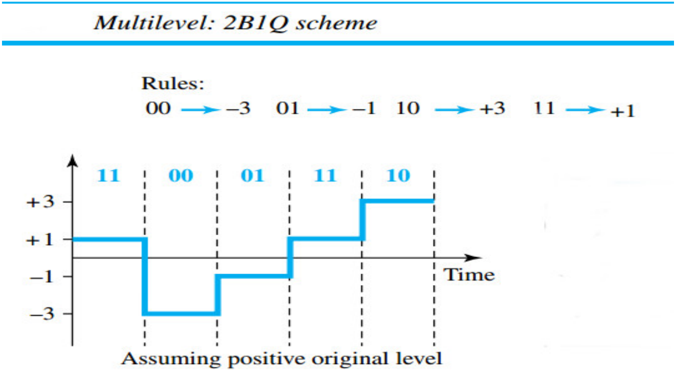
Principles of Data Communications

Reference Book: Data Communications and Networking by Behrouz A. Forouzan

Multilevel Schemes

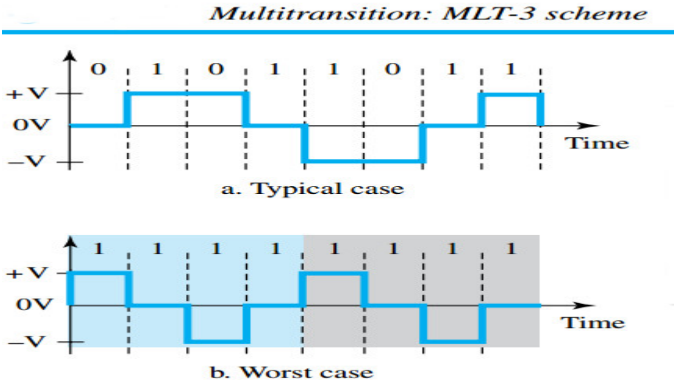
- mBnL - m is the length of the binary pattern, B means binary data, n is the length of the signal pattern, and L is the number of levels in the signaling.
- A letter is often used in place of L: B (binary) for L = 2, T (ternary) for L = 3, and Q (quaternary) for L = 4.
- Note that the first two letters define the data pattern, and the second two define the signal pattern.

2B1Q



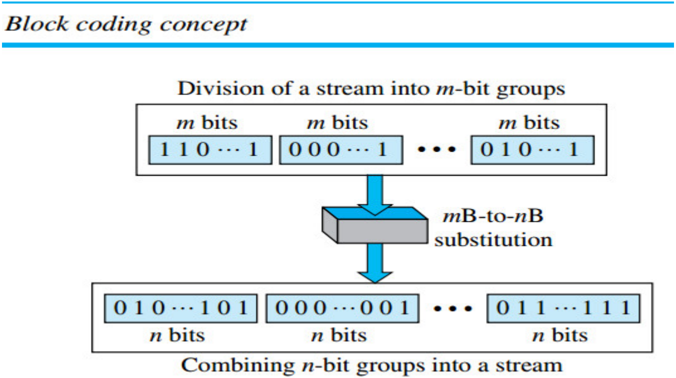
- Two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal. In this type of encoding m = 2, n = 1, and L = 4 (quaternary).
- The 2B1Q scheme is used in DSL (Digital Subscriber Line) technology to provide a high-speed connection to the Internet by using subscriber telephone lines

Multitransition: MLT-3



- The multiline transmission, three-level (MLT-3) scheme uses three levels (+V, 0, and -V) and three transition rules to move between the levels.
    - If the next bit is 0, there is no transition.
    - If the next bit is 1 and the current level is not 0, the next level is 0.
    - If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

Block Coding



- Block coding changes a block of m bits into a block of n bits, where n is larger than m. Block coding is referred to as an mB/nB encoding technique.
- Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.

4B/5B

- In 4B/5B encoding we substitute a 4-bit group with a 5-bit group.
- Finally, the n-bit groups are combined to form a stream. The new stream has more bits than the original bits.

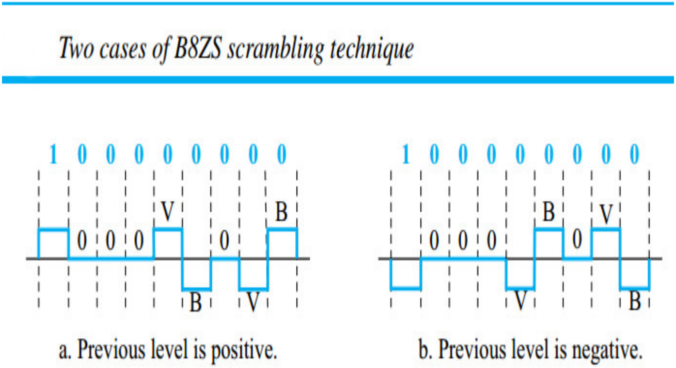
Scrambling

- A solution that substitutes long zero-level pulses with a combination of other levels.
- Two common scrambling techniques:
  - B8ZS
  - HDB3

B8ZS

- Bipolar with 8-zero substitution (B8ZS) is commonly used in North America.
- In this technique, eight consecutive zero-level voltages are replaced by the sequence 000VB0VB.
- The V in the sequence denotes violation; this is a nonzero voltage that breaks an AMI rule of encoding (opposite polarity from the previous).
- The B in the sequence denotes bipolar, which means a nonzero level voltage in accordance with the AMI rule.

