

CSIS 625 Week 2

Telephone History, Encoding of Data

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I. Overview

- A. Telecom History
- B. Telecom technology
- C. Analog Signals
- D. Digital Signals
- E. Encoding and Modulation
 - 1. Digital to Digital Conversion
 - 2. Analog to Digital Conversion
 - 3. Digital To Analog Conversion
 - 4. Analog to Analog Conversion

II. Telecom history

- A. Telephone network history
 - 1. Hell's Bells: A Radio history of the Telephone
 - a. <http://www.town.hall.org/Archives/radio/IMS/HellsBells/>
 - b. 8 Parts - 30 minutes each
 - 2. 1876 Alexander Graham Bell applies for patent on his telephone.
 - a. Race between Bell and Elisha Gray.
 - b. Bell won in court
 - 3. 1891 Almon Strowger, an undertaker, receives patent for an automatic switcher
 - 4. 1921 Graham-Willis act establishes AT&T as a “natural monopoly”
 - 5. 1934 Federal Communications Commission (FCC) created
 - a. With PUCs - regulates AT&T
 - 6. 1940s - Hush-A-Phone device
- B. Breaking up is hard to do
 - 1. 1969 MCI provides inter-city service
 - 2. 1974 US Government files antitrust suit against AT&T
 - 3. 1975 Carterphone decision
 - 4. 1984 - Modified Final Judgement (MFJ)
 - 5. Ma Bell broken up into AT&T and 7 RBOCS.
 - 6. RBOCS - Regional Bell Operating Companies
 - a. Nynex
 - b. Bell Atlantic
 - c. BellSouth
 - d. Ameritech
 - e. Southwest Bell
 - f. US West
 - g. Pacific Telesis
 - 7. Local and Intra-Lata long distance is kept as monopoly while other services are competitive.
- C. 1996 - Telecommunications Act

1. Deregulate the local loop.
2. Facilities Based
 - a. Carrier provides its own cables to the customer premise
3. Non-Facilities Based
 - a. Carrier rents or leases equipment and lines from local telcos at a discount rate.
4. Allows BOCs to enter long distance market
 - a. Provided that they show an open competitive environment exists in local loop.
5. Creates a lot of mergers
 - a. Bell Atlantic merges with Nynex
 - b. Bell Atlantic & GTE \Rightarrow Verizon
 - c. US West & Qwest \Rightarrow Qwest
 - d. SBC, Pac Bell, & Ameritech \Rightarrow SBC

III. Telecom Technology

A. Tariffs

1. A tariff is a description of a service that offers an appropriate rate of charge for that service, and the rules under which the service is to be provided.
2. 50 different regulators rule on tariffs
3. FCC governs rates & services for Long Distance providers
4. Tariffs are written by phone companies and reviewed and enforced by regulators.

B. Sound

1. Banging of molecules together at a rapid rate
2. This banging is called compression and rarefaction
3. Rate of compression (pitch, or frequency) per unit time (seconds) is measured in Hertz (Hz).
4. Human voice has frequency range between 100 and 5000 Hertz.
5. Sound also has loudness attribute, or amplitude.
6. Human ear is responsive to variations in frequency between 25 and 25000 Hz.
7. Through empirical testing, phone companies realized that the majority of useful information is carried in a 3 KHz range
8. The actual voice envelope (spectrum) carried by the phone is 200Hz to 3500Hz.
9. Thus, the bandwidth of the transmitted voice is 3.3 KHz
10. The actual bandwidth of the voice line is 4KHz, but margins are suppressed by bandpass filters to allow multiple channels on the same media

C. Telephone Network

1. Topology of connections is used
2. Twisted Pair connects DEMARK point with the wire center (frame).
3. Wire Center is connected to the Switch (Central Office)
4. Switches are interconnected together to form a network.
5. Switches make routing decisions based on the requested destination and available capacity

D. Pre-84 Network Topology

1. Over 19000 End (Class 5) Offices
2. Over 940 Toll Centers
3. 170 Class 3 Offices (Primary Centers)
4. Over 50 Sectional Centers (Class 2)
5. 10 Regional (Class 1) Centers

6. See Figure 1

E. Post-84 Network Topology

1. The LEC's owned the local or class 5 and class 4 offices
2. The Long distance hand off occurred between the class 4 and class 3 offices.
3. The new long distance players didn't necessarily keep the upper 3 levels anymore
4. AT&T didn't maintain the upper layers as rigidly either.
5. See Figure 2

