Data Encoding and Modulation

References:
Chapter 5 - Stallings
Chapters 4 & 5 - Forouzan
Study Guide 4

Review of Lecture 3

- What is the relationship between the wavelength and frequency of a sine wave?

Review of Lecture 3

- What is the relationship between the wavelength and frequency of a sine wave?
- Answer- wavelength * frequency = speed at which the signal is travelling

Review of Lecture 3

- Define channel capacity.

Review of Lecture 3

- Define channel capacity.

- Answer- The rate at which data can be transmitted over a given communications path, or channel, under given conditions.

Review of Lecture 3

- What key factors affect channel capacity?

Review of Lecture 3

- What key factors affect channel capacity?
- Answer- Bandwidth, noise and error rate.

Lecture 4 Objectives

- To differentiate between data and transmission;
- Understand the different types of data signals;
- Understand the concept of data encoding and signal modulation;
- To be familiar with different encoding techniques to convert digital data to digital signal;
- To describe techniques to encode analog data into digital data;
- Describe and differentiate among frequency, phase and amplitude modulation techniques to convert digital or analog data into analog signal;

Lecture 4 Objectives

- To be familiar with quantisation and the Nyquist Sampling theorem;
- To differentiate between the meaning of baud rate and data rate; and
- To understand AM and FM broadcasting.

Introduction

- In data communications, a distinction is made between analog and digital data and analog and digital signals
- For digital signalling, which may be either digital or analog, is encoded into a digital signal
  - The actual form of the converted signal depends on the encoding technique and is chosen to optimise the use of transmission medium
    - For example, the encoding may be chosen to conserve bandwidth or to minimise errors

Introduction Contd.

- The basis for analog signalling is a continuous constant-frequency signal known as the carrier signal
  - The frequency of the carrier signal is chosen to be compatible with the transmission medium used
  - The process of encoding source data onto a carrier signal frequency (f_c) is known as modulation
  - All modulation techniques involve operation on one or more of the three fundamental frequency domain parameters: amplitude, frequency, and phase

Introduction Contd.

- The input signal may be analog or digital and is called the modulation signal or baseband signal
- The result of modulating the carrier signal is called the modulated signal
  - The modulated signal is a bandlimited (bandpass) signal
  - The location of the bandwidth on the spectrum is related to f_c and is often centred on f_c
  - The actual form of the encoding is chosen to optimise some characteristic of the transmission

Introduction Contd.

- Digital data to digital signal encoding may be used as the equipment for encoding digital data into a digital signal is less complex and less expensive than digital-to-analog modulation equipment
- Analog data to digital signal conversion permits the use of modern digital transmission and switching equipment
- Digital data to analog signal may be used as some transmission media, such as optical fibre and unguided media, will only propagate analog signals

Introduction Contd.

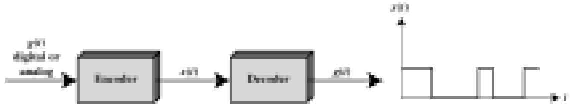
- Analog data and analog signal combination will be used as analog data in electrical form can be transmitted as baseband signals easily and cheaply
  - This is done with voice transmission over voice-grade lines
  - One common use of modulation is to shift the bandwidth of a baseband signal to another portion of the spectrum
  - In this way multiple signals, each at a different position on the spectrum, can share the same medium
    - This is known as frequency division multiplexing

Data Encoding

- Digital data to digital signal
  - computer communication using digital line (eg. ISDN)
- Digital data to analog signal
  - computer communication using voice (telephone) line
- Analog data to analog signal
  - home telephone systems
- Analog data to digital signal
  - digital mobile communication systems

1. Digital Data, Digital Signal

- Digital data
  - Binary data encoded into signal elements – we need an encoding scheme
  - The simplest method of digital encoding uses one voltage level to represent 1 and another level to represent 0, eg +5V for 1 and -5V for 0
- Digital signal
  - Discrete, discontinuous voltage pulses
  - Each pulse is a signal element



Encoding onto a digital signal

Interpreting Signals

- Need to know
  - Timing of bits - when they start and end
  - Signal levels
- Factors affecting successful interpreting of signals
  - Signal to noise ratio
  - Data rate
  - Bandwidth
- Need to choose a suitable encoding scheme

