CSE3020 - Network Technology

4 - Data Encoding

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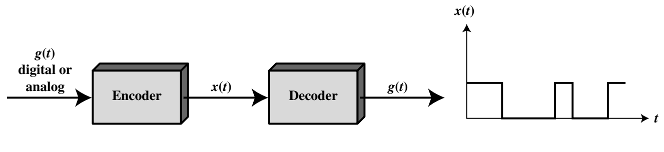
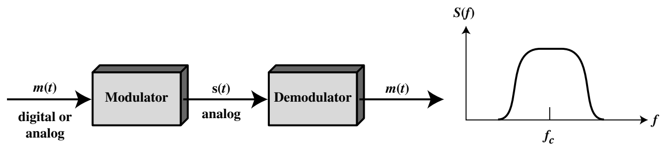
Note: These slides contain figures from Stallings, and are based on a set developed by Dr. A Pullin.

Encoding Techniques

1. Digital data, digital signal.
2. Digital data, analog signal.
3. Analog data, digital signal.
4. Analog data, analog signal.



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

1. Digital Data, Digital Signal

- Digital signal:
  - Discrete, discontinuous voltage pulses.
  - Each pulse is a signal element.
  - Binary data encoded into signal elements.
- **Unipolar -** All signal elements have the same sign.
- **Polar -** One logic state represented by positive voltage the other by negative voltage.
- **Data rate -** Rate of data transmission in bits per second.
- **Duration or length of a bit -** Time taken for transmitter to emit the bit ($1/Re$).
- **Modulation rate -**
  - Rate at which the signal level changes.
  - Measured in baud = signal elements per second.
- **Mark and Space -** Binary 1 and Binary 0 respectively.

Interpreting Signals

- Need to know:
  - Timing of bits - when they start and end.
  - Signal levels - determine high (1) or low (0).
- Factors affecting successful interpreting of signals:
  - Data rate - increase produces higher bit error rate (BER).
  - Signal to noise ratio - increase provides lower bit error rate.
  - Bandwidth - increase allows higher data rate.
- Encoding scheme may improve the performance of signal interpretation.

Comparison of Encoding Schemes

- Signal Spectrum:
  - Lack of high frequencies reduces required bandwidth.
  - Lack of dc component allows ac coupling via transformer, providing isolation (reduces interference).
  - Concentrate power in the middle of the bandwidth (avoid poor band edges).
- Clocking:
  - Need to synchronize the transmitter and receiver.
  - Could provide an external clock - expensive.
  - Sync mechanism based on signal.
- Error detection:
  - Can be built in to signal encoding.
- Signal interference and noise immunity:
  - Some codes are better than others in the presence of noise.
- Cost and complexity:
  - Higher signal rate (and thus data rate) lead to higher costs.
  - Some codes require signal rate greater than data rate.

Encoding Schemes

- Nonreturn to Zero-Level (NRZ-L).
- Nonreturn to Zero Inverted (NRZI).
- Bipolar-AMI.
- Pseudoternary.
- Manchester.
- Differential Manchester.
- B8ZS.
- HDB3.

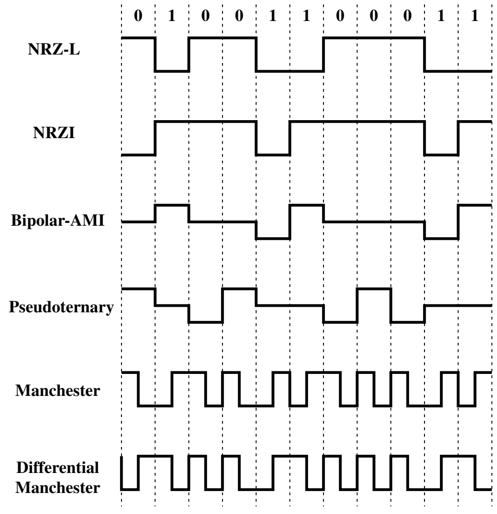
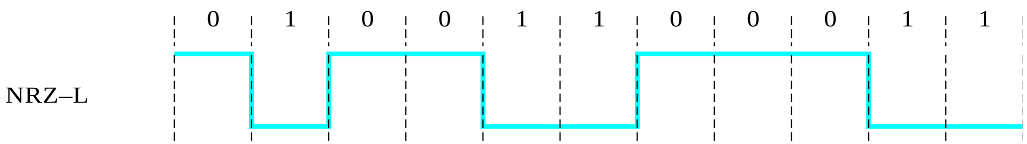