F. North American Numbering Plan

1. Area Code
 - a. 160 (152) in 60's, 800 right now ($8 * 2 * 10$ to $8 * 10 * 10$)
 - b. Originally: N 0/1 X (N = 2-9, X= 0-9)
 - c. Pre-1995: N 0/1 X (N = 2-9, X= 0-9)
 - d. Post 1995: N X X (N = 2-9, X= 0-9)
2. Central Office (Exchange) Code
 - a. 640 originally ($8 * 8 * 10$)
 - b. Expanded to 800 in 1960's ($8 * 10 * 10$)
 - c. Originally: N N X (N = 2-9, X= 0-9)
 - d. After conversion in 1960s: N X X (N = 2-9, X= 0-9)

G. Local Access and Transport Area - LATA

1. "Turf" division between Local and Long Distance Companies
2. Based on Geographical area and Population Density
3. Different Rules applied as to who could route the calls where.

H. Classifications of telephone companies

1. LEC - Local Exchange Carrier
 - a. LEC terminates services at the Network Interface Unit (or Demarcation Point)
 - b. Customer takes over from there on
 - c. Main Service Provided: Dial tone
 - d. Other services can be purchased.
 - (1) Either dedicated or party line services is offered
 - (2) Residential Dialing Service (Direct Distance Dialing)
 - (3) Business Services (DID, DOD)
2. ILEC - Incumbent Local Exchange Carrier
3. CLEC - Competitive Local Exchange Carrier
4. BLEC - Building or Business Local Exchange Carrier
5. DLEC - Data Local Exchange Carrier
6. IXC - Inter Exchange Carrier

I. Lines VS Trunks

1. Lines
 - a. Low Capacity
 - b. Non-intelligent (lack signaling)
 - c. Normal Voice Load
 - d. Typically dedicated to 1 consumer
 - e. Allocated on demand
 - f. Can be blocked
2. Trunks
 - a. Between switching elements
 - b. Intelligent (carry signaling information)

- c. High Capacity
- d. Statically Allocated Capacity
- 3. Types of Lines and Trunks
 - a. POTS - Plain Old Telephony Service
 - (1) normal voice telephony service
 - b. Direct Inward Dial
 - c. Direct Outward Dial
 - d. FX -- Foreign Exchange -- provides dial tone from the remote (foreign) exchange.
 - (1) Typical use -- airline reservation system
 - e. OPX -- Off-premise Extension -- permits a remote phone to function as a local phone.
 - (1) Typical use -- “remote” extensions in business offices.
 - f. Tie Lines -- private point-to-point circuit used to connect two voice facilities

J. Line signaling types

- 1. Loop start
- 2. Ground start
- 3. Reverse Battery

IV. Analog and Digital Signals

A. Signal - an electromagnetic wave that transfers information

B. Analog Signal - Continuous set of data

- 1. Real Numbers
- 2. See Figure 3

C. Digital Signals - Discrete set of data

- 1. Integer Numbers
- 2. Often binary (1 or 0 only)
- 3. See Figure 4

V. Signal Definitions

A. Periodic Signal

- 1. A signal that completes a pattern in a measurable time frame
- 2. See figure 5

B. Aperiodic Signal

- 1. A signal that does not exhibit a pattern
- 2. All aperiodic signals can be shown to be a combination of periodic signals
- 3. See Figure 6

C. Amplitude - The “height” of a signal. Measured in Volts, Amps, Watts, etc.

- 1. See figure 7

D. Period - The amount of time to complete one cycle

- 1. See figure 7

E. Frequency - The number of periods per second.

- 1. Measured in Hertz (Hz)
- 2. Calculated by $1 / \text{Period}$

F. Phase - The position of a sine wave relative to time zero.

- 1. Measured in degrees.
- 2. See Figure 8

VI. Bandwidth

- A. Bandwidth - A range of frequencies
- B. Analog - measured in Hz
 1. Bandwidth = High-Freq – Low-Freq
- C. Spectrum - synonym - used only in analog measurements.
- D. Bandwidth in digital realm - often used to refer to bits-per-second

VII. Bit Rate

- A. Most digital signals are aperiodic
- B. Period and frequency are not appropriate to describe digital signals
- C. Bit Interval - time to send one bit
- D. Bit rate - number of bits send in a second. Measured in bits per second
- E. bps - Bits Per Second
- F. Do NOT use Hz when you mean bps or vice-versa

VIII. VIII. Decomposing a digital signal

- A. A digital signal can be decomposed into an infinite number of simple sine waves
- B. It is not practical or necessary to send all of these components
- C. Significant Bandwidth - Those frequencies necessary to recreate a digital bit pattern
- D. Significant Bandwidth is related to bit rate
 1. Greater bit rate = Greater significant bandwidth

IX. Medium Bandwidth and Significant Bandwidth

- A. All transmission mediums have limited bandwidth
- B. The significant bandwidth of a digital bit rate must fit within the limited bandwidth of the medium that carries it.