Comparison of Encoding Schemes

Different digital encoding techniques can be compared in terms of

- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth
  - Lack of dc component allows ac coupling via transformer, providing isolation
  - Concentrate power in the middle of the bandwidth
- Clocking
  - Synchronizing transmitter and receiver
  - External clock - expensive
  - Sync mechanism based on signal

Comparison of Encoding Schemes…

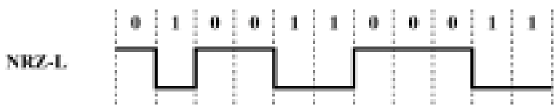
- Error detection
  - Can be built in to signal encoding
- Signal interference and noise immunity
  - Some codes are better than others
- Cost and complexity
  - Higher signal rate (& thus data rate) lead to higher costs
  - Some codes require signal rate greater than data rate

Encoding Schemes

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

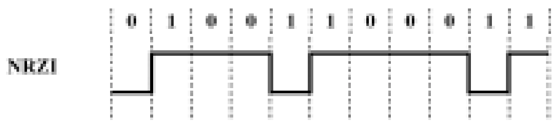
Nonreturn to Zero-Level (NRZ-L)

- 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



Nonreturn to Zero Inverted (NRZI)

- 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
  - More reliable to detect a transition

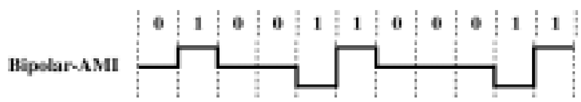


NRZ pros and cons

- Pros
  - Easy to engineer
  - Make good use of bandwidth
- Cons
  - dc component
  - Lack of synchronization capability
- Used for digital magnetic recording
- Not often used for signal transmission

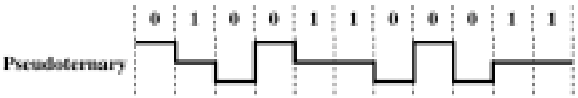
Bi-polar AMI

- Multilevel binary signal (+A, 0, -A)
- 0 is represented by no line signal (0 volt)
- 1is represented by positive or negative pulse in alternate (+A, -A,+A volts)
- No loss of sync if a long string of 1s (0s still a problem)
- No net dc component
- Lower bandwidth
- Easy error detection



Pseudoternary

- similar to Bi-polar AMI
- 1 is represented by absence of line signal (0 volt)
- 0 is represented by alternating positive and negative pulse in alternate (+A, -A,+A volts)
- No particular advantage or disadvantage over bipolar-AMI

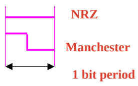


Multilevel Binary-pros and cons

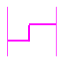
- Pros
  - some support of synchronisation
  - pulse alteration provides simple means of error detection
- Cons
  - Receiver must distinguish between three levels (+A, -A, 0)
  - Requires approximately 3dB more signal power for same probability of bit error
  - Each signal element could represent $\log_2 3 = 1.58$ bits of information, but bears only 1 bit of information

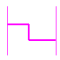
Manchester Coding

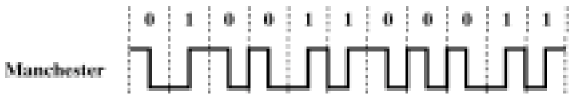
- The transition occurs at the middle of bit period



- A low-to-high transition represents 1
- A high-to-low represents 0
- Transition serves as clock and data

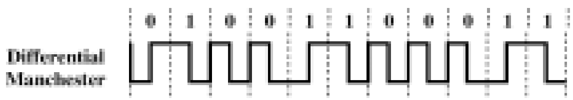






Differential Manchester

- Midbit transition is clocking only
- Transition at start of a bit period represents 0
- No transition at start of a bit period represents 1



Biphase Pros and Cons

- Pros
  - Synchronization on mid bit transition (self clocking)
  - No dc component
  - Error detection
    - Absence of expected transition
- Con
  - At least one transition per bit time and possibly two
  - Maximum modulation rate is twice NRZ
  - Requires more bandwidth

Scrambling

- Biphase techniques used in LAN but not in long-distance application
  - high signaling rate relative to data rate
- Use scrambling to replace sequences that would produce constant voltage
- Filling sequence
  - must produce enough transitions to maintain sync
  - must be recognized by receiver and replaced with original data
  - same length as original data
- Goal
  - No dc component
  - No long sequences of zero level line signal
  - No reduction in data rate
  - Error detection capability

