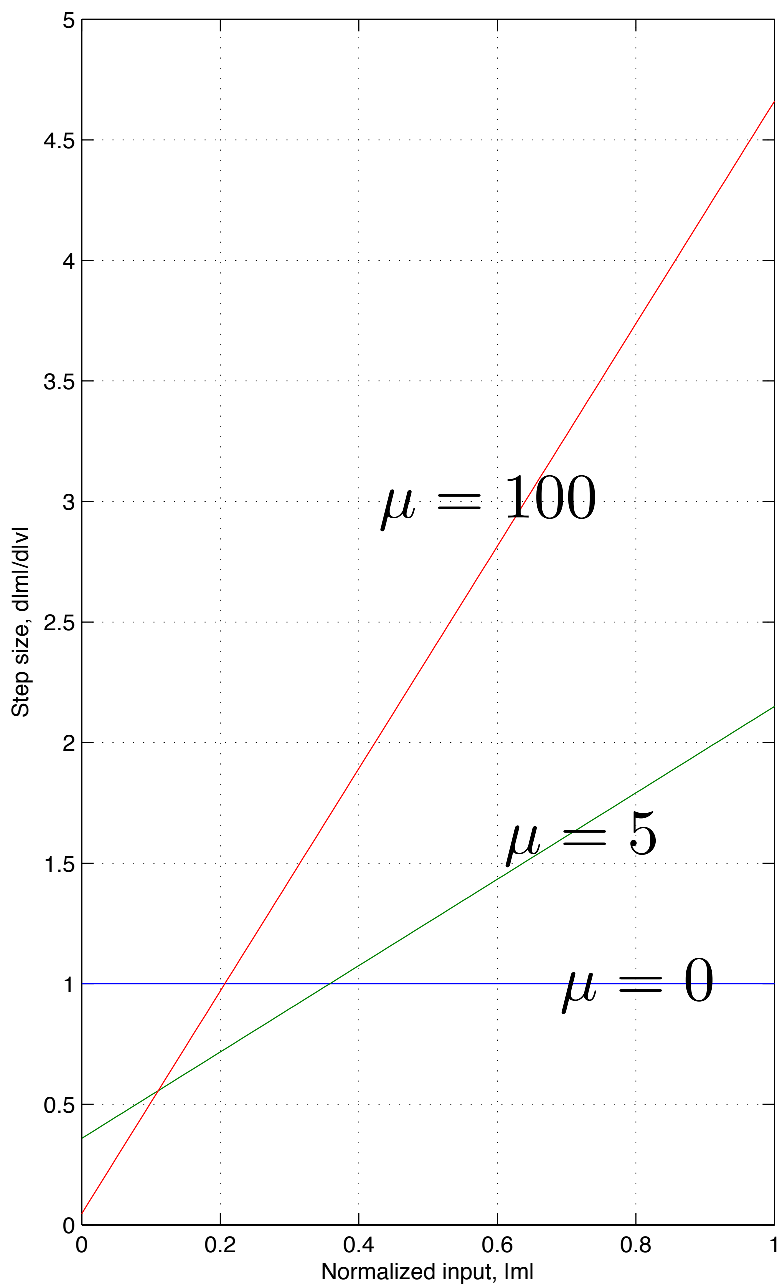
- Two different compressions
  - In practical system, $\mu = 255$ and $A = 100$ or near those values are often used.