Figure 5.2 Digital Signal Encoding Formats

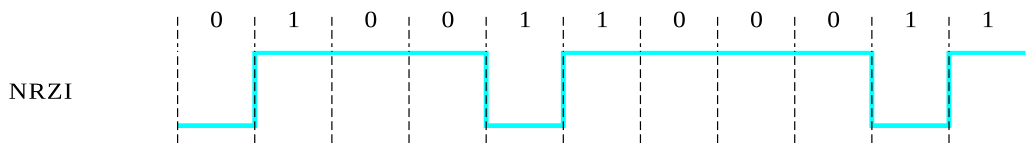
Nonreturn to Zero-Level (NRZ-L)

- Simple: two different voltages for 0 and 1 bits.
- Voltage constant during bit interval:
  - No transition, i.e. no return to zero voltage.
- e.g. Absence of voltage for zero, constant positive voltage for one.
- More often, negative voltage for one value and positive for the other.
- This is NRZ-Level (NRZ-L).



Nonreturn to Zero Inverted

- Nonreturn to zero inverted on ones.
- Constant voltage pulse for duration of bit.
- Data encoded as presence or absence of signal transition at beginning of bit time.
- Transition (low to high or high to low) denotes a binary 1.
- No transition denotes binary 0.
- An example of differential encoding:
  - Data represented by changes rather than levels.
  - More reliable detection of transition rather than level.
  - In complex transmission layouts it is easy to lose sense of polarity.

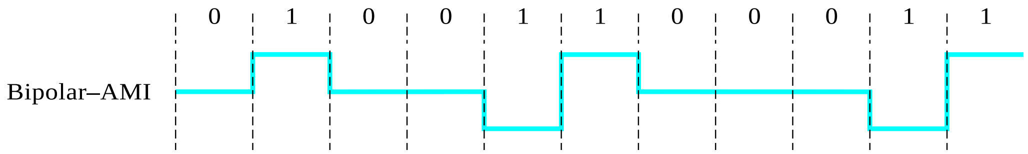


NRZ Pros and Cons

- Pros:
  - Easy to engineer.
  - Make good use of bandwidth.
- Cons:
  - dc component.
  - Lack of synchronization capability.
- Used for magnetic recording due to simplicity and low frequency.
- Not often used for signal transmission applications.

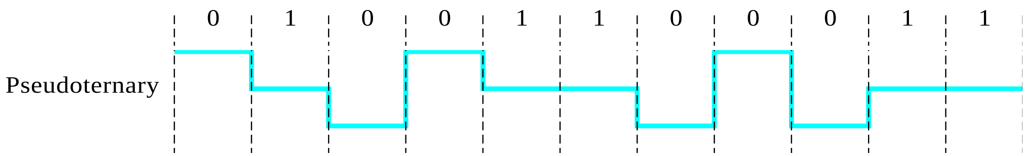
Multilevel Binary

- Use more than two levels.
- Bipolar-AMI (alternate mark inversion):
  - Zero represented by no line signal.
  - One represented by positive or negative pulse.
  - One pulses alternate in polarity.
  - No loss of sync if a long string of ones (zeros still a problem).
  - No net dc component.
  - Lower bandwidth than NRZ.
  - Simple error detection.



Pseudoternary

- An exchange of mark for space in AMI:
  - One represented by absence of line signal.
  - Zero represented by alternating positive and negative.
- No advantage or disadvantage over bipolar-AMI.



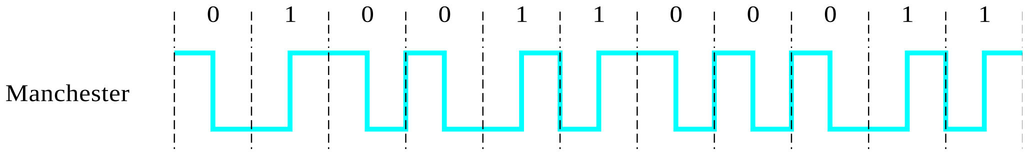
- Some degree of synchronisation provided by multilevel binary signals.
- Still problems with a long string of 0s (AMI) or 1s (pseudoternary).

