الهيئة العامة للتعليم التطبيقي والتدريب

كلية التكنولوجيا

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اتصالات



Public Authority for Applied Education and Training

# ENC 251
# DIGITAL COMMUNICATION

## CHAPTER 1: INTRODUCTION
## PART 1

## Chapter1 Objectives

- Introduce applications of communications
- Understand what is communication
- Overview of communication systems

## Highlights:

- Grading:
  - Attendance: 10%
  - 3 quizes: 15%
  - 2 Midterms: 20% each
  - Final Exam: 35%
- For any inquiries and questions & updates:
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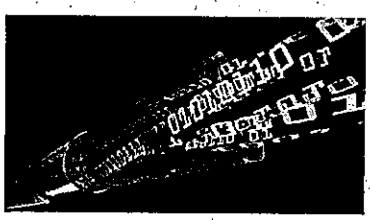
## Introduction

- Communication is one of the fastest growing fields today.
- We live in the era of communication and communication devices.
  - Telephone, television, radio, computers
  - Email, video, web applications
  - Satellite and complex modern communication systems
  - Almost everything is connected together!
- Think of the world as one big village!

## Cont. Introduction

- Rapid development in the field of digital communications within the last two decades.

http://goo.gl/8pXdj



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## Communication

- What is communication?
  - The process of transferring data "information" reliably from one point to another.
- It is important to receive the same information that was transmitted regardless of the complexity of the system.
  - Lead to an error in understanding the meaning of the information or changes the context of the information.

# Example

- Instructor is entering the final grades for a class through the use of a computer and a communication network.
- A binary code called ASCII code is used to represent the alphabets and numerical digits in computers.
- The letter "A" is "1000001" in ASCII code
- The letter "C" is "1100001" in ASCII code

Note: ASCII was the most commonly used character encoding on the World Wide Web until December 2007, when it was surpassed by UTF-8.

# Cont. Example

- If for some reason an error occurs during transmission such that the second digit changes from "0" to "1" the grade will differ from A to C.
- This example illustrates the concept of reliability in data transmission.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 0 | NUL | DLE | space | 0 | @ | P | ` | p |
| 1 | SOH | DC1 XON | ! | 1 | A | Q | a | q |
| 2 | STX | DC2 | " | 2 | B | R | b | r |
| 3 | ETX | DC3 XOFF | # | 3 | C | S | c | s |
| 4 | EOT | DC4 | $ | 4 | D | T | d | t |
| 5 | ENQ | NAK | % | 5 | E | U | e | u |
| 6 | ACK | SYN | & | 6 | F | V | f | v |
| 7 | BEL | ETB | ' | 7 | G | W | g | w |
| 8 | BS | CAN | ( | 8 | H | X | h | x |
| 9 | HT | EM | ) | 9 | I | Y | i | y |
| A | LF | SUB | * | : | J | Z | j | z |
| B | VT | ESC | + | ; | K | [ | k | { |
| C | FF | FS | , | < | L | \ | l | \| |
| D | CR | GS | - | = | M | ] | m | } |
| E | SO | RS | . | > | N | ^ | n | ~ |
| F | SI | US | / | ? | O | _ | o | del |

http://ascii-table.com/img/ascii-table.gif

## Communication Systems

- A system that allows transfer of information reliably.
- Communication systems basic components:
  - Data information
  - Sender
  - Receiver
  - Channel
  - Protocol

## Cont. Communication Systems

- Information to be transmitted is converted into electrical signals, that is voltage or current signals, before being sent across a channel from source to destination.
- Figure 1, shows a general block diagram of a general communication system.

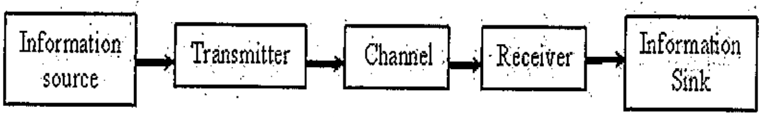



Figure 1: Block diagram of typical communication system.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 5

## Cont. Communication Systems

- **Information Source:** source from which data or information originates, or it is the device producing information.
  - Human talking, keyboard, a broadcasting station, a data storage device such as a CD.

## Cont. Communication Systems

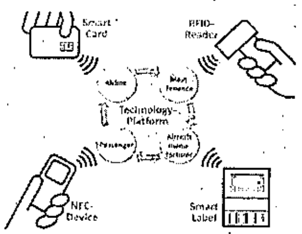
- Information sources can be classified as:
  - Discrete sources
    - Generates a finite set of outcomes or messages
    - Examples: a keyboard, calculator a textbook
    - Digital signals
  - Continuous sources
    - Generates an infinite set of outcomes or messages
    - Examples: human voice, sound of musical instrument taking temperature value over a period of time
    - Analog signals
- Difference between discrete and continuous signals is explained in later sections.

# Cont. Communication Systems

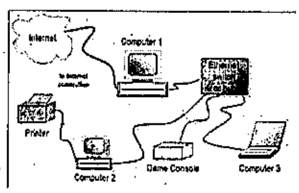
- **Transmitter:** convert the information into a form suitable for transmission through the physical channel or the transmission medium of the communication system.
- Transmitter can perform different operation that include filtering, amplification, modulation, analog to digital conversion coding and many others.

# Cont. Communication Systems

- **Channel:** the physical medium used to send the signal (message) from the transmitter to the receiver.
- Channels are either:
  - Wired transmission mediums such as twisted pair, coaxial cable, optical fiber
  - Wireless transmission mediums like air, light, and sound.




http://www.tuhh.de/lks/img/Wireless_Communication.JPG




http://goo.gl/B8cgK

# Cont. Communication Systems

- Physical channels have limitations:
  - Limited channel bandwidth ( $f_{min} \rightarrow f_{max}$ )
  - Noise: undesired random signal corrupting the transmitted signal and degrades it
    - Noise sources:
      - Electronic equipments in the communication system
      - Thermal noise: thermal agitation of electrons
      - Atmospheric electromagnetic noise (Interference with another signals that are being transmitted at the same channel)
  - Attenuation: weaken the signal strength as it travels over the transmission medium
  - Delay: limits the data rate or speed over the transmission channel

# Cont. Communication Systems

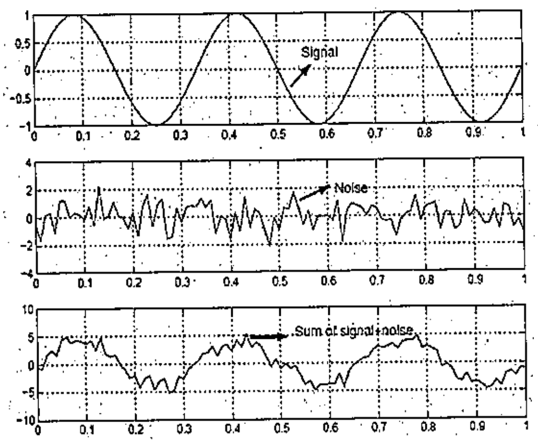
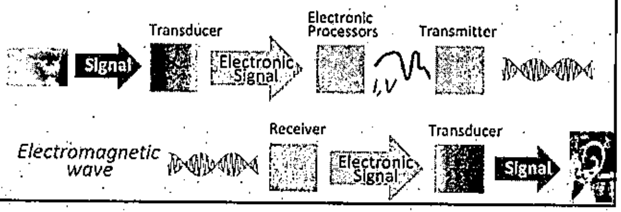



Figure 2: Effect of noise on some transmitted signal.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 9

## Cont. Communication Systems

- **Receiver:** extracts the message signal contained in the received signal.
- Delivers the actual information generated from the source into the information sink in a meaningful way to the user.
- Example: convert the transmitted, as electromagnetic wave, information (speech) into understandable sound wave.

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## Cont. Communication Systems

- **Information sink:** the final stage of the communication process.
  - Human or a data storage device like a disk

## Summary

- Importance of communications
- What is meant by communication
- Overview of communication systems basic components

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# ENC 251 DIGITAL COMMUNICATION

## CHAPTER 1: INTRODUCTION PART 2

## Chapter1 Objectives

- Overview of a digital communication system
- Understand each component of a digital communication system
- Discuss the advantage and disadvantages of digital communications

# Digital Communication System

- Our focus is digital communications systems where data is represented in binary format.
- Figure 3 shows a general block diagram of a digital communication system.

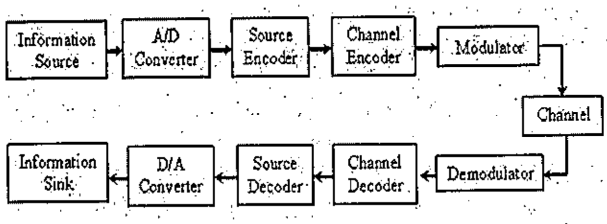



Figure 3: Block diagram of typical digital communication system.

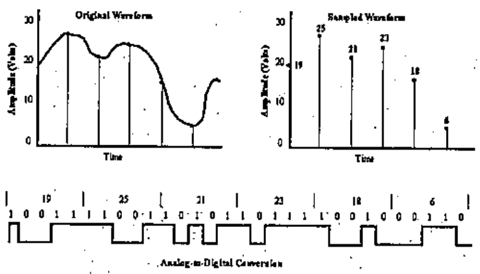
Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 5

# Cont. Digital Communication System

- **Information Source:** generates messages.
  - Discrete or Digital source is one which produces a finite set of possible messages or outcomes.
    - keyboard, binary numbers, hex numbers, etc.
  - Continuous or an Analog source is one which produces an infinite set of possible messages or outcomes.
    - Microphone, speech signal, image, video, etc.

## Cont. Digital Communication System

- **Analog to digital converter A/D:** convert analog signal to digital signal.
  - If source produces digital data then there is no need to use the A/D converter.



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## Cont. Digital Communication System

- Three basic steps to convert analog signal to digital signal:
  1. Sampling: convert a continuous time signal to a discrete time signal, i.e., make the signal have values at certain periods of time.
  2. Quantization: convert the amplitude from continuous values to discrete values.
  3. Coding: assign a binary code to every finite amplitude value.

## Cont. Digital Communication System

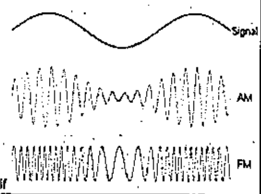
- **Source encoder (Data compression):**
  - Represent the transmitted symbols or data efficiently
    - Transmitting the same information with smaller average number of binary digits to be used in representing the message.
  - Remove redundant and irrelevant information from the data without affecting the meaning or value of the data
    - Redundant information: word "write" is pronounced "rite"
    - Irrelevant information: high frequency components in speech signals or music signals
      - Human ear can only hear voices with frequencies up to 20 KHz

## Cont. Digital Communication System

- Two encoding methods:
  1. Lossless coding or Lossless data compression:
     - Data is compressed with the ability to reverse the encoding process and return to the original data form without any loss in data
  2. Lossy coding or Lossy data compression:
     - Unessential or not important data parts are lost
     - Lost data cannot be recovered
     - Results in reducing the size of the data several times more than lossless compression

## Cont. Digital Communication System

- **Channel encoder (Error Correction):** introduce redundancy in the binary data that the receiver can use to detect and possibly correct errors due to noise.
- **Modulator:** represents the data in such a way to make it compatible with the channel.
- **Channel:** media in which the signal propagates. The channel adds noise to the transmitted data whether the signal is analog or digital.



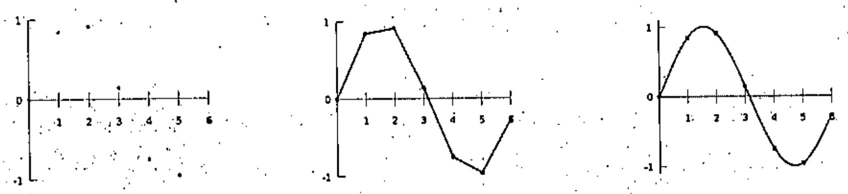

http://en.wikipedia.org/wiki/File:Amfm3-en-de.gif

## Cont. Digital Communication System

- **Demodulator:** reverses the operation of the modulator.
- **Channel decoder:** detects and corrects any errors in the data introduced during transmission.
- **Source decoder (Data decompression) :** decode the data and represent it in its original binary form.
  - If the data is compressed using some zipping technique, the source decoder will perform unzipping process to recover the data.

## Cont. Digital Communication System

- **Digital to analog converter D/A:** converts binary data to a sequence of symbols which is then converted to analog signals through filtering and interpolation processes.
- **Information sink:** takes the received message and accepts it as the original transmitted message.



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## Summary

- A digital communication system has several components working together to send messages reliably.
- The process of converting analog signal to digital signal occurs on three steps, sampling, quantization and coding.
- There are two encoding methods, Lossless coding and Lossly coding method.

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# ENC 251
# DIGITAL COMMUNICATION

## CHAPTER 2: ANALOG TO DIGITAL (A/D) CONVERSION
## PART 1

## Chapter 2 Objectives

- A very brief introduction about waves and their terminology.
- Discuss the representation of signals in time domain and frequency domain.
- Discuss the process of converting an analog signal to digital signal.

## What is a signal?*

- A signal is basically some information encoded as a wave.
- Everything travels as a wave.
- Electrical signal is usually represented either in time domain or frequency domain.

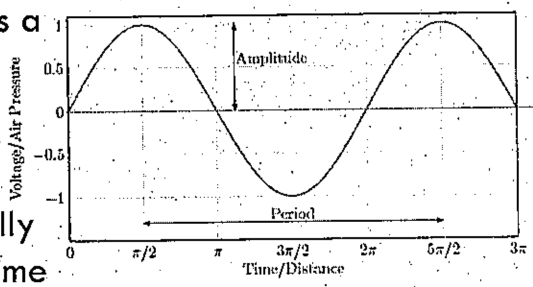
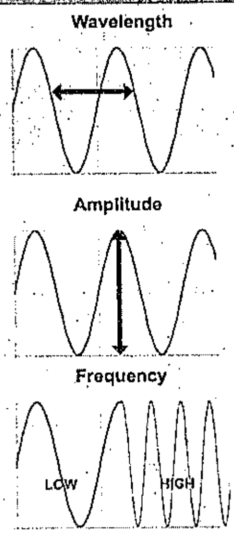



Figure 1: Analog Sin Wave.