X. Encoding

- A. Information must often be encoded before being sent over a medium
- B. Four basic types of encoding
 1. Digital to Digital
 2. Analog to Digital
 3. Digital to Analog
 4. Analog to Analog
- C. Encoding schemes may be stacked
 1. Voice to digital data to radio waves
- D. Digital to Digital Encoding
 1. Using a digital signal to represent digital data
 2. Binary data is translated to different voltage, current, or light pulses that can be transported over the medium.
 3. Types
 - a. Unipolar - uses 1 signal level
 - b. Polar - uses 2 signal levels
 - c. Bipolar - uses 2 signal levels and 0
 - d. See Figure 9 for the various types

4. Unipolar Encoding

- a. Simplest scheme
- b. Uses two signal levels
 - (1) 1's are encoded with signal present
 - (2) 0's are encoded by absence of a signal
 - (3) (Sometimes inverse of the above)
- c. Long run of 0s or 1s can't be handled by some mediums
- d. Unipolar encoding - synchronization
 - (1) When a signal isn't varying, receiver can't determine beginning and ending of each bit
 - (2) Solutions:
 - (a) A separate line with a clock signal
 - (b) Asynchronous Serial lines wrap each byte with start and stop bit
 - (c) Scrambling of data to ensure enough transitions
 - (d) Use of additional coding schemes like 8b10b

5. Polar Encoding

- a. Uses a positive and a negative signal
 - (1) but not a zero level
- b. Several types of Polar encoding
 - (1) NRZ - Non-Return to Zero
 - (2) RZ - Return to Zero
 - (3) Biphase
- c. NRZL - Non-Return to Zero - Level
 - (1) Simple - exactly like Polar, except
 - (a) 1's are encoded with positive signal
 - (b) 0's are encoded with negative signal
 - (c) (Sometimes inverse of the above)
 - (2) Same synchronization problems and solutions
- d. NRZI - Non-Return to Zero - Invert on Ones
 - (1) A change in voltage level indicates a 1
 - (2) No change in voltage level indicates a 0
 - (3) Synchronization less of a problem
 - (a) Every 1 bit causes a signal change
 - (b) A string of 0's still causes problems
 - (1) Same synchronization solutions
- e. RZ - Return to Zero
 - (1) Not strictly polar - uses 0 in addition to positive and negative
 - (2) Works like NRZL, except it goes to zero between each bit.
 - (3) Transition to/from zero provides for synchronization
 - (4) Because there are more transitions (2 per bit time) it has a higher significant bandwidth than NRZ
- f. Manchester Coding
 - (1) A biphase mechanism
 - (2) Inversion of signal in middle of each bit
 - (a) low to high transition is 1
 - (b) high to low transition is 0
 - (3) Mid-bit inversion provides for both data and synchronization information

- (4) May have transition between bits so that right transition can be made in middle of a bit
- g. Differential Manchester
 - (1) A biphasic mechanism
 - (2) Always has a mid-bit inversion to provide timing information
 - (3) Inversion at beginning of bit time provides data
 - (a) Presence of inversion means 0
 - (b) No inversion means 1
- 6. Bipolar Encoding
 - a. Bipolar AMI
 - (1) Bipolar Alternate Mark Inversion
 - (2) Mark comes from old telegraphy - means 1
 - (3) Encoding
 - (a) 0 = lack of signal (0)
 - (b) 1 = positive or negative values alternating for successive ones
 - b. Pseudoternary
 - (1) Same as Bipolar AMI, but inverts 1s and 0s
 - (2) Encoding
 - (a) 0 = positive or negative values alternating for successive zeros
 - (b) 1 = lack of signal (0)
 - c. B8ZS
 - (1) Bipolar 8-Zero Substitution
 - (2) A modification of Bipolar AMI to solve the synchronization problem that occurs when a long string of 0s occurs
 - (3) Substitutes 8 consecutive 0s with fixed pattern that contains 2 AMI violations
 - (4) Commonly used in North American Telephony systems
 - (5) See Figure 10
 - d. HDB3
 - (1) High Density Bipolar - 3 Zeros
 - (2) Similar to B8ZS
 - (3) Substitutes 4 zeros with a pattern that contains 1 AMI violation
 - (4) See figure 11

E. Analog to Digital Encoding

1. Digitizing - analog to digital conversion
2. Approximate analog information with a digital signal
3. Reduces infinite number of analog values to a finite number of digital values.
4. Codec - **C**oder-**D**ecoder
 - a. Analog to digital converter
5. Pulse Amplitude Modulation (PAM)
 - a. First step to analog to digital encoding
 - b. Sample analog amplitude information at equal intervals
 - c. PAM alone not useful as measurements are still analog values
6. Pulse Code Modulation (PCM)
 - a. Modifies PAM output to create completely digital signal
 - b. PCM quantizes Take the samples from PAM and assigns digital values to each measurement.