Tradeoff for Multilevel Binary

- With suitable modification can overcome problems with NRZ codes.
- However, not as efficient as NRZ:
  - Each signal element only represents one bit.
  - In a 3 level system could represent $\log_2 3 = 1.58$ bits.
  - Receiver must distinguish between three levels (+A, -A, 0) instead of two.
  - Requires approx. 3dB more signal power for same probability of bit error.

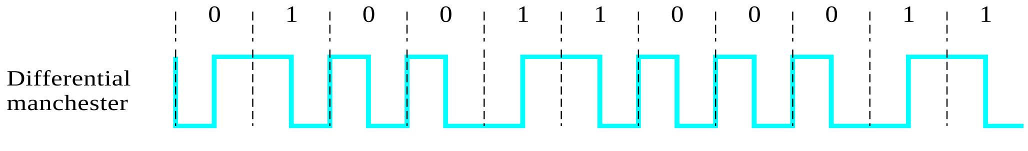
Biphase - Manchester

- Transition in the middle of each bit period.
- Transition serves as clock and data.
- Low to high represents one.
- High to low represents zero.
- Used by IEEE 802.3 - baseband coax and twisted-pair CSMA/CD bus LANs.



Biphase - Differential Manchester

- Mid-bit transition is clocking only.
- Transition at start of a bit period represents zero.
- No transition at start of a bit period represents one.
- Note: this is a differential encoding scheme.
- Used by IEEE 802.5 - STP token ring LAN.



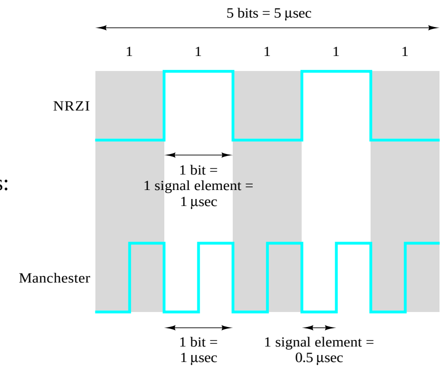
Biphase Pros and Cons

- Con:
  - At least one transition per bit time and possibly two.
  - Maximum modulation rate is twice NRZ.
  - Requires more bandwidth.
- Pros:
  - Synchronization on mid bit transition (self clocking).
  - No dc component.
  - Error detection:
    - Absence of expected transition.
    - Noise would have to invert both before and after expected transition.

Modulation/Baud Rate

- Baud rate, also known as signaling rate or modulation rate:
  - Signal elements per second (baud).
  - The rate at which signal elements are transmitted.
  - Bit rate = baud rate $\times M$, where M is the number of bits per signal element.
  - For two-level signaling (binary), bit rate is equal to the baud rate.

A stream of binary ones at 1 Mbps:



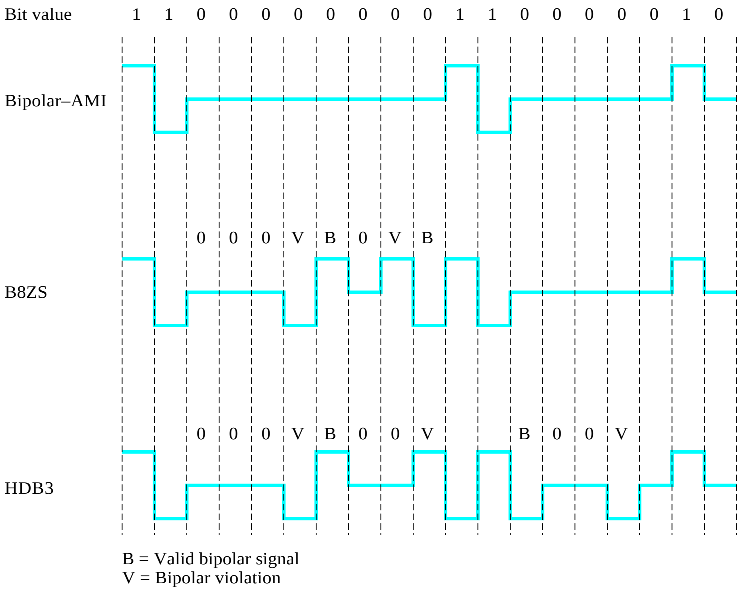
Scrambling

- Biphase techniques require high signaling rate: improve multilevel binary techniques.
- Use scrambling to replace sequences that would produce constant voltage.
- Filling sequence:
  - Must produce enough transitions to sync.
  - Must be recognized by receiver and replace with original data.
  - Same length as original: no data rate increase.
- Design goals:
  - No dc component.
  - No long sequences of zero level line signal.
  - No reduction in data rate.
  - Error detection capability.