* http://www.theparticle.com/cs/bc/mcs/signalnotes.pdf

## Wave Properties*

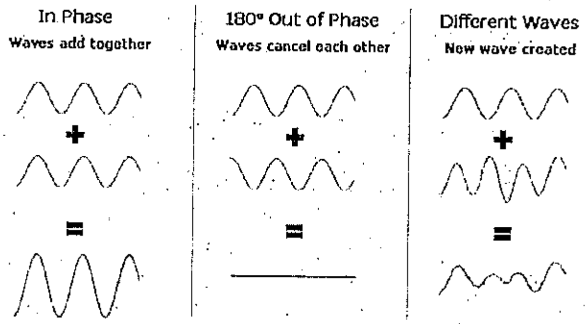
- **Wavelength:** The distance between any point on a wave and the equivalent point on the next phase.
- **Amplitude:** The strength or power of a wave signal.
- **Frequency:** The number of times the wavelength occurs in one second.




*http://www.mediacollege.com/audio/01/wave-properties.html

# Cont. Wave Properties

- **Phase:** measured in degrees, indicates the current position of the wave relative to a reference position*




http://www.mediacollege.com/audio/01/wave-interaction.html

*http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/rad/basics/wv.rxml

# Time Domain

- Signal value is plotted against time.
- The value of this signal can be determined at any instant of time.

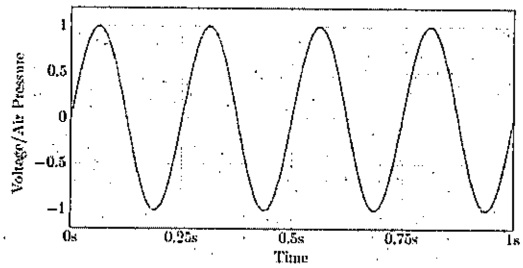



Figure 2: 4Hz Sin Wave; $\sin(2\pi 4t)$

http://www.theparticle.com/cs/bc/mcs/signalnotes.pdf

## Frequency Domain

- The domain for analysis of signals with respect to frequency, rather than time.
- Shows how much of the signal lies within each given frequency band over a range of frequencies.
- Includes information on the phase shift that must be applied to each sinusoid in order to be able to recombine the frequency components to recover the original time signal.

http://en.wikipedia.org/wiki/Frequency_domain

## Cont. Frequency Domain

- A signal can be converted between the time and frequency domains some mathematical operations called a transform.
- Fourier transform is used to transfer a time domain signal to frequency domain.

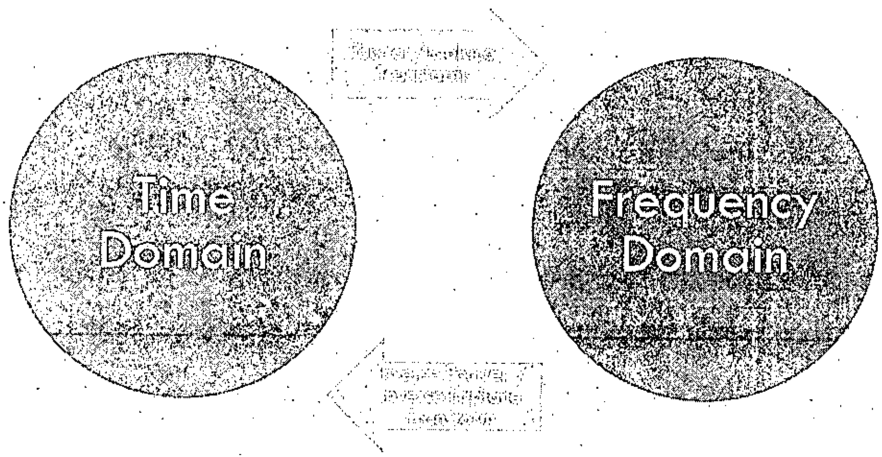
$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt$$

## Cont. Frequency Domain

- The inverse Fourier transform is used to transfer from frequency domain to time domain.

$$x(t)=\int_{-\infty}^{\infty}X(f)e^{j2\pi ft}df$$

## Time Domain vs Frequency Domain

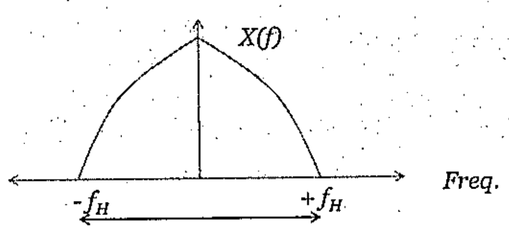


# Spectrum

- The spectrum of a signal is a plot which shows the range of frequencies the signal contains.
- Shows how the signal amplitude or power is distributed as a function of frequency.

# Bandlimited Signal

- A signal who has a finite spectrum.
- Frequencies of a signal is contained within a finite range of frequencies.
- The spectrum of the signal becomes smaller and approaches zero as the frequency f increases.




Lecture notes by Abdullah Almeshal, Chapter 2: Analog to Digital Conversion (A/D), slide 10

# Converting an Analog Signal to a Digital Signal (A/D)

- Three basic steps:
  1. Sampling
  2. Quantization: convert the amplitude from continuous values to discrete values.
  3. Coding: assign a binary code to every finite amplitude value.

# Sampling

- Convert a continuous time signal to a discrete time signal.
- A discrete time signal is one which is defined at specific values of times.
- Sampling is done by taking "samples" at specific times spaced regularly.
  - V(t) is an analog signal
  - $V(nT_s)$ is the sampled signal
    - $T_s$ = positive real number that represent the spacing of the sampling time
    - n = sample number integer

Lecture notes by Abdullah Almeshal, Chapter 2: Analog to Digital Conversion (A/D), slide 12

# Cont. Sampling

- The closer the signal samples that is the smaller the value of $T_s$, the closer the sampled signal resemble the original signal.

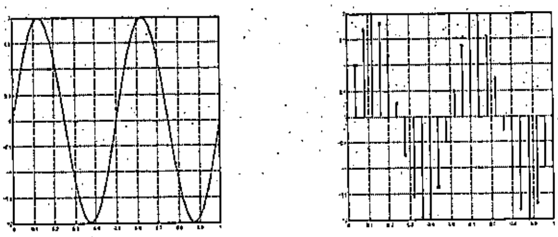


Figure 6: (a) analog signal before sampling (b) analog signal after sampling



# Cont. Sampling

- The signal values between successive sampled values are lost.
- Can we go back from a discrete time signal to the original analog signal even though some values were lost?
  - YES! By satisfying conditions given by the sampling theorem.

## Sampling Theorem

- A bandlimited signal having no spectral components above $f_{max}$ Hz, can be determined uniquely by values sampled at uniform intervals of $T_s$ seconds where $Ts \leq \frac{1}{2f_{max}}$
- The signal must be bandlimited that is having a finite spectrum
- The sampling frequency must be at least twice the signal bandwidth.

## Summary

- Electric Signals can be represented either in Time domain or frequency domain.
- Frequency domain is the domain for analysis of mathematical functions or signals with respect to frequency*
- A bandlimited signal is a signal who has a finite spectrum.
- Bandwidth is the difference between the upper and lower frequencies in a spectrum plot.

*http://en.wikipedia.org/wiki/Frequency_domain

# Cont. Summary

- An analog signal can be reconstructed from a sampled signal without any loss of information if and only if it is:
  - Bandlimited signal
  - The sampling frequency is at least twice the signal bandwidth

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# ENC 251 DIGITAL COMMUNICATION

# CHAPTER 2: ANALOG TO DIGITAL (A/D) CONVERSION PART 2

## Chapter 2 Objectives

- Discuss the process of converting an analog signal to digital signal.

## Converting an Analog Signal to a Digital Signal (A/D)

- Three basic steps:
  1. Sampling
  2. Quantization
  3. Coding

## Quantization

- The sampled signal has values at specific times which are Ts apart.
- The amplitude of the discrete time samples takes on infinite number of possible values.
- Quantization is the process of converting the amplitude from continuous values to discrete values.

# Cont. Quantization

- The amplitude of each pulse is expressed as a level from a finite number of predetermined levels.
- Each level can be represented by a symbol or a number from a finite set.
- To start the quantization process, we first define a quantity called the dynamic range of a signal.

# Cont. Quantization

- Dynamic range: the difference between the highest to lowest value the signal can takes.

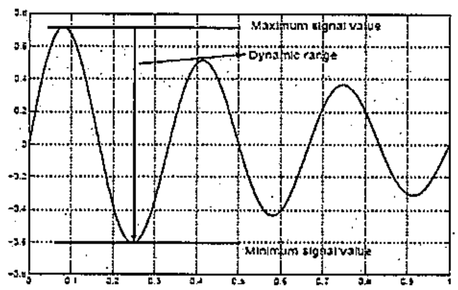



Figure 7: Dynamic range of a random signal.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 22

## Cont. Quantization

- In the Quantization process, the dynamic range of a signal is divided into L amplitude levels denoted by $m_k$, where $k = 1, 2, 3, .. L$
- L is an integer power of 2, $L = 2^x$ where x is the number of bits needed to represent the amplitude level.
- For example, if we divide the dynamic range to 8 levels, $L = 8 = 2^3$, therefore three bits to represent these 8 levels.

## Cont. Quantization

- The amplitude levels are called representation levels or reconstruction levels.
- Each level represent a range of values.
- If a signal sample falls within some particular range or level it is assigned a specific value within this range.

# Example1

- Suppose we have an analog signal with the values between [0, 10].
  - We can divide the signal into four levels.
  - Next, for every level we assign a value if the signal values or its samples fall within the some range $m_k$ it takes on this particular value.

$$Q[v(t)] = \begin{cases} M_1 = 1.25 & \text{if} \quad 0 \le v(t) < 2.5 \\ M_2 = 3.75 & \text{if} \quad 2.5 \le v(t) < 5 \\ M_3 = 6.25 & \text{if} \quad 5 \le v(t) < 7.5 \\ M_4 = 8.75 & \text{if} \quad 7.5 \le v(t) \le 10. \end{cases}$$

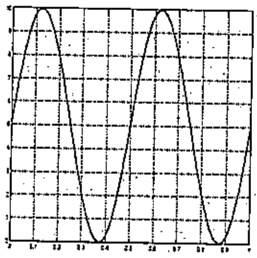
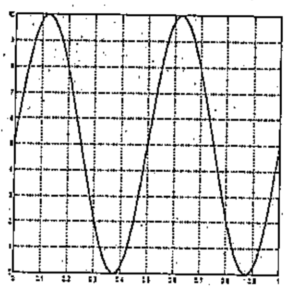


Figure 8: (a) signal before quantization

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 22-23

# Cont. Example1

- The resulting quantized signal is shown in figure 8-b.
- In this example the quantization process is applied to the continuous signals without any sampling.



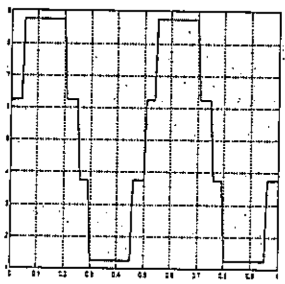


Figure 8: (a) signal before quantization (b) signal after quantization

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 23

## Cont. Example1

- Figure 9 shows a discrete time voltage $v(nTs)$ signal and its corresponding quantized version denoted by $Q[v(nTs)]$.

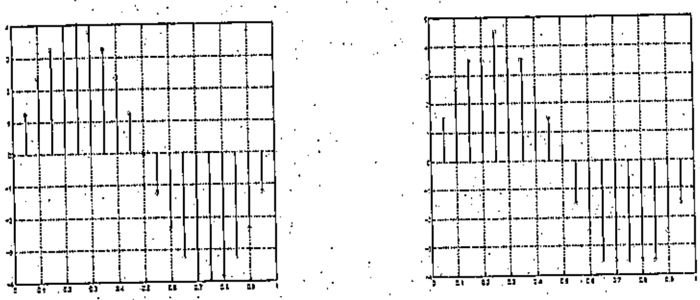


Figure 9: (a) signal before quantization (b) Quantized signal

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 23

## Quantization

- The more quantization levels we take the closer the quantized values are to the actual values.
- Quantization step

$$\Delta = \frac{Dynamic\ \ Range}{No.\ of\ \ Quantization\ \ levels} = \frac{S_{max} - S_{min}}{L}$$

- The smaller the $\Delta$ the smaller the error.

Lecture notes by Abdullah Almeshal, Chapter 2: Analog to Digital Conversion (A/D), slide 23

## Cont. Quantization

- Quantization error is the difference between the original samples and quantized samples.

$$Quantization\ Error = v(nT_s) - Q[v(nT_s)]$$

- After quantization process the signal becomes discrete in time and in amplitude.

## Coding

- Coding is the process of assigning a binary code to each quantization level.
- Each quantized level is encoded into *l bits* where $x = log_2 L$, where L is the number of quantization levels.
- For example, suppose we have a signal which is quantized to 16 levels.

| Step | Code | Step | Code | Step | Code | Step | Code |
|---|---|---|---|---|---|---|---|
| 0 | 0000 | 4 | 0100 | 8 | 1000 | 12 | 1100 |
| 1 | 0001 | 5 | 0101 | 9 | 1001 | 13 | 1101 |
| 2 | 0010 | 6 | 0110 | 10 | 1010 | 14 | 1110 |
| 3 | 0011 | 7 | 0111 | 11 | 1011 | 15 | 1111 |

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 24

## Cont. Coding

- The binary codes are represented as binary pulses.

