

# Aspects of Digital Communication

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## Table of contents

<b>TABLE OF CONTENTS</b> .....	<b>1</b>
<b>TABLE OF FIGURES</b> .....	<b>2</b>
<b>TABLE OF TABLES</b> .....	<b>2</b>
<b>CHAPTER 1. INTRODUCTION</b> .....	<b>2</b>
1.1. REASONS FOR DIGITAL COMMUNICATION .....	2
1.2. GOALS FOR DIGITAL COMMUNICATION.....	2
1.3. DIGITAL COMMUNICATION VIA PORTABLE MEDIA .....	2
<b>CHAPTER 2. SIMPLE COMMUNICATION SYSTEMS</b> .....	<b>2</b>
2.1. TECHNIQUE #1: COUNT SERIAL .....	2
2.1.1. <i>Line States</i> .....	2
2.1.2. <i>Timing Considerations</i> .....	2
2.1.3. <i>Protocols</i> .....	2
2.1.4. <i>Possible problems</i> .....	2
2.1.5. <i>Advantages</i> .....	2
2.1.6. <i>Disadvantages</i> .....	2
2.2. TECHNIQUE #2 BINARY CODED SERIAL.....	2
2.2.1. <i>Timing Considerations</i> .....	2
2.2.2. <i>Protocols</i> .....	2
2.2.3. <i>Possible problems</i> .....	2
2.2.4. <i>Advantages</i> .....	2
2.2.5. <i>Disadvantages</i> .....	2
2.3. TECHNIQUE #3 ENCODED - MORSE CODE .....	2
2.3.1. <i>Timing Considerations</i> .....	2
2.3.2. <i>Protocols</i> .....	2
2.3.3. <i>Possible problems</i> .....	2
2.3.4. <i>Advantages</i> .....	2
2.3.5. <i>Disadvantages</i> .....	2
2.4. TECHNIQUE #4 ASYNCHRONOUS SERIAL - ASCII.....	2
2.4.1. <i>Timing Considerations</i> .....	2
2.4.2. <i>Protocols</i> .....	2
2.4.3. <i>Advantages</i> .....	2
2.4.4. <i>Disadvantages</i> .....	2
2.5. TECHNIQUE #5 SYNCHRONOUS .....	2
2.5.1. <i>Timing Considerations</i> .....	2
2.5.2. <i>Protocols</i> .....	2
2.5.3. <i>Advantages</i> .....	2
2.5.4. <i>Disadvantages</i> .....	2
2.6. TWO WAY COMMUNICATIONS .....	2

# Aspects of Digital Communication

## Table of contents

2.6.1.	<i>Half Duplex</i> .....	2
2.6.2.	<i>Line States</i> .....	2
2.6.3.	<i>Timing Considerations</i> .....	2
2.6.4.	<i>Protocols</i> .....	2
2.6.5.	<i>Possible problems</i> .....	2
2.6.6.	<i>Advantages</i> .....	2
2.6.7.	<i>Disadvantages</i> .....	2
2.7.	<b>FULL DUPLEX</b> .....	2
2.7.1.	<i>Timing Considerations</i> .....	2
2.7.2.	<i>Protocols</i> .....	2
2.7.3.	<i>Possible problems</i> .....	2
2.7.4.	<i>Advantages</i> .....	2
2.7.5.	<i>Disadvantages</i> .....	2
2.8.	<b>FLOW CONTROL</b> .....	2
2.9.	<b>SAMPLE DIALOGS FOR SIMPLE PROTOCOLS - POINT TO POINT</b> .....	2
2.10.	<b>OTHER SIMPLE COMMUNICATION TECHNIQUES</b> .....	2
2.10.1.	<i>Fiber Optic Based</i> .....	2
2.10.2.	<i>Wireless</i> .....	2
<b>3.</b>	<b>MANY COMMUNICATORS – NETWORK TOPOLOGY</b> .....	<b>2</b>
3.1.	<b>MULTI-DROP</b> .....	2
3.1.1.	<i>Timing Considerations</i> .....	2
3.1.2.	<i>Protocols</i> .....	2
3.1.3.	<i>Possible problems</i> .....	2
3.1.4.	<i>Advantages</i> .....	2
3.1.5.	<i>Disadvantages</i> .....	2
3.2.	<b>MEDIUM ACCESS CONTROL (MAC) - MANAGING THE PARTY LINE</b> .....	2
3.3.	<b>BIT FORWARDING DEVICES</b> .....	2
3.3.1.	<i>Repeaters</i> .....	2
3.3.2.	<i>Repeaters - Hubs</i> .....	2
3.4.	<b>PACKET FORWARDERS</b> .....	2
3.4.1.	<i>Bridges</i> .....	2
3.4.2.	<i>Switches</i> .....	2
3.4.3.	<i>Routers</i> .....	2
3.5.	<b>SAMPLE DIALOGS FOR A ROUTED NETWORK</b> .....	2
3.5.1.	<i>Routed Network</i> .....	2
3.6.	<b>GATEWAYS</b> .....	2
<b>4.</b>	<b>OVERVIEW OF WIRED AND WIRELESS NETWORKING</b> .....	<b>2</b>
4.1.	<b>GENERAL</b> .....	2
4.2.	<b>WIRELESS</b> .....	2
<b>CHAPTER 5.</b>	<b>ERROR CONTROL</b> .....	<b>2</b>
5.1.	<b>ERROR PREVENTION</b> .....	2
5.2.	<b>ERROR DETECTION</b> .....	2
5.3.	<b>ERROR CORRECTION</b> .....	2
5.4.	<b>EXAMPLES</b> .....	2
<b>CHAPTER 6.</b>	<b>ELEMENTS OF DIGITAL COMMUNICATION</b> .....	<b>2</b>
6.1.	<b>ISO - OSI</b> .....	2
6.2.	<b>PHYSICAL LAYER</b> .....	2
6.2.1.	<i>Parallel</i> .....	2
6.2.2.	<i>Serial - Point to Point Links</i> .....	2

## Aspects of Digital Communication Table of Figures

6.2.3. <i>Serial - Multiaccess</i> .....	2
6.3. DATA LINK LAYER .....	2
6.3.1. <i>Codes used for information exchange (character sets)</i> .....	2
6.3.2. <i>Framing</i> .....	2
6.4. NETWORK LAYER .....	2
6.4.1. <i>Geographical Classification</i> .....	2
6.4.2. <i>Topological Classification</i> .....	2
6.4.3. <i>Routing issues</i> .....	2
6.4.4. <i>Addressing</i> .....	2
6.5. NETWORK MANAGEMENT .....	2
6.6. SECURITY .....	2
6.7. SOCIOLOGICAL ISSUES .....	2
<b>CHAPTER 7. DATA REPRESENTATIONS AND COMPRESSION</b> .....	<b>2</b>
7.1. FORMS OF DIGITAL INFORMATION .....	2
7.1.1. <i>Logical Variables</i> .....	2
7.1.2. <i>Binary numbers</i> .....	2
7.1.3. <i>Floating Point numbers</i> .....	2
7.1.4. <i>Machine Level Programs</i> .....	2
7.1.5. <i>Coded "text"</i> .....	2
7.2. SPECIFIC REPRESENTATIONS .....	2
7.2.1. <i>Textual Information</i> .....	2
7.2.2. <i>Tokens</i> .....	2
7.2.3. <i>Storage of Numerical Data</i> .....	2
7.2.4. <i>Graphical representations</i> .....	2
7.3. SYSTEMATIC COMPRESSION, DECOMPRESSION .....	2
<b>CHAPTER 8. REAL NETWORKS</b> .....	<b>2</b>
8.1. TCP/IP .....	2
8.1.1. <i>IPv4 Addresses</i> .....	2
8.1.2. <i>IPv6 Addresses</i> .....	2
<b>CHAPTER 9. HUMAN-MACHINE INTERFACE</b> .....	<b>2</b>
9.1. UNIT RECORD EQUIPMENT .....	2
9.2. EARLY TERMINALS .....	2
9.2.1. <i>Specific Example: TeleTYpe (TTY) (Current loop)</i> .....	2
9.3. "CRT" TERMINALS .....	2
9.3.1. <i>Specific Example: VT100</i> .....	2
9.4. WORKSTATIONS .....	2
9.4.1. <i>User Interface Input devices</i> .....	2
9.4.2. <i>User Interface Output devices</i> .....	2
9.4.3. <i>Examples</i> .....	2
9.5. TERMINAL EMULATION .....	2
9.6. REAL WORKSTATION TERMINAL EMULATION (COMMUNICATION) PROGRAMS .....	2

## Table of Figures

FIGURE 1 - MAP OF MICHIGAN .....	2
FIGURE 2 - A SIMPLE COMMUNICATION SETUP .....	2
FIGURE 3 - TIMING FOR TECHNIQUE #1 .....	2
FIGURE 4 - TIMING FOR TECHNIQUE #2 .....	2
FIGURE 5 - EXAMPLE 1 .....	2
FIGURE 6 - EXAMPLE 2 .....	2

## Aspects of Digital Communication Table of Figures

FIGURE 7 - TIMING FOR TECHNIQUE #3 - MORSE CODE.....	2
FIGURE 8 - ASYNCHRONOUS SERIAL TIMING .....	2
FIGURE 9 - INTER-FRAME TIMING .....	2
FIGURE 10 - SIMPLE DATA PACKET.....	2
FIGURE 11 - DATA PACKET: BYTE COUNT .....	2
FIGURE 12 - DATA PACKET: SPECIAL TERMINATOR.....	2
FIGURE 13 - HALF DUPLEX COMMUNICATION .....	2
FIGURE 14 - FULL DUPLEX COMMUNICATION .....	2
FIGURE 15 - FLOW CONTROL .....	2
FIGURE 16 - FIBER OPTIC TRANSMISSION.....	2
FIGURE 17 - NETWORK TOPOLOGY .....	2
FIGURE 18 - HIERARCHY OF STARS .....	2
FIGURE 19 - MIXTURE OF TOPOLOGIES .....	2
FIGURE 20 - MULTI-DROP OR PARTY LINE OR BUSED COMMUNICATION.....	2
FIGURE 21 - REPEATERS.....	2
FIGURE 22 - HUBS .....	2
FIGURE 23 - BRIDGE.....	2
FIGURE 24 - CPU BASED SWITCH.....	2
FIGURE 25 - CROSSBAR SWITCH.....	2
FIGURE 26 - CROSS SECTION VIEW OF CROSSBAR SWITCH.....	2
FIGURE 27 - ROUTERS .....	2
FIGURE 28 - AN EXAMPLE ROUTED NETWORK.....	2
FIGURE 29 - ONE TO ONE COMMUNICATION .....	2
FIGURE 30 - ONE TO MANY COMMUNICATION .....	2
FIGURE 31 - COMPLEX COMMUNICATION TOPOLOGY EXAMPLE .....	2
FIGURE 32 - WIRELESS TRANSMISSION.....	2
FIGURE 33 - FOLDED DIPOLE PROPAGATION PATTERNS.....	2
FIGURE 34 - ADDITIONAL ANTENNA EFFECTS .....	2
FIGURE 35 - DISTORTION OF SIGNAL PROPAGATION .....	2
FIGURE 36 - MULTIPATH DISTORTION .....	2
FIGURE 37 - ASSOCIATING NODES TO AN ACCESS POINT.....	2
FIGURE 38 - MULTIPLE ACCESS POINTS .....	2
FIGURE 39 - ACCESS POINT ASSOCIATED WITH MULTIPLE NODES .....	2
FIGURE 40 - WIRED/WIRELESS NETWORK CONFIGURATIONS.....	2
FIGURE 41 - OSI MODEL: PROTOCOL STACKS.....	2
FIGURE 42 - OSI MESSAGE FORMATS .....	2
FIGURE 43 - OSI MODEL OF NETWORK DEVICES .....	2
FIGURE 44 - OSI MODEL OF NETWORK DEVICES CONT. ....	2
FIGURE 45 - OSI MODEL OF NETWORK DEVICES CONT. ....	2
FIGURE 46 - OSI MODEL: MULTIPLE LOGICAL NETWORKS.....	2
FIGURE 47 - OSI MODEL: SHARED LOWER LEVELS .....	2
FIGURE 48 - OSI MODEL: SHARED LOWER LEVELS CONT. ....	2
FIGURE 49 - RS-232C - FULL IMPLEMENTATION.....	2
FIGURE 50 - RS-232C - TYPICAL MODEM IMPLEMENTATION.....	2
FIGURE 51 - RS-232C - SIMPLE TERMINAL IMPLEMENTATION.....	2
FIGURE 52 - RS-232C - DEFEATING MODEM CONTROL (SOFTWARE FLOW CONTROL).....	2
FIGURE 53 - RS-232C - DEFEATING MODEM CONTROL (HARDWARE FLOW CONTROL) .....	2
FIGURE 54 - TEXT FILE: REGULAR VIEW.....	2
FIGURE 55 - TEXT FILE : FIXED LENGTH RECORDS, BLANK FILLED .....	2
FIGURE 56 - TEXT FILE: VARIABLE RECORD LINKS .....	2
FIGURE 57 - TEXT FILE: TOKENS.....	2
FIGURE 58 - ARRAY STORAGE.....	2
FIGURE 59 - ABRAHAM LINCOLN (120 PIXELS PER INCH) .....	2

## Aspects of Digital Communication Table of Tables

FIGURE 60 - ABRAHAM LINCOLN (16 PIXELS/INCH) .....	2
FIGURE 61 - GRAYSCALE.....	2
FIGURE 62 - ABRAHAM LINCOLN DETAIL (120 PIXELS PER INCH) .....	2
FIGURE 63 - ABRAHAM LINCOLN DETAIL (120 PIXELS PER INCH MAGNIFIED).....	2
FIGURE 64 - HALFTONE (GRAYSCALE).....	2
FIGURE 65 - HALFTONE DITHERING 2X2 .....	2
FIGURE 66 - HALFTONE DITHERING 3X3 .....	2
FIGURE 67 - THE RESPONSE OF THE HUMAN EYE TO LIGHT .....	2
FIGURE 68 - RESOLUTION ELEMENT FOR COLOR CRT .....	2
FIGURE 69 - A SIMPLE GRAPHICAL ELEMENT: LINE.....	2
FIGURE 70 - A GRAPHICAL OBJECT: SOLID ARROW .....	2
FIGURE 71 - COMPRESSION FACILITY .....	2
FIGURE 72 - REAL TIME COMPRESSION FACILITIES.....	2
FIGURE 73 - LOGICAL AND PHYSICAL ADDRESSES .....	2
FIGURE 74 - MAC ADDRESS SPACE .....	2
FIGURE 75 - TCP/IP PROTOCOLS.....	2
FIGURE 76 - IP NETWORK ADDRESS ASSIGNMENTS .....	2
FIGURE 77 - TELETYPE (TTY) KEYBOARD .....	2
FIGURE 78 - DEC VT100 KEYBOARD .....	2

## Table of Tables

TABLE 1 - CONVENTION 1 .....	2
TABLE 2 - CONVENTION 2 .....	2
TABLE 3 - EXAMPLE TEMPERATURES AND PULSE COUNTS .....	2
TABLE 4 - INTERNATIONAL MORSE CODE .....	2
TABLE 5 - ASCII CHARACTER CODES .....	2
TABLE 6 - ASCII CONTROL CHARACTERS .....	2
TABLE 7 - LINE STATES (HALF DUPLEX).....	2
TABLE 8 - DIALOG 1 TIME COURSE OF SAMPLE DIALOG: POINT TO POINT.....	2
TABLE 9 - NUMBER OF LINKS IN A FULLY CONNECTED NET.....	2
TABLE 10 - DIALOG 2 TIME COURSE OF SAMPLE DIALOG: ROUTED NETWORK.....	2
TABLE 11 - ISO-OSI MODEL.....	2
TABLE 12 - RS-232 (REVISION C) - SIGNAL DEFINITIONS .....	2
TABLE 13 - PIN ASSIGNMENTS FOR DB-9 (ZENITH, IBM) .....	2
TABLE 14 - RS-232 (REVISION C) - VOLTAGE LEVELS.....	2
TABLE 15 - RS-232 (REVISION C) - BRIEF SIGNAL DEFINITIONS.....	2
TABLE 16 - TRANSFER TIMES FOR DISPLAYS .....	2
TABLE 17 - TRANSFER TIMES FOR DISK VOLUMES .....	2
TABLE 18 - TOKEN TRANSLATION TABLE .....	2
TABLE 19 - ARRAY STORAGE: GENERALIZED 3X3 MATRIX.....	2
TABLE 20 - EXAMPLE 3X3 ARRAY .....	2
TABLE 21 - ARRAY STORAGE: ALL ELEMENTS STORED .....	2
TABLE 22 - ARRAY STORAGE: NON-ZERO ELEMENTS STORED.....	2
TABLE 23 - RASTER GRAPHICS DEVICE.....	2
TABLE 24 - INFORMATION CONTENT BY RESOLUTION (1 BIT/PIXEL).....	2
TABLE 25 - INFORMATION CONTENT BY RESOLUTION (8 BIT/PIXEL).....	2
TABLE 26 - INFORMATION CONTENT BY RESOLUTION (24 BIT/PIXEL).....	2
TABLE 27 - STORAGE VOLUMES OF VIDEO IMAGES.....	2
TABLE 28 - SET OF VISIBLE PIXELS .....	2
TABLE 29 - COMPRESSION RESULTS FOR LZ COMPRESSION .....	2
TABLE 30 - IP NETWORK ADDRESS ASSIGNMENT .....	2

## Aspects of Digital Communication Chapter Introduction

TABLE 31 - IP RESERVED ADDRESSES.....	2
TABLE 32 - MSU SIGNIFICANT IP ADDRESSES AND MASKS.....	2
TABLE 33 - IPV6 ADDRESSING EXAMPLES .....	2
TABLE 34 - IPV6/IPV4 ADDRESSING EXAMPLES .....	2
TABLE 35 - TTY INPUT FROM KEYBOARD .....	2
TABLE 36 - TTY INPUT FROM KEYBOARD 2.....	2
TABLE 37 - TTY OUTPUT .....	2
TABLE 38 - TTY INPUT FROM KEYBOARD .....	2
TABLE 39 - TTY INPUT FROM KEYBOARD .....	2
TABLE 40 - VT100 INPUT FROM KEYPAD.....	2
TABLE 41 - VT100 INPUT FROM KEYPAD.....	2
TABLE 42 - VT100 INPUT FROM CURSER KEYS.....	2
TABLE 43 - VT100 OUTPUT .....	2

### Chapter 1. Introduction

The continued growth of the computer as a tool in the modern work place is a fact that would be disputed by few. Certainly, the tools provided by the modern computer are essential to the teaching, research, and outreach missions of our university. Changes in technology have made possible the distribution of a spectrum of large, medium and small computer systems throughout organizations such as MSU. This trend has promoted a change in style computer usage. The individual no longer uses a single central facility but now uses multiple computers located in ever widening geographical domains: department, campus, state, nation, and world. No doubt, at some not too distant time, someone at MSU will desire to sit at his or her desk and plug into computer resources in a space station, probe, or station located on another planet. Coupled with the increased utility and availability of the computer in the work place, more and more information crucial to the operation of an organization is being maintained in electronic form. Of course, such information must be moved around within the organization. As a consequence of and paralleling these developments has been the growth of digital communication, the means of passing information among computers and other digital devices without the manual transportation of cards, tapes, and other portable computer readable media. This article will explore the nature of modern digital communication, the state of digital communication at MSU, and future trends.