Scrambling Techniques

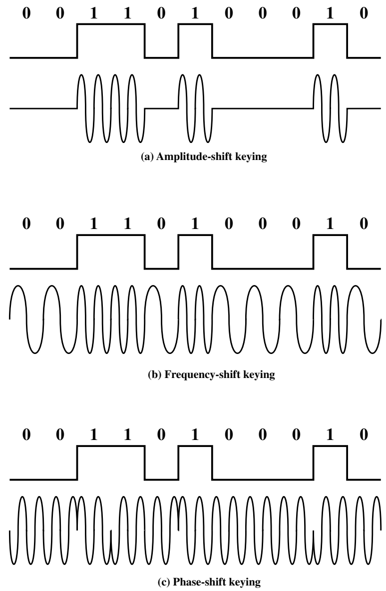
- Two techniques commonly used in long-distance transmission.
- Based on bipolar-AMI.
- B8ZS:
  - Bipolar with 8 Zeros Substitution.
  - If octet of all zeros and last voltage pulse preceding was positive encode as 000+-0-+
  - If octet of all zeros and last voltage pulse preceding was negative encode as 000-+0+-
  - Causes two violations of AMI code.
  - Unlikely to occur as a result of noise.
  - Receiver detects and interprets as octet of all zeros.
- HDB3:
  - High Density Bipolar 3 zeros.
  - String of four zeros replaced with one or two pulses.

B8ZS and HDB3



2. Digital Data, Analog Signal

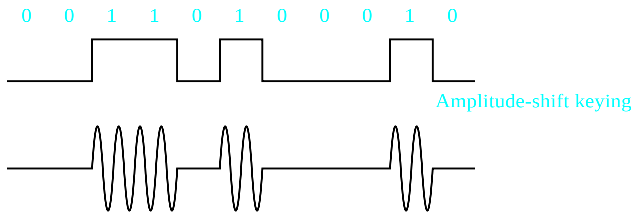
- Public telephone system:
  - Designed for 300Hz to 3400Hz analog signals.
  - Use modem (modulator-demodulator).
  - Same techniques can be used at higher frequencies (e.g. microwave).
- Perform operations on one or more of the carrier signals characteristics:
  - Amplitude shift keying (ASK).
  - Frequency shift keying (FSK).
  - Phase shift keying (PSK).



Amplitude Shift Keying

- Values represented by different amplitudes of the carrier.
- Usually, one amplitude is zero.
  - i.e. presence and absence of carrier is used.
- Susceptible to sudden gain changes.
- Inefficient.
- Up to 1200bps on voice grade lines.
- Used over optical fiber.

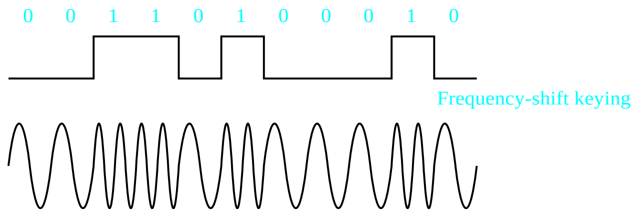
$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{bin } 1 \\ 0 & \text{bin } 0 \end{cases}$$