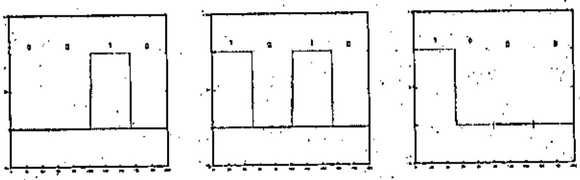


Figure 10: (a) signal coding 2 (b) signal coding for 4 (c) signal coding for 8

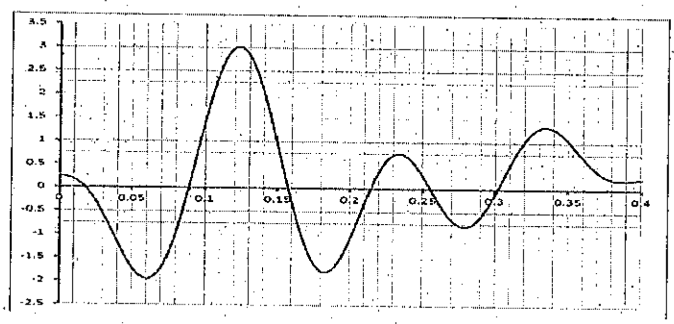


## Converting an Analog Signal to a Digital Signal (A/D)

- After the A/D conversion process the signal is ready to be transmitted as a digital signal.
- The next step in the digital communication block diagram is to pass the signal through the source encoder.
- The source encoder represents the data efficiently, i.e., removes redundant and irrelevant information and the represent the data with the fewest number of bits.

## Example2

- Given the below analog signal in time domain having a maximum frequency of 10 Hz.
  - Find the minimum sampling frequency




## Summary

- Quantization is the process of converting the amplitude from continuous values to discrete values.
- Dynamic range: the difference between the highest to lowest value the signal can takes.
- The quantization processes results in a signal that is both discrete in time and amplitude.
- The more quantization levels we take the closer the quantized values are to the actual values.
- Coding is the process of assigning a binary code to each quantization level.

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# ENC 251
# DIGITAL COMMUNICATION

# CHAPTER 3: SOURCE CODING
# PART 1

## Chapter 3 Objectives

- Meaning of information
- Introduce probability concepts

## Measure of Information

- What is information? How is it measured?
  - Scientists in the field of Information theory link information to the element of surprise or uncertainty.
  - The more uncertain a person about some event the more information this person will get when this event occurs.
  - This can be expressed in terms of probability.
    - The more probable an event to occur the less the information we get if it occurs.
    - The less probable an event to occur the more information we get if it occurs.

## Example 1

- The probability of traffic jams in the period from 7:30 - 8:30 AM, is extremely high.
- A person leaving home and going to work at that time:
  - Not surprised if he sees high volume of cars.
  - Surprised if streets empty!
- This person will start talking to his family and friends about this unusual experience.
- Therefore, we say the case of empty streets during rush hour is more surprising and hence gives more information.

## Example 2

- Summer in Kuwait is very hot and it does not rain.
  - People are not surprised if temperature reaches over 40°C.
  - People will be surprised if temperatures drop below 30°C or it rains during the summer season.
- The chance of these two events occurring are rare, people will talk about it as some kind of new information.
- More information is given to people when the chance of happening of some events is very small.

## Probability Review

- For any given event, the frequency of occurrence of this event is used to define a number called the probability of that event.
- Probability is a measure of how likely an event is to occur.

## Concepts of Probability

- **Experiment:** any procedure that satisfies the following two conditions:
  - The experiment can be repeated, theoretically, an infinite number of times.
  - The experiment has a well defined set of possible outcomes.
- For example, tossing a coin or rolling a dice or selecting a card from a deck of cards.

## Cont. Concepts of Probability

- **Sample space:** the set of all possible outcomes that can occur when performing an experiment.
- **Event:** one of the possible outcomes that can occur when performing a experiment.
- **Set:** a collection of elements.
  - For example, the set of non-moving objects in a room, the set of the English alphabet, the set of smokers in a group of people etc.
- In probability a finite set can include one or more events.

# Cont. Concepts of Probability

- Probability is linked to what is known as a random experiment.
- An experiment is random if it satisfies three basic conditions:
  1. The experiment is repeatable under identical conditions.
  2. On any trial of the experiment, the outcome is unpredictable.
  3. For large number of trials of the experiment, the outcomes exhibit statistical regularly.

# Cont. Concepts of Probability

- Given some random experiment, the rules in assigning a probability to every possible event:
  1. There exist a sample space S, which represents the set of all possible elementary events or outcomes.
  2. A class E of events that are subsets of S.
  3. A probability measure *p(.) assigned to each event A in the class E, with the* following properties:
     - The probability of the sample space is p(S) = 1 this is called the certain event or the sure event.
     - The probability of any outcome in the experiment is a number between zero and one
     - If AUB is the union of two mutually exclusive events in E, then p(AUB) = p(A) + p(B).

## Cont. Concepts of Probability

- Two events are mutually exclusive if the occurrence of one of them excludes the occurrence of the other.
- If one of the events occurs the other can not occur.
- For example, in a true false test, the answers are mutually exclusive.
- If the answer is true then it cannot be false and if it is false it can not be true.

## Example 3

- **Experiment:** Toss a fair coin
- **Possible outcomes:** head $\{H\}$ *and* tail $\{T\}$
- **Sample space set:** $S = \{H, T\}$
- **Subset:** Both the event {H} and the event {T} are subsets of the sample space S.
- Since the chance of getting a head is the same as the chance of getting a tail.
  - p(H) = 1/2 and p(T) = 1/2

# Example 4

- **Experiment:** role a dice once.
- **Possible outcomes:** 1, 2, 3, 4, 5 or 6
- **Sample space:** $S = \{1, 2, 3, 4, 5, 6\}$.
- *All events are equally likely to occur*
  - $p(1) = p(2) = p(3) = p(4) = p(5) = p(6) = 1/6$
- What is the probability of getting the number 7 in one trial?
  - *$p(7) = 0$, it is impossible to the number 7 to occur in one role.*
- What is the probability of getting a number less than 7 in one trial?
  - *$p(\text{number} < 7) = 1$, because we are certain that any number we get in one trial is below 7.*

# Example 5

- **Experiment:** discrete source which generates 3 bits per symbol.
- **Sample space:** $S = \{000, 001, 010, 011, 100, 101, 110, 111\}$
- What is the probability that we get two binary 1's per symbol?
  - Assuming all outcomes are equally likely
  - There are three ways of getting two bits
  - P(two 1's per symbol) =3/8.

## Example 4

- **Experiment:** draw a random card out of a deck of 52 cards
- **Sample space:** all possible 52 playing cards.
- What is the probability of a king in one draw?
  - There are four kings in a deck of cards
  - *p( drawing a king card )* = 4/52 .
- What is the probability of getting a card from heart denomination?
  - There are four denominations heart, spade, clubs, and diamond.
  - Each denomination has13 cards
  - *p( card from heart denomination )* = 13/52 = 1/4 .
- What is the probability of getting a red card?
  - Half the cards are red and the other half are black
  - *p( red card )* = 26/52 = 1/2 .

## Example 5

- **Experiment:** a box contain 5 red balls, 10 black balls, and 15 white balls.
- Find the probability of selecting a white ball.
- The total number of balls 5 + 10 + 15 = 30 balls
- p(white) =15/30 = 1/2
- p(red) = 5/30 = 1/6
- p(black) = 10/30 = 1/3

## Summary

- The less probable an event to occur the more information we get if it occurs.
- The concepts of probability are experiment, sample outcome, sample space, event and set.

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# ENC 251 DIGITAL COMMUNICATION

# CHAPTER 3: SOURCE CODING PART 2

## Chapter 3 Objectives

- Probability review
- Independence in probability
- Dependence in probability

## Probability Review

- Given a sample space S let A and B be some subsets in this sample space.
- The union of two sets A and B is the set of all elements in A, B or both and it is denoted by A U B.
- The probability of the union of two events is given by $P(A \cup B) = P(A) + P(B) - P(A \cap B)$.
- The intersection of two sets A and B is the set of all elements common to A and B and it is denoted by $A \cap B$.
- The probability of the intersection of two events is given by $P(A \cap B) = P(A) + P(B) - P(A \cup B)$.

## Cont. Probability Review

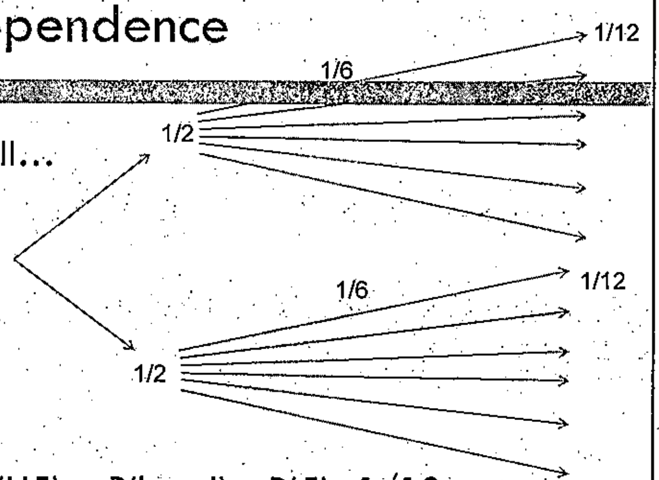
- The compliment of a set A, denoted by $A^c$, is the set of all elements not in A.
  - $A^c = S - A$
- The probability of the compliment of an event *A*
  - $P(A^c) = 1 - P(A)$

# Cont. Probability Review

- For mutually exclusive events
  - P(A U B) = P(A) + P(B)
  - P(A ∩ B) = 0
- In coin tossing example the events head and tail are mutually exclusive
- If the event head occurs then the event tail will not occur
- If the event tail occurs the event head will not occur

# Cont. Independence

- A toss then a roll…




- P(head ∩ 5)=P(H5) = P(head) x P(5)=1/12
- The sum of all the probabilities:
  P(H1)+P(H2)+…+P(T1)+P(T2)+…=1

## Example 1

- A card is selected at random from an ordinary deck of 52 cards.
- If E is the event that the selected card is a 4 and F is the event that it is a spade.
  - E and F are independent
- P(E) = 4/52
- P(F) = 13/52
- $P(E \cap F) = P(E) \times P(F) = 4/52 \times 13/52 = 1/52$

## Example 2

- **Experiment:** tossing a coin and rolling a dice once
- What is the probability of getting a tail and even number?
- Rolling a dice and tossing a coin are two independent events.
- $P(Tail \cap Even) = P(Tail) \times P(Even) = ½ \times 3/6 = 1/4$

## Independence

- The result of independence can be extended to more than two events
- Suppose we have N events which are independent. Namely $A_1, A_2, A_3, \ldots, A_N$
- Then it can be shown that:

$$P(A_1 \cap A_2 \cap A_3 \ldots \cap A_N) = P(A_1).P(A_2).P(A_3) \ldots P(A_N).$$

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 35

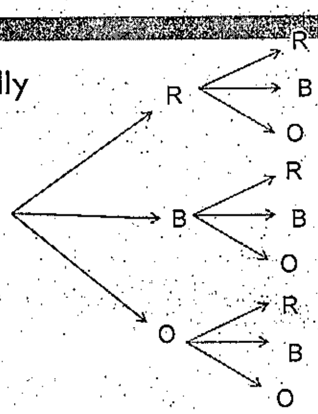
## Dependence

- When two **sequential events** are dependent, then the probabilities **CHANGE** on the second event, **depending** on what happened in the first event
  - There are 3 Red, 4 Blue and 5 orange balls in a box.
  - The experiment consists of picking out 2 balls without putting back the ball inside the box.
  - Find the probability of having a red ball THEN a blue ball.

Lecture notes by Ahmad Albaqsami, Probability Review – Part 2, slide 6

## Cont. Dependence

- Pick 2 balls sequentially

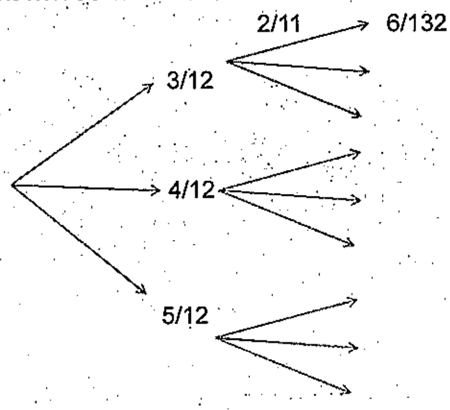



- The sample space S = {RR,RB,RO,BR,BB,BO,OR,OO,OB}



## Cont. Dependence

- What are the probabilities in this case…




- The "2/11" is called the conditional probability

## Cont. Dependence

- Conditional Probability is represented as P(B|A), which means the probability of **event B** occurring **given** that event A has already occurred
- P(A)P(B|A) = P(AB)
- P(A) means the probability of event A occurring
- P(AB) means the probability of event A occurring **THEN** event B occurring



## Cont. Dependence

- What are the probabilities in this case…

| XY | number of balls in the box that are X (nX) | number of balls in the box that are Y (nY) | P(X) = nX/12 | P(Y\|X) = nY/11 | P(XY) = P(X)*P(Y\|X) |
|---|---|---|---|---|---|
| RR | 3 | 2 | 0.25 | 0.181818182 | 0.045454545 |
| RB | 3 | 4 | 0.25 | 0.363636364 | 0.090909091 |
| RO | 3 | 5 | 0.25 | 0.454545455 | 0.113636364 |
| BR | 4 | 3 | 0.333333333 | 0.272727273 | 0.090909091 |
| BB | 4 | 3 | 0.333333333 | 0.272727273 | 0.090909091 |
| BO | 4 | 5 | 0.333333333 | 0.454545455 | 0.151515152 |
| OR | 5 | 3 | 0.416666667 | 0.272727273 | 0.113636364 |
| OB | 5 | 4 | 0.416666667 | 0.363636364 | 0.151515152 |
| OO | 5 | 4 | 0.416666667 | 0.363636364 | 0.151515152 |
| | | | | | SUM: 1 |

## Cont. Dependence

- What is the probability that a red ball is picked then a blue ball is picked?
  - P(R) = 3/12
  - P(B | R) = 4/11
  - P(Red then Blue) = P(RB) = 3/12 * 4/11 = 12/132
- In the example of the dice and coin, the conditional probability is the SAME as the probability of the Event
  - P(B | A) = P(B)
  - P(5 | H) = P(5)
  - This rule only applies if the events are **independent**

Lecture notes by Ahmad Albaqsami, Probability Review – Part 2, slide 11

## Summary

- The probability of the compliment of an event *A*
  - $P(A^c) = 1 - P(A)$
- Independence in probability when the occurrence of one event does not affect the occurrence of another event.
- If two events are independent, we may use the multiplication rule.
- Dependence in probability when the occurrence of one event affects the occurrence of another event.