The roots of digital communication are found in the developments of telegraphy and telephony, which began in the middle of the nineteenth century. Not only has the technology of digital communications been drawn from and/or evolved from these two areas, but so has much of the terminology and formalizations. As a simple example, one talks of a program, and perhaps the human activating that program, on one computer placing a "call" to another program on the same or different computer via some appropriate communication link. This is analogous to a person placing a "call" to another person via the voice telephone network. Once the "call" is placed a "conversation" occurs between the two parties according to a predefined protocol, which specifies the "language" of the conversation and when each can speak, among other things. The postal

## **Aspects of Digital Communication**

### **Chapter Introduction**

system is another human institution that has had an impact on the shaping of digital communication, especially electronic mail. Often, the instantaneous, i.e. real time, exchange of information is not necessary. Simply placing the piece of information, message or file, in a place where the other party can pick it up at a later time is often sufficient. This idea is embodied in file transfers, electronic mail, bulletin boards, and conferences.

Digital communication systems are usually thought of as consisting of multiple layers with the physical interconnect system on the bottom and the high level services such as mail on the top. The foundation of any digital communication system is a physical means of interconnecting all the players in the system: the users, actually their terminals or PCs, the various larger computers, and any other digital equipment that provide electronic services. This connection scheme, usually called a network, can have a multitude of forms ranging from modems and the individual telephone lines to a single "wire" connecting all systems. At one extreme, a network can have an individual physical link between each and every member of the network. This is generally not very desirable. Can you imagine having a separate telephone wire between your house and every other house in your city? At the other extreme, every member of the network is plugged into one single physical link such as wire or fiber. In this case, some mechanism is provided to allow the single link to be shared among the many conversations of all of the members. In addition to the physical interconnection system, is a set of rules or protocols.

Reverting to our telephone analogy, having the phone system is not enough. There must be a way of identifying to whom you wish to speak. To have a meaningful conversation, each party must understand the language of the other. Implicit or explicit rules as to who speaks when are also required. The collection of rules and protocols for a particular implementation are often called network architecture. IBM's Systems Network Architecture (SNA), DEC's Digital Network Architecture (DNA), and the Department of Defense's ARPANET Suite, of which TCP/IP is a part, are examples.

In some cases a physical interconnection system can support more than one network architecture at the same time. Conversely, some architectures can support more than one type of physical interconnection system. Included in this system of hardware and software will be the means to establish, manage, and eventually break a communication link between two members of the system and a means of identifying the individual members. Supplementing these primitive services, most systems will have many higher level services such as directory of members, remote login, file transfer, electronic mail, bulletin boards, and conferences. In each of these higher level cases, the user interacts with a piece of software that implements the service and takes care of the details of establishing the communication links, etc. As an example, in electronic mail, the user creates the message and "hands" it and the recipient's address to the mail system which then delivers it to the "mailbox" of the recipient via the appropriate network.

# Aspects of Digital Communication

## Chapter Introduction

### **1.1. Reasons for digital communication**

1. Human-human dialog
2. Human-machine dialog
3. Machine-Machine dialog
  - 3.1. CPU-peripheral dialog
  - 3.2. CPU-CPU dialog
  - 3.3. CPU-Robot
  - 3.4. Robot-Robot
4. Interchange and distribution of software
5. Data gathering, POS
6. Distributed computing
7. Electronic mail
8. Touch-tone phones
9. Machine preparation of printed materials
  - 9.1. Word-processing
  - 9.2. Typesetting, composing
  - 9.3. Submission of scientific materials for publication
10. Interchange of Documents (Purchase orders, Bills of Lading, Invoices, and Status of orders)
11. Automatic Bank Tellers
12. Improved audio
  - 12.1. Digital recordings
  - 12.2. Digital voice
13. Improved video

# Aspects of Digital Communication

## Chapter Introduction

### **1.2. Goals for Digital Communication**

3. Send/Receive/Store Messages
4. Remote interactive sessions
5. File copying
6. Remote file access (record by record)
7. Remote file system access (DIR, CD, MKDIR)
8. Remote processing (queues)
9. Remote printing
10. Distributed processing
11. Virtual Disks
12. Network Management
13. Routing of messages through complex networks

### **1.3. Digital Communication via Portable Media**

1. Bar codes (UPC)
2. Railroad car codes
3. Bank check codes
4. Printed copy [in conjunction with Optical Character Recognition (OCR) equipment]
5. Mark sense forms

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

## **Chapter 2. Simple Communication Systems**

To begin the discussion of digital communication, imagine the following. The time is the middle 1800's. There is no TV, no radio, no telephone but there happens to be a pair of copper wires strung from Muskegon, MI to Lansing, MI (See Figure 1 - Map of Michigan). As Michigan residents are certainly aware, at least at this time, the predominate weather patterns are such that the majority of the weather fronts move from the west and northwest to the east and southeast first across Lake Michigan and then across Michigan. As a consequence of this, the prediction of the weather for Lansing can be based on the knowledge of the weather in Muskegon. That is, whatever the weather in Muskegon, the weather in Lansing should be the same in a matter of hours. This statement is not universally true, but is certainly true a large portion of the time. To take advantage of this situation and be able to predict the weather in Lansing, a mechanism would have to exist that would allow a message to be sent from Muskegon to Lansing periodically, say every hour.



**Figure 1 - Map of Michigan**

We will expand our thought experiment by adding a switch and battery to the location in Muskegon. A light bulb will be installed in the Lansing location. The components will be

## Aspects of Digital Communication

### Chapter Simple Communication Systems

hooked up as follows. When the switch in Muskegon is closed a current will flow and the bulb in Lansing will light. If the switch is opened, there will be no light. As will be shown, this simple mechanism can be used as the basis for several techniques for transferring information between the two end points of the wires.

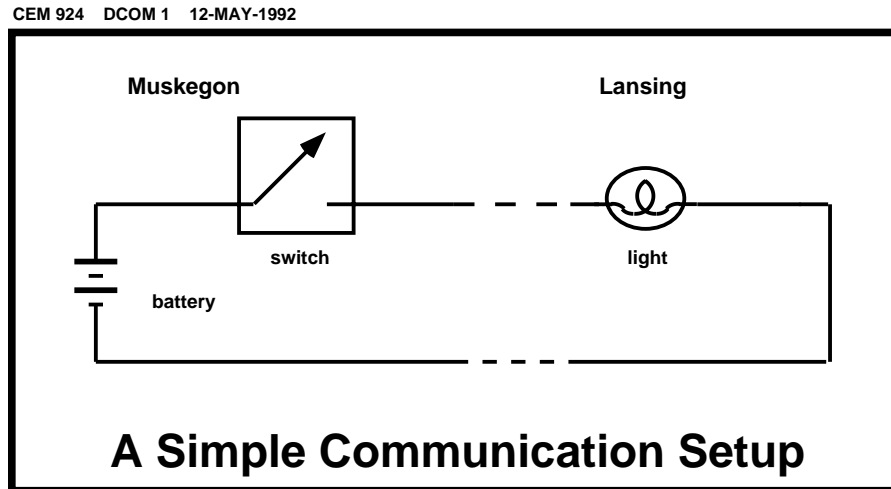


Figure 2 - A Simple Communication Setup

Having defined the hardware, a great deal remains to be specified before these piece of wire, battery, switches, and lights may be used to transmit information. In fact, we will look at four different ways that this hardware configuration can be used to accomplish the transfer of information.

#### **2.1. Technique #1: Count Serial**

Let us assume that every hour on the hour, a person in Muskegon measures the temperature and then toggles the switch on-then-off one time for each degree Fahrenheit the temperature is above -50 degrees. The light bulb in Lansing will flash an equal number of times. If a person is present at the appointed time in Lansing and counts the number of flashes, he or she will then know what is the current temperature in Muskegon, information will have been transferred, and the goal is accomplished.

In this technique, the time course of the state of the hardware is shown in Figure 3. Note that either of the two conventions for assignment of 0 and 1 to the state of the line can be used.

# Aspects of Digital Communication

## Chapter Simple Communication Systems

CEM 924 DCOM 2 12-MAY-1992

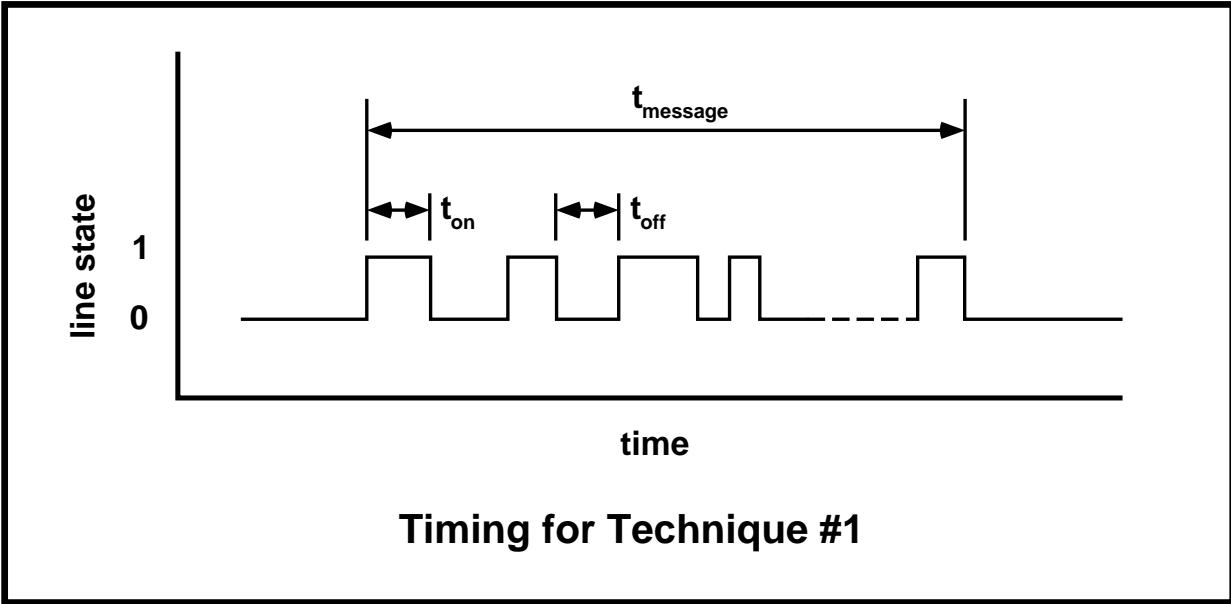


Figure 3 - Timing for Technique #1

In effect, a series of pulses is being sent along the wire from Muskegon to Lansing. The information, i.e. the temperature at Muskegon at the time of transmission, is encoded in the number of pulses transmitted. In actual fact, the information is encoded in the number of off-on (or on-off) transitions of the state of the line (the current flowing in the wires).

### 2.1.1. Line States

Table 1 - Convention 1

Line State	Current	Light
0	off	off
1	on	on

Table 2 - Convention 2

Line State	Current	Light
1	off	off
0	on	on

### 2.1.2. Timing Considerations

1.  $t_{on}$  and  $t_{off}$  may vary during a message.

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

2.  $t_{on}$ ,  $t_{off}$  have to be long enough to allow the receiving operator to distinguish the light change (from off-to on-to off).
3.  $t_{on}$ ,  $t_{off}$  have to be long enough to allow the receiving operator to correctly count the number of pulses.
4. Length of message =  $N*(t_{on} + t_{off})$ . The number of pulses required to transfer the several temperatures at different resolutions is shown in Table 3. Don't forget that there are 3600 seconds in an hour.

**Table 3 - Example Temperatures and Pulse Counts**

Temp (deg F)	N (deg)	N (0.1 deg)	N (0.01 deg)
109	159	1590	15900
81	131	1310	13100
20	70	700	7000
-30	20	200	2000

**2.1.3. Protocols**

1. Information flows from Muskegon to Lansing only.
2. Synchronization of the two operators is primarily based on the fact that transmissions begin on the hour. Secondly, the line will be in the idle state for a long period of time before the first pulse of the message arrives.
3. Number of Pulses =  $T$  (deg F) rounded to nearest integer + 50
4.  $t_{on}$ ,  $t_{off}$  = 0.1 to 1.0 second. Depends on the skill of the operators.

**2.1.4. Possible problems**

1. Missing the beginning of message.
2. Missed counts.
3. Noise on the line generating false pulses or obscuring pulses.
4. Abilities of transmitting and receiving operators not matched.

**2.1.5. Advantages**

1. Simple

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

2. Only two line states, thus the benefits of the inherent noise immunity of digital techniques

**2.1.6. Disadvantages**

1. Can only send numbers.
2. Demands extreme concentration on the part of the two operators
3. Messages of similar content vary greatly in length
4. Low line utilization. Small amounts of information can take a long time to send. If the messages were to be the temperature in hundredths of a degree instead, the length of the message would be so long that one message would not be finished before the next should begin.
5. In order to handle negative numbers, the numbers have to be offset by a constant (e.g. 50). This offset must be chosen to accommodate the most negative number to be encountered.
6. Don't know if the message was received or received correctly.

**2.2. Technique #2 Binary Coded Serial**

Representing the temperature as a binary number leads to a more sophisticated method of sending the information over the same hardware. In this case, the temperature is first converted to a binary number. The transmitting operator again manages the state of the line by toggling the switch. The receiving operator again extracts information by observing the state of the line (bulb). Now, however the message is not just a simple series of pulses but is formatted into a fixed number of time slots, each of which will represent a binary bit, i.e. the coefficient of a power of two in the binary representation of the number. For a given time slot, a line state of 1 at the middle of the time slot will be taken to be a "1" for that slot. A line state of 0 at the middle of the slot will indicate a "0". The temperature thus will be given by the following.

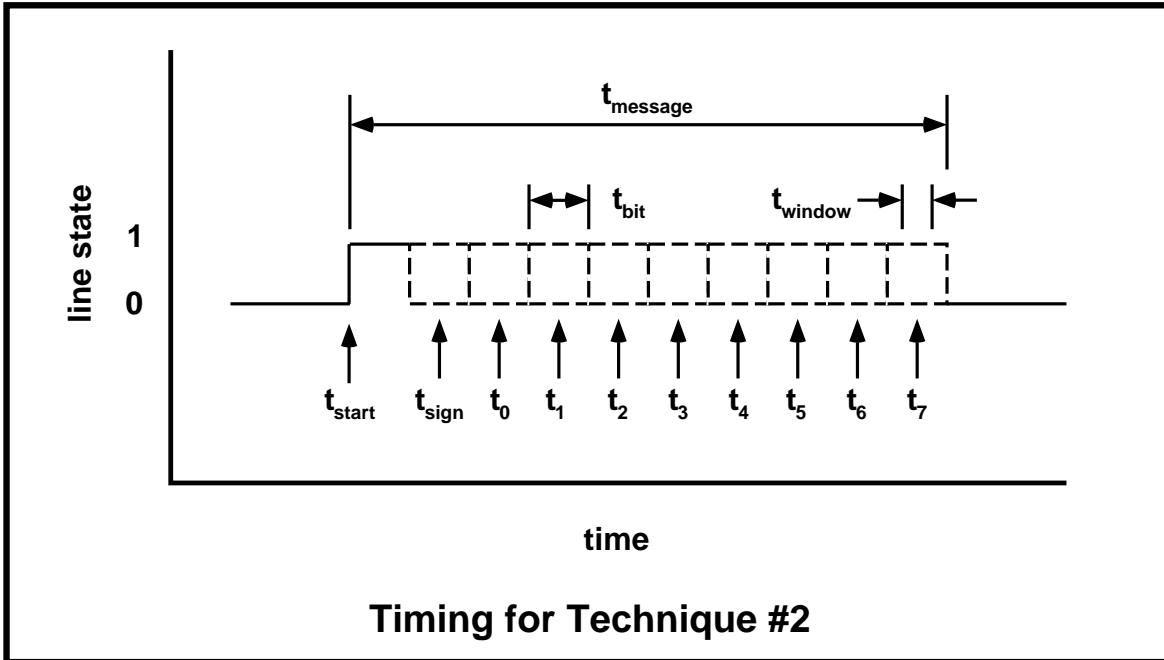
$$T(^{\circ}F) = \sum_{i=0}^n b_i 2^i$$

where  $b_i$  is the line state at the middle of the time slot  $i$ . The first time slot, start slot, will always contain a "1" to insure a transition between the idle state of the line (i.e. between messages) and "1". This edge can be used to synchronize the receiver with the transmitter. The second slot, sign slot, will indicate the sign of the number (1 = negative, 0 = positive).