Bipolar with 8 Zeros Substitution (B8ZS)

- Bipolar with 8 Zeros Substitution
- Based on bipolar-AMI
- 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
- Commonly used in North America

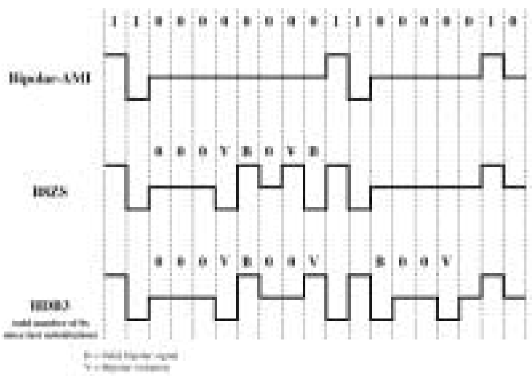
High Density Bipolar 3 Zeros (HDB3)

- High Density Bipolar 3 Zeros
- Based on bipolar-AMI
- String of four zeros replaced with one or two pulses
- Commonly used Europe and Japan

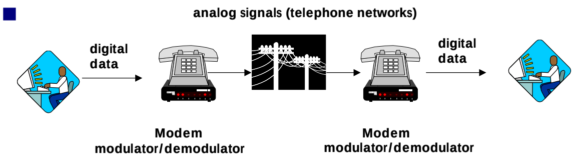
Polarity of preceding Pulse	Odd	Even
-	000-	+00+
+	000+	-00-

- If the last violation is negative, current will be positive and vice versa

B8ZS and HDB3



2. Digital Data, Analog Signal



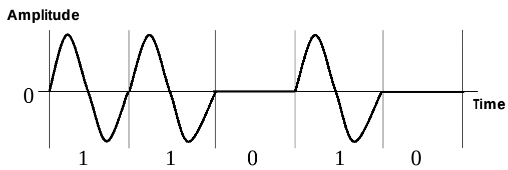
Encoding Techniques

There are three basic encoding or modulation techniques for transforming digital data into analog signals -

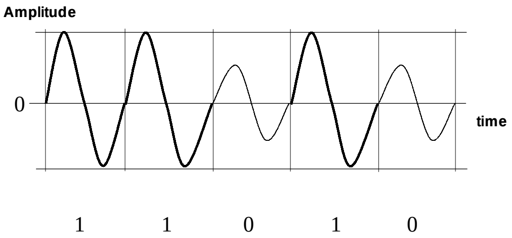
- Amplitude-shift Keying (ASK)
- Frequency-shift Keying (FSK)
- Phase-shift keying (PSK)

Amplitude Shift Keying (ASK)

- Values represented by different amplitudes of carrier. Usually, one amplitude is 0
- Inefficient
- Up to 1200bps on voice grade lines
- Used over optical fiber

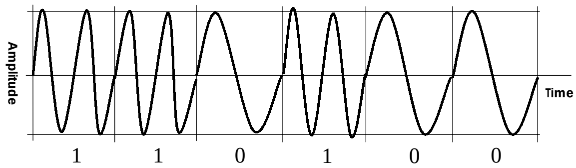


Amplitude Shift Keying…

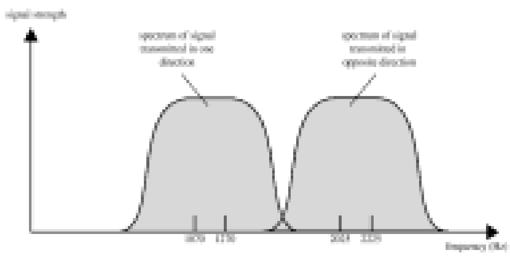
- 

Frequency Shift Keying (FSK)

- Binary values are represented by different frequencies (near carrier frequency)
- Less susceptible to error than ASK
- Up to 1200bps on voice grade lines
- Used in high frequency radio transmission
- Even higher frequency on LANs using coaxial cable