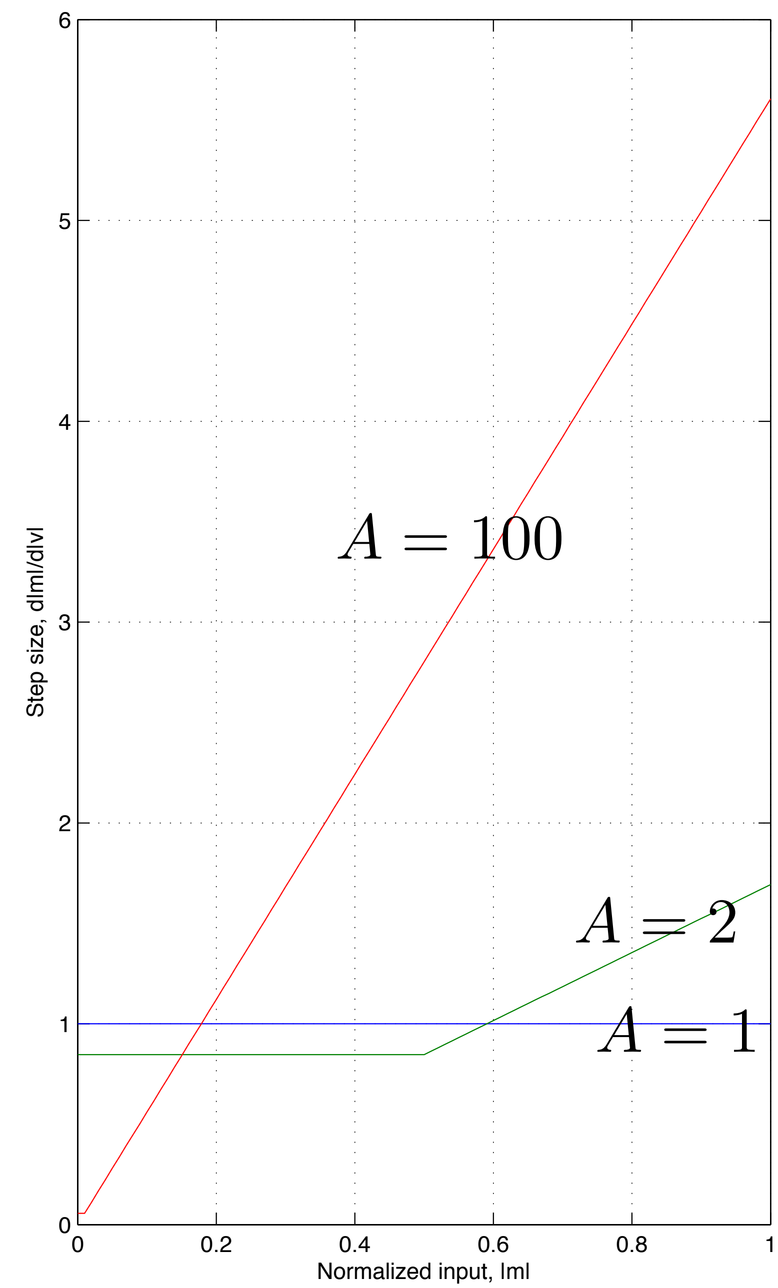




Step size of two different compressors

$$\mu - law: \quad \frac{d|m|}{d|v|} = \frac{\ln(1+\mu)}{\mu}(1+\mu|m|) \;, \quad A - law: \quad \frac{d|m|}{d|v|} = \begin{cases} \frac{1+\ln A}{A}, & 0 \le |m| \le \frac{1}{A} \\ (1+\ln A)|m|, & \frac{1}{A} \le |m| \le 1 \end{cases}$$