# Aspects of Digital Communication

## Chapter Simple Communication Systems

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**Figure 4 - Timing for Technique #2**

To illustrate this concept, consider the following two examples and the resultant timing diagrams. In these examples the 8 data bits will allow temperatures in the range of +/- 128 degrees F.

$$T = -7 \text{ (deg F)} = -00000111 = -7 \text{ (octal)} = -7 \text{ (hexadecimal)}$$

**Figure 5 - Example 1**

$$T = 78 \text{ (deg F)} = 01001110 = 116 \text{ (octal)} = 4E \text{ (hexadecimal)}$$

**Figure 6 - Example 2**

### 2.2.1. Timing Considerations

1.  $t_{\text{bit}}$  must be long enough for the receiver to interpret the line during each time slot.
2. Each time slot will be read half way through the time slot to minimize edge effects such as settling time.
3.  $t_{\text{message}} = (n + 3) * t_{\text{bit}}$  where "n" is the number of bits to be used to express the temperatures.

## Aspects of Digital Communication

### Chapter Simple Communication Systems

4. Transmitter and receiver's clocks must be precise to  $\pm t_{\text{window}}$  in  $t_{\text{message}}$ . An acceptable value for  $t_{\text{window}}$  depends on how severe the edge effects between time slots might be. Without this agreement in time bases, the receiver would read the "line" at the wrong time and erroneously determine the bits of the message.

#### 2.2.2. Protocols

1. Current flowing (light on) is line state 1. No current flowing (light off) is line state 0.
2. Information flows from Muskegon to Lansing only.
3. Synchronization of two operators is primarily based on the fact that transmissions begin on the hour. Secondly, the line will be in the idle state for a long period of time before the first pulse of the message arrives.
4. Both parties agree on  $t_{\text{bit}}$ .
5. Encoding scheme as described above.

#### 2.2.3. Possible problems

1. Some or the entire message is missed.
2. The state of the lamp is observed at the wrong time for a particular time slot. (Clocks drift)
3. Noise on the line generating false line states at time of reading.
4. Abilities of transmitting and receiving operators are not matched causing errors in information transmission.

#### 2.2.4. Advantages

1. Only two line states, thus the benefits of the noise immunity of digital techniques.
2. Efficient use of the line. Messages are all of fixed length.
3. Can handle signed numbers.
4. Can handle large ranges of numbers by increasing  $n$ .

#### 2.2.5. Disadvantages

1. Timing is more demanding.

## Aspects of Digital Communication

### Chapter Simple Communication Systems

2. Must convert temperatures to binary then back again.
3. Don't know if the message was received or received correctly.

#### 2.3. Technique #3 Encoded - Morse Code

In this technique, the message is translated into a code which can represent textual material as well as numbers. As an example, we will use the Morse code utilized in telegraphy and early radio communications. This code uses specific combinations of short ("dit", ".") and long pulses ("dah", "-") of sound or light to represent each character in a defined set. Unlike the first two techniques, we can now think of messages containing characters, words, sentences, and paragraphs.

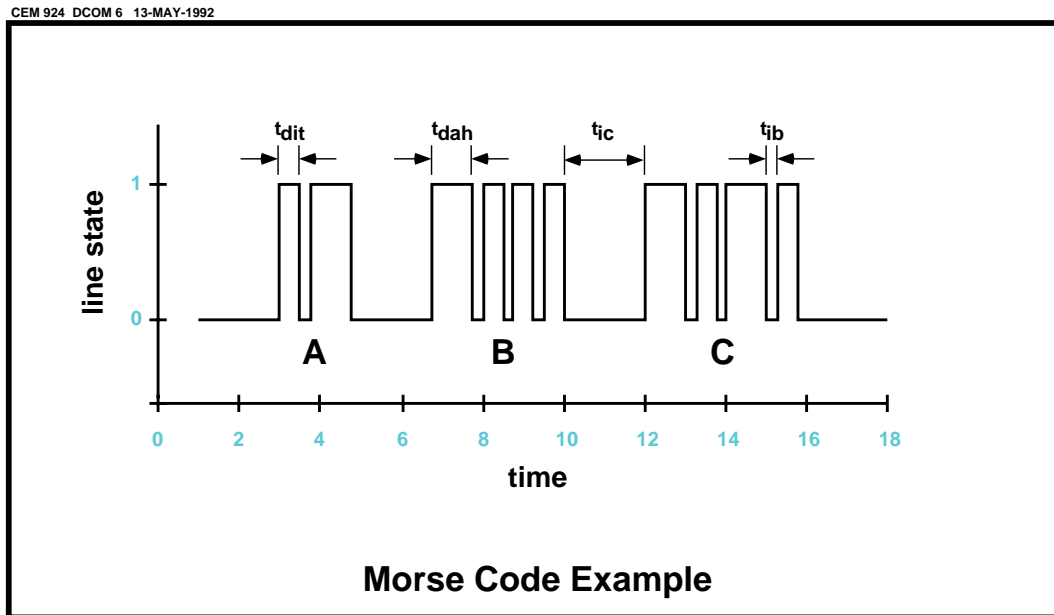


Figure 7 - Timing for Technique #3 - Morse Code

Table 4 - International Morse Code

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

Char	Code	Char	Code	Char	Code	Char	Code
A	.-	N	-.	1	.----	.	.-.-.
B	-...	O	---	2	..---	,	---..
C	-.-	P	.-.	3	...--	?	..-..
D	-..	Q	--.	4	....-	ERR	.....
E	.	R	.-.	5	.....	--	-...-
F	..-	S	...	6	-....	:	---...
G	---	T	-	7	--...	;	-.-.-
H	....	U	..-	8	---..	(	-.-.-
I	..	V	...-	9	----.	/	-..-
J	.-.	W	.-.	0	-----	WAIT	.-...
K	-.-	X	-..-			EOM	.-.-.
L	.-.	Y	-.-			ITT	.-.
M	--	Z	--..			END	...-.

**2.3.1. Timing Considerations**

1. Pulses within a character are separated by  $t_{iB}$  (i.e. inter-bit time).
2. Characters are separated by  $t_{iC}$  (i.e. inter-character time).
3.  $t_{iC} > t_{iB}$  to allow differentiation.
4. Other delimiters will be included text.

**2.3.2. Protocols**

1. Current flowing (light on) is line state 1. No current flowing (light off) is line state 0.
2. Information flows from Muskegon to Lansing only.
3. Synchronization of two operators is primarily based on the fact that transmissions begin on the hour. Secondly, the line will be in the idle state for a long period of time before the first pulse of the first character of the message arrives. (NOTE: In actual practice, a message can begin at anytime the line is at rest. A series of characters will wake up the receiver.)
4. Both parties agree on  $t_{iB}$  and  $t_{iC}$ . (Note: In actual practice the transmitter sets the timing and the receiver adapts.)
5. The message will be text and will be encoded as described above.
6. Language of the message will be defined.

## **Aspects of Digital Communication**

### **Chapter Simple Communication Systems**

#### **2.3.3. Possible problems**

1. Noise on the line obscuring width of pulses or masquerading as pulses.
2. Abilities of transmitting and receiving operators not matched.
3. Don't know if the message has been received (at all or correctly).

#### **2.3.4. Advantages**

1. Only two line states, thus the benefits of the noise immunity of digital techniques still apply to a large extent.
2. Fairly efficient use of the line.
3. Can handle signed numbers.
4. Can handle any range of numbers.
5. Can handle any textual message in any language that uses the characters contained in International Morse Code set.
6. In our example, the temperature does not have to be converted, merely encoded.

#### **2.3.5. Disadvantages**

1. Timing is demanding although less than for the binary coded case. To a large degree the timing is relative and operators (human operators, at least) can adapt within a message.
2. Have to remember the code.
3. Limited code set
4. Don't know if the message was received or received correctly.

#### **2.4. Technique #4 Asynchronous Serial - ASCII**

In this technique, the messages will again be encoded text. The message is encoded according to a code such as the ASCII shown in Table 5 and Table 6. The main difference between the Morse Code and this case is the structure of the transmitted character. In fact, this case bears more resemblance to the binary code case than the Morse Code case. Again, the information is sent as a groups of bits each of which is assigned to one particular time slot. The information is received by observing the state of the transmission line during the appropriate time slots. In the asynchronous serial case, the line is assumed to be in the idle state before the character begins. The character begins with a change of state insuring a leading edge that will allow synchronization of

# Aspects of Digital Communication

## Chapter Simple Communication Systems

the receiver. Following this start bit, are several bits containing the information, i.e. character. Next, is an optional error control bit used for parity (see later discussion). Finally, there are one, or more stop bits, bits in the idle state of the line. The stop bits in combination with the start bit of the next character guarantee a falling edge at the start of each character.

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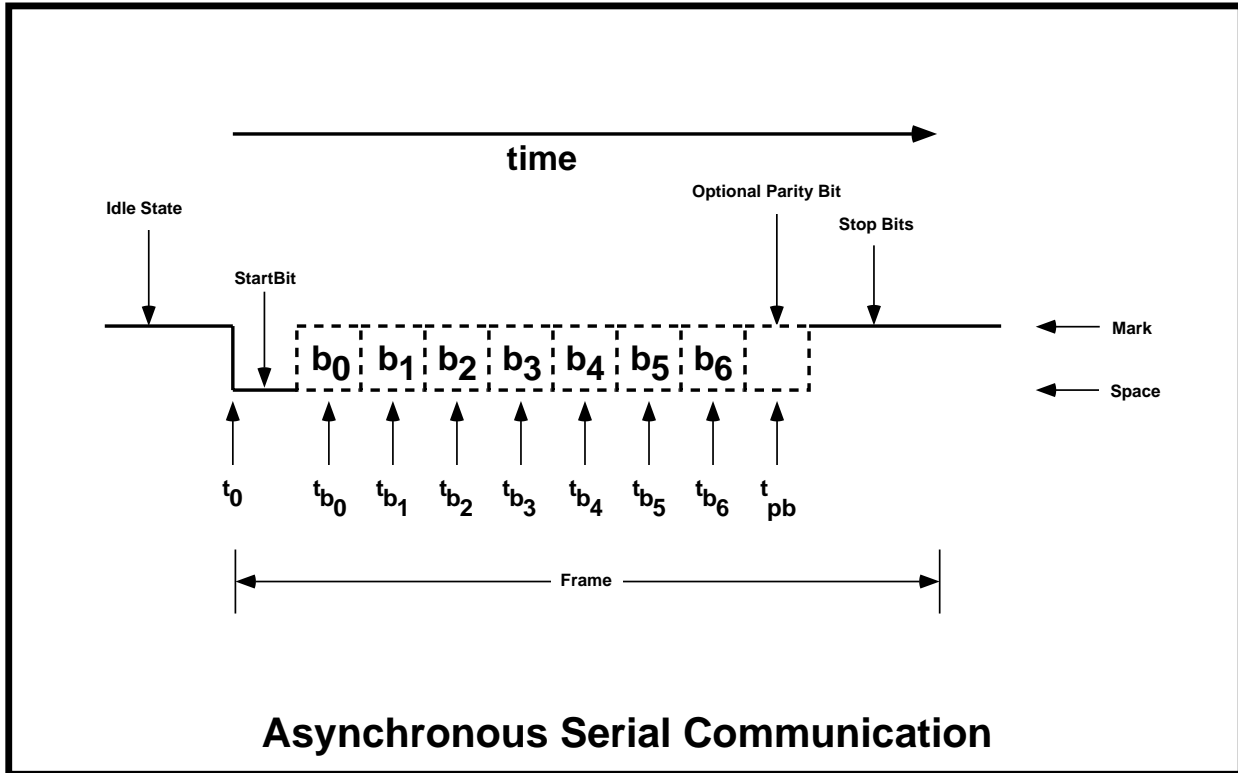


Figure 8 - Asynchronous Serial Timing

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

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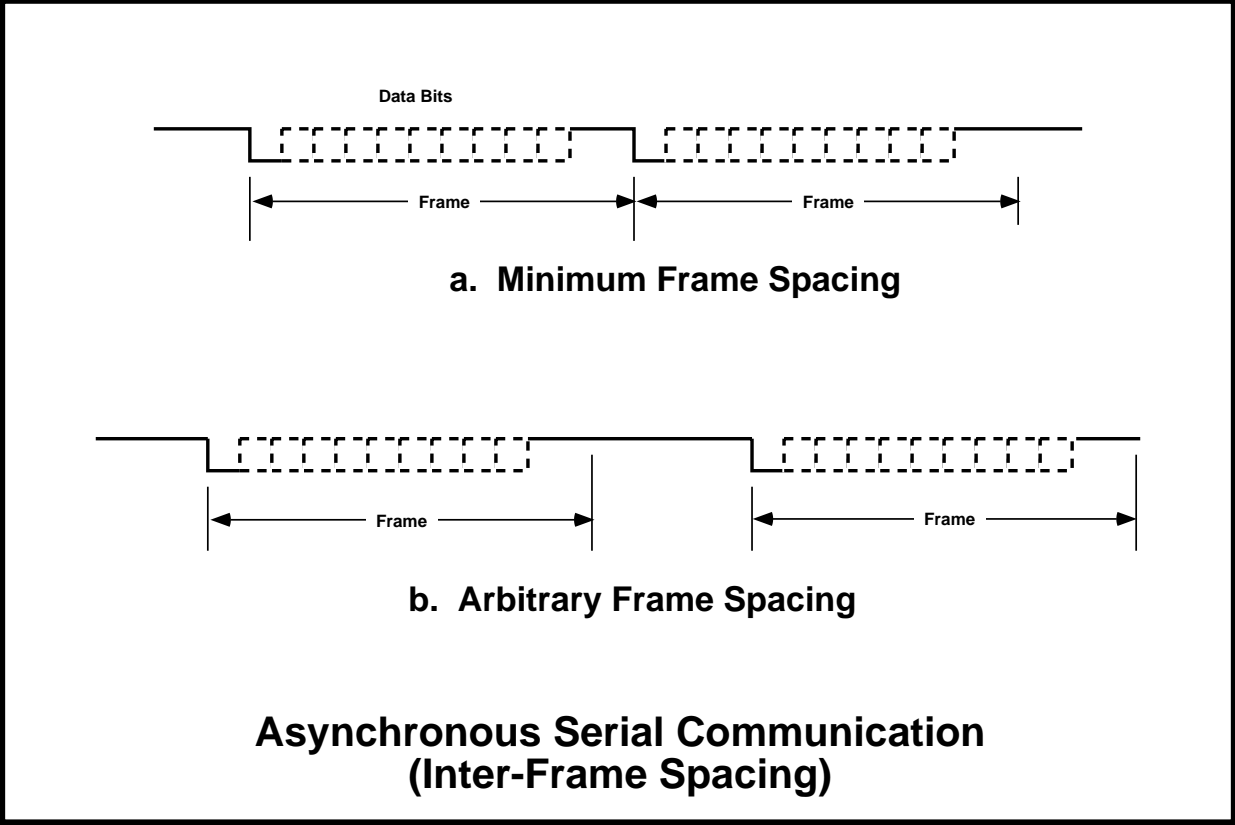


Figure 9 - Inter-Frame Timing

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

**Table 5 - ASCII Character Codes**

Character	Octal	Dec	Hex	Char	Octal	Dec	Hex	Char	Octal	Dec	Hex	Char	Octal	Dec	Hex
<NULL>	0	0	0		40	32	20	@	100	64	40	`	140	96	60
<SOH>	1	1	1	!	41	33	21	A	101	65	41	a	141	97	61
<STX>	2	2	2	"	42	34	22	B	102	66	42	b	142	98	62
<ETX>	3	3	3	#	43	35	23	C	103	67	43	c	143	99	63
<EOT>	4	4	4	\$	44	36	24	D	104	68	44	d	144	100	64
<ENQ>	5	5	5	%	45	37	25	E	105	69	45	e	145	101	65
<ACK>	6	6	6	&	46	38	26	F	106	70	46	f	146	102	66
<BEL>	7	7	7	'	47	39	27	G	107	71	47	g	147	103	67
<BS>	10	8	8	(	50	40	28	H	110	72	48	h	150	104	68
<HT>	11	9	9	)	51	41	29	I	111	73	49	i	151	105	69
<LF>	12	10	A	*	52	42	2A	J	112	74	4A	j	152	106	6A
<VT>	13	11	B	+	53	43	2B	K	113	75	4B	k	153	107	6B
<FF>	14	12	C	,	54	44	2C	L	114	76	4C	l	154	108	6C
<CR>	15	13	D	-	55	45	2D	M	115	77	4D	m	155	109	6D
<SO>	16	14	E	.	56	46	2E	N	116	78	4E	n	156	110	6E
<SI>	17	15	F	/	57	47	2F	O	117	79	4F	o	157	111	6F
<DLE>	20	16	10	0	60	48	30	P	120	80	50	p	160	112	70
<DC1>	21	17	11	1	61	49	31	Q	121	81	51	q	161	113	71
<DC2>	22	18	12	2	62	50	32	R	122	82	52	r	162	114	72
<DC3>	23	19	13	3	63	51	33	S	123	83	53	s	163	115	73
<DC4>	24	20	14	4	64	52	34	T	124	84	54	t	164	116	74
<NAK>	25	21	15	5	65	53	35	U	125	85	55	u	165	117	75
<SYN>	26	22	16	6	66	54	36	V	126	86	56	v	166	118	76
<ETB>	27	23	17	7	67	55	37	W	127	87	57	w	167	119	77
<CAN>	30	24	18	8	70	56	38	X	130	88	58	x	170	120	78
<EM>	31	25	19	9	71	57	39	Y	131	89	59	y	171	121	79
<SUB>	32	26	1A	:	72	58	3A	Z	132	90	5A	z	172	122	7A
<ESC>	33	27	1B	;	73	59	3B	[	133	91	5B	{	173	123	7B
<FS>	34	28	1C	<	74	60	3C	\	134	92	5C		174	124	7C
<GS>	35	29	1D	=	75	61	3D	]	135	93	5D	}	175	125	7D
<RS>	36	30	1E	>	76	62	3E	^	136	94	5E	~	176	126	7E
<US>	37	31	1F	?	77	63	3F	_	137	95	5F	DEL	177	127	7F

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

**Table 6 - ASCII Control Characters**

<NUL>	Null
<SOH>	Start of heading
<STX>	Start of text
<ETX>	End of text
<EOT>	End of transmission
<ENQ>	Enquiry
<ACK>	Acknowledge
<BEL>	Bell (audible signal)
<BS>	Backspace
<HT>	Horizontal Tabulation
<LF>	Line Feed - go to new line
<VT>	Vertical tabulation
<FF>	Form Feed - go to new page
<CR>	Carriage return - return to left margin
<SO>	Shift out
<SI>	Shift in
<DLE>	Data link escape
<DC1>	Device Control 1 - XON
<DC2>	Device Control 2
<DC3>	Device Control 3 - XOFF
<DC4>	Device Control 4
<NAK>	Negative Acknowledge
<SYN>	Synchronous idle
<ETB>	End of transmission block
<CAN>	Cancel
<EM>	End of medium
<SUB>	Substitute
<ESC>	Escape
<FS>	File Separator
<GS>	Group Separator
<RS>	Record Separator
<US>	Unit Separator
<DEL>	Delete

**2.4.1. Timing Considerations**

1.  $t_{bit}$  is defined and constant.
2. Character time is the sum of the number(1) of start bits, number (5, 6, 7, or 8) of data bits, number (0, or 1) of parity bits, and number (1, 1.5, or 2) of stop bits.