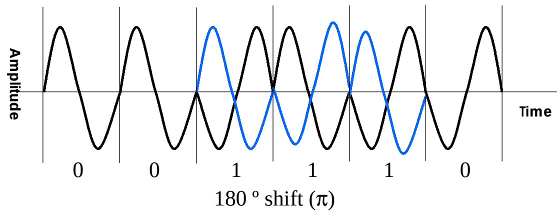
FSK on Voice Grade Line

- 

Full-Duplex FSK Transmission on a Voice-Grade Line

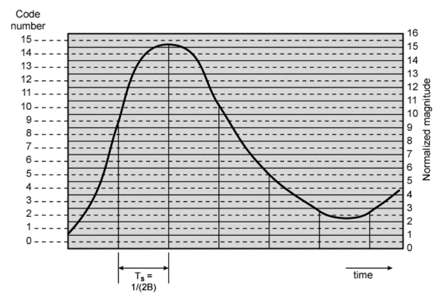
Phase Shift Keying (PSK)

- Phase of carrier signal is shifted to represent data
- More efficient use by each signal element representing more than one bit
  - 9600bps modem use 12 angles , four of which have two amplitudes



3. Analog Data, Digital Signal

- Digitization
  - Conversion of analog data into digital data
  - Digital data can then be transmitted using NRZ-L
  - 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



PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Pulse Code Modulation (PCM)

Nyquist Sampling theorem

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

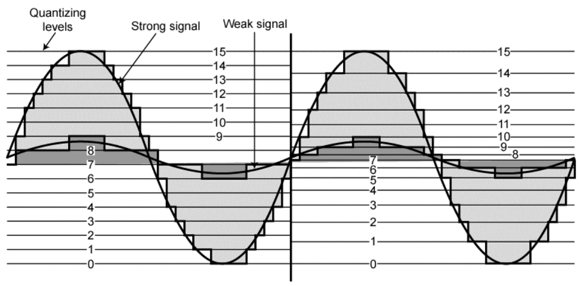
- Voice data limited to below 4000Hz
- Require 8000 sample per second
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value

Pulse Code Modulation (PCM)…

- 4 bit system gives 16 levels
- Quantized
  - Quantizing error or noise
  - Approximations mean it is impossible to recover original exactly
- 8 bit sample gives 256 levels
- Quality comparable with analog transmission
- 8000 samples per second of 8 bits each gives 64kbps

Nonlinear Encoding

- Quantization levels not evenly spaced
- Reduces overall signal distortion
- Can also be done by companding (is a process that compresses the intensity range of a signal by imparting more gain to weak signals than to strong signals on input) see next slide.

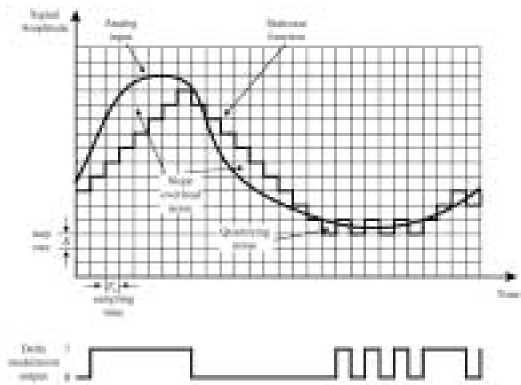


(a) Without nonlinear encoding (b) With nonlinear encoding

Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
  - Function moves up or down at each sample interval

Delta Modulation - example



Delta Modulation - Performance

- Good voice reproduction
  - PCM - 128 levels (7 bit)
  - Voice bandwidth 4khz
  - Should be 8000 x 7 = 56kbps for PCM
- Data compression can improve on this

4. Analog Data, Analog Signals

- Modulation has been defined as the process of combining an input signal m(t) and a carrier at frequency f_c to produce a signal whose bandwidth is usually centred on f_c
- There are two principal reasons for analog modulation of analog signals
  - A higher frequency may be required for effective transmission
    - For unguided transmission, it is virtually impossible to transmit baseband signals as the required antennas will be many kilometres in diameter

Analog Data, Analog Signals Contd.

  - Modulation permits frequency division multiplexing (FDM)
- The principal techniques for modulation using analog data are:
  - Amplitude modulation (AM)
  - Frequency modulation (FM)
  - Phase modulation (PM)
- AM is the simplest form of modulation
- FM and PM are special cases of angle modulation

Analog Modulation