8 Introduction to Digital Communications

8.1 Digitization and PCM

8.1. Generally, **analog** signals are continuous in time and in range (amplitude); that is, they have values at every time instant, and their values can be anything within the range. On the other hand, **digital** signals exist only at discrete points of time, and their amplitude can take on only finitely (or countably) many values.

8.2. The **analog-to-digital (A/D) converter** or **ADC** enables digital communication systems to convey analog source signals such as audio and video.

8.3. Suppose we want to convey an *analog* message $m(t)$ from a source to our destination. We now have many options.

(a) Use $m(t)$ to modulate a carrier $A\cos(2\pi f_c t)$ using AM, FM, or PM techniques studied earlier.

(b) **Sample** the continuous-time message $m(t)$ to get a discrete-time message $m[n]$.

Note that $m[n]$ is a sequence of numbers. (There are uncountably many possibilities for these numbers).

(i) Send $m[n]$ using analog pulse modulation techniques (PAM, PWM, PPM).

(ii) **Quantize** $m[n]$ into $m_q[n]$ which has finitely (or countably) many levels.

i. Send $m_q[n]$ using pulse modulation techniques (PAM, PWM, PPM).

ii. **Pulse Code Modulation (PCM)**: Convert $m_q[n]$ into binary sequence. Then use two basic pulses to represent 1 and 0.

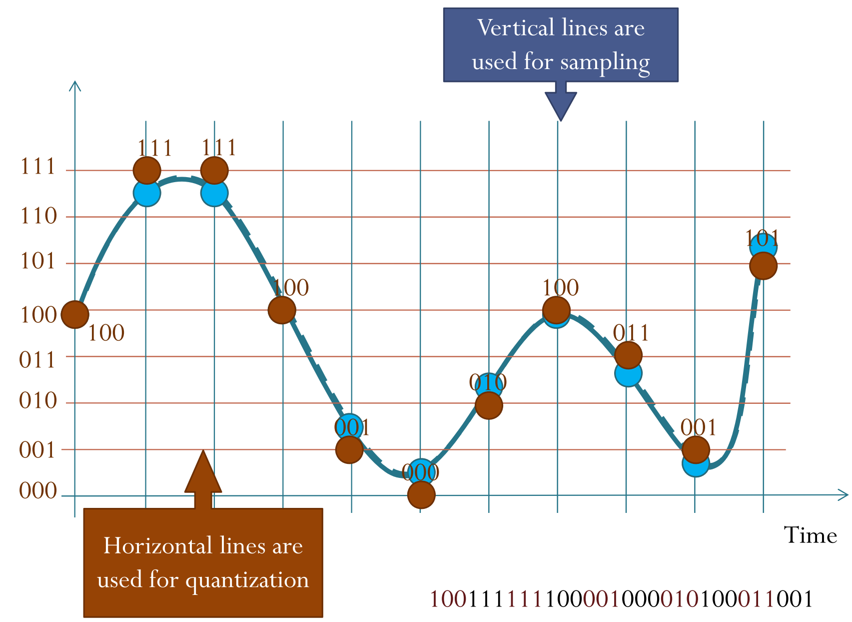

Figure 45: An overview of digitization (sampling + quantizing) and PCM

Definition 8.4. Through **quantization**, each sample is approximated, or "rounded off," to the nearest **quantized level** [5, p 320] or **quantum level** [3, p 545] (permissible number).

- This process introduces permanent errors that appear at the receiver as **quantization noise** in the reconstructed signal.

Example 8.5. Simple quantizer: Suppose amplitudes of the message signal $m(t)$ lie in the range $(-m_p, m_p)$. A simple quantizer may partition the signal range into L intervals. Each sample amplitude is approximated by the midpoint of the interval in which the sample value falls. Each sample is now represented by one of the L numbers.

- Such a signal is known as an L**-ary** digital signal.

8.6. From practical viewpoint, a **binary** digital signal (a signal that can take on only two values) is very desirable because of its simplicity, economy, and ease of engineering. We can convert an L-ary signal into a binary signal by using **pulse coding**.

- A binary digit is called a bit.
- $L = 2^\ell$ levels cam be mapped into (represented by) ℓ bits.

Example 8.7. Suppose $L = 8$. The binary code can be formed by the binary representation of the 8 decimal digits from 0 to 7.

Example 8.8. Telephone (speech) signal:

- The components above 3.4 kHz are eliminated by a low-pass filter.
  - For speech, subjective tests show that signal intelligibility is not affected if all the components above 3.4 kHz are suppressed.
- The resulting signal is then sampled at a rate of 8,000 samples per second (8 kHz).
  - This rate is intentionally kept higher than the Nyquist sampling rate of 6.8 kHz so that realizable filters can be applied for signal reconstruction.
- Each sample is finally quantized into 256 levels ($L = 256$), which requires eight bits to encode each sample ($2^8 = 256$).

[5, p 320]

Example 8.9. Compact disc (CD) audio signal:

- High-fidelity: Require the audio signal bandwidth to be 20 kHz.
- The sampling rate of 44.1 kHz is used.
- The signal is quantized into $L = 65,536$ of quantization levels, each of which is represented by 16 bits (16-bit two's complement integer) to reduce the quantizing error.