## Aspects of Digital Communication

### Chapter Simple Communication Systems

3. Transmitter and receiver clock must agree to 0.1 to 0.5 parts per character time.
4. Characters are asynchronous, i.e. inter-character time (time between the end of the last stop bit of last character and the beginning of the start bit of the next character) can be any value from 0 to infinity.

#### 2.4.2. Protocols

1. Current flowing (light on) is line state 1. No current flowing (light off) is line state 0.
2. Information flows from Muskegon to Lansing only.
3. Synchronization of two operators is primarily based on the fact that transmissions begin on the hour. Secondly, in our particular example, the line will be in the idle state for a long period of time between the hourly message. Thus, the falling edge of the start bit of the first character of the message arrives could be used to wake up the receiver. (NOTE: In actual practice, a message can begin at anytime the line is at anytime the line is at rest. If this is to happen, a defined protocol will specify a character sequence that will uniquely identify the beginning of each message and another sequence that will uniquely identify the end of that message.)
4. Agreement on number of data bits, absence, presence and type of parity, and number of stop bits.
5. Agreement on  $t_{bit}$ . ( usually defined as baud rate, i.e. essentially the number of bits that can be sent per second. (110, 150, 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 56000 bits per second).
6. The message will be text and will be encoded as described above.
7. The character codes will be defined.
8. Language of the message will be defined.

#### 2.4.3. Advantages

1. Only two line states, thus the benefits of the noise immunity of digital techniques apply.
2. Fairly efficient use of the line.
3. Can handle signed numbers.
4. Can handle any range of numbers since the numbers are expressed in textual form.

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

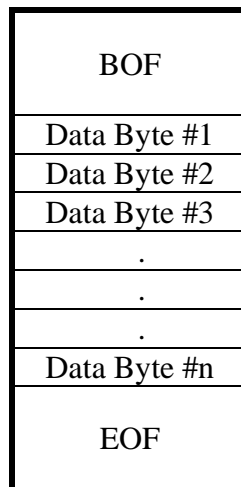
5. Can handle any textual message in any language that uses the defined character set.
6. In our example, the temperature does not have to be converted, merely encoded.
7. Characters are asynchronous, minimizing the demands on timing.
8. Binary data files could also be sent with this transmission technique.

**2.4.4. Disadvantages**

1. Line efficiency: While OK for short messages, each character includes several bits of overhead: start, parity, and stop bits. Using the typical numbers (1 + 8 + 0 + 1) as an example shows a maximum efficiency of  $8/10 = 80\%$  can be realized.
2. Timing within a character has to be fairly exact.

**2.5. Technique #5 Synchronous**

This technique is an extension of the asynchronous case. However, more than one character will be sent together. This group of characters will be called a "frame", or "packet". The initial form for our discussion is illustrated in Figure 10. Notice that the information is arranged as a list of bytes. As the message is sent, each byte in turn is shifted out on the line bit by bit. Thus, the receiver has to detect the bits as they arrive at the destination and then regroup them into bytes in a way, of course, that reconstructs the original set of characters. In terms of bit determination, the time slot method is used. Each bit of each byte of the message and any overhead is placed onto the communication line during the appropriate time slot. This typically yields very long streams of bits being transmitted down the line.



**Figure 10 - Simple Data Packet**

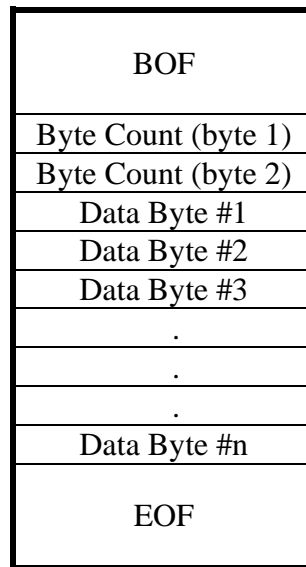
## Aspects of Digital Communication

### Chapter Simple Communication Systems

where "BOF" is a special byte or string of bytes used to identify the Beginning of a Frame, and "EOF" is a special byte or string of bytes used to identify the End of the Frame.

Several issues remain to be decided. First, since more than one data byte are sent per frame, there must be a method to specify how many data bytes are in a particular frame. There are several methods of accomplishing this.

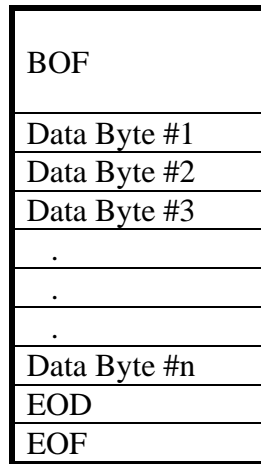
1. Fixed and defined number: All frames will have the same "n" or number of data or message bytes. While this could work for special cases where all messages are of the same length, in general it suffers from not being flexible enough to accomplish a range of messages or from having unused bytes when messages are shorter than the fixed number.
2. Byte Count: In this case, the number of message bytes is sent with the message as illustrated in Figure 11. One byte worth of byte count would allow 256 bytes of data or message. Sixteen bits (two bytes) of byte count would allow messages to be as long as 65536 (64K) bytes long. In this example the 16 bits of byte count are divided into two bytes and sent with the message. The receiver will then know how much of the frame contains message bytes.



**Figure 11 - Data Packet: Byte Count**

3. Special End of Data Mark: In this case, a reserved byte (i.e. one particular pattern of 1's and 0's) is inserted after the data area. Observation of this special pattern by the receiver signals the end of the data area. A byte with the same pattern of 0's and 1's as the END of DATA Mark can not be included in the data field of the frame.

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**



**Figure 12 - Data Packet: Special Terminator**

The second issue is how the beginning and ends of the frames are marked and/or how the receiver synchronizes with the transmitter. The general approach is to begin and end the frames with special patterns of 0's and 1's. When observed by the receiver, this pattern signals the beginning or end of a frame or packet. Again however, this special pattern cannot be included in the message or data area of the frame, limiting the character set that can be sent and/or preventing the transmission of binary data. More complicated strategies circumvent this limitation.

**2.5.1. Timing Considerations**

1.  $t_{bit}$  is defined and constant.
2. Frame time is  $8 * t_{bit}$  multiplied by the sum of the number of bytes in the Beginning Of Frame mark, the number of bytes in the data byte count, the number of data bytes, the number of bytes of error control, and the number of bytes in the End Of Frame mark.
3. Transmitter and receiver clock must be precise to 0.1 to 0.5  $t_{bit}$  per frame time or the clock information must be transmitted between the two stations in some manner.
4. Frames are asynchronous, i.e. inter-frame time (time between last bit of the last End Of Frame mark byte and the first bit of the first byte of the Beginning of Frame mark of the next frame) can be any value from 0 to infinity.
5. Characters within a frame are synchronous. One follows immediately after another.

## Aspects of Digital Communication

### Chapter Simple Communication Systems

#### 2.5.2. Protocols

1. Current flowing (light on) is line state 1. No current flowing (light off) is line state 0.
2. Information flows from Muskegon to Lansing only.
3. Synchronization of two operators is based on the detection of the Beginning Of Frame mark.
4. Definition of frame marks, byte count method, range of number of data bytes allowed, and error control.
5. Agreement on  $t_{\text{bit}}$ . ( usually defined as baud rate, i.e. essentially the number of bits that can be sent per second. (110, 150, 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 56000 bits per second).
6. The message will be text and will be encoded as described above. In some cases binary data (such as machine language programs) may be sent.
7. The character codes will be defined.
8. Language of the message will be defined.

#### 2.5.3. Advantages

1. Only two line states, thus the benefits of the noise immunity of digital techniques apply.
2. Most efficient use of the line for long messages. For example, a frame of length  $(3 + 2 + 512 + 2 + 3)$  bytes yields  $512/522 = 98.08\%$  efficiency. A frame of length  $(3 + 2 + 1024 + 2 + 3)$  bytes yields  $1024/1034 = 99.03\%$  efficiency. A frame of length  $(3 + 2 + 2048 + 2 + 3)$  bytes yields  $2048/2058 = 99.51\%$  efficiency.
3. Can handle signed numbers.
4. Can handle any range of numbers since the numbers are expressed in textual form.
5. Can handle any textual message in any language using the character set defined.
6. In our example, the temperature does not have to be converted, merely encoded.
7. Binary files can be sent with this transmission technique.

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

**2.5.4. Disadvantages**

1. Poor efficiency for short messages. A message of 10 bytes and a frame of length  $(3 + 2 + 10 + 2 + 3)$  bytes yields  $10/20 = 50\%$  efficiency.
2. Timing is more demanding

**2.6. Two way communications**

The examples, so far, have only provided for information to flow in one direction, from Muskegon to Lansing. Such communication links are examples of simplex or unidirectional links. Very seldom is such unidirectional information satisfactory. This section will discuss two ways that bi-directional communication can be accomplished.

**2.6.1. Half Duplex**

The first approach will be the half duplex method. To implement this, we will have to add a light in Muskegon and a switch in Lansing arriving at the configuration shown in Figure 13.

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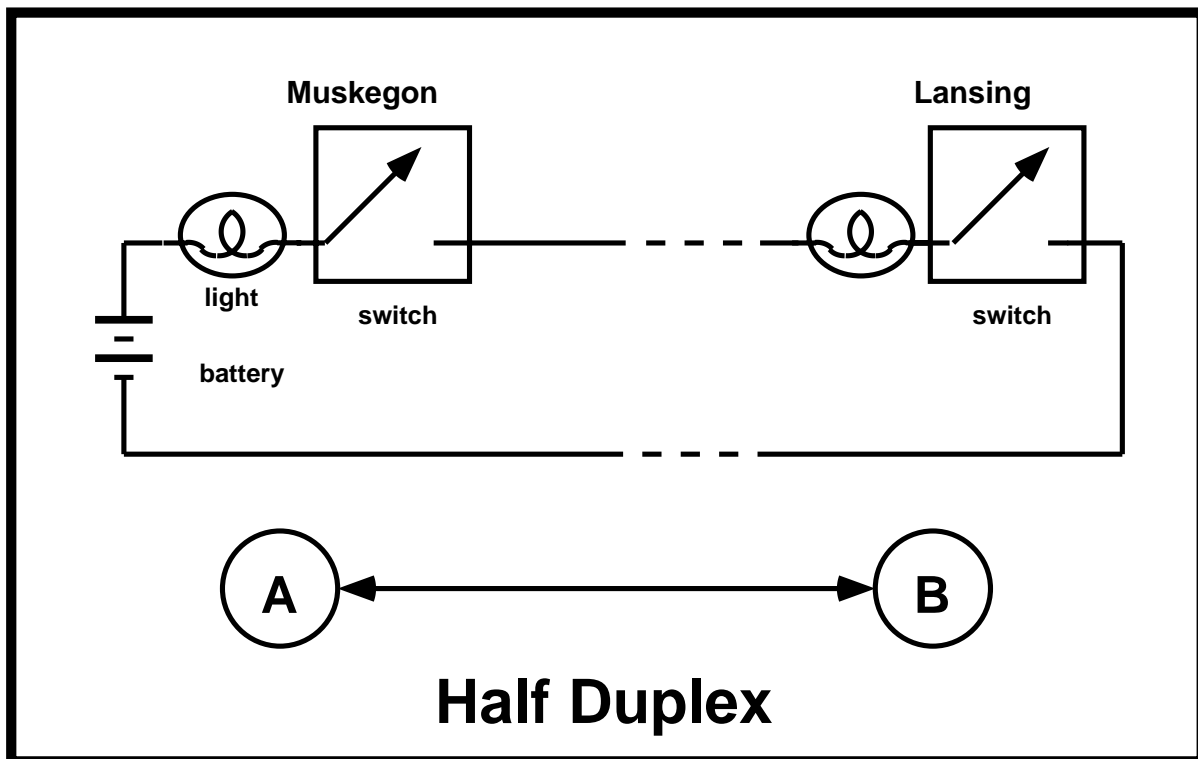


Figure 13 - Half Duplex Communication

## Aspects of Digital Communication

### Chapter Simple Communication Systems

Any of the communication techniques discussed to this point can be used with a few additions. First, only one of the two parties can send at a time. The other must keep his switch closed. The protocols will have to include a mechanism to decide when a particular party can begin sending a message and how the line will be given to the other party when the message from the first party ends.

#### 2.6.2. Line States

**Table 7 - Line States (Half Duplex)**

Line State	Current	Light
1	off	off
0	on	on

#### 2.6.3. Timing Considerations

The timing considerations will be the same as and depend on which of the five techniques described above is chosen.

#### 2.6.4. Protocols

1. All inactive stations will leave the switch for that station closed. Only the station currently transmitting information will be allowed to break the circuit.
2. To begin a session of dialog, a station must gain access to the line and become the active station. This could be done by observing the state of the line for a short period of time and begin sending if no activity is observed.
3. After a dialogue has begun, the end of a message from the active station must end with an indicator that the other party may now send. This "Line turnaround" indicator could be a unique and special byte or a unique string of characters.
4. Special messages will be exchanged at the end of the dialogue to indicate that the session is over.

#### 2.6.5. Possible problems

1. Both parties may want to start a dialogue, observe that the line is quiescent, and simultaneously begin sending a message. With luck, both parties will observe that there is only nonsense passing down the wire, backoff and try again, hopefully at slightly different times.

#### 2.6.6. Advantages

1. Simple

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

2. Only two line states, thus the benefits of the inherent noise immunity of digital techniques

**2.6.7. Disadvantages**

1. Each station only sends or receives during a particular period of time.

Aspects of Digital Communication  
Chapter Simple Communication Systems

2.7. Full Duplex

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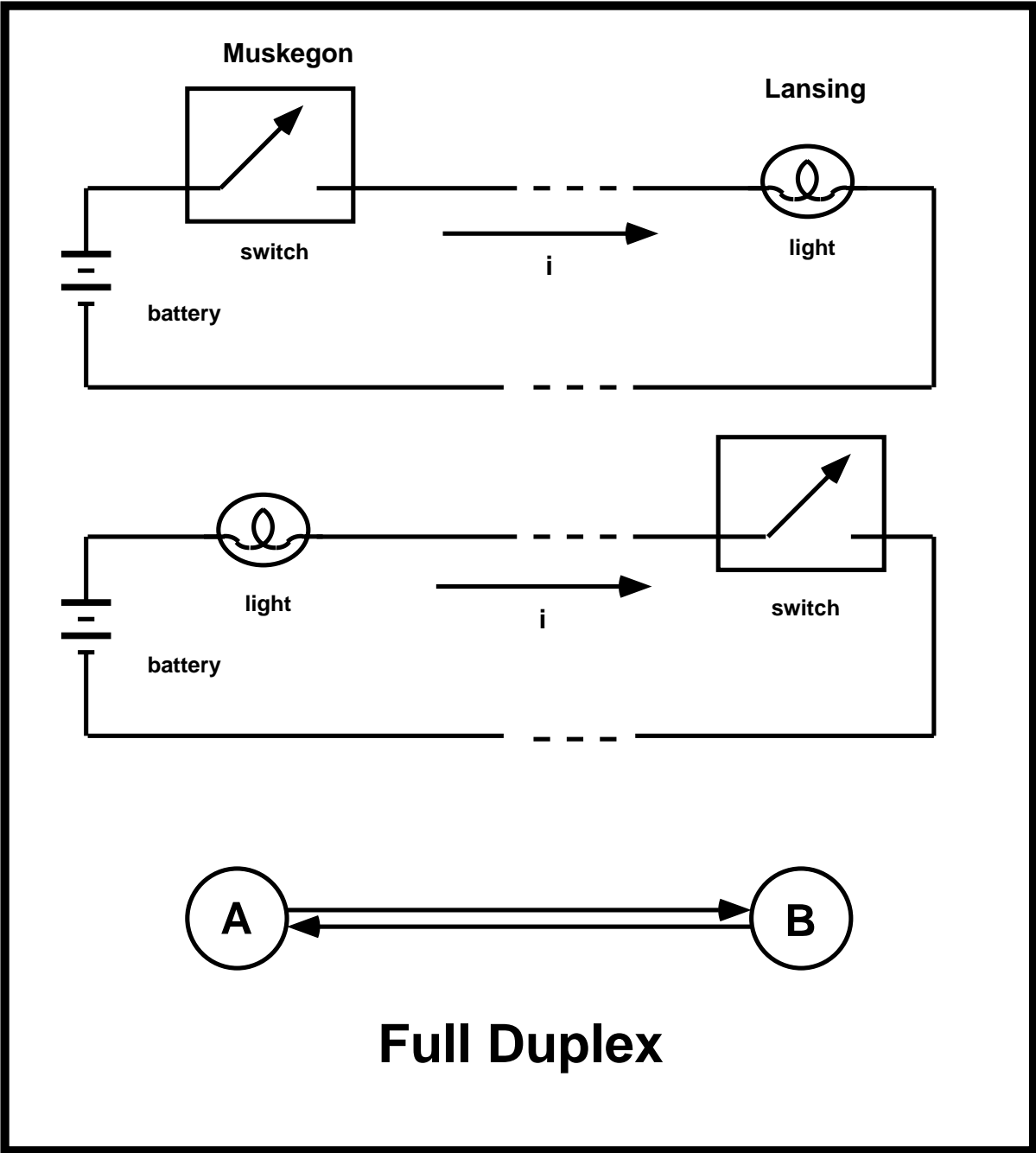


Figure 14 - Full Duplex Communication

## **Aspects of Digital Communication**

### **Chapter Simple Communication Systems**

#### **2.7.1. Timing Considerations**

The timing considerations will be the same as and depend on which of the five techniques described above is chosen. Each of the two links will probably use the same technique. However,  $t_{bit}$  may be different for the two links. With this technique, information may be flowing in opposite directions at the same time.

