Experiment 6
Pulse Code Modulation (PCM)
Part I

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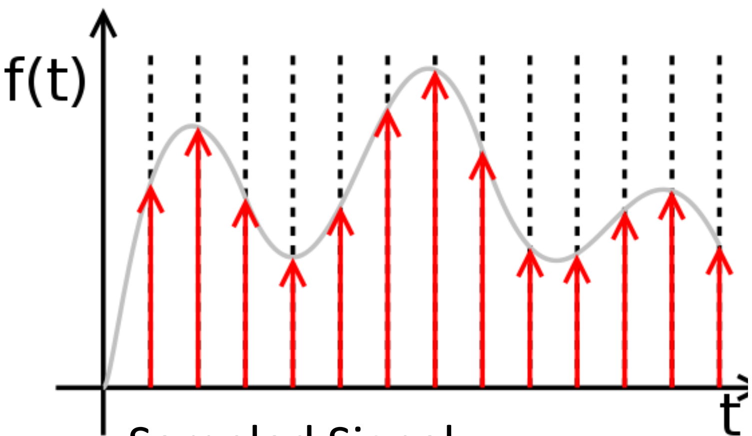
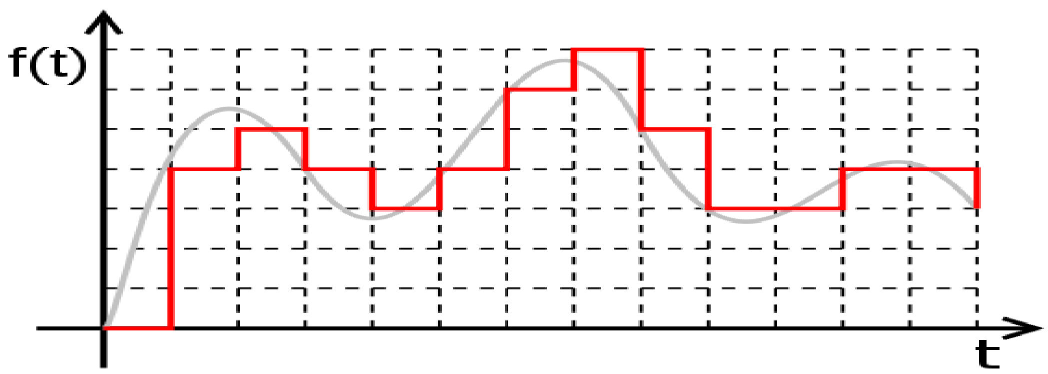
Elements of the PCM System

- The PCM system consists of three parts: Sampler, Quantizer, and Encoder.
- The **sampler** operates at a rate higher than the Nyquist rate. Its input is a continuous-time continuous-amplitude waveform and its output is a discrete-time continuous amplitude waveform. **The sampler was studies in Experiment 5**.
- The **quantizer** transforms the output of the sampler into discrete-time discrete amplitude waveform.
- The **encoder** converts the discrete amplitudes into binary digits.
- In this experiment and the next one, we will consider the following topics:
  - characteristics of the linear and nonlinear quantizers
  - Characteristics of the compressor/expander part of the PCM system
  - Resolution of the quantizer
  - Basics of the encoding part.
  - quantization noise
  - Differential Pulse Code Modulation.