[5, p 321]

8.2 Digital PAM Signals

8.10. Digital message representation (at baseband) commonly takes the form of an amplitude-modulated pulse train. We express such signals by writing

$$x(t) = \sum_n m[n]p(t - nT_s)$$

where the modulating amplitude $m[n]$ represents the nth symbol in the message sequence.

- The amplitudes belong to a set $\mathcal{A}$ of M discrete values called the **alphabet**.

8.11. Note that T_s does not necessarily equal the pulse duration but rather the pulse-to-pulse interval or the time allotted to one **symbol**. Thus, the **signaling rate** (or **symbol rate**) is $R_s = \frac{1}{T_s}$. measured in symbols per second, or **baud**.

- In the special but important case of binary signaling ($M = 2$), we write $T_s = T_b$ for the bit duration and the bit rate is $R_b = \frac{1}{T_b}$.

8.12. Figure 46 depicts various PAM formats or **line codes** for the binary message 10110100, taking rectangular pulses for clarity.

(a) The simple on-off waveform in Figure 46a represents each 0 by an "off" pulse and each 1 by an "on" pulse.

  (i) In the a **return-to-zero** (**RZ**) format, the pulse duration is smaller than T_b after which the signal return to the zero level.

  (ii) A **nonreturn-to-zero** (**NRZ**) format has "on" pulses for full bit duration T_b.

(b) The **polar signal** in Figure 46b has opposite polarity pulses

  - Its DC component will be zero if the message contains 1s and 0s in equal proportion.

(c) Figure 46c, we have **bipolar signal** where successive 1s are represented by pulses with alternating polarity.

  - Also known as pseudo-trinary or alternate mark inversion (AMI)

(d) The split-phase **Manchester** format in Figure 46d represents 1s with a positive half-interval pulse followed by a negative half-interval pulse, and vice versa for the representation of 0s.

- Also called twinned binary.
- Guarantee zero DC component regardless of the message sequence.

(e) Figure 46e shows a **quaternary signal** derived by grouping the message bits in blocks of two and using four amplitude levels to prepresent the four possible combinations 00, 01, 10, and 11.

- Quaternary coding can be generalized to **M-ary coding** in which blocks of n message bits are represented by an M-level waveform with $M = 2^n$.

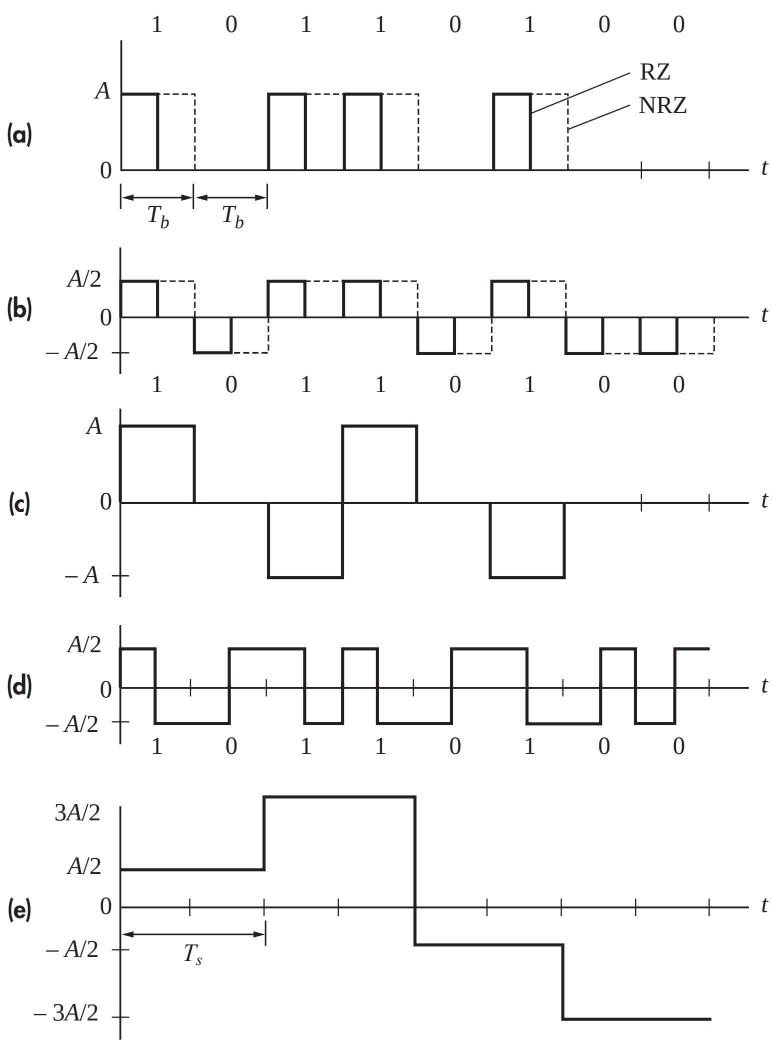

Figure 46: Line codes with rectangular pulses: (a) unipolar RZ and NRZ; (b) polar RZ and NRZ; (c) bipolar NRZ; (d) split-phase Manchester; (e) polar quaternary NRZ.