#### **2.7.2. Protocols**

1. The protocols will be those for the particular technique from above that is to be used.
2. The rules for how a station can begin a conversation must be agreed upon.
3. The uses of the simultaneous transmission capability will have to be decided.

#### **2.7.3. Possible problems**

1. Two different conversations are started at the same time.

#### **2.7.4. Advantages**

1. Up to double the transfer rate is possible since information can go both ways at one time.
2. Only two line states, thus the benefits of the inherent noise immunity of digital techniques

#### **2.7.5. Disadvantages**

1. Complexity has more than doubled.

Aspects of Digital Communication  
Chapter Simple Communication Systems

2.8. Flow Control

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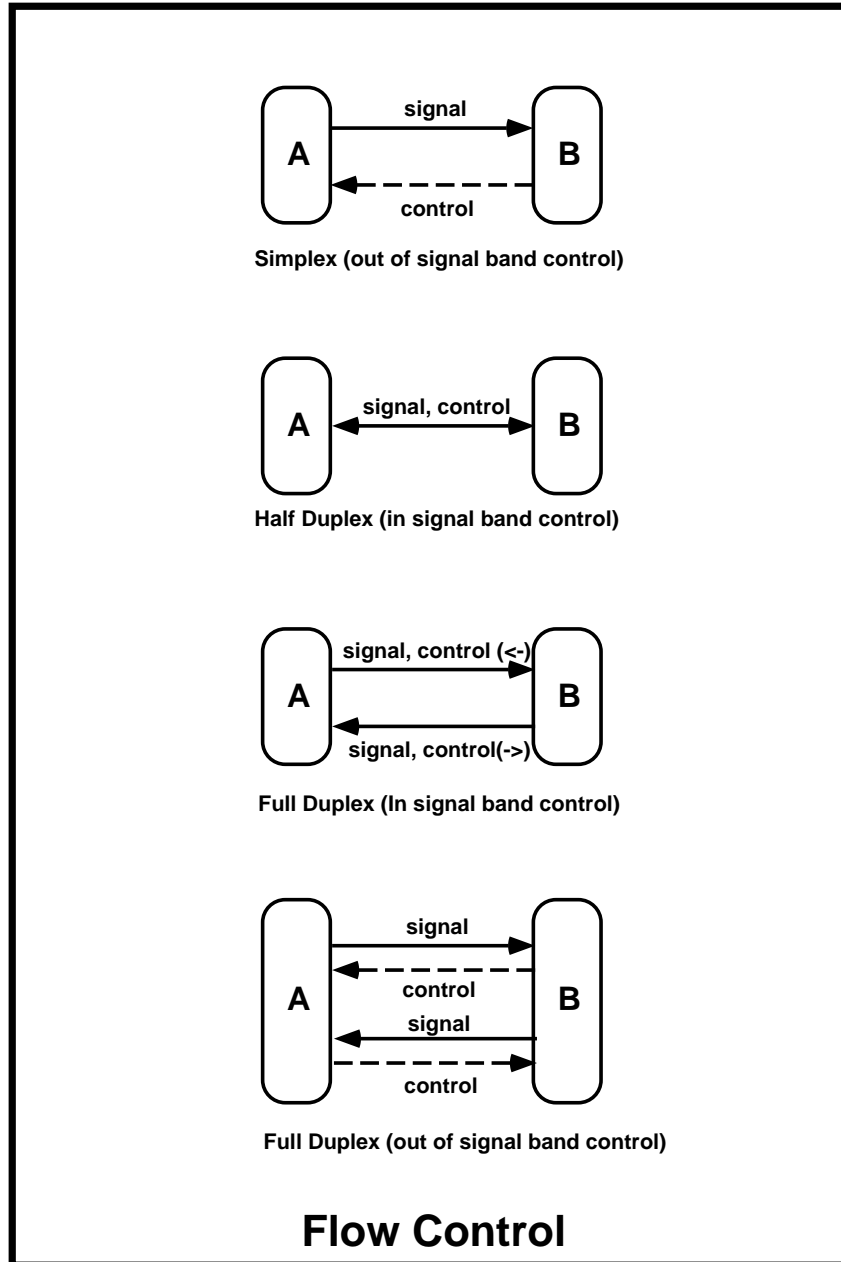


Figure 15 - Flow Control

2.9. Sample Dialogs for Simple Protocols - Point to Point

In this example Node A is connected to Node B with a simple full or half duplex link. Node A wishes to send a message to Node B. The message is to be divided into four packets. Notice that this example includes an example of errors, errors are detected in the

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

transmission of Packet 3. Methods for detecting errors are discussed in the chapter on Error Control.

**Table 8 - Dialog 1 Time Course of Sample Dialog: Point to Point**

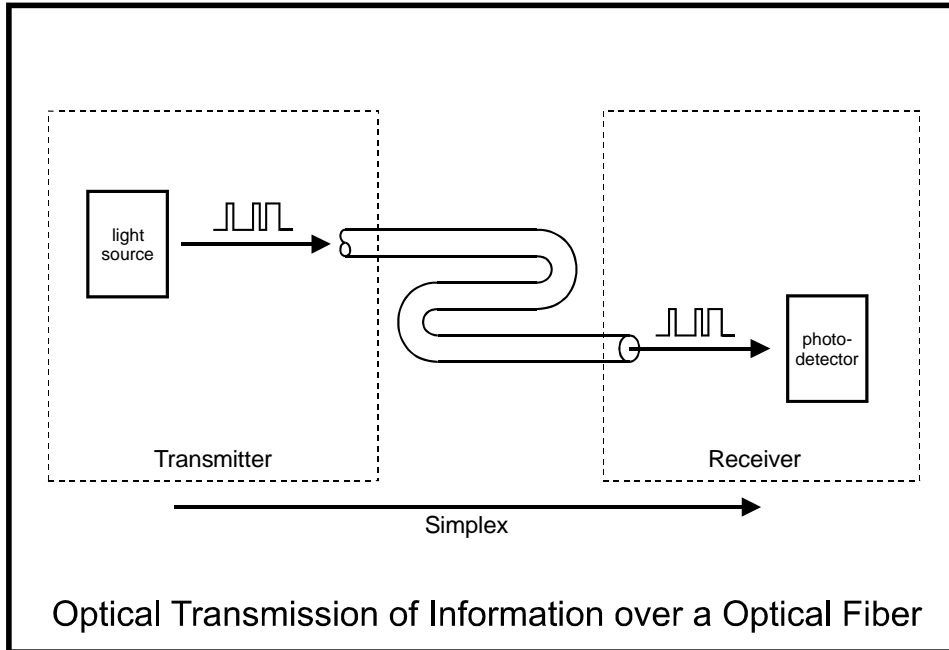
Source Node	Destination Node	Transaction
A	B	Hello Message
B	A	Acknowledge (ACK) Hello Message
A	B	Packet 1
B	A	ACK Packet 1
A	B	Packet 2
B	A	ACK Packet 2
A	B	Packet 3
B	A	Negative Acknowledge (NACK) Packet 3. Error detected by Node B.
A	B	Packet 3
B	A	NACK Packet 3
A	B	Packet 3
B	A	ACK Packet 3
A	B	Packet 4
B	A	ACK Packet 4
A	B	End of Message (EOM)
B	A	ACK EOM, GoodBye

**2.10. Other Simple Communication Techniques**

**Aspects of Digital Communication**  
**Chapter Simple Communication Systems**

**2.10.1. Fiber Optic Based**

Fiber.cdr 19-Nov-2002



**Figure 16 - Fiber Optic Transmission**

**2.10.2. Wireless**

(See the later section on Wireless)

## Aspects of Digital Communication Many Communicators – Network Topology

### 3. Many Communicators – Network Topology

The discussion so far has concentrated on communication between only two parties. Communication among many parties is, of course, the goal of real communication systems. Many approaches have been implemented as communication technology has evolved. Figure 17 generalizes the approaches to connect six nodes for the purpose of communication. The lines connecting the nodes represent communication links and could be of any of the types that were discussed above. Notice that topologies **b**, **c**, **d**, **e**, and **f** are all subsets of **a**. Topology **g** is not a subset of topology **a** and is different. The link is shared and all nodes see all the traffic on the link.

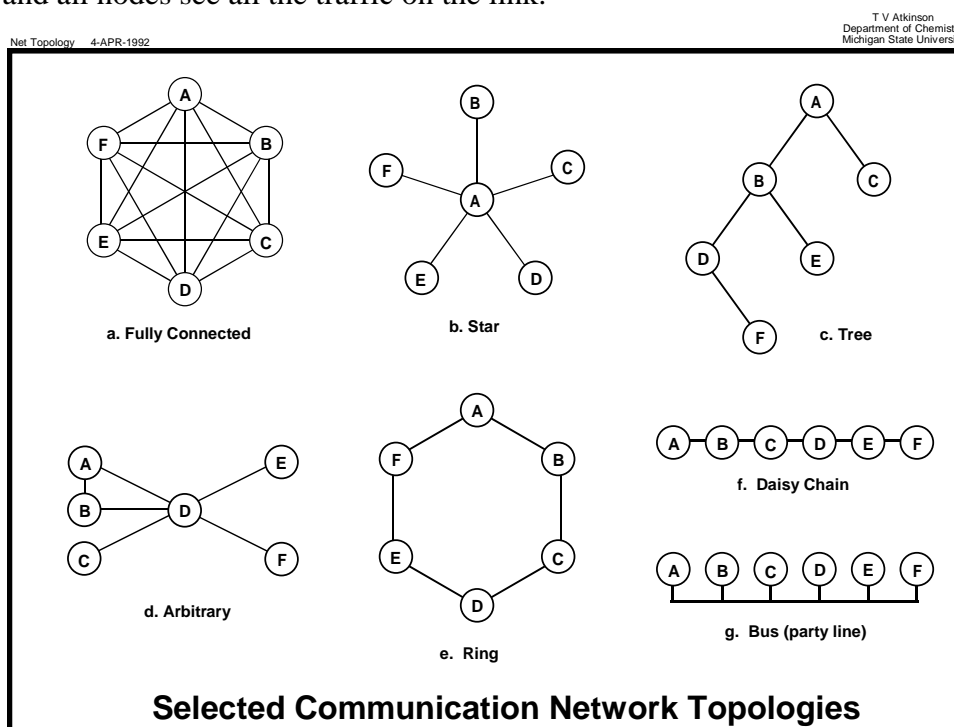


Figure 17 - Network Topology

From a communication point of view, the topology of Figure 17a is the most desirable in that there is a dedicated communication link to all other parties. Thus, communication between any two nodes can take place with no interference from any other conversations. In all other cases, there are conflicts that may impede any given conversation between two nodes. However, there are two facts that keep any real network from striving toward the goal of full connectivity. First, a human being and most machines are limited in the number of conversations in which they can participate simultaneously. Second, the number of links required to fully connect a group of nodes grows very rapidly with the number of nodes. Equation 1 shows the relationship between the number of links,  $k$ , and the number of nodes,  $n$ , to be connected in a fully connected topology.

**Aspects of Digital Communication**  
**Many Communicators – Network Topology**

$$k = \frac{n!}{(n-2)!2!}$$

**Equation 1**

Table 9 tabulates some values from this equation.

**Table 9 - Number of Links in a Fully Connected Net**

Number of Nodes	Number of Links
2	1
3	3
4	6
5	10
6	15
7	21
8	28
9	36
10	45
20	190
28	378
50	1225
100	4950
200	19900
500	124750
10000	49995000
100000	5E+09

As an example, consider the city of Lansing, MI which has about 400000 inhabitants with, say as a guess, 100000 households. A completely connected telephone network for this community would require  $5 \times 10^9$  phone lines between each home and every other house. But even worse, each home would have to have  $5 \times 10^9$  telephone instruments. Absurd!

Figure 18 illustrates a more complicated topology than those of Figure 17 and involves 28 nodes and 28 links. This set of nodes would require 378 links to be full connected, already an unwieldy number. Real communications systems can be much more complicated even if they are not fully connected. For example, consider the global phone network or the global Internet each with millions of nodes. At the other extreme are small

## Aspects of Digital Communication Many Communicators – Network Topology

local area networks involving a small number of nodes. Any network will be a compromise between the number of links and the desire for connectivity, but will be extensions of the concepts included in Figure 17 and Figure 18.

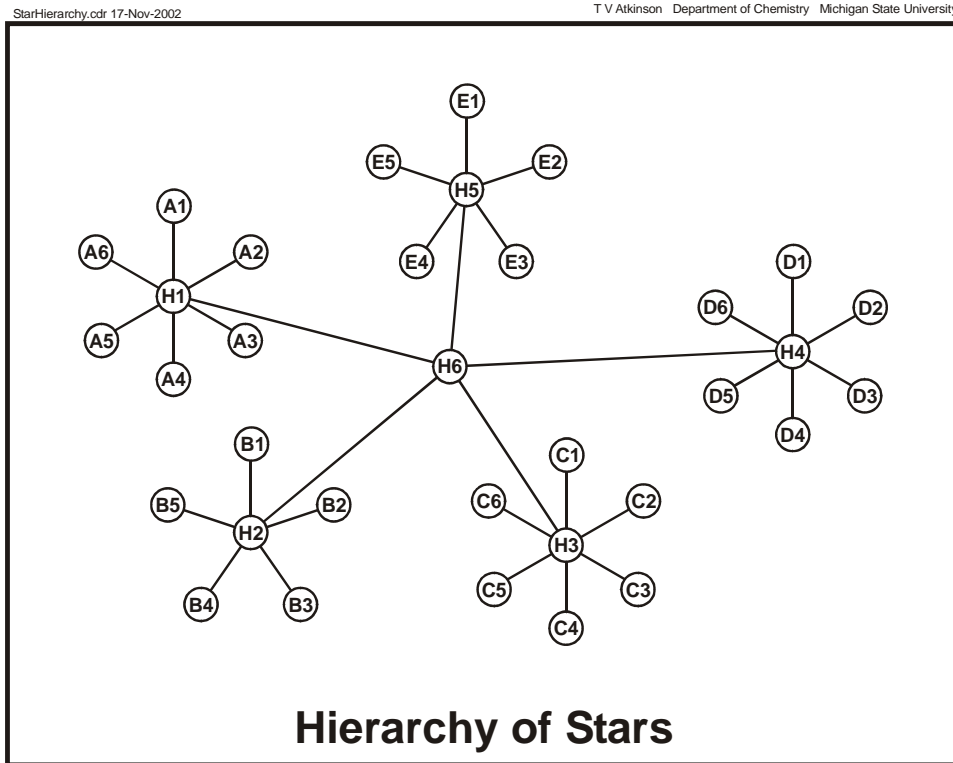


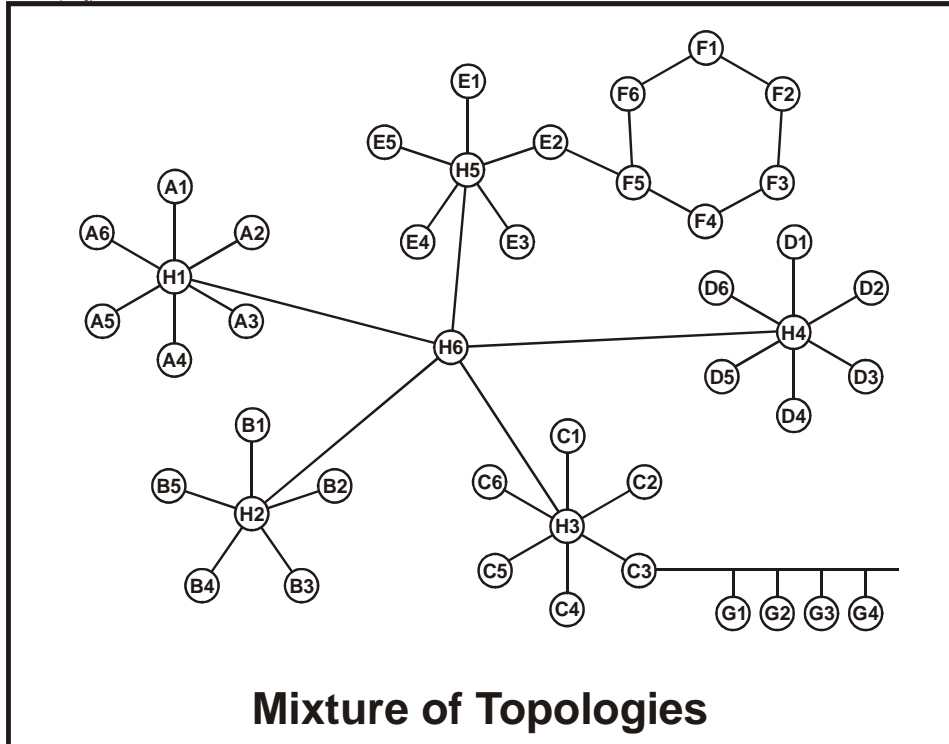
Figure 18 - Hierarchy of Stars

# Aspects of Digital Communication

## Many Communicators – Network Topology

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### Mixture of Topologies

Figure 19 - Mixture of Topologies

### 3.1. Multi-drop

Figure 20 illustrates an example of network topology **g** where all parties share a communication channel or link. This is a typical multi-drop configuration with three stations, each with a switch and light. The example can be extended to any number of stations. Notice, that all three switches must be closed in order for current to flow. When current flows, all three lights are illuminated at the same time. The opening of any switch extinguishes all lights. With this schema, the originating party observes the state of the line. If no traffic is observed, the message is begun. There will have to be an address in the message to identify who is to receive the message.