Sampling and Quantization

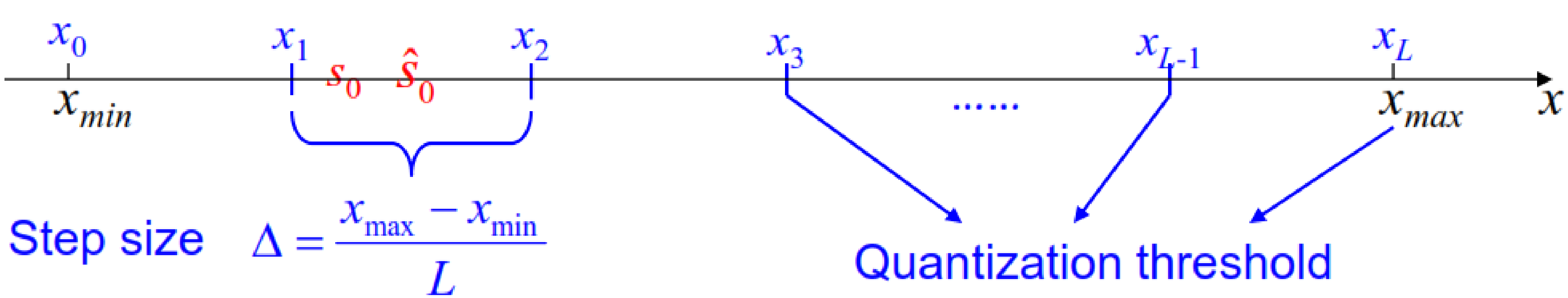


Sampled Signal



Quantized signal, small step size

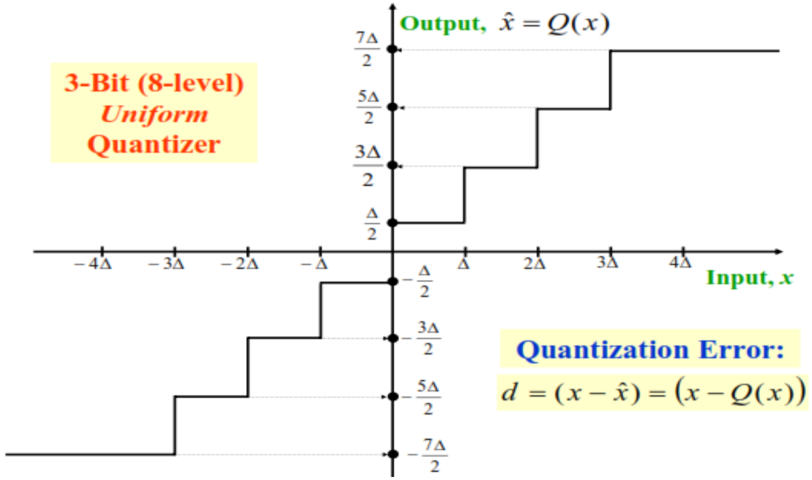
Uniform Quantizer: step size Δ= 2V/L where 2V is the peak to peak value of the message signal, L is the number of quantization levels. where L= 2^r where r is the number of bits



The Uniform Quantization

- The amplitude range of the input signal is partitioned into L intervals such that if $x(kT_s) \in R_i$, the quantizer output will be a level $\hat{x}_i = \{\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_L\}$
- The boundary points separating adjacent regions are called decision levels or threshold levels.
- The qauntizer output is called a representation or reconstruction level
- The spacing between representation levels is called the step size.
- A quantizer is called uniform when the L regions are of equal length and the spacing between representation levels is uniform and equal to Δ.
- Δ/2 is called the resolution of the quantizer
- The input-output characteristic of a uniform quantizer (midrise type) is shown below for L=8.

In the experiment, you will obtain the quantizer characteristic for different values of the step size, i.e., the number of quantization levels.



Uniform and nonuniform quantizers

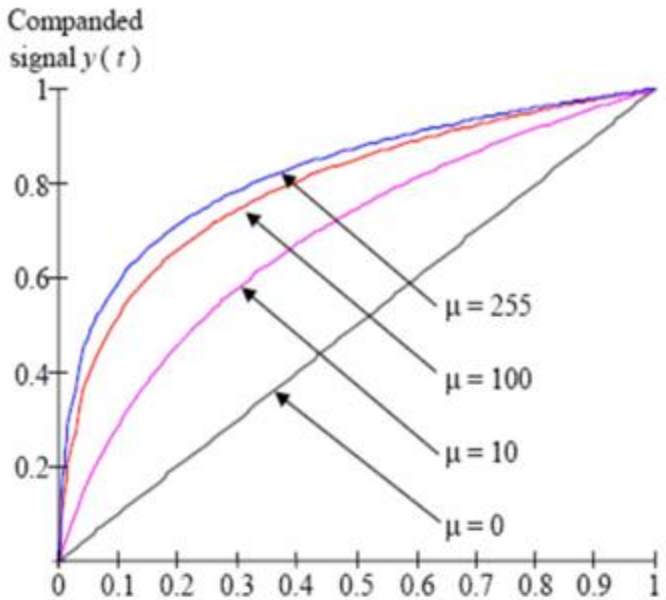
- **Problem with Uniform Quantization**
  - Typically, small signal amplitudes occur more often than large signal amplitudes, especially in speech signals.
  - The signal does not use the entire range of quantization levels available with equal probabilities.
  - Small amplitudes are not represented so well, in the uniform quantizer, as large amplitudes, implying they will be more susceptible to quantization noise.
- **Non-uniform Quantization**
  - A Non-uniform quantizer uses quantization levels of variable spacing, denser at small signal amplitudes, broader at large amplitudes, as we shall see next.
  - We will use a type of nonuniform quantizers called **companding** **t**hat does not require knowledge of the pdf of the signal to be quantized and yields an almost uniform SQNR over a wide range of signal variations.