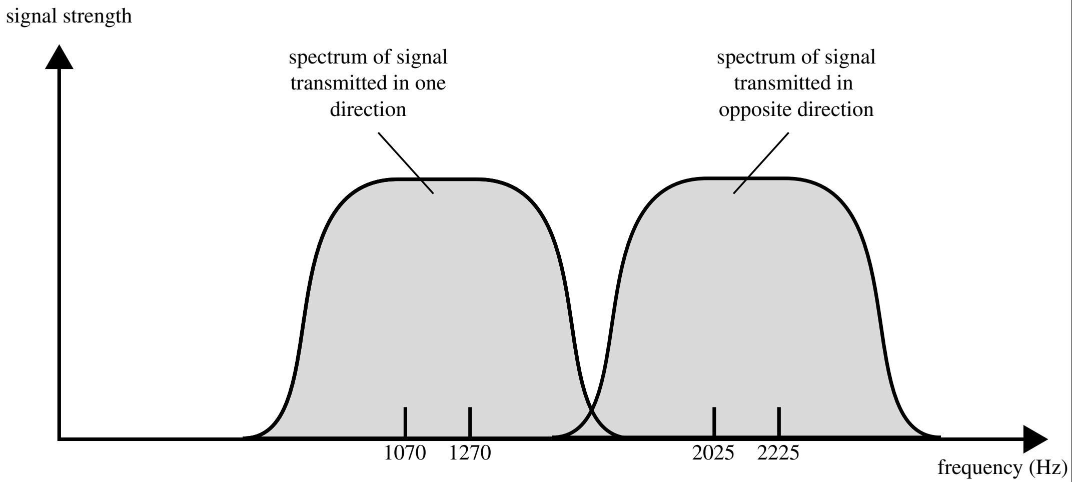
Frequency Shift Keying

- Values represented by different frequencies (near the carrier).
- Less susceptible to error than ASK.
- Up to 1200bps on voice grade lines.
- High frequency radio.
- Even higher frequency on LANs using coaxial cable.

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{bin } 1 \\ A\cos(2\pi f_2 t) & \text{bin } 0 \end{cases}$$



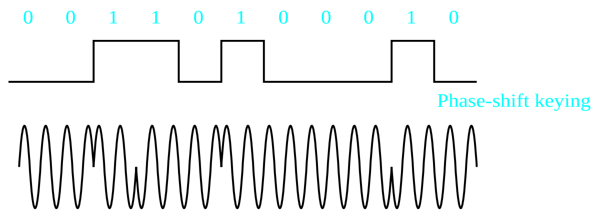
Full-Duplex FSK on a Voice Grade Line



Phase Shift Keying

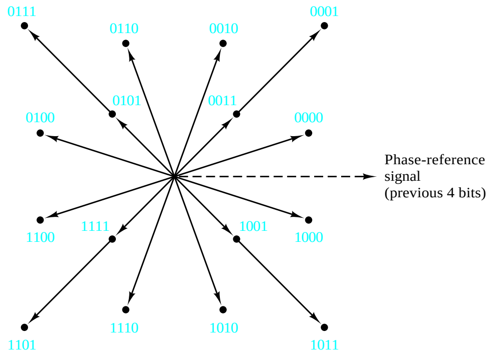
- Phase of carrier signal is shifted to represent data.
- Differential PSK:
  - Phase shifted relative to previous transmission rather than some reference signal.

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \pi) & \text{bin } 1 \\ A\cos(2\pi f_c t) & \text{bin } 0 \end{cases}$$



Quadrature PSK

- More efficient use by each signal element representing more than one bit:
  - e.g. shifts of $\pi/2$ (90°).
  - Each signal element (phase shift) represents two bits.
  - Can use 8 phase angles and have more than one amplitude.
  - Example: 9600bps modem use 12 angles, four of which have two amplitudes (QAM).

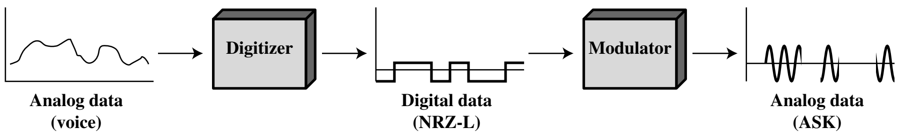


Performance of Digital to Analog Modulation Schemes

- In the previous example, 4 bits per signal element: modulation rate is (bit rate)/4:
  - Therefore 9600 bps at 2400 baud.
  - $D = \frac{R}{b} = \frac{R}{\log_2 L}$
  - D = modulation rate, R = bit rate, L = signal elements, b = bit/element.
- Bandwidth:
  - ASK and PSK bandwidth directly related to bit rate.
  - FSK bandwidth related to data rate for lower frequencies, but to offset of modulated frequency from carrier at high frequencies.
  - (See Stallings for math).
- In the presence of noise, bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK.