## Aspects of Digital Communication Many Communicators – Network Topology

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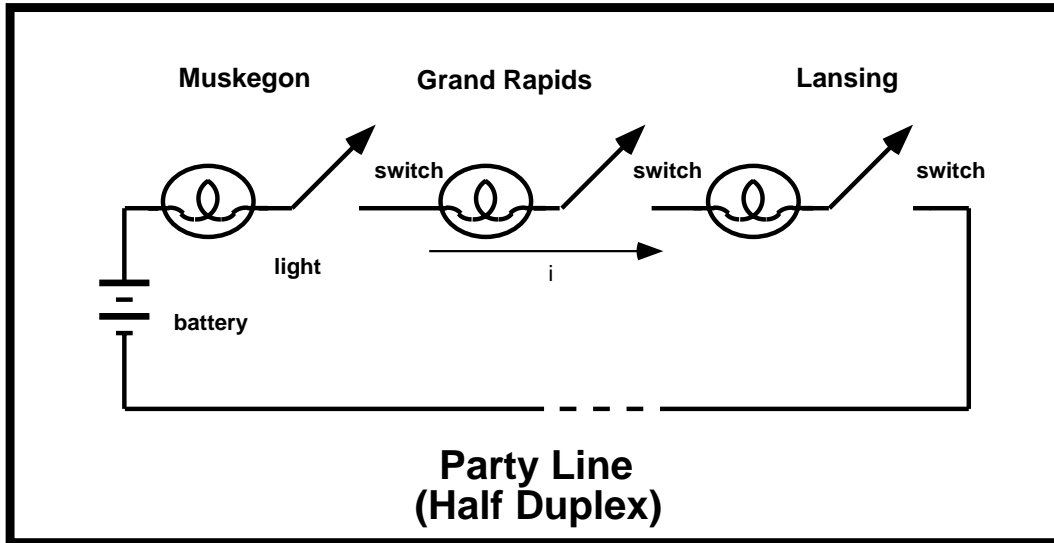


Figure 20 – Multi-drop or Party Line or Bused Communication

### 3.1.1. Timing Considerations

The timing considerations will be the same as and depend on which of the five techniques described above is chosen.

### 3.1.2. Protocols

1. All inactive stations will leave the switch for that station closed. Only the station currently transmitting information will be allowed to break the circuit.
2. To begin transmission, a station must gain access to the line and become the active station. This could be done by observing the state of the line for a short period of time and begin sending if no activity is observed.
3. After a dialogue has begun, the end of a message from the active station ends with an indicator that the other party may now send. This "Line turnaround" indicator may be a unique and special byte or a unique string of characters.
4. Special messages will be exchanged at the end of the dialogue to indicate that the session is over.
5. All messages will have to have the address of the recipient included. All stations will have to listen to all messages in order to get the ones addressed to that station.

## **Aspects of Digital Communication**

### **Many Communicators – Network Topology**

#### **3.1.3. Possible problems**

1. Two or more parties may want to start a dialogue, observe that the line is quiescent, and simultaneously begin sending a message. With luck, all parties will observe that there is only nonsense passing down the wire, backoff, and try again, hopefully at slightly different times.

#### **3.1.4. Advantages**

1. Simple
2. Only two line states, thus the benefits of the inherent noise immunity of digital techniques

#### **3.1.5. Disadvantages**

1. Each station only sends or receives during a particular period of time.
2. More complicated.
3. Whole system is at the mercy of any one station that accidentally leaves the switch open.
4. Everyone listens to all messages. Little privacy.

### **3.2. Medium Access Control (MAC) - Managing the Party Line**

The issue with shared communication channels is how to manage the use of the channel so that all parties get appropriate access to the channel in order to send a message. These control mechanisms are a form of flow control.

1. Carrier Sense Multiple Access with Collision Detection (CSMA/CD) (IEEE 802.3)

This is a common technique with Ethernet and Wireless networks. When a node has assembled a message and is ready to transmit the message, the media interface senses the line. If another node is transmitting, this node waits. If no traffic is sensed, the node begins transmitting the next packet.

However, there is the possibility that two or more nodes have sensed no traffic and have begun to transmit simultaneously. This is a collision. The protocol demands that all transmitting nodes stop transmitting and backoff. Each node waits a random (and hence, different) amount of time and begins the process again. Thus, only one of the competing nodes will start transmitting again and command control of the communication channel.

2. Token Rings (IEEE 802.5)

## Aspects of Digital Communication Many Communicators – Network Topology

For token driven networks, a special packet called a token is continually circulated. When a node is ready to transmit, the node waits until the token comes around to that node. The node removes the token (i.e. does not forward it to the next node.) and transmits the desired packet. As soon as the receiving node has finished receiving the data packet, the destination node retransmits a token packet and the ring returns to the idle state.

### 3.3. Bit Forwarding Devices

A number of devices have been built that forward messages from one link to another one bit at time.

#### 3.3.1. Repeaters

In some communication cases, the distance between stations can be greater than the link, the current loop of our simple case, can span and still give reliable results. One possible solution is the use of repeaters as illustrated in Figure 21.

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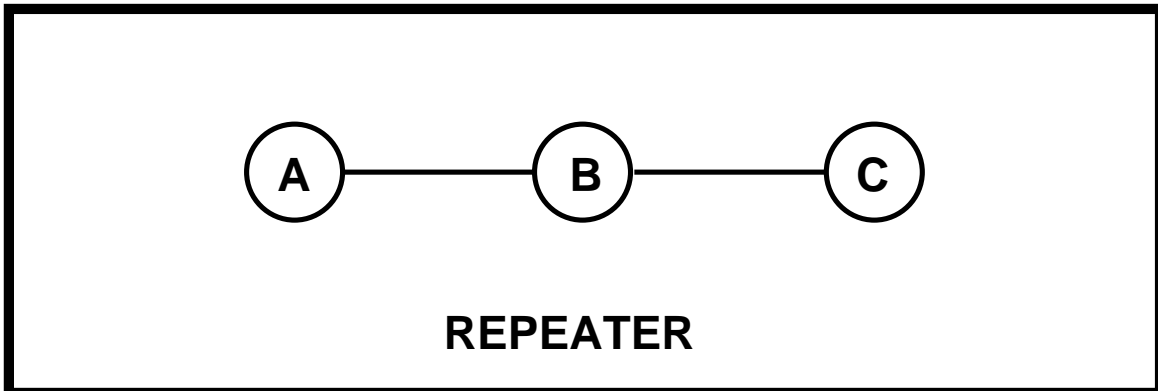


Figure 21 - Repeaters

In this case, two simplex links connect station B to station A and station C. The information originates at station A and is destined for station C, or stations B and C. Station A sends the information to station B. When station B has received the message on the A, B link the message is then retransmitted on link B, C. This process can be repeated as many times as possible to span the overall distance between locations.

#### 3.3.2. Repeaters - Hubs

The repeater concept can be expanded to allow more than two communicators be involved. Figure 22 illustrates such a situation. Node **H** provides the repeater function. A particular node transmits a message destined to one of the other nodes on the link to Node **H** which repeats the message on each of the other links. Usually this is done bit by bit at

## Aspects of Digital Communication Many Communicators – Network Topology

the physical layer. As before all nodes see all traffic and there is no privacy. This is equivalent to a bus as illustrated in Figure 17g.

Node **H** may be a peer node with the others or be dedicated to repeater function and originates or receives no messages.

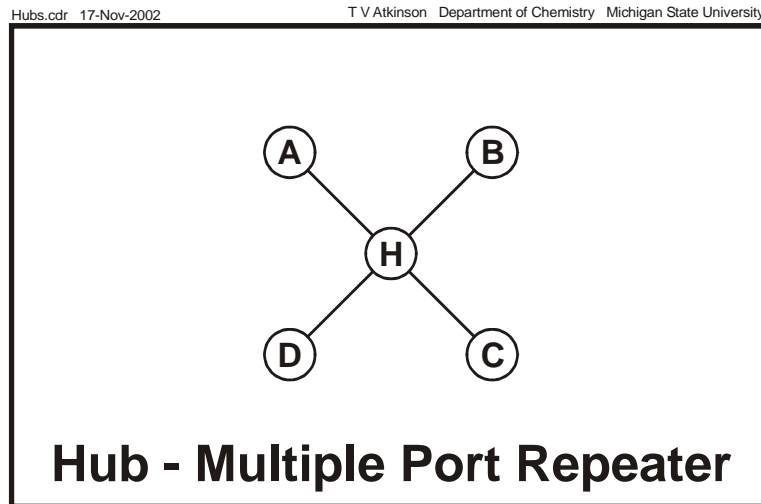


Figure 22 - Hubs

### 3.4. Packet Forwarders

Networks are collections of entities, e.g. humans, computers, printers, etc., which are connected by communication channels and will communicate in pairs or other groupings. Current networks will consist of many nodes and have topologies that are extensions of the concepts embodied in Figure 17 and Figure 18. In such topologies, the intermediate nodes, i.e. those with more than one link connected to the node, have the responsibility of forwarding any messages that should transit through the node on the way to the ultimate destination. This is necessary for all nodes to be able to communicate with all other nodes in the network.

The repeaters of the previous section forward the messages one bit at a time. The packet forwarders of this section collect a whole packet of information and then retransmit the packet down the proper link(s). Another difference between the two types of information forwarding agents is found in what links receive the forwarded message. In the case of the repeaters, all links out of the repeater get the regenerated message. In the devices of this section, decisions are made as to what links, if any, will get the forwarded information.

## Aspects of Digital Communication

### Many Communicators – Network Topology

#### 3.4.1. Bridges

Figure 23 illustrates a bridge which is a packet forwarding node that sits between two network segments, pictured as the two clouds here. The bridge watches traffic on the two segments and learns the address of the nodes in Subnet 1 and the addresses of the nodes in Subnet 2. Then each packet that comes down a link is captured and examined for destination address. If the destination node is on the same side of the bridge as the source, the packet is discarded by the bridge. If the destination node is on the other side of the bridge from the source, the packet is retransmitted on the other link.

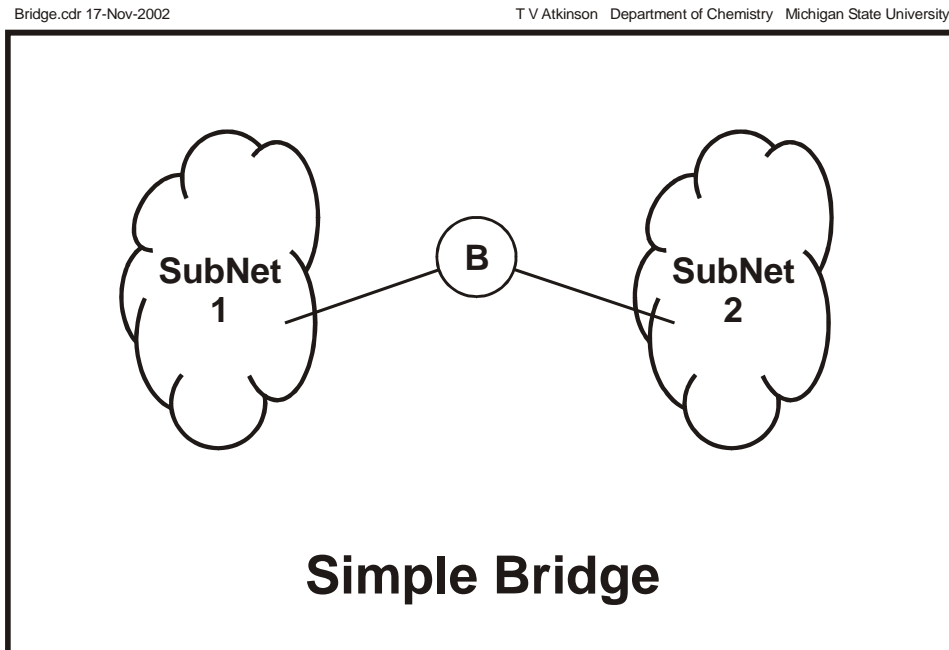


Figure 23 - Bridge

#### 3.4.2. Switches

Switches are multi-port bridges. Figure 24 and Figure 25 illustrate two ways of implementing a bridge. These two examples show a 4 port switch. Switches can have 4, 8, 12, 16, or essentially any number of ports. In addition, the figures show single nodes connected to each port of the switch. Any port could be connected to any subnet of nodes as in the case of the bridge.

The switch, again, listens to the traffic on all of the links and learns which nodes are located outbound of each port. Given the table of which nodes are down which link, packets can be captured on each link and forwarded as appropriate as in the case of the bridge. Multicast packets (those addressed to more than one node) and broadcast packets (those addressed to all nodes and, hence, a multicast packet) are forwarded out of all ports.