- c. Nyquist theorem - To ensure accurate reproduction of a signal, the sample rate must be twice the highest frequency of the original signal
- 7. PCM & Telephony
 - a. Telephony system uses 8 bits (256 levels) when quantizing
 - b. A non-linear set of quantizing levels is used so that quiet sounds are accurately reproduced
 - c. 300-3300Hz is voice range.
 - d. 8kHz sample rate is used to cover this range
 - e. $8\text{kHz} * 8 \text{ bits/sample} = 64,000 \text{ bps}$
- 8. DM - Delta Modulation
 - a. Analog data is approximated using a staircase function that moves up or down by one level each sampling time.
 - b. Digital data is a stream of 1s and 0s that specify the up and down steps.
 - c. Can be implemented using simple components.
 - d. Not as good quality as PCM
 - (1) Quantizing noise when slope changes slowly
 - (2) Slope overload noise when slope changes fast

F. Digital to Analog Conversion

- 1. Bit rate vs. Baud Rate
 - a. Bit rate is Bits per Second
 - b. Baud Rate is number of signal units per second
 - (1) Baud rate is less than or equal bit rate
 - (2) $\text{Bit Rate} = \text{Baud Rate} * \text{bits per symbol}$
 - c. Don't mix them up!
- 2. Carrier Signal
 - a. high frequency signal that is modified to carry digital signal
- 3. ASK - Amplitude Shift Keying
 - a. Amplitude of signal varied for 1 or 0
 - b. Frequency and phase remain constant
 - c. Very susceptible to noise
 - d. On-Off-Keying - signal and no-signal
 - e. Example:
- 4. FSK- Frequency Shift Keying
 - a. Frequency of the carrier signal is varied to represent a 1 or 0.
 - b. Avoids many of the noise problems of Amplitude Shift keying
 - c. Example:
- 5. PSK - Phase Shift Keying
 - a. The phase of the carrier signal is varied to represent a 1 or 0.
 - b. Avoids noise problems of ASK
 - c. Uses less bandwidth than FSK
 - d. Example:
 - e. QPSK - Quadrature PSK
 - (1) A type of PSK that uses 90° shifts instead of 180° shifts.
 - (2) Allows for 2 bits per baud to be encoded.
 - f. DPSK - Differential PSK
 - (1) The bit pattern defines the phase change, instead of the current phase
 - (2) V.22bis standard at 1200 bps uses:
 - (a) $00 \Rightarrow 90 \text{ Degree phase change}$

- (b) 01 \Rightarrow 0 Degree phase change
- (c) 10 \Rightarrow 180 Degree phase change
- (d) 11 \Rightarrow 270 Degree phase change
- 6. Quadrature Amplitude Modulation - QAM
 - a. Combination of PSK and ASK
 - b. The phase and amplitude of the carrier signal is varied to give several bits per baud
 - c. Number of different phases is usually greater than number of amplitudes
 - d. See Figure 15
 - e. Trellis Coded Modulation
 - (1) Uses QAM, but includes extra data
 - (2) Trellis coding is a specific type of convolutional encoding
 - (3) Viterbi Decoder - a specific algorithm for decoding convolutionally encoded data.
 - (4) Convolutional codes add redundancy to the data, which makes it more resistant to noise.
 - (5) Resistance to noise is more important as data rates get higher
 - (6) Considered a form of (FEC) Forward Error Correction.
 - f. Constellation diagrams
 - (1) Constellation diagram shows relationship between amplitude and phase of different signal levels
 - (2) polar diagram,
 - (a) amplitude shown as distance from center
 - (b) phase shown as degrees around circle
 - (3) See Figure 16
- 7. Bandwidth required
 - a. Amplitude Shift Keying
 - (1) bandwidth = baud rate * (1 + noise factor)
 - (a) noise factor is 0 in ideal world
 - b. Frequency Shift Keying
 - (1) bandwidth = $(f_{c1} - f_{c0}) + \text{baud rate}$
 - c. Phase Shift Keying & QAM
 - (1) bandwidth = baud rate * (1 + noise factor)
 - (2) **but** bit rate is higher because more than one bit per baud