3. Analog Data, Digital Signal

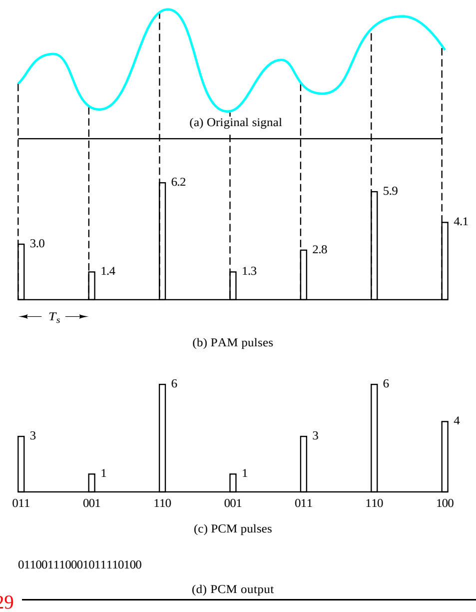
- Digitization:
  - Conversion of analog data into digital data.
    - Digital data can then be transmitted using NRZ-L digital signal.
    - Digital data can then be transmitted using code other than NRZ-L.
    - Digital data can then be converted to analog signal.
  - Analog to digital conversion done using a codec.
    - Pulse code modulation.
    - Delta modulation.

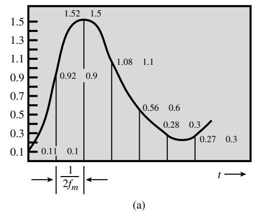


Pulse Code Modulation (PCM)

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal.
  - (Proof - Stallings appendix 4A)
- Voice data limited to below 4000Hz - require 8000 sample per second.
- Analog samples (Pulse Amplitude Modulation, PAM).
- Each sample assigned a digital value (e.g. 4 bit system gives 16 levels).
- Samples are quantized:
  - Approximations mean it is impossible to recover original exactly.
  - Quantizing error or noise.
  - n-bit encoding, there are 2^n levels: SNR = $20\log 2^n + 1.76$ dB $\approx 6n$ dB.
- Using 8 bit samples gives 256 levels - quality comparable with analog transmission.
- Therefore, 8000 samples per second of 8 bits each gives 64kbps.

PCM

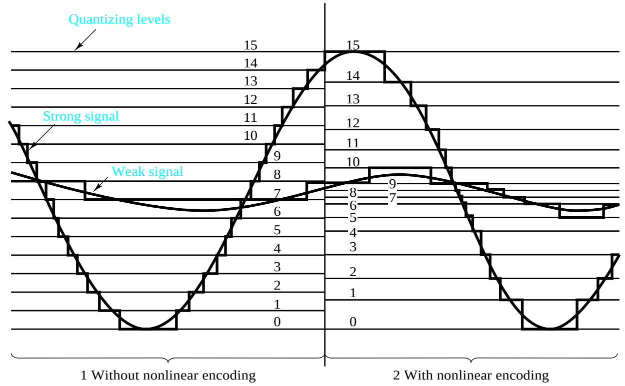




Digit	Binary Equivalent	PCM waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	

Nonlinear Encoding

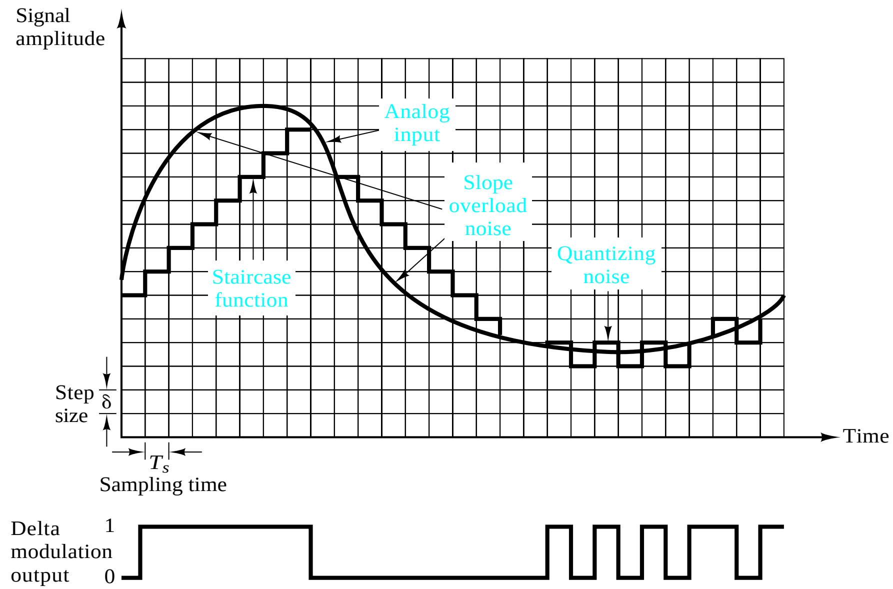
- Quantization levels not evenly spaced.
- Reduces overall signal distortion: lower amplitudes are less distorted.
- Can also be done by companding (24-30dB improvement for voice):
  - Uniform quantisation followed by compressing (expanding) the input.