# Aspects of Digital Communication

## Many Communicators – Network Topology

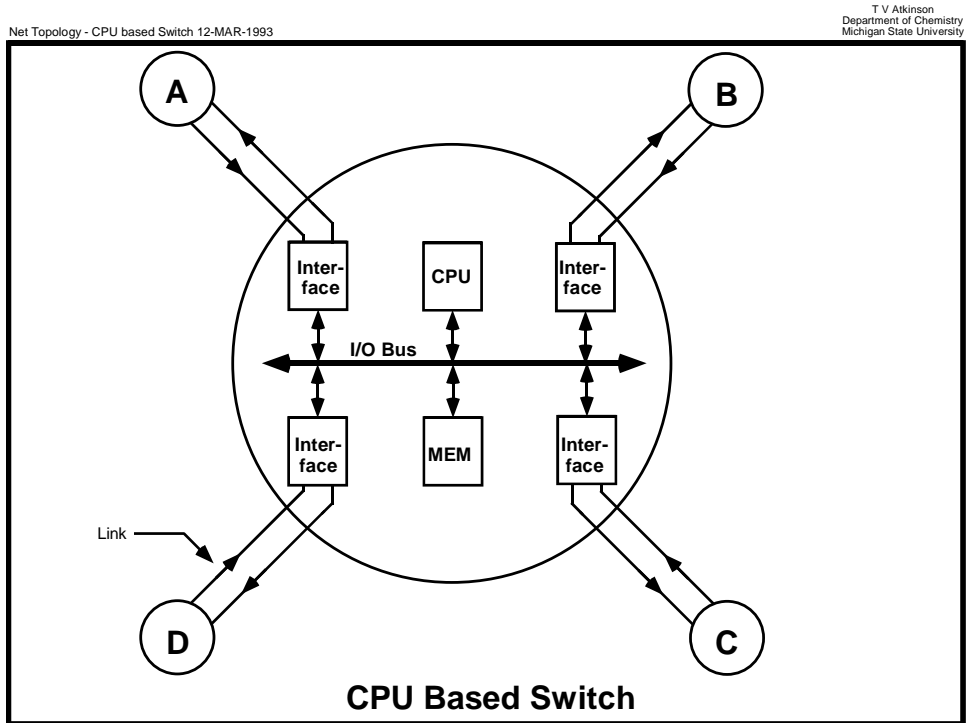


Figure 24 – CPU Based Switch

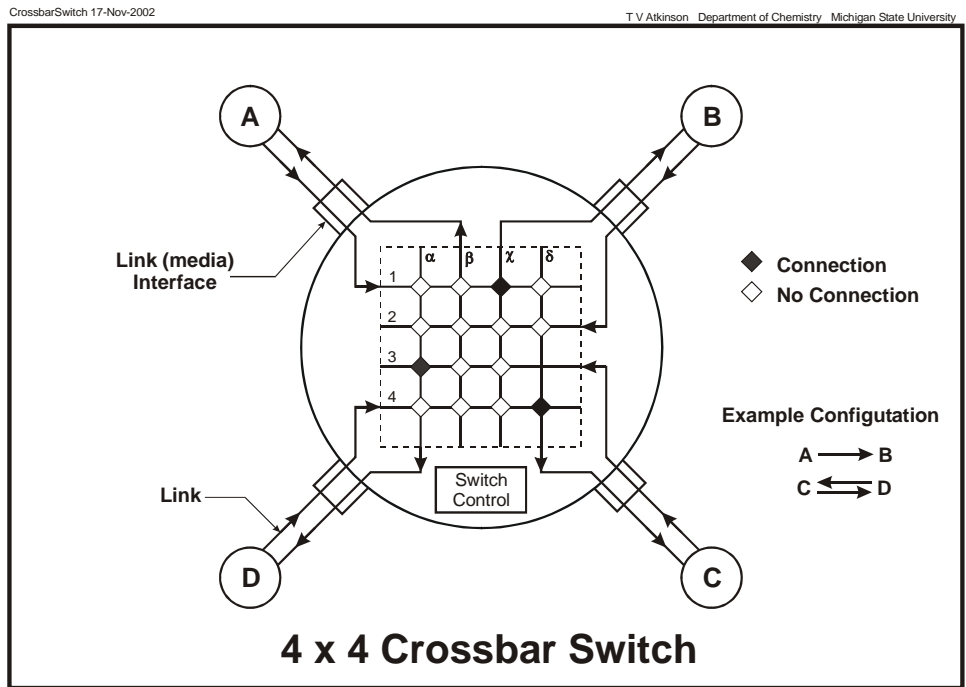


Figure 25 – Crossbar Switch

# Aspects of Digital Communication

## Many Communicators – Network Topology

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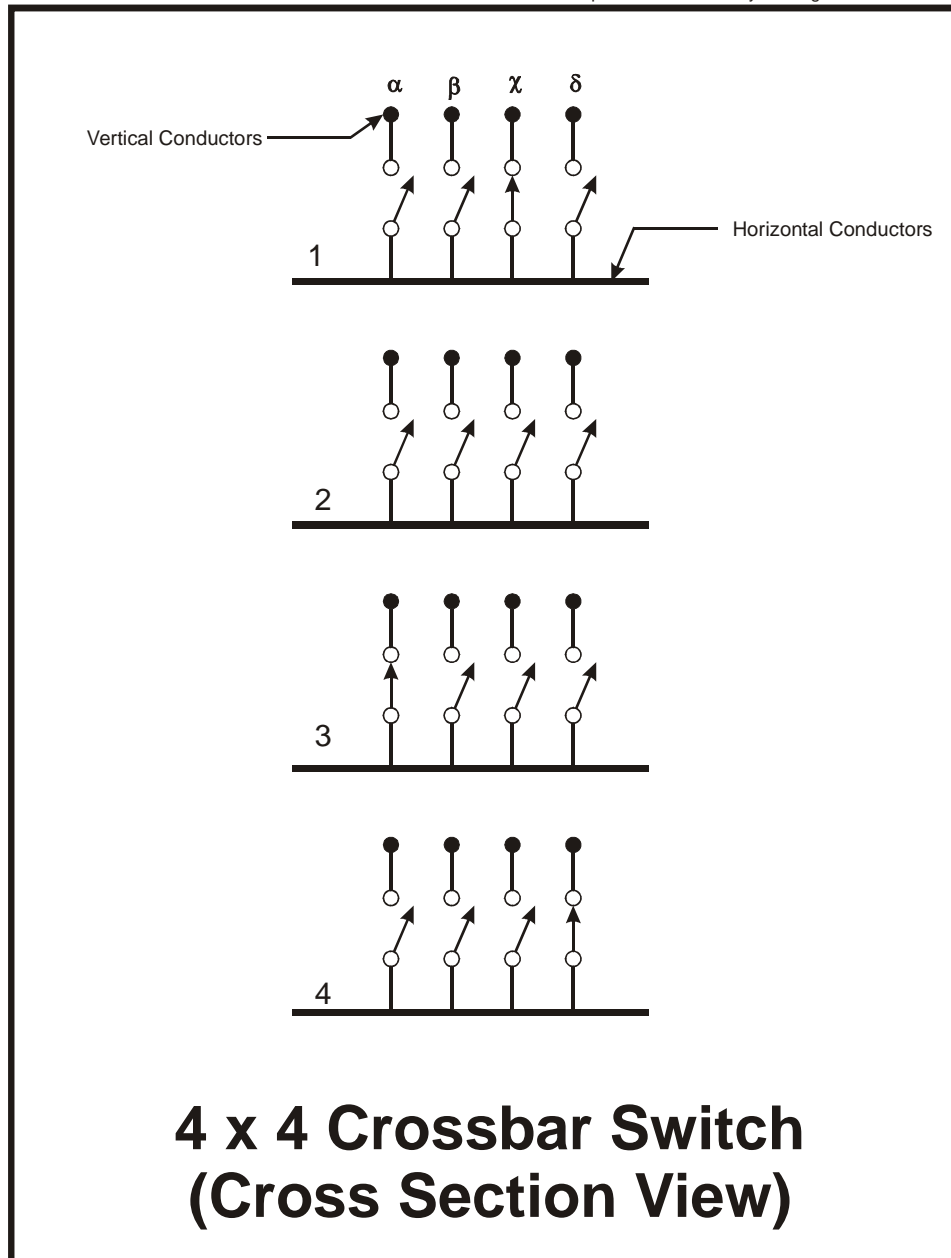


Figure 26 – Cross Section View of Crossbar Switch

### 3.4.3. Routers

Routers are a higher level packet forwarder. Unlike the bridge and switch which makes forwarding decisions solely on the basis of the address of the destination node, routers examine the content of the packets further and make forwarding decisions based on higher level aspects of the protocols being used to communicate. For instance, the router

## Aspects of Digital Communication Many Communicators – Network Topology

may only forward TCP/IP packets and block packets of any other protocol family, e.g. Appletalk or Novell. Routers also do not forward multicast packets.

Another approach to providing communication among multiple stations involves a configuration such as that shown in Figure 27.

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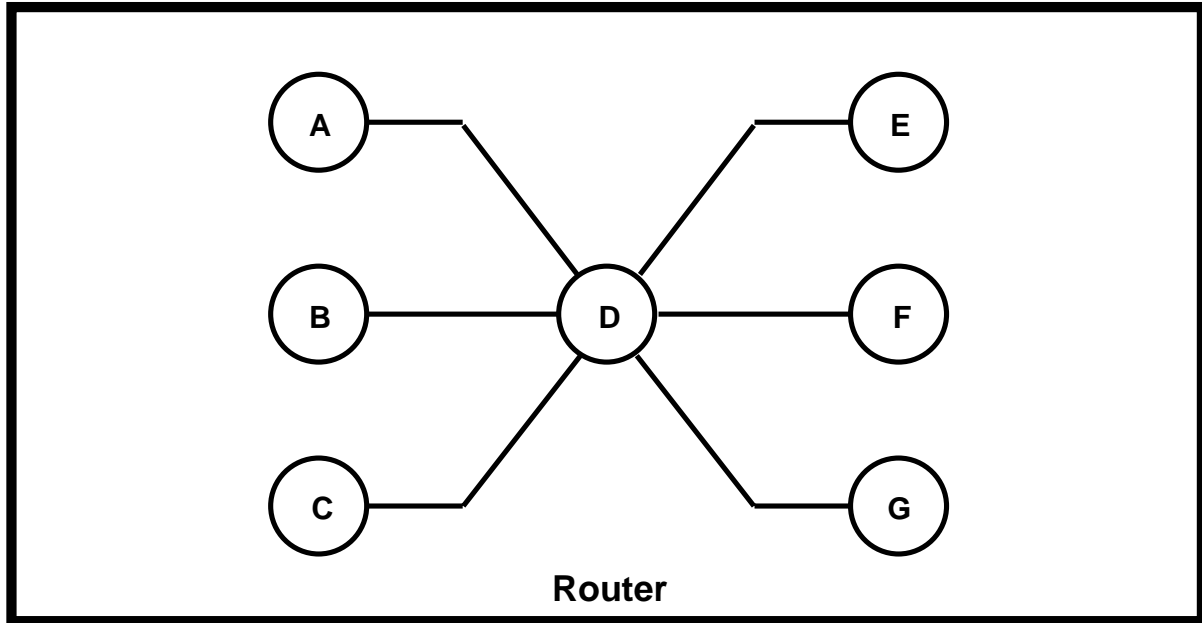


Figure 27 - Routers

In this configuration, D acts as the router of the whole system. Nodes A, B, C, E, F, and G are end nodes. A given station, e.g. A, desires to send a message to, say, station G. A dialog with D is first established. The message is sent to D. D then establishes a dialog with G and relays the message. The individual links may be essentially any of the types discussed. All links do not have to be of the same type or speed.

### 3.4.3.1. Protocols

1. The protocols specific to the techniques used for each link will be obeyed for that link.
2. An addressing scheme must be implemented to tell the router to whom to send the message.
3. A scheme will be required to determine who can talk to the router at any given time.

## **Aspects of Digital Communication**

### **Many Communicators – Network Topology**

#### **3.4.3.2. Advantages**

1. Allows large collections of stations.
2. If the router is trustworthy, privacy is better than multi-drop.
3. Failure of a end node effects only that node. The remainder of the system can still operate.

#### **3.4.3.3. Disadvantages**

1. Complexity of the router's job is great.
2. Whole system fails if the router fails.
3. Router must know the complete topology of the system.

### **3.5. Sample Dialogs for a Routed Network**

This section will very briefly examine what a typical conversation on a network would look like and address the following questions.

1. How does the sender know the receiver got the correct message?
2. For multiparty systems, how does the sender know the intended receiver is listening?
3. For multiparty systems, how does the sender know the correct party got the message?

#### **3.5.1. Routed Network**

In this example Node A wishes to send a message to Node F. Both nodes are members of the network shown in Figure 28. The message is to be divided into two packets. Notice that an error is detected. Methods for detecting errors are discussed in the chapter on Error Control.

**Aspects of Digital Communication**  
**Many Communicators – Network Topology**

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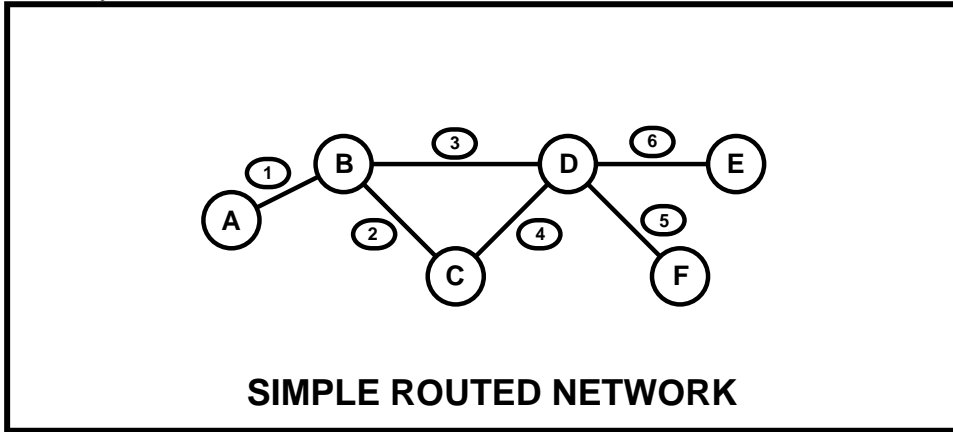


Figure 28 - An Example Routed Network

Table 10 - Dialog 2 Time Course of Sample Dialog: Routed Network

Source	Destination	Link	Transaction
A	B	1	Hello (From Node A To Node F)
B	D	3	Hello (From Node A To Node F)
D	F	6	Hello (From Node A To Node F)
F	D	6	ACK Hello (From Node F to Node A)
D	B	3	ACK Hello (From Node F to Node A)
B	A	1	ACK Hello (From Node F to Node A)
A	B	1	Packet 1 (From Node A To Node F)
B	D	3	Packet 1 (From Node A To Node F)
D	F	6	Packet 1 (From Node A To Node F)
F	D	6	ACK Packet 1 (From Node F to Node A)
D	B	3	ACK Packet 1 (From Node F to Node A)
B	A	1	ACK Packet 1 (From Node F to Node A)
A	B	1	Packet 2 (From Node A To Node F)
B	D	3	Packet 2 (From Node A To Node F)
D	F	6	Packet 2 (From Node A To Node F)
F	D	6	NACK Packet 2 (From Node F to Node A)
D	B	3	NACK Packet 2 (From Node F to Node A)
B	A	1	NACK Packet 2 (From Node F to Node A)
A	B	1	Packet 2 (From Node A To Node F)
B	D	3	Packet 2 (From Node A To Node F)
D	F	6	Packet 2 (From Node A To Node F)
F	D	6	ACK Packet 2 (From Node F to Node A)
D	B	3	ACK Packet 2 (From Node F to Node A)
B	A	1	ACK Packet 2 (From Node F to Node A)
A	B	1	EOM (From Node A To Node F)

## Aspects of Digital Communication Overview of Wired and Wireless Networking

Source	Destination	Link	Transaction
B	D	3	EOM (From Node A To Node F)
D	F	6	EOM (From Node A To Node F)
F	D	6	ACK EOM, Good Bye (From Node F to Node A)
D	B	3	ACK EOM, Good Bye (From Node F to Node A)
B	A	1	ACK EOM, Good Bye (From Node F to Node A)

### 3.6. Gateways

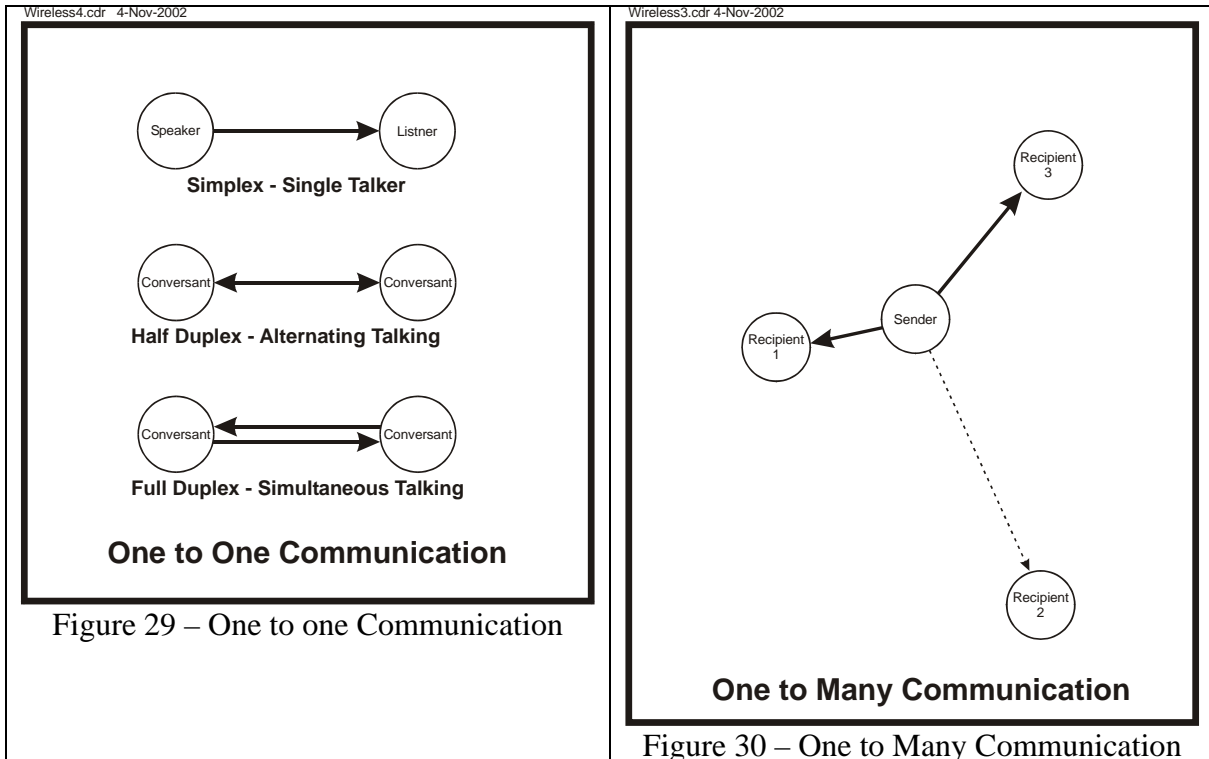
Gateways are even higher level packet forwarding agents that connect dissimilar networks, e.g. one that does TCP/IP and one that does Appletalk. In this case not only are routing decisions made but also translations from one protocol to the other. This is analogous to having a phone operator translating the conversation of a person on one phone who only speaks one language, say Italian, and another person on a second phone who only speaks a second language, say Korean.

## 4. Overview of Wired and Wireless Networking

### 4.1. General

Modern data networks are the current instantiation of one and one half centuries of evolution of communication technology which includes telegraphy, telephony, radio, and television. The goal of communication technology is to allow the intrinsic human motivation to communicate to occur among individuals that are separated by distances that preclude communication via the intrinsic human senses and capabilities. One may categorize human communication into two categories: dialog (Figure 29), communication between two individuals and oration (Figure 30) the communication between one speaker and two or more listeners.

## Aspects of Digital Communication Overview of Wired and Wireless Networking



Networks are collections of communication mechanisms that allow a collection of entities, i.e. nodes, to interchange information. In the current incarnations, the information is transferred between entities by encoding the information on signals which propagate through solid materials such as conductors (wires) and optical fibers or encoding the information on the properties of electromagnetic radiation; e.g. visible light, infrared light, microwaves, or radio waves; or acoustical radiation. When solid materials carry the information, the communication channel is by necessity spatially constrained and very thin, e. g. millimeters or even micrometers in diameters. Such channels are intrinsically appropriate for one-to-one communication. When electromagnetic or acoustical radiation is used the information is encoded in the properties (frequency, amplitude, or phase) of the radiated waves. This approach is often called “wireless” since no conductors are used to carry the signals once outside of the transmitter. The physical dimensions of the communication channel in this case may be physically constrained to some degree, i.e. focused and directional, but is usually “unconstrained” and omni directional. Traditionally, consumer radio and TV made use of the omni directional characteristics to “broadcast” the same information to many individuals at one time. Furthermore, the information transfer is one way, i.e. the listeners do not respond.