G. Analog to Analog Encoding

1. AM - Amplitude Modulation
 - a. The amplitude of the carrier is modified
 - b. Bandwidth = 2x Bandwidth of modulating signal
 - c. Most common example is AM radio.
2. FM- Frequency Modulation
 - a. The frequency of the carrier is modified
 - b. Bandwidth = 10x Bandwidth of modulation signal
 - c. Most common example is FM radio
3. Phase Modulation
 - a. The phase of the carrier is modified
 - b. Phase Modulation and FM are a special case of Angle modulation
 - c. Observing the signal, it is impossible to tell apart FM and phase modulation

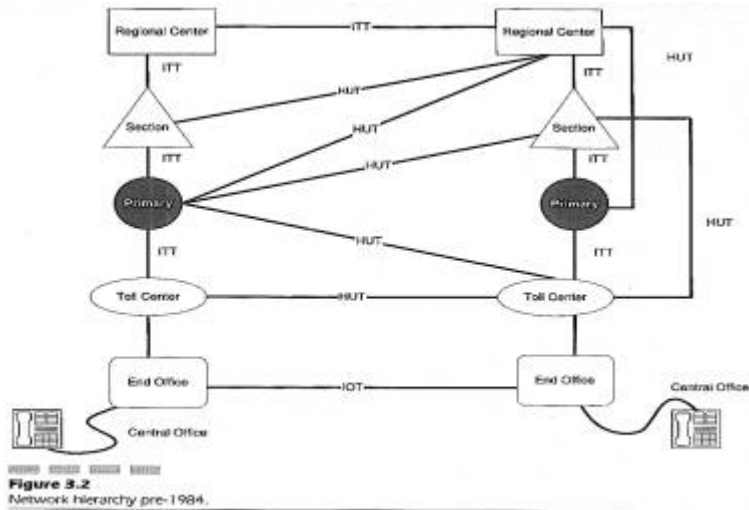


Figure 1: Pre-1984 North American Network (Image from “Voice & Data Communications” by Regis J. “Bud” Bates & Donald W. Gregory. Third Edition – 2000)

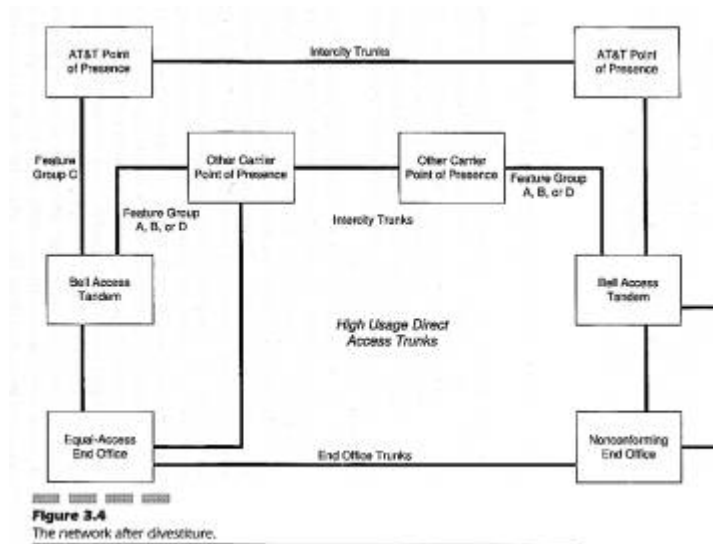


Figure 2: Post Breakup of AT&T - North American Network (Image from “Voice & Data Communications” by Regis J. “Bud” Bates & Donald W. Gregory. Third Edition - 2000)



Figure 3: Analog Signal

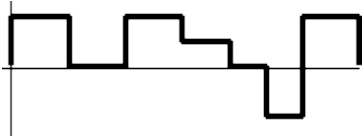


Figure 4: Digital Signal (note not just two levels)