B8ZS



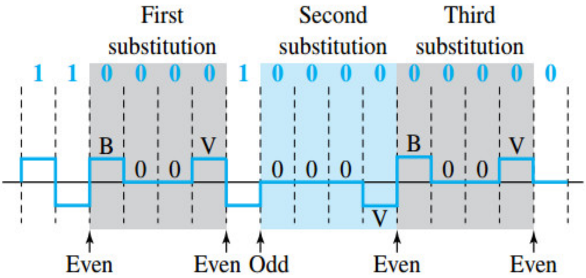
- B8ZS substitutes eight consecutive zeros with 000VB0VB.
- The V (violation) means the same polarity as the polarity of the previous nonzero pulse; B (bipolar) means the polarity opposite to the polarity of the previous nonzero pulse.

HDB3

- High-density bipolar 3-zero (HDB3) is commonly used outside of North America.
- In this technique, which is more conservative than B8ZS, four consecutive zero-level voltages are replaced with a sequence of 000V or B00V

HDB3

Different situations in HDB3 scrambling technique



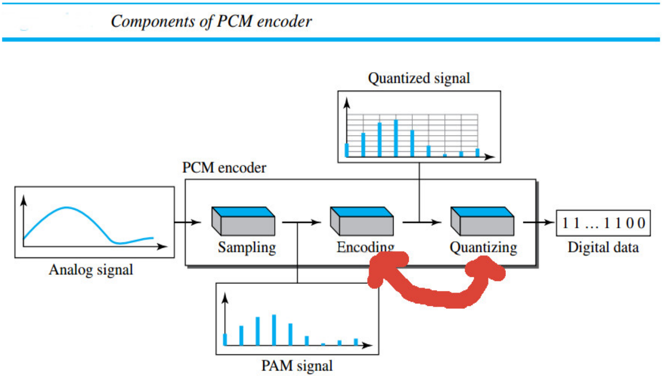
- The two rules can be stated as follows:
  - If the number of nonzero pulses after the last substitution is odd, the substitution pattern will be 000V, which makes the total number of nonzero pulses even.
  - If the number of nonzero pulses after the last substitution is even, the substitution pattern will be B00V, which makes the total number of nonzero pulses even.

- First, before the first substitution, the number of nonzero pulses is even, so the first substitution is B00V.
- After this substitution, the polarity of the 1 bit is changed because the AMI scheme, after each substitution, must follow its own rule.
- After this bit, we need another substitution, which is 000V because we have only one nonzero pulse (odd) after the last substitution.
- The third substitution is B00V because there are no nonzero pulses after the second substitution (even).
- HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution.

ANALOG-TO-DIGITAL CONVERSION

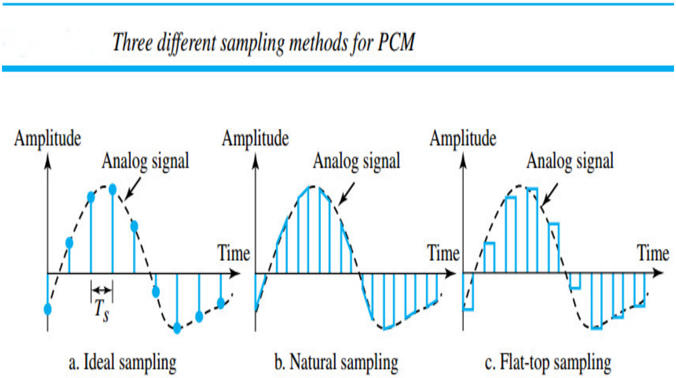
- Sometimes, however, we have an analog signal such as one created by a microphone or camera.
- Change an analog signal to digital data.
- Two techniques: pulse code modulation and delta modulation.
- After the digital data are created (digitization), we can use one of the techniques described earlier to convert the digital data to a digital signal.

Pulse Code Modulation (PCM)



- The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).
- A PCM encoder has three processes:
  - The analog signal is sampled.
  - The sampled signal is quantized.
  - The quantized values are encoded as streams of bits.