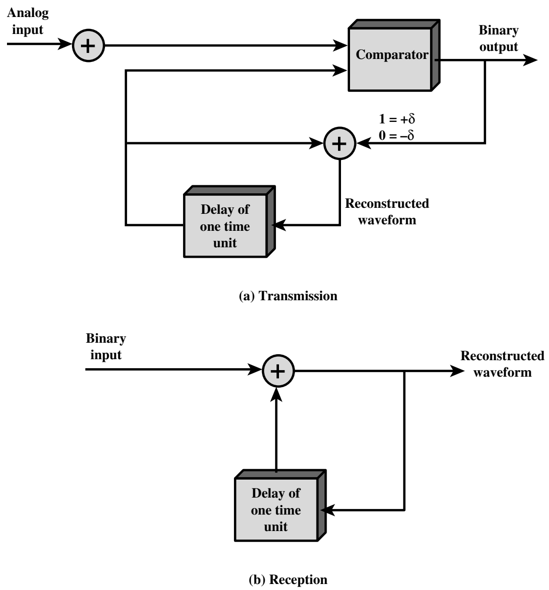
Delta Modulation (DM)

- Reduce complexity of PCM (at the expense of quality).
- Analog input is approximated by a staircase function.
- Move up or down one quantisation level (δ) at each sample interval T_S.
- Binary behavior:
  - Function moves up or down by δ at each sample interval.
- Produces a stream of binary values for each sample.
- Analog to digital performance issue:
  - Good voice reproduction using PCM:
    - 128 levels (7 bit), voice bandwidth 4kHz.
    - Should be 8000 x 7 = 56kbps : 28kHz bandwidth (Nyquist).
  - Data compression can improve on this:
    - e.g. Interframe coding techniques for video, MPEG, etc.

Delta Modulation - Example

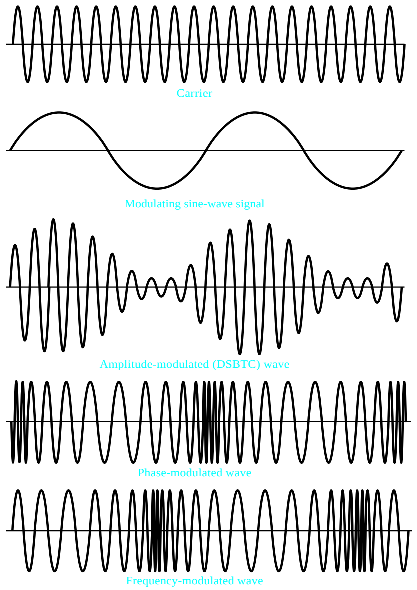


Delta Modulation - Operation



4. Analog Data, Analog Signals

- Modulation: combine an input signal $m(t)$ with a carrier f_c to produce a signal $s(t)$.
- Why modulate analog signals?
  – Higher frequency can give more efficient transmission.
  – Unguided transmission needs HF.
  – Permits frequency division multiplexing (chapter 8).
- Types of analog modulation:
  – Amplitude (AM).
  – Frequency (FM).
  – Phase (PM).



Spread Spectrum

- Analog or digital data.
- Analog signal.
- Spread data over wide bandwidth.
- Makes jamming and interception harder.
- Frequency hoping:
  – Signal broadcast over seemingly random series of frequencies.
- Direct Sequence:
  – Each bit is represented by multiple bits in transmitted signal.
  – Chipping code.

Further Reading

- **Stallings, W. Data and Computer Communications (6th Edition), Prentice Hall, 1999. Chapters 5.**