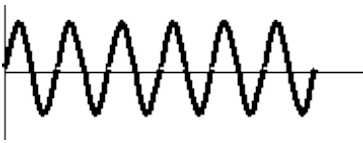


Figure 5: Periodic Signal

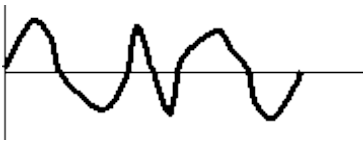


Figure 6: Aperiodic Signal

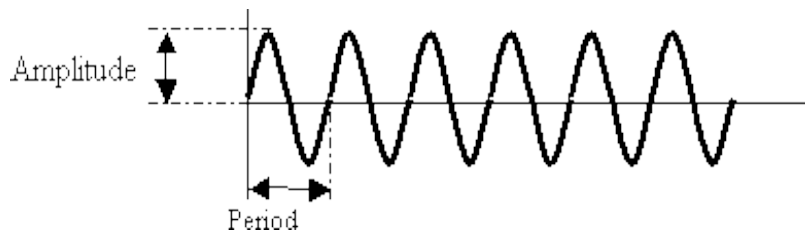


Figure 7: Period and Amplitude of a signal

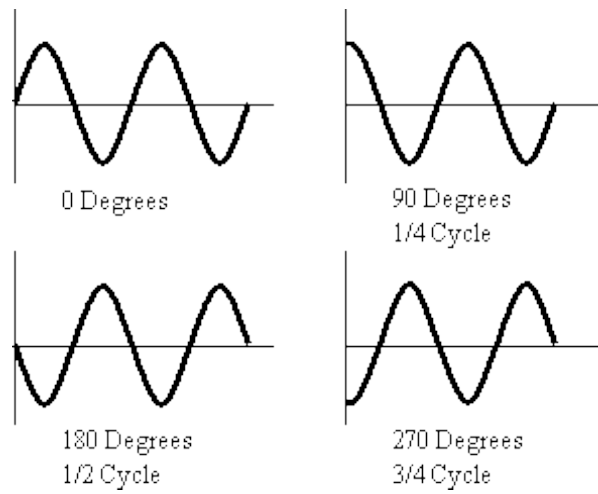


Figure 8: Phase of a signal

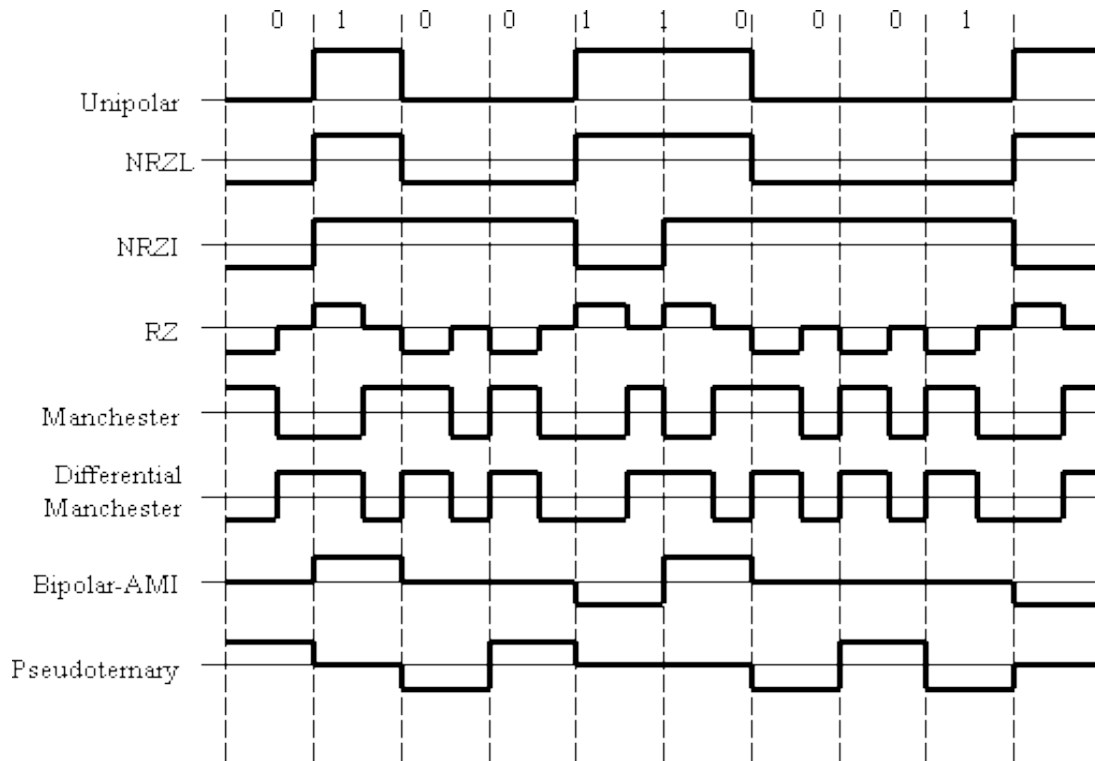
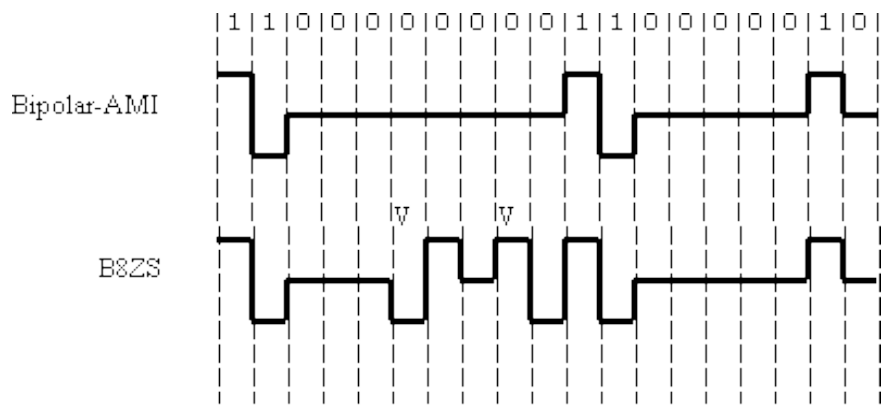
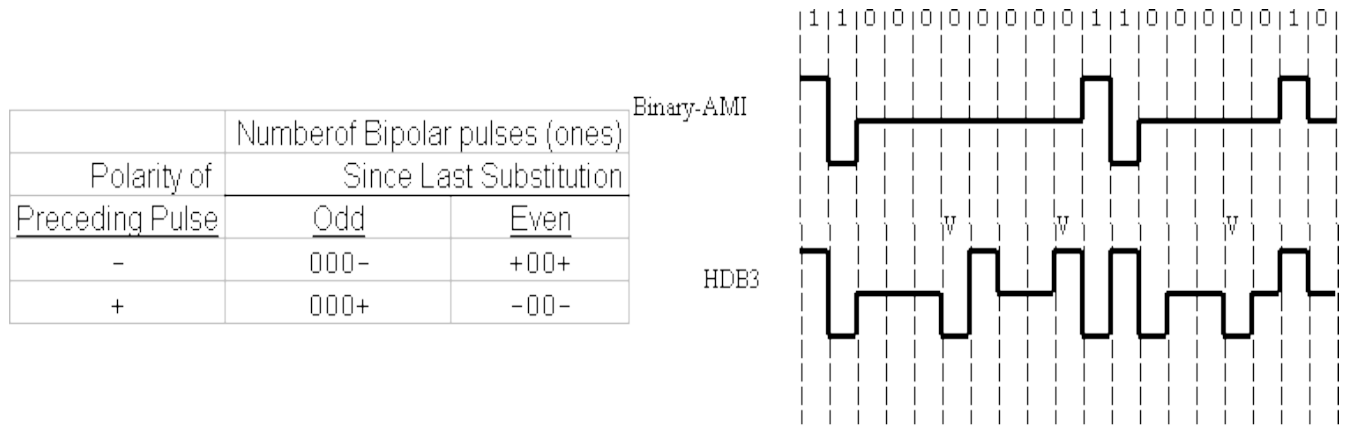