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# ENC 251 DIGITAL COMMUNICATION

# CHAPTER 3: SOURCE CODING PART 3

## Chapter 3 Objectives

- Measure of information
- What is entropy?
- Source Coding Theorem
- Huffman Coding Algorithm

## Measure of Information

- After reviewing the basic concepts in probability theory and presenting some examples to illustrate these concepts.
- We now apply some of the above concepts to determine the amount of information obtained when conducting some random experiment.

## Cont. Measure of Information

- How can we measure information?
  - Given a digital source with N possible outcomes "messages", the information sent from the digital source when the $j^{th}$ message is transmitted is given by the following equation:

$$I_j = \log_2\left(\frac{1}{p_j}\right) \quad \text{[ Bits ]}$$

- *I* stands for the amount of information, and *pj* is the probability of the *jth* message or outcome.

## Example 1

- Find the information content of a message that takes on one of four possible outcomes equally likely
- The probability of each outcome P = 0.25

$$I = \log_2\left(\frac{1}{0.25}\right) = \frac{\log\left(\frac{1}{0.25}\right)}{\log(2)} = 2 \quad bits$$



## Example 2

- Suppose we have a digital source that generates binary bits.
  - The probability that it generates "0" is 0.25
  - The probability that it generates "1" is 0.75
- Calculate the amount of information conveyed by every bit.

## Cont. Example 2

- For the binary "0" :

$$I = \log_2(\frac{1}{0.25}) = 2 \ bits$$

- For the binary "1":

$$I = \log_2(\frac{1}{0.75}) = 0.42 \quad bits$$

- Information conveyed by the "0" is more than the information conveyed by the "1"



## Example 3

- A discrete source generates a sequence of (n) bits. How many possible messages can we receive from this source?
- Assuming all the messages are equally likely to occur, how much information is conveyed by each message?

## Cont. Example 3

- The source generates a sequence of n bits, each bit takes one of two possible values
  - A discrete source generates either "0" or "1"
- Therefore:
  - We have $2^n$ possible outcomes
- The probability of each message is $P=1/2^n$
- The Information conveyed by each outcome

$$I = \log_2(\frac{1}{1/2^n}) = \log_2(2^n) = n\log_2(2) = n \ bits$$

Lecture notes by Abdullah Almeshal, Chapter 3: Source Coding, slide 11

## Entropy

- Entropy gives an average to the measure of information.

$$H(S) = \sum_{j=1}^{m} p_j \log_2(\frac{1}{p_j})$$

- m represents the number of symbols or outcomes produced by the source S.
- Suppose we have M different and independent messages $m_1, m_2, m_3, \ldots, m_M$ with probability of occurrence $p_1, p_2, p_3, \ldots, p_M$.
- Then the average information of these messages is called the entropy.

## Example 4

- Experiment: Select a card at random from a deck of 52 cards.
- Suppose we are interested in the following events. Getting a picture, getting a number less than 3, and getting a number between 3 and 10.
- Calculate the entropy of this random experiment.

## Cont. Example 4

- P(getting a picture) = 12/52
- P(number < 3) = 8/52
- P(3 <= number <= 10) = 32/52
- The entropy is given by: $H(s) = \sum_{j=1}^{3} p_j \log_2(\frac{1}{p_j})$ $[bits]$
- Therefore,

$$H(s) = \frac{12}{52}\log_2(\frac{52}{12}) + \frac{8}{52}\log_2(\frac{52}{8}) + \frac{32}{52}\log_2(\frac{52}{32}) = 1.335\ bit$$

## Importance of Entropy

- The entropy is an important in source coding (data compression).
- Two types of data compression lossless and lossy compression.

## Source Coding Theorem

- First discovered by Claud Shannon.
- **Source Coding Theorem:** A discrete source with entropy rate H can be encoded with randomly small error probability at any rate L bits per source output as long as L > H.
  - H represent the entropy of the source
  - L is encoding rate of the source symbols (average codeword length of the source symbols)
- Encode the source with L > H → Trivial amount of errors
- Encode the source with L < H → An error will occur

## Cont. Source Coding Theorem

- The average codeword length is defined as:

$$L = \sum_{j=1}^{m} P_j l_j$$

- Where,
  - Pj is the probability of occurrence of the jth symbol
  - lj is the codeword length of the jth symbol.

## Lossless Data Compression

- Data compression
  - Encoding information in a relatively smaller size than their original size
    - Like ZIP files (WinZIP), RAR files (WinRAR), etc..
- Data compression:
  - Lossless: compressed data are an exact copy of the original data
  - Lossy: compressed data may be different than the original data
- Lossless data compression techniques:
  - Huffman coding algorithm
  - Lempel-Ziv Source coding algorithm

## Huffman Coding Algorithm

- Assign to each symbol or to each outcome of a discrete data source a sequence of bits roughly equal in length to the amount of information conveyed by the symbol in question.

## Huffman Coding Algorithm Procedure

1. The source symbols are listed in order of decreasing probability. The two source symbols of lowest probability are assigned a "0" and a "1".
2. Combine the two source symbols into a new source symbol with probability equal to the sum of the two original probabilities. The new symbol is placed in the list according to its probability value.
3. The procedure is repeated until we are left with a final list of source symbols of only two for which a "0" or "1" are assigned.
4. The code for each source symbol is found by working backward and tracing the sequence of 00s and 10s assigned to that symbol as well as its successors.

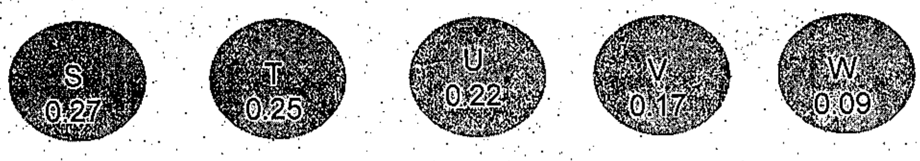
# Example 5

- A discrete source generates five symbols with the following probabilities.
  - Symbol S has probability P(S) = 0.27
  - Symbol T has probability P(T) = 0.25
  - Symbol U has probability P(U) = 0.22
  - Symbol V has probability P(V) = 0.17
  - Symbol W has probability P(W) = 0.09
- Use Huffman encoding algorithm to compress this source.



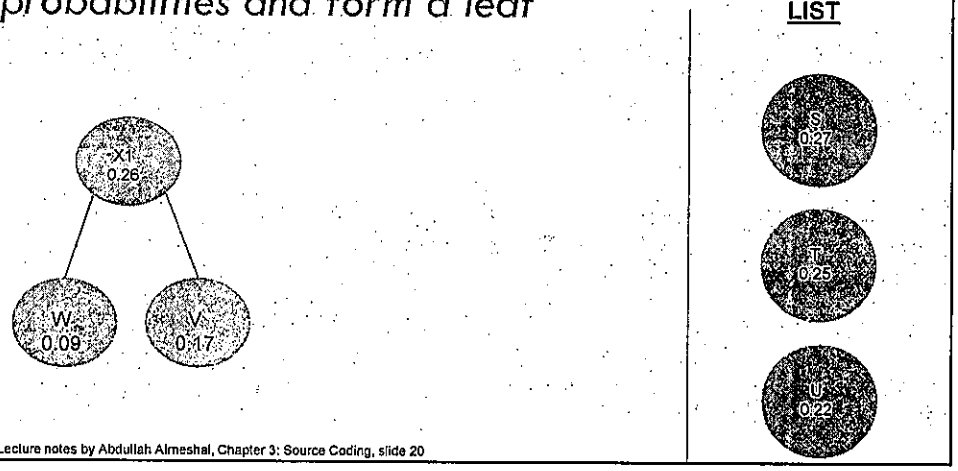
# Cont. Example 5

*Step1: Arrange the symbols in a descending order according to their probabilities*



## Cont. Example 5

*Step 2: take the symbols with the lowest probabilities and form a leaf*

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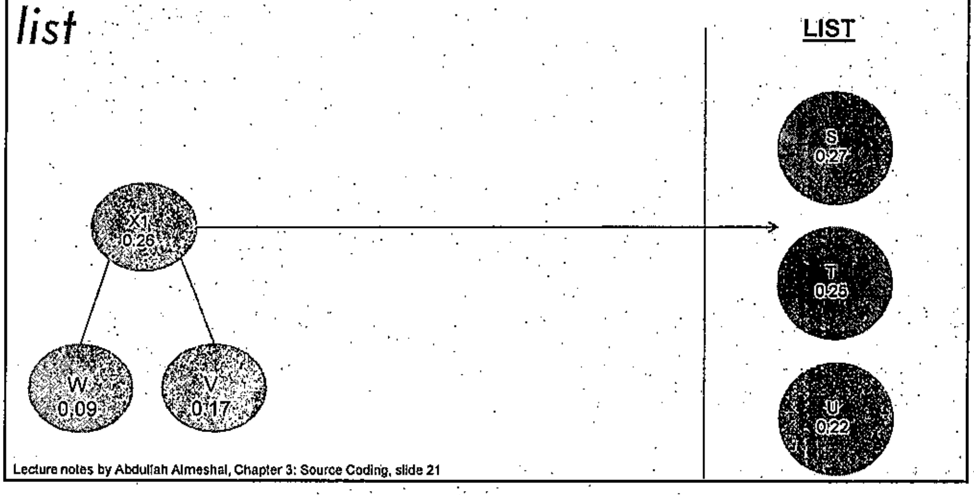
## Cont. Example 5

*Step 3: Insert the parent node to the list*

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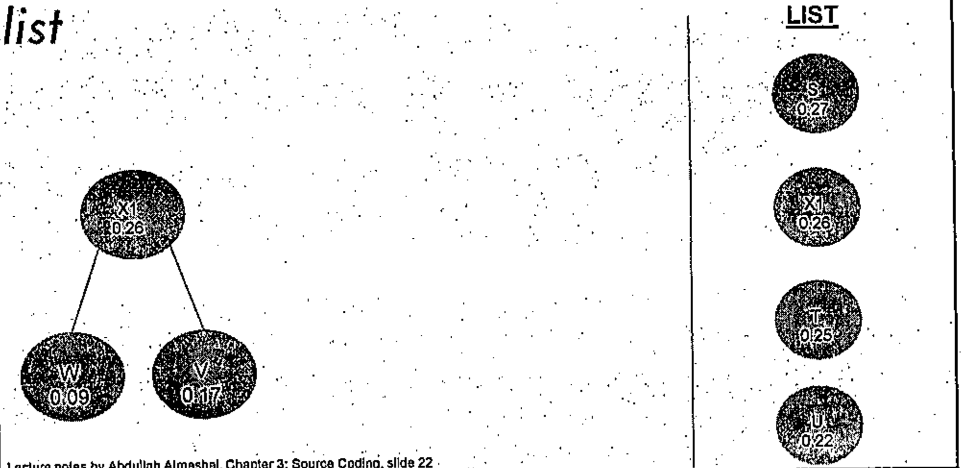
## Cont. Example 5

*Step 3: Insert the parent node to the list*

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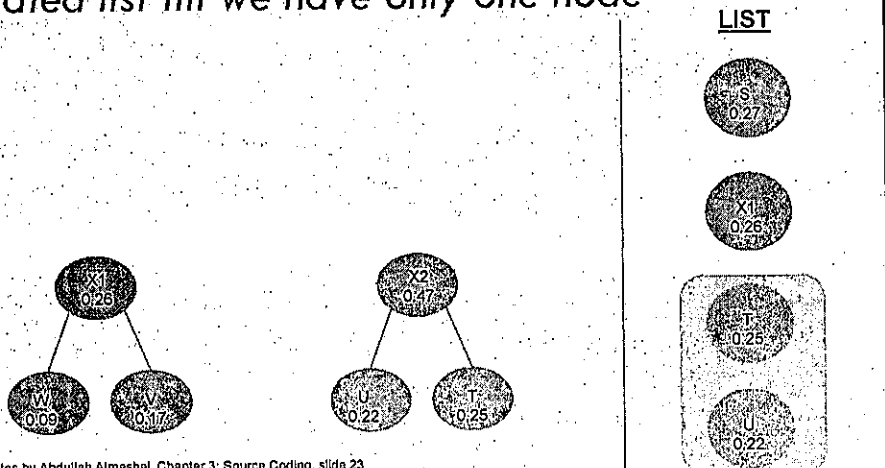
## Cont. Example 5

*Step 4: Repeat the same procedure on the updated list till we have only one node*

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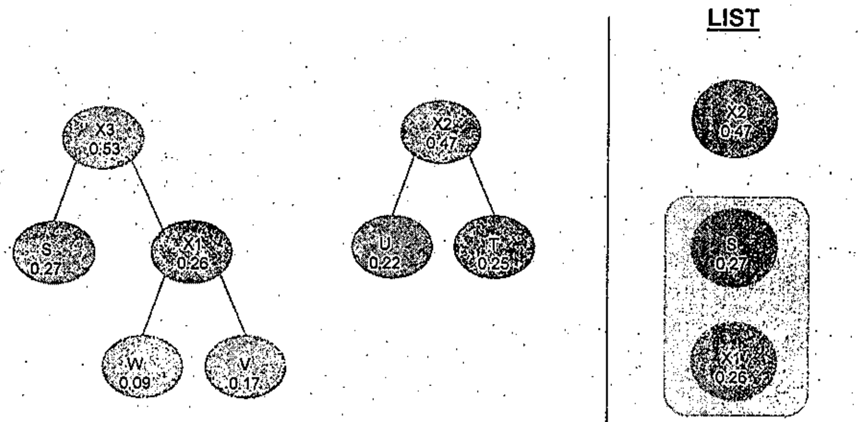
## Cont. Example 5