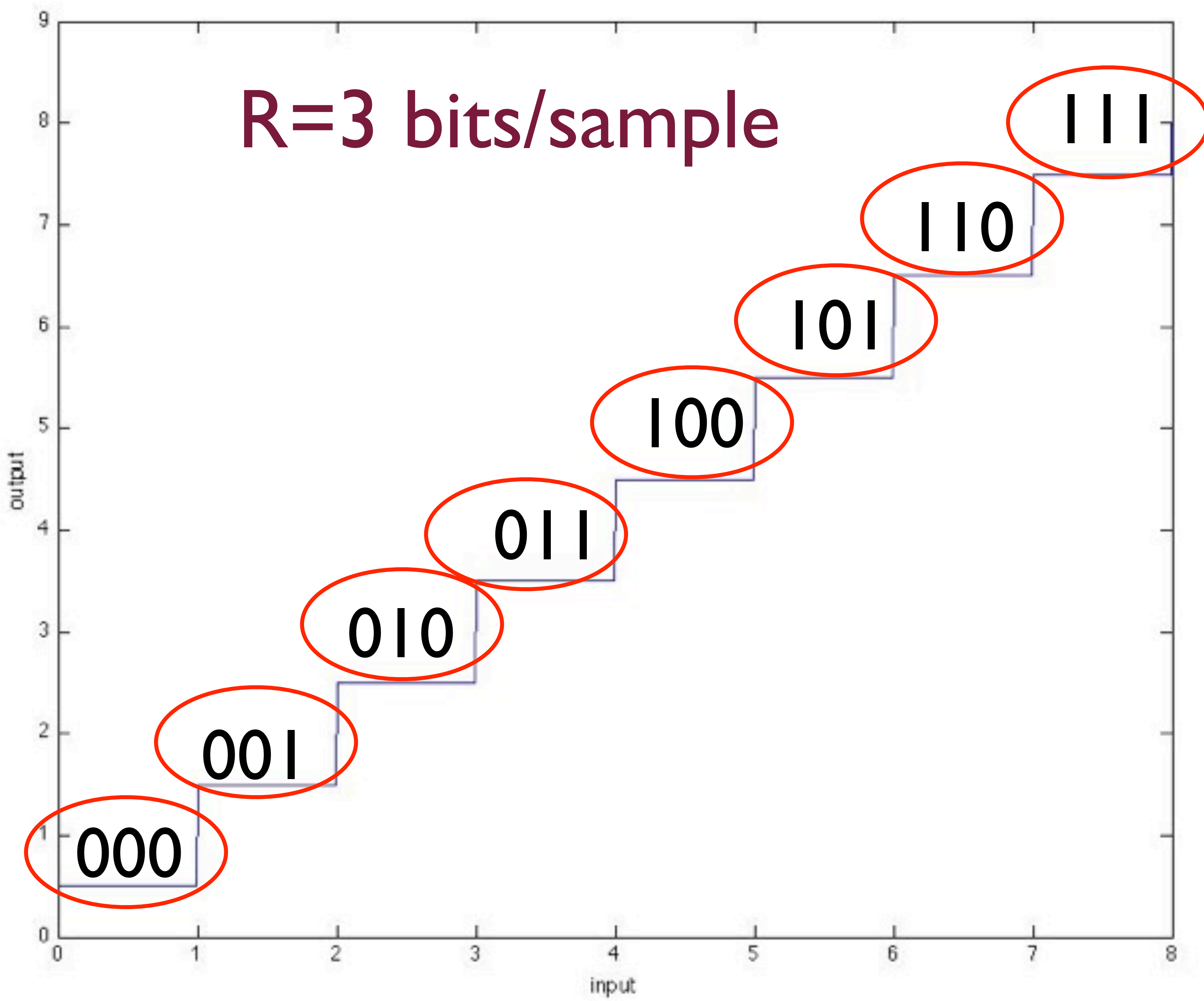




- Encoding
  - Binary encoding
    - The quantized signal in each discrete level is converted into a binary digit which consists of R bits.
    - For example, 256 quantized level can be represented by an 8-bit *code word*.