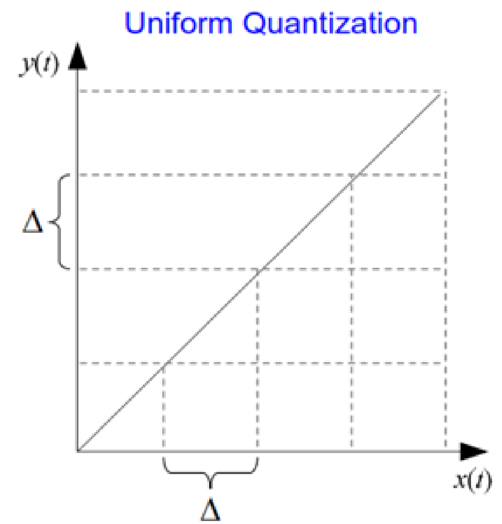
Companding

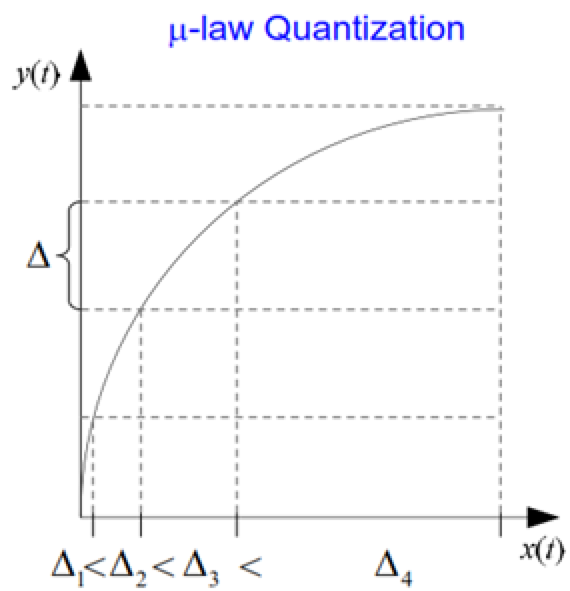
- The process of pre-distorting the signal at the transmitter is known as (signal) **compression**. At the receiver, this process is reversed to remove distortion and is known (signal) **expansion.** The two operations together are typically referred to as **companding**.
- The compressor amplifies weak signal values more than it amplifies large signal values. This will improve the SQNR of the smaller signals but will degrade that for larger signals.
- Since the probability of smaller amplitudes is higher than the larger amplitudes, the overall result is an improvement.
- In North America, μ -law companding (with μ=255) is the standard.
- In summary, companding is performed as follows:
  - Compress the signal using the μ -law. The output is approximately uniformly distributed.
  - Apply the compressed sample to a uniform quantizer
  - Transmit the quantized sample to the receiver.
  - Apply the received sample to the expander. The output is the desired signal value.

Companding

- The characteristic of the non-linear (compressing) and the quantization process are shown next







μ-law :

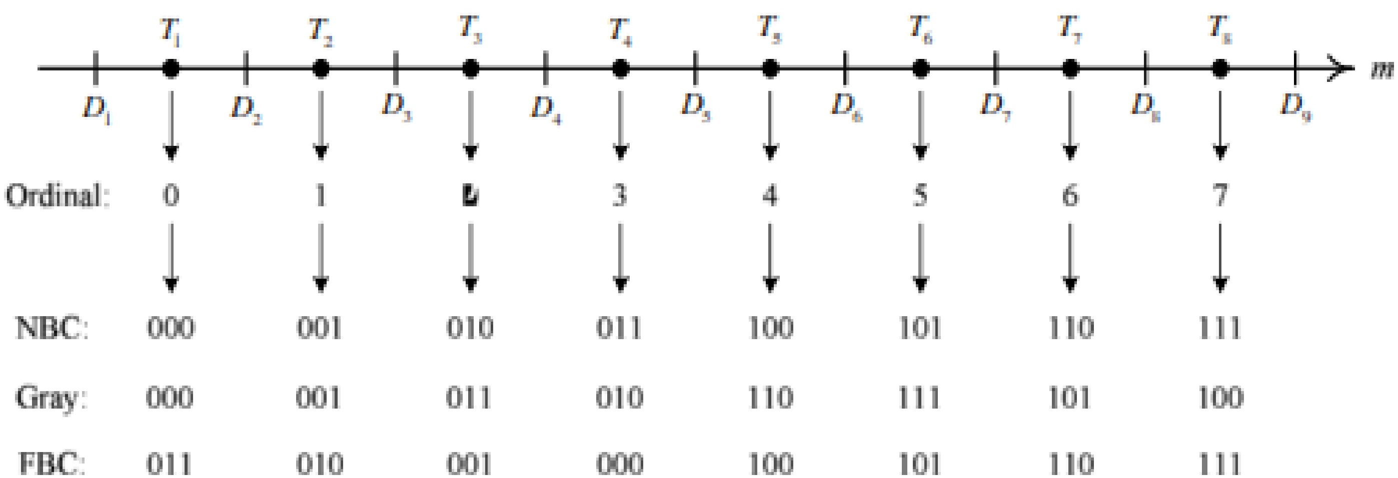
$$y = y_{\max} \frac{\ln[1+\mu(|x|/x_{\max})]}{\ln(1+\mu)} \operatorname{sgn}(x)$$

$$\operatorname{sgn}(x) = 1 \ \text{ if } \ x > 0$$

$$\operatorname{sgn}(x) = -1 \quad \text{if} \quad x < 0$$

Encoding

- It is the assignment of binary digits for each one of the quantized values. There are several mapping encoding schemes. Below, we show the mapping for an 8-level quantizer for three types:
  - Natural Binary
  - Folded Binary
  - Gray Code



Compressor-Expander