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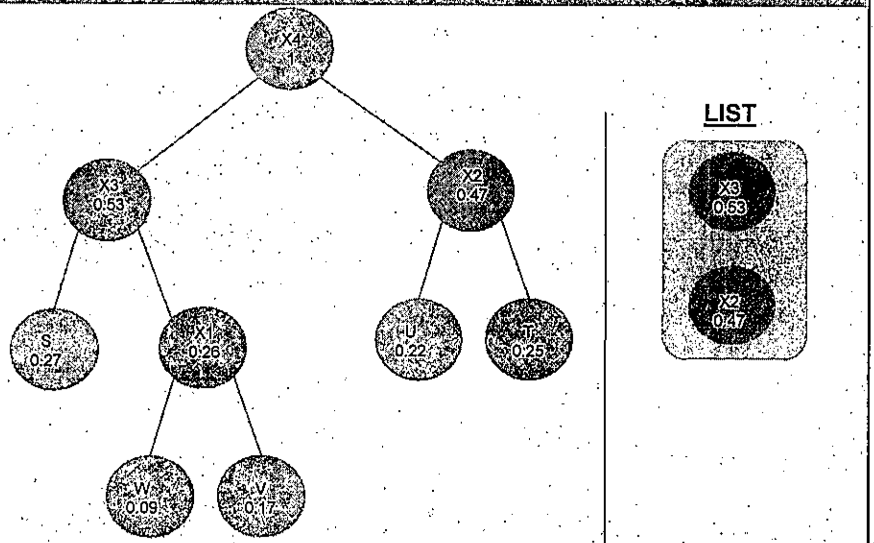
## Cont. Example 5

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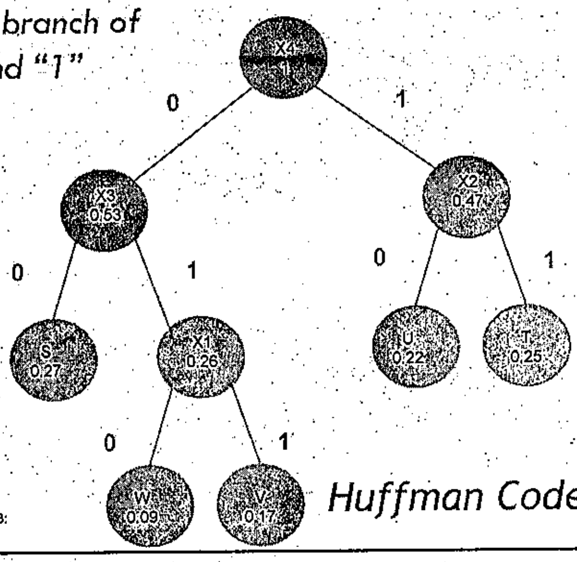
## Cont. Example 5

*Step 5: Label each branch of the tree with "0" and "1"*




*Huffman Code Tree*

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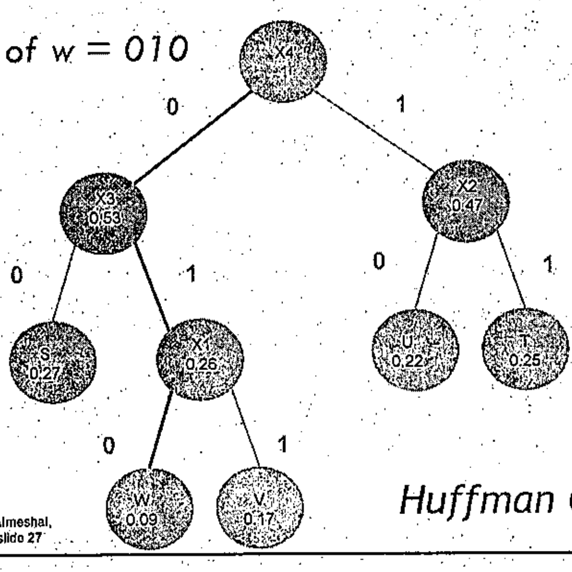
## Cont. Example 5

Codeword of $w = 010$




*Huffman Code Tree*

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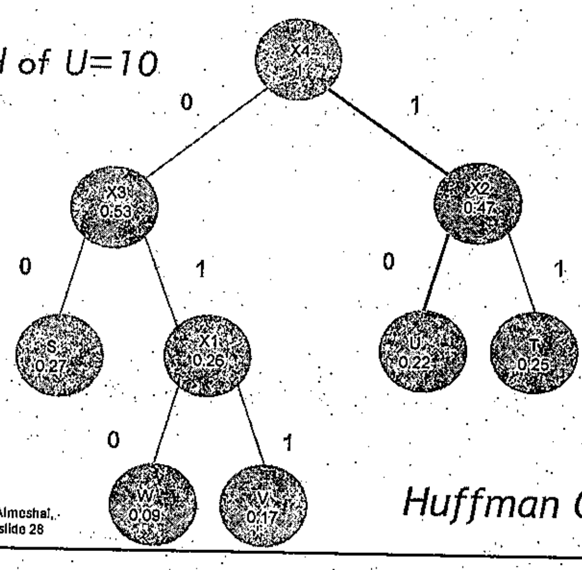
## Cont. Example 5

Codeword of U=10




*Huffman Code Tree*

Lecture notes by Abdullah Almeshal, Chapter 3: Source Coding, slide 28

## Cont. Example 5

As a result:

| Symbol | Probability | Codeword |
|---|---|---|
| S | 0.27 | 00 |
| T | 0.25 | 11 |
| U | 0.22 | 10 |
| V | 0.17 | 011 |
| W | 0.09 | 010 |

Symbols with higher probability of occurrence have a shorter codeword length, while symbols with lower probability of occurrence have longer codeword length.

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## Average codeword length

- The Average codeword length can be calculated by:

$$L = \sum_{j=1}^{m} P_j l_j$$

- For the previous example we have the average codeword length as follows:

$$L = (0.27 \times 2) + (0.25 \times 2) + (0.22 \times 2) + (0.17 \times 3) + (0.09 \times 3)$$

$$L = 2.26 \ bits$$



## Entropy

- The average to the measure of information (Entropy):

$$H(S) = \sum_{j=1}^{m} p_j \log_2 \left(\frac{1}{p_j}\right)$$

- For the previous example we have the average measure of information as follows:

$$H = \frac{0.27 * \log\frac{1}{0.27} + 0.25 * \log\frac{1}{0.25} + 0.22 * \log\frac{1}{0.22} + 0.17 * \log\frac{1}{0.17} + 0.09 * \log\frac{1}{0.09}}{\log 2}$$

$$H = 2.237 bits$$

## Example 6

- For the previous example 5:
  - L = 2.26 bits
  - H = 2.237 bits
- L > H → Trivial amount of errors

## Summary

- Calculated the amount of information obtained when conducting some random experiment.
- The entropy is an important quantity in information theory.
- Entropy is the threshold point which separate lossy from lossless compression.
- Huffman encoding algorithm reduces the average number of bits needed to represent the symbols.

Public Authority for Applied Education and Training

# ENC 251
# DIGITAL COMMUNICATION

# CHAPTER 4: CHANNEL ENCODING
# PART 1

## Chapter 4 Objectives

- Error Detection Techniques
- Error Correction Techniques

# Channel Encoding

- In digital communication systems an optimum system minimizes the probability of bit error.
- Errors occurs in the transmitted data due to transmission in a non-ideal system which is the channel.
- The channel introduces noise to the transmitted signal.
  - Must protect the data from noise effect
- Channel coding is the technique used to protect the data from noise

# Cont. Channel Encoding

- Two basic approaches to handle errors data received in digital communication systems:
  - Automatic Repeat Request (ARQ)
  - Forward Error Correction (FEC)

## Automatic Repeat Request (ARQ)

- When a receiver circuit detects errors in a block of data it requests that the data block be retransmitted.
- This request continues until the block is received correctly.
- ARQ error control systems are used in two-way communication systems
- The major advantage of ARQ systems:
  - Error detection requires much simpler decoding equipment
- The disadvantage of ARQ systems:
  - Retransmissions must be sent too frequently if error rate is high therefore lowering the information rate

## Forward Error Correction (FEC)

- Most common technique used to combat errors that can occur in transmission.
- Used in both one-way and two-way communication.
- Transmitted data is encoded so that the receiver can correct as well as detect errors.
- Improves performance in digital communication systems:
  - Coding introduces redundancy in the transmitted data in a controlled way.
  - Noise averaging: error control code is designed so that the receiver can average out the noise over long time periods.

## Error Control Coding

- The channel encoder converts the original transmitted data to a form that will allow the receiver to reduce the number of errors that might occur in its output due to channel noise.
- Introduce in a controlled manner some redundancy in the binary information sequence which can be used at the receiver to overcome the effects of noise and interference encountered in the transmission of the signal through the channel.

## Error Control Coding

- Coding for data protection against noise can be divide into two parts
  - Error Detection: check if there is an error in the received data or not.
    - Techniques for error detection:
      - Parity Check
      - Cyclic Redundancy Check (CRC)
  - Error Correction: if an error or more detected in the received data and they can be corrected, then we proceed to the correction stage.
    - Techniques for error correction:
      - Repetition Code
      - Hamming Code

## Error Detection Techniques

- Simple technique used for error detection is the addition of one bit called parity bit.
- In parity bit detection, one bit is added to a block of k bits to get a block of k+1 bits.
- The value of the parity bit depends on the number of binary 1's in the k bits.
  - Odd parity: total number of 1's in the k+1 block odd.
  - Even parity: total number of 1's in the k+1 block even.

## Odd Parity Check Example

- Given the following sequence 1011100
- The number of 1's is even we make the parity bit 1.
- Transmitted signal is 10111001.

## Odd Parity Check Example

- Given the following sequence 1011011.
- The number of 1's is odd we make the parity bit 0.
- Transmitted signal is 10110110.

## Parity Error Detection

- Main disadvantage is that if an even number of errors occur it will not be detected and the receiver assumes the data is correct which is clearly not.
- Example, for transmitted sequence 10110110.
- We have an odd number of 1's
- Due to noise we receive the sequence 10110000.
- The total number of 1's is still odd and the error will not be detected.

## Summary

- Data must be protected from noise while travelling through channel.
- Two basic approaches to handle errors data received in digital communication systems:
  - Automatic Repeat Request (ARQ)
  - Forward Error Correction (FEC)
- Coding for data protection against noise is divided into Error Detection and Error Correction.

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# ENC 251
# DIGITAL COMMUNICATION

# CHAPTER 4: CHANNEL ENCODING
# PART 2

## Chapter 4 Objectives

- Error Detection Techniques
- Error Correction Techniques

# Error Control Coding

- Coding for data protection against noise can be divide into two parts
  - Error Detection: check if there is an error in the received data or not.
    - Techniques for error detection:
      - Parity Check
      - Cyclic Redundancy Check (CRC)
  - Error Correction: if an error or more detected in the received data and they can be corrected, then we proceed to the correction stage.
    - Techniques for error correction:
      - Repetition Code
      - Hamming Code

# Cyclic Redundancy Check (CRC)

- A more powerful technique used for error detection
- Detect errors that can occur with very high probability.
- Given a block of k bits, the transmitter generates an n bit sequence, known as frame check sequence (FCS).
- FCS is added to the original data sequence to result in a frame of length k+n bits.

## Cont. CRC

- The FCS is generated using the original message and some predetermined pattern.
- At the receiver, the received signal is divided by the predetermined pattern.
  - No remainder ← error free
  - Remainder ← error in the received data

## Cont. CRC

- In CRC procedure we define:
  - Let M be the message of length k.
  - Let F be the frame checksum of length n bits.
  - Let T be the frame to be transmitted of length k + n.
  - Let P be some predetermined pattern of length n + 1 bits.

# Cont. CRC

- First, concatenate n zeros to the transmitted message.
- Second, generate the frame checksum F by dividing ($M*2^n$) sequence by P.
  - Align P under ($M*2^n$) from the leftmost bit
  - If the input bit above the leftmost divisor bit is 0, do nothing.
  - If the input bit above the leftmost divisor bit is 1, the divisor is XORed into the input.
  - The divisor is then shifted one bit to the right, and the process is repeated until the divisor reaches the right-hand end of the input row.

http://en.wikipedia.org/wiki/Cyclic_redundancy_check

# Cont. CRC

- When the division process ends the only bits in the input row that can be nonzero are the n bits at the right-hand end of the row.
- These n bits are the remainder of the division step.
- The receiver checks the validity of a received message performing the same calculations again, this time with the check value added instead of zeroes. The remainder should equal zero if there are no detectable errors.

http://en.wikipedia.org/wiki/Cyclic_redundancy_check

# Example 1

- Using CRC for error detection and given a message M = 10110 with P = 110, compute the following
  - Frame check Sum (FCS)
  - Transmitted frame
  - Received frame and check if there is any error in the data



# Cont. Example 1

- Since P = 3 bits, then n+1 = 3, therefore n = 2
  - The FCS length is 2 bits
- Concatenate two 0's to M's right
  - $M*2^5 = 1011000$
- $2^{nd}$ FCS = $(M*2^2)/P$ =
  (1011000)/(110)

## Cont. Example 1

```
1 0 1 1 0 | 0 0
1 1 0 ↓ ↓ | ↓ ↓
---------------
0 1 1 1 ↓ | ↓ ↓
  1 1 0 ↓ | ↓ ↓
---------------
  0 0 1 0 | ↓ ↓
    0 0 0 | ↓ ↓
---------------
      1 0 | 0 ↓
      1 1 | 0 ↓
---------------
      0 1 | 0 0
        1 | 1 0
---------------
        0 | 1 0   ← Remainder
```

## Cont. Example 1

- FCS = 10
- Transmitted Message = 1011010

# Cont. Example 1

- At the receiver
  - 1011010/110
- Since there is no remainder at the receiver, then the message does not contain any errors

```
1 0 1 1 0 | 1 0
1 1 0 ↓ ↓ | ↓ ↓
---------------
0 1 1 1 ↓ | ↓ ↓
  1 1 0 ↓ | ↓ ↓
---------------
  0 0 1 0 | ↓ ↓
    0 0 0 | ↓ ↓
---------------
      1 0 | 1 ↓
      1 1 | 0 ↓
---------------
      0 1 | 1 0
        1 | 1 0
---------------
        0 | 0 0  ←  Remainder
```