Encoding

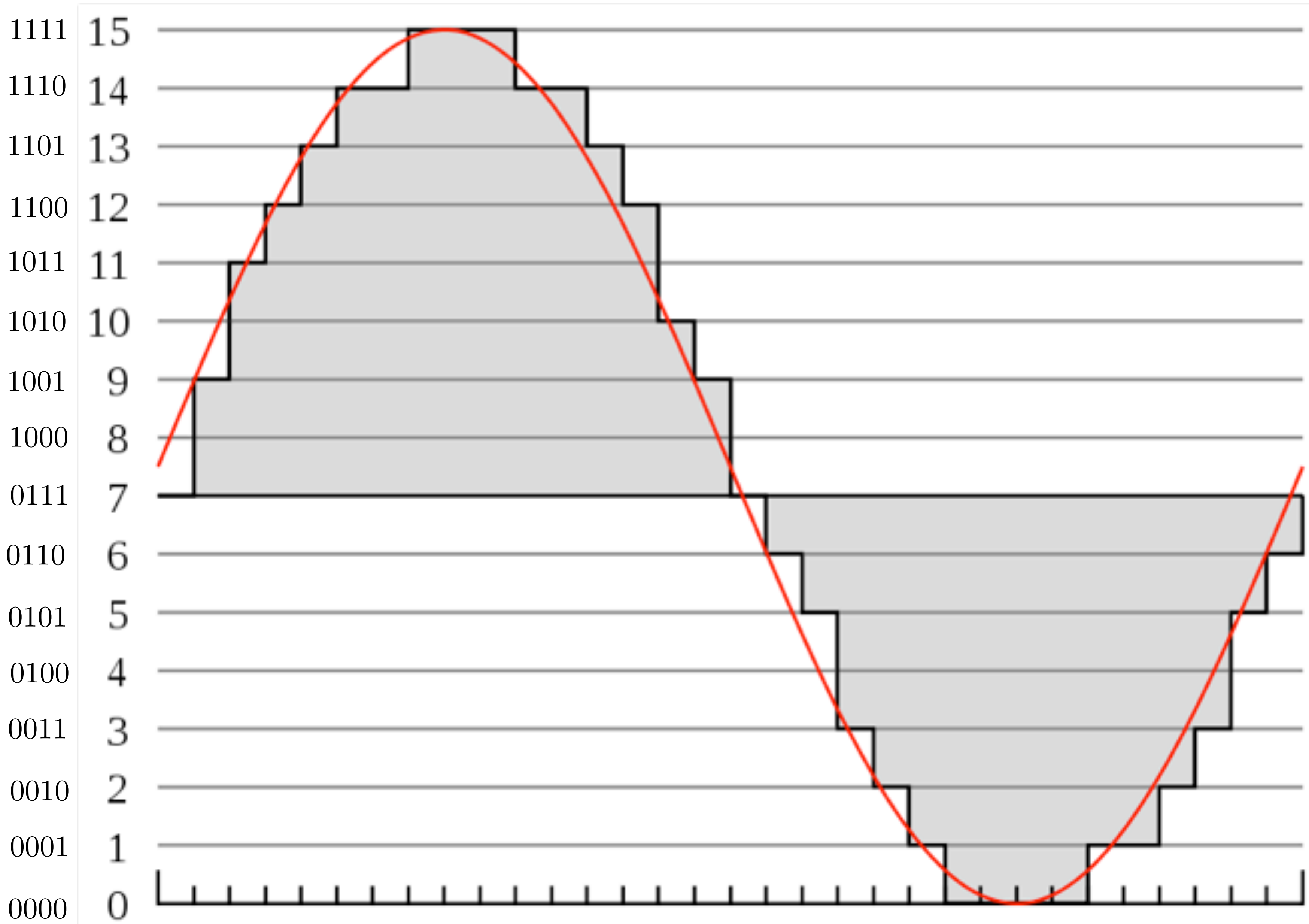
- Sampled value is digitized using the binary digits (bits).



codeword

codeword length= 2^R

Example of PCM



- Encoded PCM sequences: 1001101111001101111011111110110111001010.....