Figure 9: Comparison of various Digital to Digital line encodings.



V = Bipolar AMI Violation

Figure 10: B8ZS compared to Bipolar-AMI



V = Bipolar AMI Violation

Figure 11: B8ZS and HDB3 compared

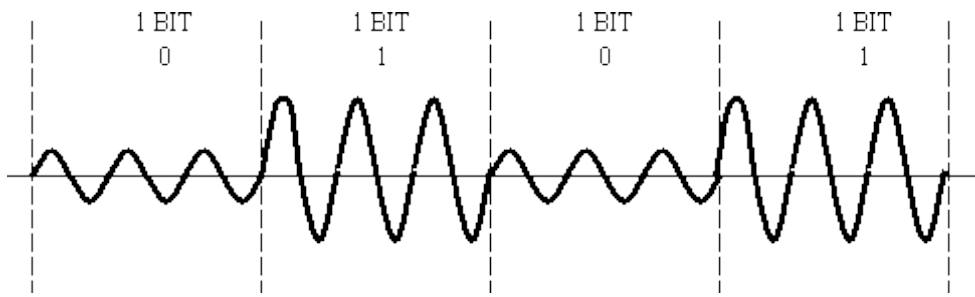


Figure 12: ASK example

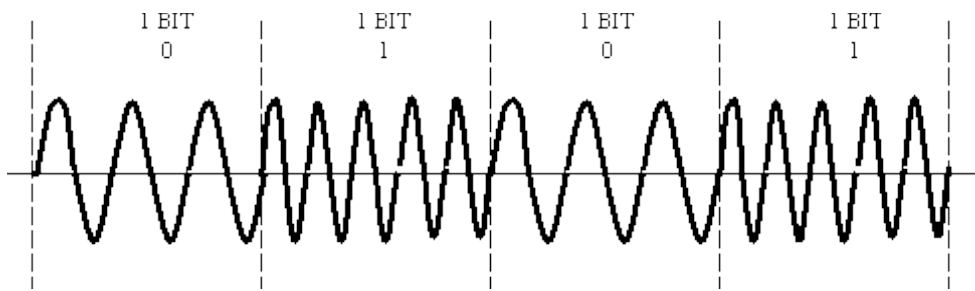


Figure 13: FSK example

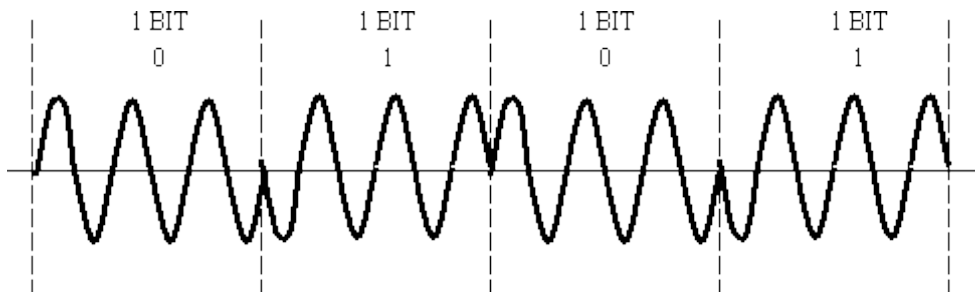


Figure 14: PSK example

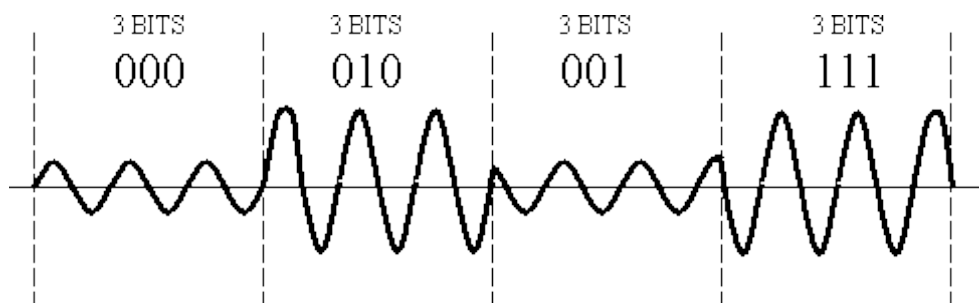


Figure 15: QAM example

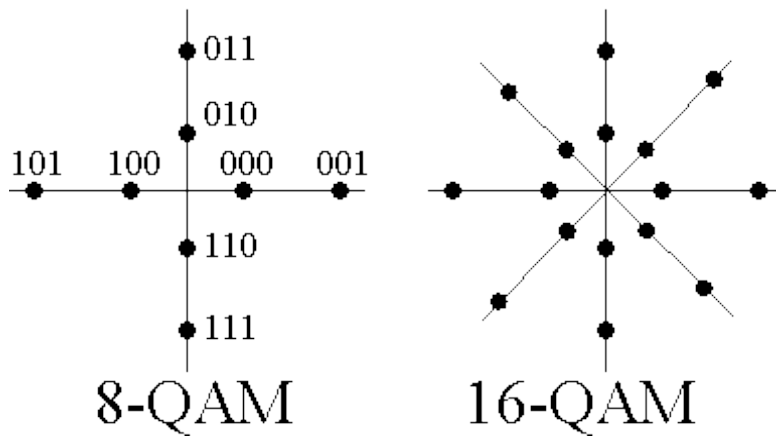
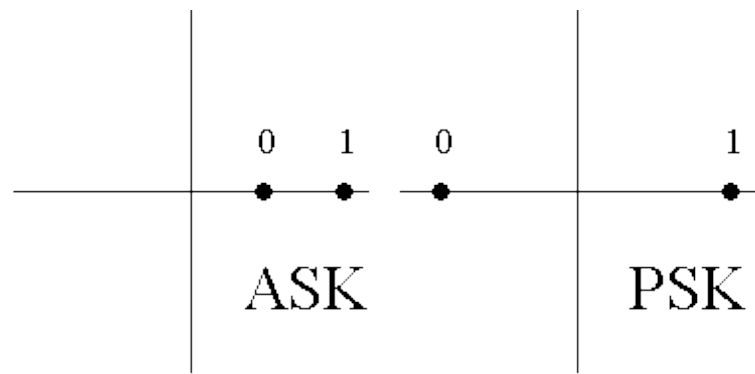


Figure 16: Constellation diagrams For ASK, PSK and QAM