# Example 2

- Let M = 111001 and P = 11001
- Compute the following:
  - Frame check Sum (FCS)
  - Transmitted frame
  - Received frame and check if there is any error in the data

# Cont. Example 2

- Since P = 5 bits, then n+1 = 5, therefore n = 4
  - The FCS length is 4 bits
- Concatenate four 0's to M's right
  - $M*2^5 = 1110010000$
- $2^{nd}$ FCS = $(M*2^4)/P$ = (1110010000)/ (11001)

# Cont. Example 2

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | |
| 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | ↓ | ↓ | ↓ | |
| 0 | 0 | 1 | 0 | 1 | 1 | ↓ | ↓ | ↓ | ↓ | |
| | 0 | 0 | 0 | 0 | 0 | ↓ | ↓ | ↓ | ↓ | |
| | | 1 | 0 | 1 | 1 | 0 | ↓ | ↓ | ↓ | |
| | | 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | ↓ | |
| | | 0 | 1 | 1 | 1 | 1 | 0 | ↓ | ↓ | |
| | | | 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | |
| | | | 0 | 0 | 1 | 1 | 1 | 0 | ↓ | |
| | | | | 0 | 0 | 0 | 0 | 0 | ↓ | |
| | | | | | 1 | 1 | 1 | 0 | 0 | |
| | | | | | 1 | 1 | 0 | 0 | 1 | |
| | | | | | 0 | 0 | 1 | 0 | 1 | ← Remainder |

## Cont. Example 2

- FCS = 0101
- Transmitted Message = 1110010101

## Cont. Example 2

- At the receiver
  - 1110010101/11001
- Since there is no remainder at the receiver, then the message does not contain any errors

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | |
| 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | ↓ | ↓ | ↓ | |
| 0 | 0 | 1 | 0 | 1 | 1 | ↓ | ↓ | ↓ | ↓ | |
| | 0 | 0 | 0 | 0 | 0 | ↓ | ↓ | ↓ | ↓ | |
| | | 1 | 0 | 1 | 1 | 0 | ↓ | ↓ | ↓ | |
| | | 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | ↓ | |
| | | 0 | 1 | 1 | 1 | 1 | 1 | ↓ | ↓ | |
| | | | 1 | 1 | 0 | 0 | 1 | ↓ | ↓ | |
| | | | 0 | 0 | 1 | 1 | 0 | 0 | ↓ | |
| | | | | 0 | 0 | 0 | 0 | 0 | ↓ | |
| | | | | | 1 | 1 | 0 | 0 | 1 | |
| | | | | | 1 | 1 | 0 | 0 | 1 | |
| | | | | | 0 | 0 | 0 | 0 | 0 | ← Remainder |

## CRC

- The original message is extracted by taking the first k bits, starting from the far left.
- It is important to know the error detection techniques typically do not indicate the location of the error, they just indicate whether the data contains error or not.

## Summary

- CRC is a powerful technique for error detection

Public Authority for Applied Education and Training

# ENC 251
# DIGITAL COMMUNICATION

## CHAPTER 4: CHANNEL ENCODING
## PART 3

## Chapter 4 Objectives

- Error Correction Techniques

# Error Correction Techniques

- Repetition Code
- Hamming Code

# Repetition Code

- One of the simplest techniques used in error control coding.
- Repeat each transmitted bit k times, where k is an odd number.
- Suppose we want to transmit m = 101.
- If k = 5 then every bit is repeated five times.
- Transmitted signal is C = 111110000011111.

## Cont. Repetition Code

- At the decoder we take each group of k = 5 bits.
  - If the number of "1" is more than the number of "0" we assume binary "1" is transmitted.
  - If the number of "0" is more than the number of "1" we say "0" is transmitted.
- If received code C = 101110001101110.
- The received information is 101 which is the same as original transmitted information.

## Cont. Repetition Code

- The advantage of repetition code is its simplicity.
- The main disadvantage in the repetition code is the large redundancy.

# Hamming Code

- A Hamming Code can be use to detect and correct one-bit change in an encoded code word.
- Consider the table below which has 15 positions.
- Data is stored in every position except 1, 2, 4 and 8. These positions (which are powers of 2) are used to store parity (error correction) bits.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_0$ | $P_1$ | D | $P_2$ | D | D | D | $P_3$ | D | D | D | D | D | D | D |

# Cont. Hamming Code

- Secondly, find the positions where the binary is "1".
- Thirdly, get the binary representation of the positions.
- Fourthly, perform exclusive OR (XOR) on the resultant values.
- Finally, the result is placed in the parity bits locations.
- The resultant encoded word is then sent off.

# Example 1

- Encode the following message using hamming code
  m= 10101101011

# Cont. Example 1

- After placing the data in the table we find that in positions 3, 6, 9, 10, 12, 14 and 15 we have a '1'.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_0$ | $P_1$ | 1 | $P_2$ | 0 | 1 | 0 | $P_3$ | 1 | 1 | 0 | 1 | 0 | 1 | 1 |

# Cont. Example 1

- Get the binary representation for each of these position values.
- XOR resulting values
  - Set parity bit to 1 if odd number of 1's else set to 0

| | $P_0$ | $P_1$ | $P_2$ | $P_3$ | Position |
|---|---|---|---|---|---|
| | 1 | 1 | 0 | 0 | 3 |
| | 0 | 1 | 1 | 0 | 6 |
| | 1 | 0 | 0 | 1 | 9 |
| | 0 | 1 | 0 | 1 | 10 |
| | 0 | 0 | 1 | 1 | 12 |
| | 0 | 1 | 1 | 1 | 14 |
| | 1 | 1 | 1 | 1 | 15 |
| XOR | 1 | 1 | 0 | 1 | |

# Cont. Example 1

- The parity bits are then put in the proper locations

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |

## Hamming Code

- The receiving side would re-compute the parity bits and compare them to the ones received.
- If they were the same no error occurred.
- If they were different the location of the flipped bit is determined.

## Example 2

- Assume the bit in position 14 was flipped during transmission.
- The receiving end would see the following encoded sequence:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |

# Cont. Example 2

- The receiving node calculates the parity bits values.

| | $P_0$ | $P_1$ | $P_2$ | $P_3$ | Position |
|---|---|---|---|---|---|
| | 1 | 1 | 0 | 0 | 3 |
| | 0 | 1 | 1 | 0 | 6 |
| | 1 | 0 | 0 | 1 | 9 |
| | 0 | 1 | 0 | 1 | 10 |
| | 0 | 0 | 1 | 1 | 12 |
| | 1 | 1 | 1 | 1 | 15 |
| XOR | 1 | 0 | 1 | 0 | |

# Cont. Example 2

- The re-calculated parity information is then compared to the parity information sent/received.

| | | | | |
|---|---|---|---|---|
| 1 | 1 | 0 | 1 | Parity bits from the received message |
| 1 | 0 | 1 | 0 | Parity bits from re-calculation at the receiver |

- If they are equal ← No Error
- If they are NOT equal ← Error

## Cont. Example 2

- If they are NOT equal ← Error
  - Perform XOR to get the position of the bit with the error and flip it
- The error is in bit 14 (8+4+2)
- Since bit 14 is 0 we flip it to 1

| | | | |
|---|---|---|---|
| 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 |

- Message received with error = 10101101001
- Message after error detection and correction = 10101101011

## Summary

- When data is transmitted from one location to another there is always the possibility that an error may occur.
- There are a number of reliable codes that can be used to encode data so that the error can be detected and corrected.
- Repetition code is one of the simplest techniques used in error control coding.
- Hamming Code can be use to detect and correct one-bit change in an encoded code word.

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# ENC 251
# DIGITAL COMMUNICATION

# CHAPTER 5: MODULATION TECHNIQUES
# PART 1

## Chapter 5 Objectives

- Understand modulation
- Discuss data transmission in digital systems
- Discuss baseband transmission technique

# Digital Communication System

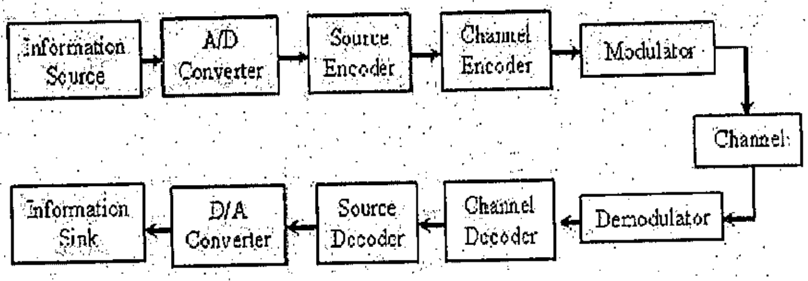



Figure 3: Block diagram of typical digital communication system.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 5

# Cont. Digital Communication System

- **Information Source:** generates messages.
- **Analog to digital converter A/D:** convert analog signal to digital signal.
  - Sampling, Quantization and Coding
- **Source encoder (Data Compression):** Transmitting the same information with smaller average number of binary digits
  - Huffman Coding
- **Channel encoder (Error Correction):** introduce redundancy in the binary data
  - Techniques for error detection: Parity Check and CRC
  - Techniques for error correction: Repetition Code and Hamming Code

# Modulation

- After the binary data is channel encoded it is ready to be transmitted through the channel.
- In order to transmit the binary data electronically we must convert it to an electrical signal.
- The binary data is converted back to some type of an analog signal to transmit it through the channel.
- This is done through a process called data modulation.

# Cont. Modulation

- Modulation is the process of changing a parameter of a signal using another signal.
- One of the most common signals used is the sinusoidal signal.
- The general form for a sinusoidal signal is:
  - $v(t) = A.\sin(\omega t + \mu)$
    - A is the amplitude of the sinusoidal signal
    - $\omega$ is the radian frequency
    - $\mu$ is the phase shift
- In modulation, the transmitted signal (the message signal) is used to change one of these parameters.

## Cont. Modulation

- If the amplitude of the sinusoidal signal changes in accordance with the transmitted message, this process is called amplitude modulation.
- If the frequency of the sinusoidal signal changes in accordance with the transmitted message, this process is called frequency modulation
- The signal which gets modulated by the data is often called the modulated signal or the carrier signal
  - For example here, the sinusoidal signal is the carrier signal.

## Cont. Modulation

- In digital data transmission there are two types of data transmission.
  - Baseband data transmission
    - Low frequency carrier signal is used to transmit the data
  - Bandpass data transmission
    - High frequency carrier signal is used to transmit the data

## Baseband Data Transmission (Line Coding)

- Data transmission the binary data is converted into an electrical signal in order to transmit it through a communication channel.
- Baseband transmission or line coding is the process of expressing this electrical signal in a form of an electrical pulse.

## Cont. Baseband Data Transmission

- Baseband consists of representing the digital signal to be transported, by an amplitude- and time-discrete
- The waveform pattern of voltage or current used to represent the 1s and 0s of a digital signal on a transmission link is called line encoding.

## Cont. Baseband Data Transmission

- Baseband signaling techniques:
  - Non-return to zero (NRZ)
  - Unipolar Return to zero (Unipolar-RZ)
  - Bipolar-RZ
  - Return to zero-alternate mark inversion (RZ-AMI)
  - NRZ-mark
  - Biphase (Manchester coding)

## Non-return to zero (NRZ)

- Binary "1" is represented by some level and binary "0" is represented by the opposite level.
- The term non-return to zero means the signal switched from one level to another without taking the zero value at any time during transmission.
- For example, suppose we want to transmit the following data sequence m = 1011010

# Cont. NRZ

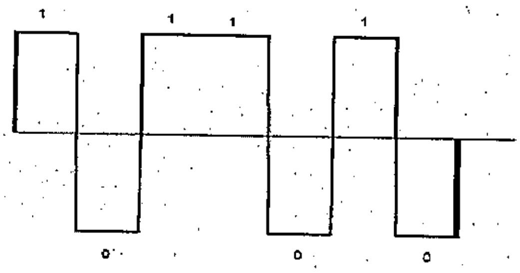



Figure 15: NRZ encoding procedure.



# Unipolar Return to zero (Unipolar-RZ)

- Binary "1" is represented by some level of half the signal width and binary "0" is represented by the absence of a pulse.
- For example, suppose we want to transmit the following data sequence m = 1011010

# Cont. Unipolar-RZ

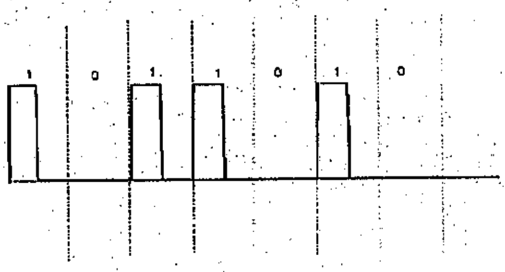



Figure 16: Unipolar-RZ encoding procedure.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 61

# NRZ vs Unipolar-RZ

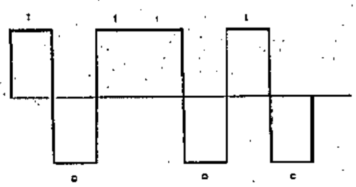


Figure 15: NRZ encoding procedure.

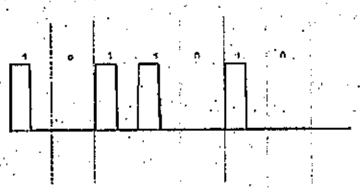


Figure 16: Unipolar-RZ encoding procedure.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 61

# Bipolar-RZ

- Binary "1" is represented by a pulse half width and binary "0" is represented by a pulse of half width but with opposite sign.
- For example, suppose we want to transmit the following data sequence m = 1011010

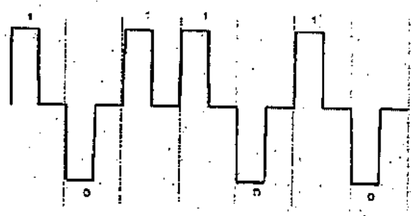
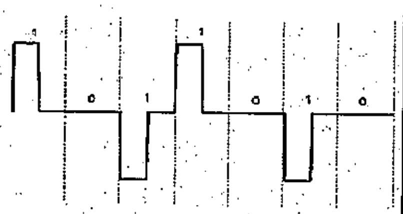


Figure 17: Bipolar-RZ encoding procedure.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 62

# return to zero-alternate mark inversion (RZ-AMI)

- binary "1" is represented by a pulse alternating in sign and binary "0" is represented by no pulse.



Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 62

Figure 18: RZ-AMI encoding procedure.

# NRZ-mark

- Also known as differential encoding the waveform takes on some value or state say high or low.
- Binary "1" represents a change of state from high to low or from low to high, while binary "0" represents no change of state.

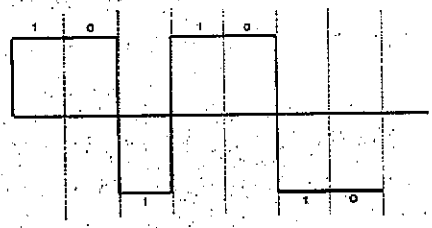


Figure 19: NRZ-mark encoding procedure.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 63

# Biphase (Manchester Coding)

- Binary "1" is represented by a positive pulse of half width followed by negative pulse.
- Binary "0" is represented by negative pulse of half width followed by a positive pulse.

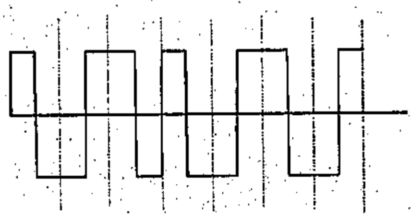


Figure 20: Manchester encoding procedure.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 63

# Digital Modulation Techniques

- Each of these schemes has its own applications.
- Factors which help in comparing and selecting a particular scheme include:
  - Signal Spectrum: available transmission bandwidth
  - Clocking: One expensive approach is to provide a separate clock lead to synchronize the transmitter and receiver. The alternative is to provide some synchronization mechanism that is based on the transmitted signal.
  - Error detection: error detection capability built into the signaling encoding scheme.
  - Signal interference and noise immunity: Certain encoding techniques exhibit superior performance in the presence of noise.
  - Cost and complexity

# Digital Modulation Techniques Summary

| Modulation Scheme | Binary 1 | Binary 0 |
|---|---|---|
| NRZ | Pulse | Opposite pulse |
| Unipolar-RZ | Pulse of half width | No pulse |
| Bipolar-RZ | Pulse of half width | Opposite pulse of half width |
| RZ-AMI | Pulse of half width alternating in sign | No pulse |
| NRZ-mark | Change of state | No change of state |
| Biphase | Positive pulse of half width followed by negative pulse | Negative pulse of half width followed by positive pulse |

## Summary

- Modulation is the process of changing a parameter of a signal using another signal.
- Each baseband encoding modulation schemes has its own applications and various factors help in comparing and selecting a particular scheme.

Public Authority for Applied Education and Training

# ENC 251
# DIGITAL COMMUNICATION

## CHAPTER 5: MODULATION TECHNIQUES
## PART 2

## Chapter 5 Objectives

- Understand scrambling techniques
- Define some data transmission terms

## Scrambling Techniques

- Data scrambling is to replace a sequence of bits with another sequence to achieve certain goals.
- In many digital communication applications we often receive binary sequences that would result in a constant voltage level on the transmission line.
  - A long sequence of zeros or long sequence of ones.
- Replace these sequences by special sequences using two techniques:
  - Bipolar 8-zeros substitution (B8ZS)
  - High density bipolar-3 zeros (HDB3)

## Bipolar 8-zeros Substitution

- The B8ZS coding scheme is used in North America to replace 8 zeros with a special sequence.
- The coding scheme is based on bipolar-AMI.
- A sequence of 8 binary zeros is replaced with another sequence based on the following rules:
  - If an octet (8) of all zeros occurs and the last voltage pulse preceding this octet was positive, then the eight zeros of the octet are encoded based on bipolar-AMI technique as 000+-0-+.
  - If an octet of all zeros occurs and the last voltage pulse preceding this octet was negative, then the eight zeros of the octet are encoded based on bipolar-AMI technique as 000-+0+-.

# Cont. B8ZS

- Encode the following sequence: 1100000000110000010
- Using Bipolar-AMI the signaling waveform

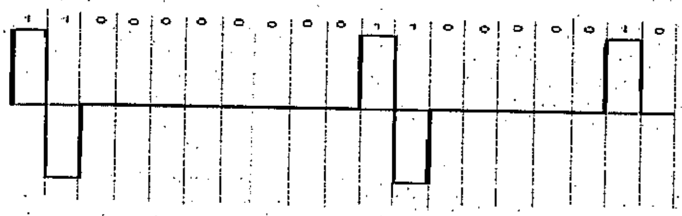


Figure 21: Bipolar-AMI encoded sequence.



# Cont. B8ZS

- Sequence of 8 zeros and the last voltage pulse was negative.
- Encode as 000-+0+-.

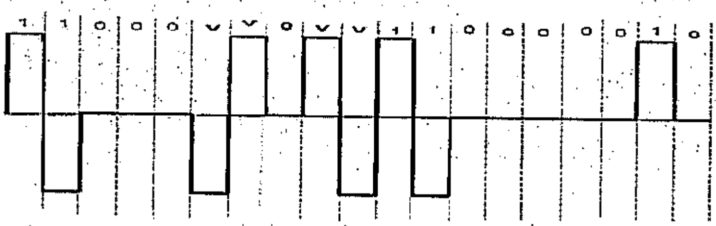


Figure 22: B8ZS scrambled sequence.

# High Density Bipolar-3 Zeros

- The HDB3 technique is used in Europe and Japan, and it is based on using AMI signaling technique.
- The technique replaces a sequence of four zeros with sequences containing one or two pulses.
- In each case, the fourth zero is replaced.
- Summary of HDB3 encoding rules

| Transmitted Data | HDB3 Encoded Pattern |
|---|---|
| 0 | 0 |
| 1 | Alternate Mark Inversion (AMI) |
| 0000 | 000V (three 0's and a violation) |
| 0000 0000 | B00V B00V |

http://en.wikipedia.org/wiki/Modified_AMI_code#HDB3_.28European_E-carrier.29

# Cont. HDB3

- The substitution of the four zeros is done based on the following rules:

| Number of +/- bits since last Violation | Pattern | Polarity of last Pulse | Coded |
|---|---|---|---|
| Odd | 000V | + | 000+ |
| | | − | 000− |
| Even | B00V | + | −00− |
| | | − | +00+ |

- To determine which pattern to use, count the number of pluses (+) and the number of minuses (−) since the last violation bit V and subtract one from the other.
  - Odd number then 000− or 000+ is used.
  - Even number then +00+ or −00− is used.

http://en.wikipedia.org/wiki/Modified_AMI_code#HDB3_.28European_E-carrier.29

## Example 1

- The pattern of bits: 1 <u>0 0 0 0</u> 1 1 0
- Encoded in HDB3 is: + <u>0 0 0 V</u> − + 0
- Final result is: + <u>0 0 0 +</u> − + 0

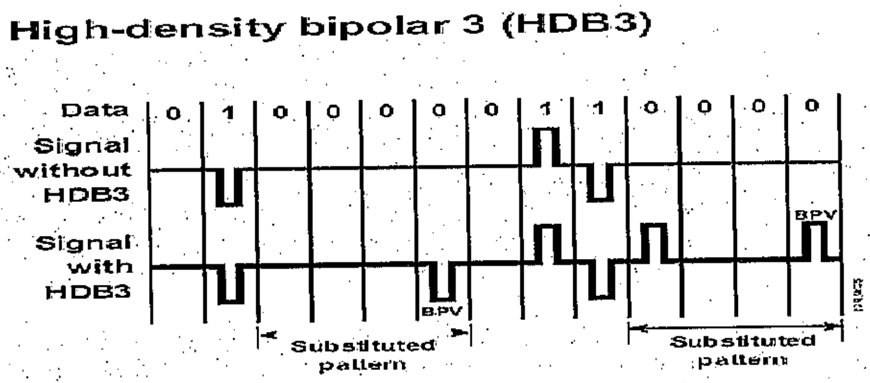
## Example 2

- The pattern of bits:
  - 1 0 1 <u>0 0 0 0</u> 0 1 1 <u>0 0 0 0</u> 1 1 <u>0 0 0 0</u> 0 0
- Encoded in HDB3 is:
  - + 0 − <u>0 0 0 V</u> 0 + − <u>B 0 0 V</u> + − <u>B 0 0 V</u> 0 0
- Final result is:
  - + 0 − <u>0 0 0 −</u> 0 + − <u>+ 0 0 +</u> + − <u>+ 0 0 +</u> 0 0

# Example 3

- The pattern of bits:
  - 1 0 1 0 0 0 0 1 0 0 0 0 1 1 0 0 0 0 1 1 1 0 0 0 0 1 1 1 1 0 0 0 0 1 0 1 0 0 0 0
- Encoded in HDB3 is:
  - \+ 0 – 0 0 0 V + 0 0 0 V - + B 0 0 V - + - 0 0 0 V + - + - B 0 0 V + 0 - B 0 0 V
- Final result is:
  - \+ 0 – 0 0 0 - + 0 0 0 + - + - 0 0 - - + - 0 0 0 - + - + - + 0 0 + + 0 - + 0 0 +

# Example 4




Lecture notes by Abdullah Almeshal, Chapter 5: Modulation Techniques, slide 9

## Example 5

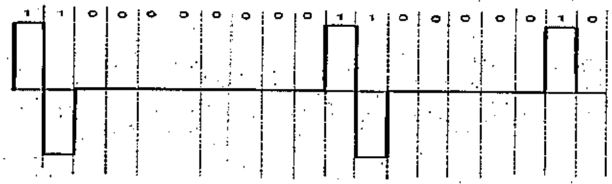


Figure 21: Bipolar-AMI encoded sequence.

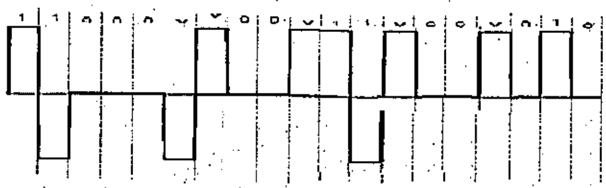


Figure 23: HDB3 scrambled sequence.

## Data Transmission Terms

- The following are some the important terms often used in data communication:
  - Bandwidth
  - Bit Rate
  - Baud Rate (Symbol Rate)
  - Throughput
  - Latency

## Transmission Bandwidth

- Transmission bandwidth: the band of frequencies allowed for signal transmission
- Frequency of the transmitted signal must be within the range of frequencies of the transmission bandwidth

## Cont. Transmission Bandwidth

- For a low frequency transmission bandwidth the system can pass signals with frequencies up to $f_{max}$
- If the transmitted signal have frequencies above $f_{max}$ then these frequencies will not pass and the signal will not be a replica of the transmitted signal.

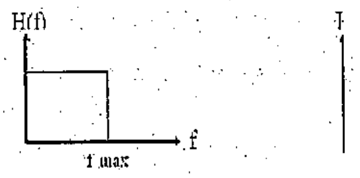
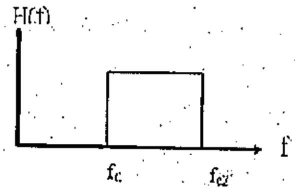



Figure 24: (a) low pass transmission system

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 67

# Cont. Transmission Bandwidth

- For bandlimited transmissions, any frequencies falls outside this range will be suppressed.
- Therefore, if a signal has frequencies outside this band, these frequencies will not pass and the signal will be distorted.




(b) Bandlimited transmission system

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# Bit Rate

- Bit rate: the bit rate is the number of bits transferred between devices per second.
- If each bit is represented by a pulse of width $T_b$, then the bit rate:

$$R_b = \frac{1}{T_b} \quad bits/\sec$$

## Example 6

- Suppose we have a binary data source which generates bits.
- Each bit is represented by a binary pulse of width $T_b = 0.1$ msec calculate the bit rate for this source.

$$R_b = \frac{1}{T_b} = \frac{1}{0.1 \times 10^{-3}} = 10000 \quad bits/\text{sec}$$

## Example 7

- Suppose we have an image frame of size 200x200 pixels
- Each pixel is represented by three primary colours red, green, and blue (RGB)
- Each one of these colours is represented by 8 bits.
- If we transmit 1000 frames in 5 seconds what is the bit rate for this image.

## Cont. Example 7

- We have a total size of 200x200 = 40000 pixels
- Each pixel has three colors, RGB that each of them has 8 bits.
  - 3 x 8 = 24 bits (for each pixel with RGB)
- Therefore, for the whole image we have a total size of 24 x 40000 = 960000 bits
- Since we have 1000 frames in 5 seconds, then the total number of bits transmitted will be 1000 x 960000 = 960000000 bits in 5 seconds
- Bit rate = 96000000/5 = 192000000 bits/second

## Baud Rate (Symbol Rate)

- Baud rate or symbol rate: is the number of symbols transmitted per second through the communication channel.
- The symbol rate is related to the bit rate by the following equation:

$$R_s = \frac{R_b}{N}$$

  - $R_b$ = bit rate
  - $R_s$ = symbol rate
  - N = Number of bits per symbol

# Example 8

- A binary data source transmits binary data, the bit duration is 1μsec, Suppose we want to transmit symbols rather than bits, if each symbol is represented by four bits. what is the symbol rate?



# Cont. Example 8

- Each bit is represented by a pulse of duration 1μ second, hence the bit rate

$$R_b = \frac{1}{1\times 10^{-6}} = 1000000 \;\; bits/\mathrm{sec}$$

- Therefore, the symbol rate will be

$$R_s = \frac{R_b}{N} = \frac{1000000}{4} = 250000 \;\; symbols/\mathrm{sec}$$

## Throughput

- Throughput: the rate at which the system sends or receives data.
- For example, if over ten seconds, twenty packets are transferred.
  - Throughput = 20/10 = 2 packets per second.
- Throughput measures the amount of data that is transferred over a period of time.
  - bits/second, bytes/second, or packets/second

## Latency

- Latency: the time a request leaves to the time the response arrives back.
- The unit of latency is time in seconds.