Regeneration of the PCM

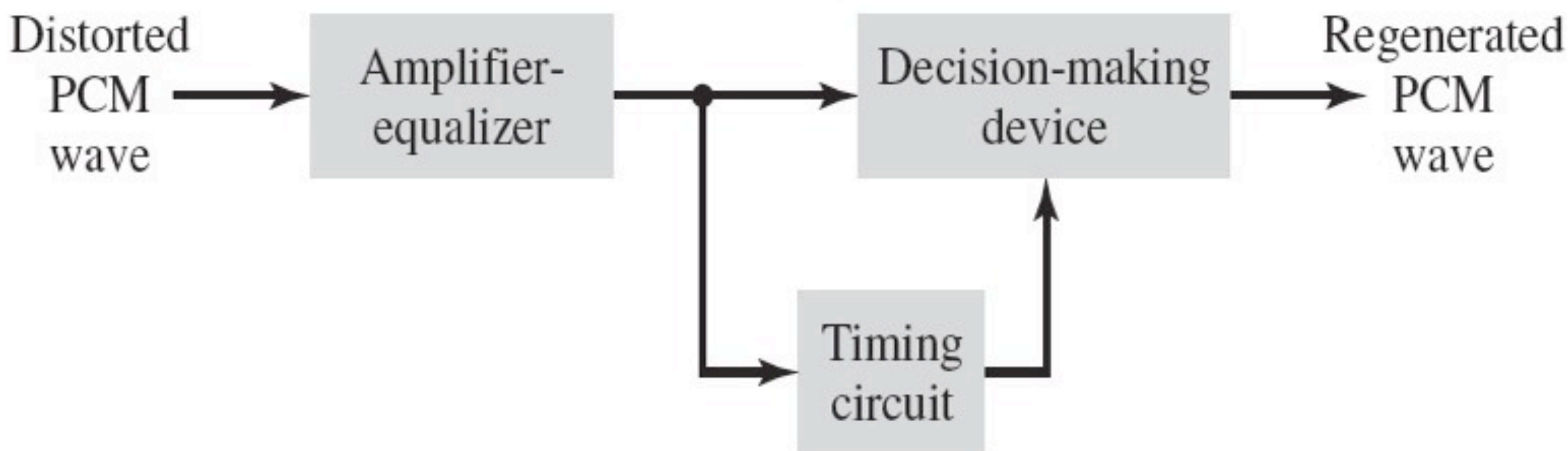


FIGURE 5.13 Block diagram of a regenerative repeater.