Sampling

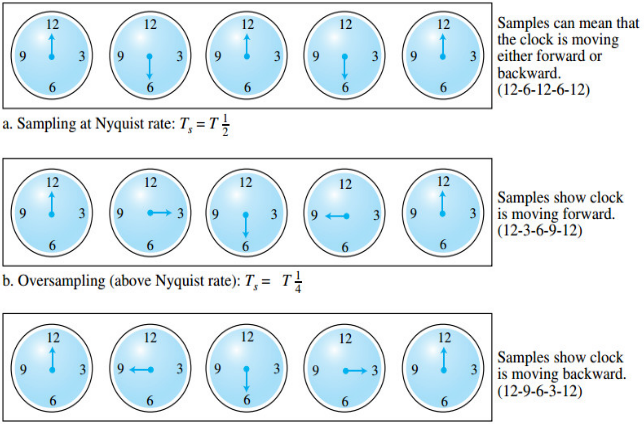


- The first step in PCM is sampling. The analog signal is sampled every T_s s, where T_s is the sample interval or period.
- The inverse of the sampling interval is called the sampling rate or sampling frequency and denoted by f_s, where $f_s = 1/T_s$.
- There are three sampling methods: ideal, natural, flat-top

- One important consideration is the sampling rate or frequency.
- What are the restrictions on T_s? This question was answered by Nyquist.
- **According to the Nyquist theorem, to reproduce the original analog signal, one necessary condition is that the sampling rate be at least twice the highest frequency in the original signal.**
- **According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.**

Sampling

Sampling of a clock with only one hand



a. Sampling at Nyquist rate: $T_s = T\frac{1}{2}$

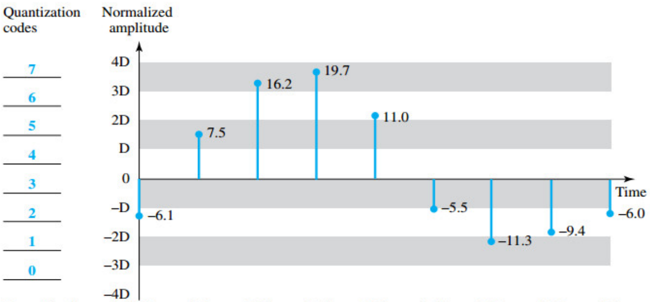
b. Oversampling (above Nyquist rate): $T_s = T\frac{1}{4}$

c. Undersampling (below Nyquist rate): $T_s = T\frac{3}{4}$

Quantization

- The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal.
- The following are the steps in quantization:
    - We assume that the original analog signal has instantaneous amplitudes between V_{min} and V_{max}.
    - We divide the range into L zones, each of height Δ.
    - $\Delta = (V_{max} - V_{min})/L$
    - We assign quantized values of 0 to $L - 1$ to the midpoint of each zone.
    - We approximate the value of the sample amplitude to the quantized values.
- As a simple example, assume that we have a sampled signal and the sample amplitudes are between -20 and +20 V.
- We decide to have eight levels (L = 8). This means that $\Delta = 5V$.

Quantization and encoding of a sampled signal

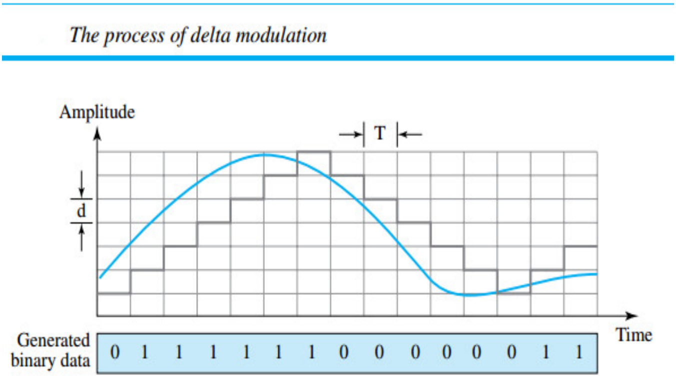


Normalized PAM values	–1.22	1.50	3.24	3.94	2.20	–1.10	–2.26	–1.88	–1.20
Normalized quantized values	–1.50	1.50	3.50	3.50	2.50	–1.50	–2.50	–1.50	–1.50
Normalized error	–0.38	0	+0.26	–0.44	+0.30	–0.40	–0.24	+0.38	–0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Quantization

- The value at the top of each sample in the graph shows the actual amplitude.
- In the chart, the first row is the normalized value for each sample (actual amplitude/Δ).
- The quantization process selects the quantization value from the middle of each zone.
- This means that the normalized quantized values (second row) are different from the normalized amplitudes.
- The difference is called the normalized error (third row).
- The fourth row is the quantization code for each sample based on the quantization levels at the left of the graph.
- The encoded words (fifth row) are the final products of the conversion.

Delta Modulation (DM)



- PCM is a very complex technique. Other techniques have been developed to reduce the complexity of PCM. The simplest is delta modulation. PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample.

Summary

- Line Coding
- Block Coding
- Scrambling
- Analog to Digital Conversion

THANK YOU