## Summary

- Data scrambling is to replace a sequence of bits with another sequence to achieve certain goals.
- Replace these sequences by special sequences using two techniques:
  - Bipolar 8-zeros substitution
  - High density bipolar-3 zeros
- Definitions are often used in to evaluate the merit or the quality of a digital communication system.

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# ENC 251 DIGITAL COMMUNICATION

# CHAPTER 5: MODULATION TECHNIQUES PART 3

## Chapter 5 Objectives

- Discuss bandpass data transmission technique

## Bandpass Data Transmission

- In communication, modulation is used for several reasons:
  - Reduce the size of the antenna used.
    - Antenna height = 1/4 wavelength
    - 1 Hz ($\lambda$=3*10^8 m) = 75,000 Km!
    - 88 MHZ ( $\lambda$ = 3.4 m ) = 0.8522 m
  - Transmit several signal at the same time over a communication (multiplexing).
  - Simplify the design of the electronic systems used to transmit the message.
  - Transmit data with low loss, and low dispersion.
    - Adopt data to the channel used to transmit it.

## Bandpass Data Transmission

- Digital modulation is the process by which digital symbols are transformed into waveforms that are compatible with the characteristics of the channel.
- In bandpass transmission the digital data is used to modulate a carrier signal.
- Regardless of the modulation method, any form of digital modulation uses a finite number of distinct signals to represent digital data.

## Cont. Bandpass Data Transmission

- Different modulation techniques:
  - Phase modulation: finite number of phases are used.
  - Frequency modulation: finite number of frequencies are used.
  - Amplitude modulation: finite number of amplitudes are used.

## Cont. Bandpass Data Transmission

- Each of these phases, frequencies or amplitudes are assigned a unique pattern of binary bits.
- Usually, each phase, frequency or amplitude encodes an equal number of bits.
- This number of bits comprises the symbol that is represented by the particular phase, frequency, or amplitude.

## Cont. Bandpass Data Transmission

- The following are the general steps used by the modulator to transmit data:
  - Accept incoming digital data
  - Group the data into symbols
  - Use these symbols to set or change the phase, frequency or amplitude of the reference carrier signal appropriately.

## Common Bandpass Modulation Techniques

- Amplitude shift keying (ASK)
- Phase shift keying (PSK)
- Frequency shift keying (FSK)
- Multilevel Signaling ($M_{ary}$ Modulation)

## Multilevel Signaling ($M_{ary}$ Modulation)

- With multilevel signaling, digital inputs with more than two modulation levels are allowed on the transmitter input.
- The data is transmitted in the form of symbols, each symbol is represented by k bits
  - $M=2^K$ different symbols
- There are many different $M_{ary}$ modulation techniques, some of these techniques modulate one parameter like the amplitude, or phase, or frequency



## Cont. $M_{ary}$ Modulation

- Multilevel Signaling ($M_{ary}$ Modulation)
  - $M_{ary}$ Amplitude Modulation
    - Changing the Amplitude using different levels
  - $M_{ary}$ Phase Shift Keying ($M_{ary}$ PSK)
    - Changing the phase using different levels
  - $M_{ary}$ Frequency Shift Keying ($M_{ary}$ FSK)
    - Changing the frequency using different levels

## $M_{ary}$ Amplitude Modulation

- In multi level amplitude modulation the amplitude of the transmitted (carrier) signal takes on M different levels.
- For a group of k bits we need $M=2^k$ different amplitude levels
- Used in both baseband and bandpass transmission
  - Baseband → $M_{ary}$ Pulse Amplitude Modulation (PAM)
  - Bandpass → $M_{ary}$ Amplitude Shift Keying (ASK)



## $M_{ary}$ Amplitude Modulation

- Suppose the maximum allowed value for the voltage is A, then all M possible values at baseband are in the range[-A,A] and they are given by:

$$v_i = \frac{2A}{M-1} i - A \quad ;where \ \ i = 0,1,..M-1$$

- And the difference between one symbol and another is given by $\delta = \frac{2A}{M-1}$

# Example

- Show how to transmit the message

m=100110001101010111

Using $8_{ary}$ Pulse Amplitude Modulation. Find the corresponding amplitudes of the transmitted signal and calculate the difference between the symbols. Given that the maximum amplitude is 4 Volts



# Example - Solution

- Since we will be using $8_{ary}$ modulation then the signal must be divided into symbols each of 3 bits
  - Because $2^3 = 8$
- Therefore,
  - m=100110001101010111
  - m = 100 110 001 101 010 111

$S_4$ $S_6$ $S_1$ $S_5$ $S_2$ $S_7$

## Example – Solution (Cont.)

- Amplitude calculations

$$v_i = \frac{2A}{M-1} i - A$$

$$v_4 = \frac{2(4)}{8-1}(4) - 4 = 0.5714 \quad volts$$

$$v_6 = \frac{2(4)}{8-1}(6) - 4 = 2.8571 \quad volts$$

$$v_1 = \frac{2(4)}{8-1}(1) - 4 = -2.8571 \quad volts$$



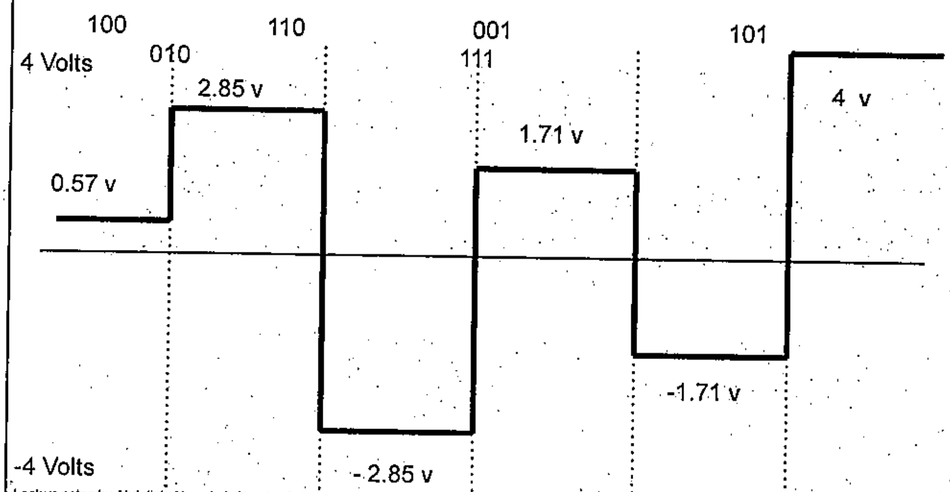
## Example – Solution (Cont.)

$$v_5 = \frac{2(4)}{8-1}(5) - 4 = 1.7142 \quad volts$$

$$v_2 = \frac{2(4)}{8-1}(2) - 4 = -1.7142 \quad volts$$

$$v_7 = \frac{2(4)}{8-1}(7) - 4 = 4 \quad volts$$

## Example – Solution (Cont.)






## Example – Solution (Cont.)

- Difference between each symbol and another can be calculated as follows:

$$\delta = \frac{2A}{M-1} = \frac{2(4)}{8-1} = 1.1428 \ volts$$

## Summary

- Modulation combines a (low frequency) signal with a (high frequency) carrier.
- Combining of signal and carrier can be done in three major ways, amplitude, frequency and phase modulation.
- In multi level amplitude modulation the amplitude of the transmitted (carrier) signal takes on M different levels.

## Multiplexing

- In telecommunications, multiplexing is the process of combining two or more signals into one communication link.
- Multiplexing allows several transmission sources to share a larger transmission capacity or transmission medium.
- Multiplexing makes very efficient use of high speed telecommunications lines.

## Cont. Multiplexing

- Sending some multimedia signal like voice signal which is a low frequency signal over a transmission channel with very large bandwidth.
- Most of the transmission channel bandwidth is not utilized.
  - Because the bandwidth of the transmission channel is much larger than the bandwidth of the transmitted signal.
- Therefore, transmit other signals over the same communication link but with different carrier frequencies.
  - All the signals can be transmitted simultaneously without any problem.

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# ENC 251
# DIGITAL COMMUNICATION

# CHAPTER 6: MULTIPLEXING

## Chapter 6 Objectives

- Discuss multiplexing
- Understand different multiplexing techniques

# Cont. Multiplexing

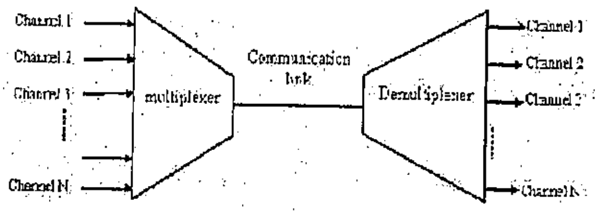



Figure 38: Illustration of multiplexing process.

Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 86

# Cont. Multiplexing

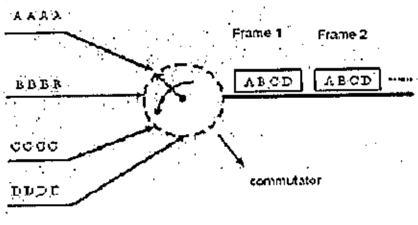
- Some of the common techniques used to multiplex signals:
  - Time-division multiplexing (TDM)
  - Frequency-division multiplexing (FDM)
  - Code division multiplexing and code division multiple access (CDMA)
  - Wave division multiplexing

# Time Division Multiplexing (TDM)

- A multiplexing technique in which two or more apparently simultaneous signals or channels are combined on one communication link in the time domain.
- The multiplexing process can be carried on a single transmission path by interleaving portions of each signal in time.
- Time division multiplexing can be applied to both analog signals and digital signals.

# Cont. TDM

- A device called commutator which takes a sample from the first signal, then the commutator moves and takes a sample from the second signal, next, the commutator takes a sample from the third signal.
- After the commutator makes one complete cycle it returns back to the first signal




Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 87 Figure 39: Time division multiplexing process.

## Cont. TDM

- Two types of time division multiplexing:
  - Synchronous Time Division Multiplexing
  - Asynchronous Time Division Multiplexing

## Synchronous Time Division Multiplexing

- In synchronous time division multiplexing each signal is assigned a time slot.
- This time slot is used by one particular signal or device, no other signal can use this time slot.
- Each time the allocated time slot for some particular signal comes up, the signal or the device has the opportunity to send a portion of its data.
- If the device or the signal is unable to transmit or does not have data to send, its time slot remains empty.

## Cont. Synchronous Time Division Multiplexing

- Once the commutator makes one complete cycle a group of N slots are formed, the N time slots are grouped into frames.

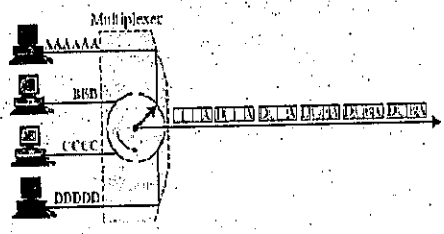



Figure 40: Time division multiplexing process.



## Cont. Synchronous Time Division Multiplexing

- At the receiver, the demultiplexer decomposes each frame by extracting each portion or character in turn.
- As a signal portion is removed from the particular coming frame, it is passed to the appropriate receiving device or signal.

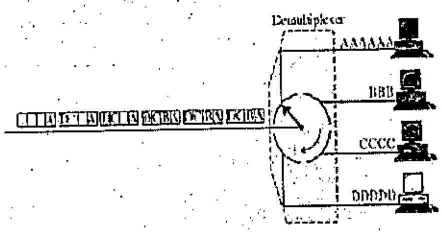



Figure 41: Time division multiplexing process.

## Cont. Synchronous Time Division Multiplexing

- Framing bits: are additional synchronization bits added to the beginning of each frame to determine the beginning and the end of the frames.
- Framing bits allow the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately.
- Typically, the synchronization information consists of one bit per frame, alternating between "0" and "1", that is the synchronization sequence is (0101010101 ...).
- Frame size consist of the number of bits per character for each signal plus the additional framing bits.

## Example 1

- Suppose we want to time multiplex four devices, each device sends 250 characters per second.
- Each frame carries 1 character from each device, and one synchronization bit.
- Assume each character is eight bits long.
- What is the total bit rate?

## Cont. Example 1

- Each frame contains four characters.
- Each device sends 250 characters per second and each frame contains one character from each device.
- Hence, in one second we have a total of 250 frames and each frame contains four characters one from each device.
- Since each character is eight bits long then each frame has $4 * 8 + 1 = 33$ bits
  - 32 information bits and one framing bit.
- Bit Rate = 33*250 = 8250 bits/second.
- Note: the total number of information bits is 8000 bits and 250 bits are overhead used for synchronization.

## Frequency Division Multiplexing (FDM)

- Several signals are transmitted simultaneously on the same medium or same transmission link by allocating to each signal a different frequency band.
- The multiplexing process is done by assigning to each transmitted signal different carrier signal.

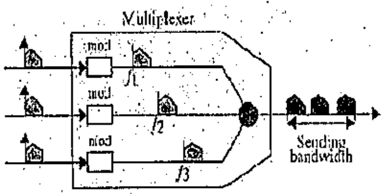



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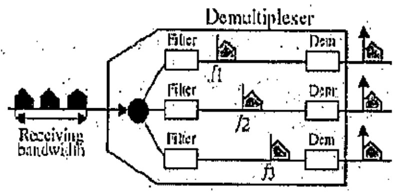
Figure 42: Frequency division multiplexing process.

## Cont. FDM

- At the receiver, the desired signals is extracted by using band pass filters.
- Frequency division multiplexing is typically used for analog signal.
- A direct application of frequency division multiplexing is broadcast stations, i.e., radio and television.




Fundamentals of Digital Communications and Data Transmission, Dr. Faisal Alturki, page 92 Figure 43: Frequency division demultiplexing process.

## Summary

- Multiplexing techniques are used often in communication systems.
- Time-division multiplexing combines many signals on the same link with respect to time.
- Two types of time division multiplexing, synchronous and asynchronous time division multiplexing.
- Frequency division multiplexing is typically used for analog signal.