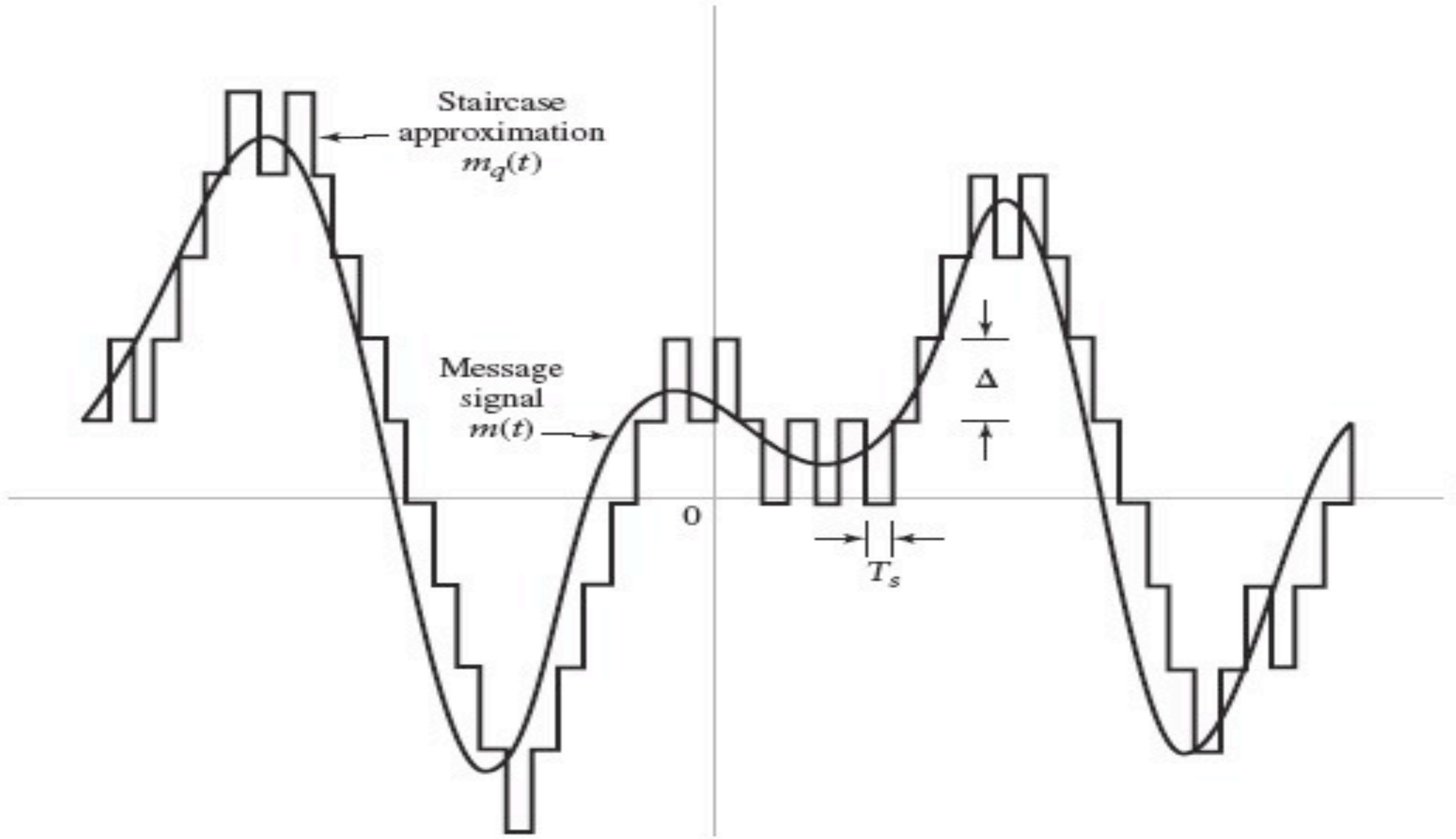
[Ref: Haykin Textbook]

- Operation in the Receiver
  - Decoding and Expanding
    - Decoding: regenerating a pulse whose amplitude is the linear sum of all pulses in the codeword
    - Expander: a subsystem in the receive with a characteristic complementary to the compressor
  - Reconstruction
    - Recover the message signal: passing the expander output through a low-pass reconstruction filter.

Delta Modulation

- An incoming message signal is oversampled to purposely increase the correlation between adjacent samples of the signal.
- The difference between the input signal and its approximation is quantized into only two levels - corresponding to positive and negative differences

$$\begin{aligned} e(nT_s) &= m(nT_s) - m_q(nT_s - T_s) \\ e_q(nT_s) &= \Delta \mathrm{sgn}[e(nT_s)] \\ m_q(nT_s) &= m_q(nT_s - T_s) + e_q(nT_s) \end{aligned}$$



(a)

Binary sequence at modulator output 10111101000000000111111010010101111010000000110111

(b)

FIGURE 5.14 Illustration of delta modulation. (*a*) Analog waveform $m(t)$ and its staircase approximation $m_q(t)$. (*b*) Binary sequence at the modulator output.

[Ref: Haykin Textbook]

- System details
  - Comparator
    - Computes the difference between its two inputs
  - Quantizer
    - Consider of a hard limiter with an input-output characteristic that is a scaled version of the signum function
  - Accumulator
    - Operates on the quantizer output so as to produce an approximation to the message signal

$$
\begin{aligned}
m_q(nT_s) &= m_q(nT_s - T_s) + e_q(nT_s) \\
&= m_q(nT_s - 2T_s) + e_q(nT_s - T_s) + e_q(nT_s) \\
&\vdots \\
&= \sum_{i=1}^{n} e_q(iT_s)
\end{aligned}
$$