For very interesting historical, economic, and technological reasons that are way beyond the scope of this document, the broadcast wireless approach is often used to implement one-to-one communication. And, the typically one-to-one approach of using “wires” is often used for one-to-many communication. Figure 31 illustrates one simple example of a

## Aspects of Digital Communication Overview of Wired and Wireless Networking

complex topology in which one-to-one links are used to provide communication among a large community of individuals. In such a case, individuals **B, C, D,** and **F** have the responsibility of forwarding information, when appropriate, in order for the outlying individuals **E, G, H, I, J, K, L, M, N,** and **O** to communicate with all members of the set. In fact, individuals **B, C, D,** and **F** often are dedicated to the function of forwarding and are not “peers” in typical wired networks

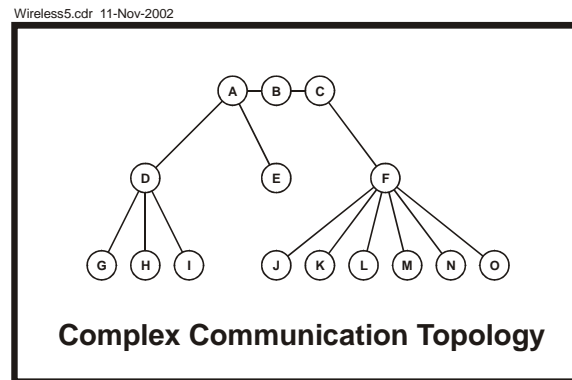


Figure 31 – Complex Communication Topology Example

### 4.2. Wireless

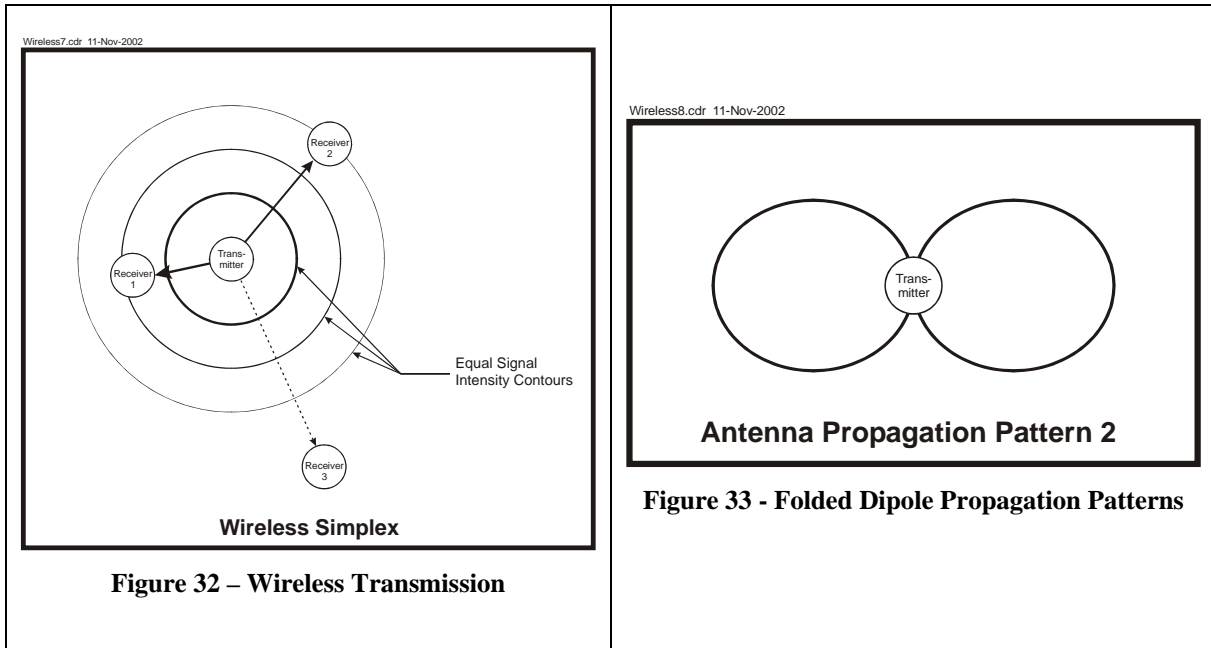
Figure 32 illustrates the basis of wireless communication in general and WLAN technology in particular. A transmitter broadcasts a signal consisting of information encoded upon an electromagnetic radiation carrier. Any number of receivers, e.g. Receiver 1, 2, and 3, can capture the signal and extract the information. Thus, any number of simultaneous simplex communication links can be implemented. Figure 32 also illustrates the fact that the intensity of the radiated signal diminishes as the distance between the transmitter and receiver increases. As the signal level at the receiver decreases, the extraction of the information from the carrier becomes more difficult and there will be some geographical boundary beyond which communication will be impossible.

Figure 32 implies an idealized transmission, i.e. the only parameter affecting signal strength, and hence quality, at the receiver is the distance from the transmitter. In reality, several factors cause deviations from this ideality. For one, the design of the transmitter antennae greatly affects the radiation patterns. Figure 33 and Figure 34 illustrate additional propagation patterns that can be achieved with the use of different antenna designs. Other factors will modify the propagation characteristics of a given transmitter/antenna. For instance, the reflective, adsorptive, and diffractive properties of physical objects in the area of the signal can alter the patterns. Figure 35 illustrates how objects such as building materials, trees, leaves, even rain drops and snow flakes can alter the propagation patterns and hence, define where appropriate reception can be achieved. Figure 36 illustrates another problem. If an object reflects the transmitted signal, a receiver will see a composite of the two copies of the signal separated in time. The

## Aspects of Digital Communication Overview of Wired and Wireless Networking

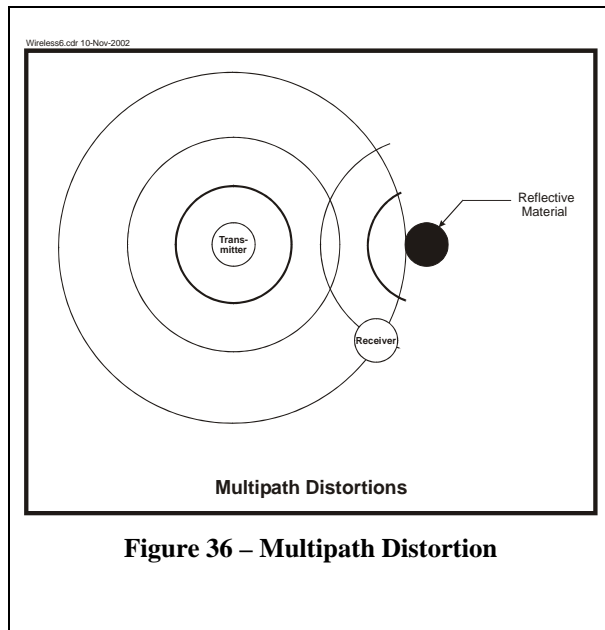
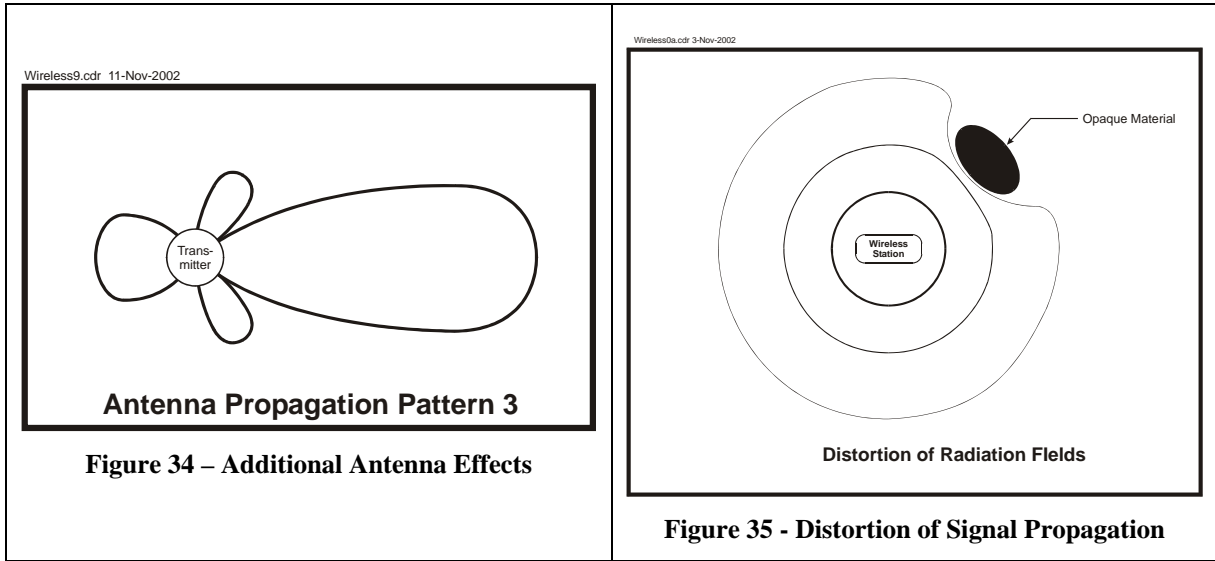
separation results from the path traveled by the two signals being different. This can cause confusion in the extraction of the information since the receiver does not know, a priori, which part of the composite signal received belongs to the primary copy and which to the reflected copy of the signal.

The bottom line in all of this is where can receivers be and still receive a signal of sufficient quality to enable the correct extraction of the encoded information, i.e. the correct transmission of the information from sender to receiver.



# Aspects of Digital Communication

## Overview of Wired and Wireless Networking

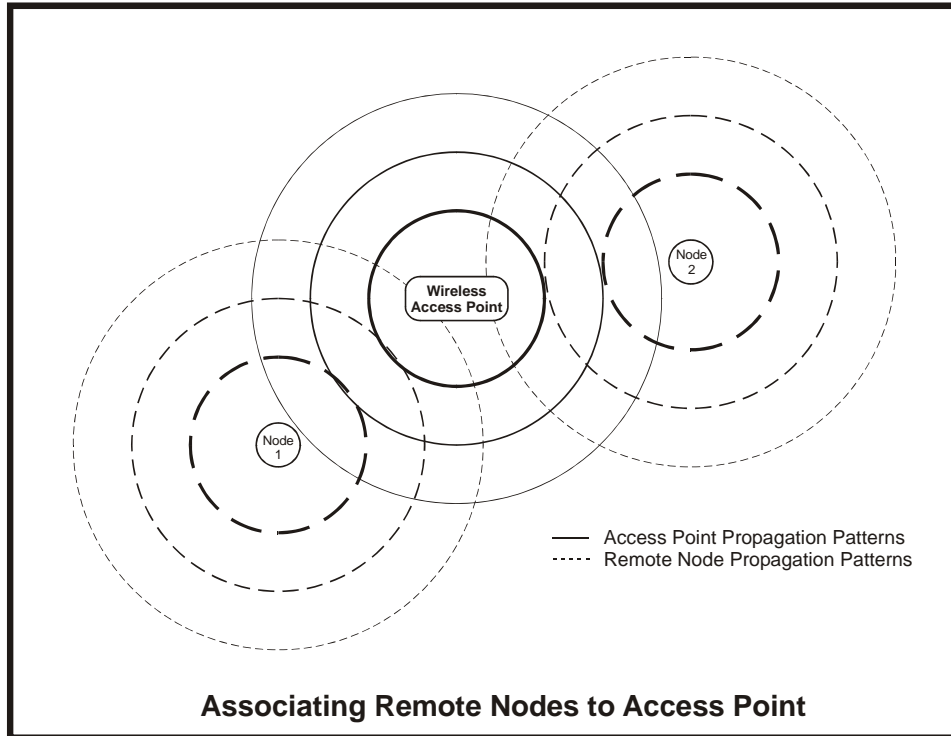


Wireless access point is essentially a hub implementing a communication segment shared by a community of users within the range of the radio transmission that provides the carriage for the communication channel.

# Aspects of Digital Communication

## Overview of Wired and Wireless Networking

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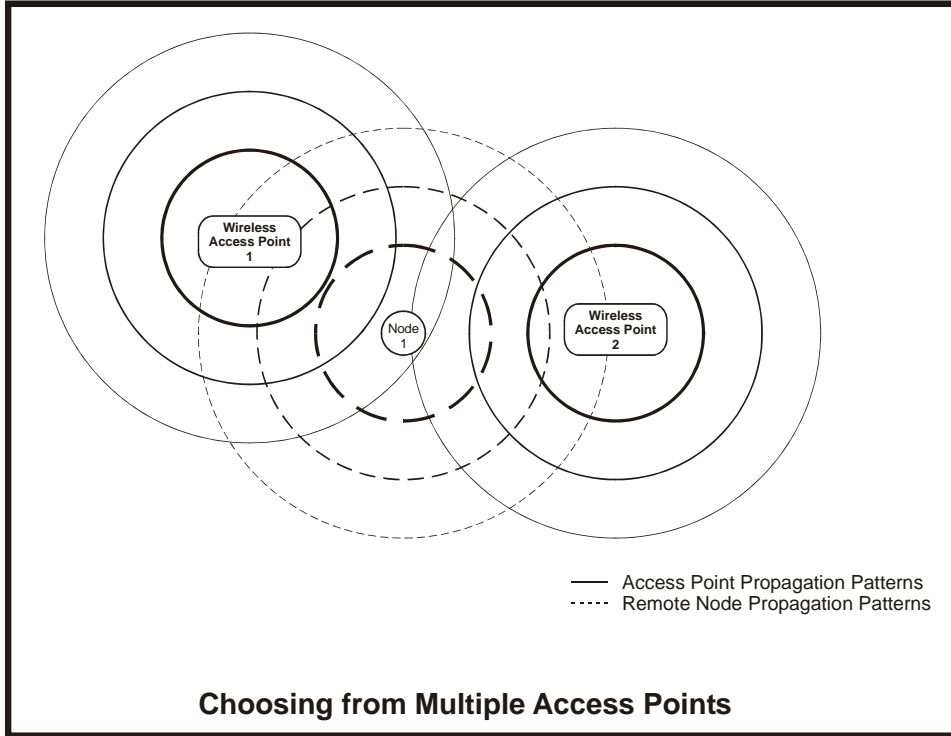


**Figure 37 – Associating Nodes to an Access Point**

# Aspects of Digital Communication

## Overview of Wired and Wireless Networking

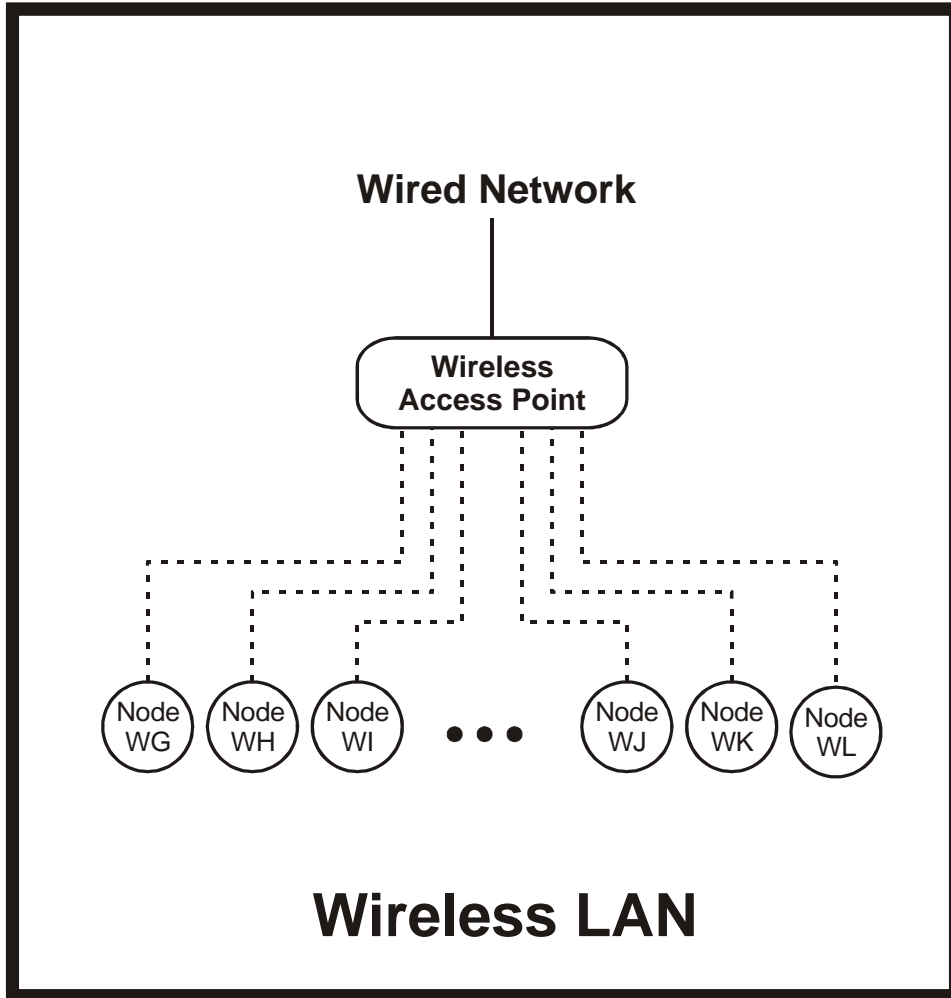
Wireless11.cdr 11-Nov-2002



**Figure 38 – Multiple Access Points**

**Aspects of Digital Communication  
Overview of Wired and Wireless Networking**

Wireless12.cdr 11-Nov-2002



**Figure 39 – Access Point Associated with Multiple Nodes**

# Aspects of Digital Communication

## Overview of Wired and Wireless Networking

DepartmentNetworka.cdr 10-Nov-2002

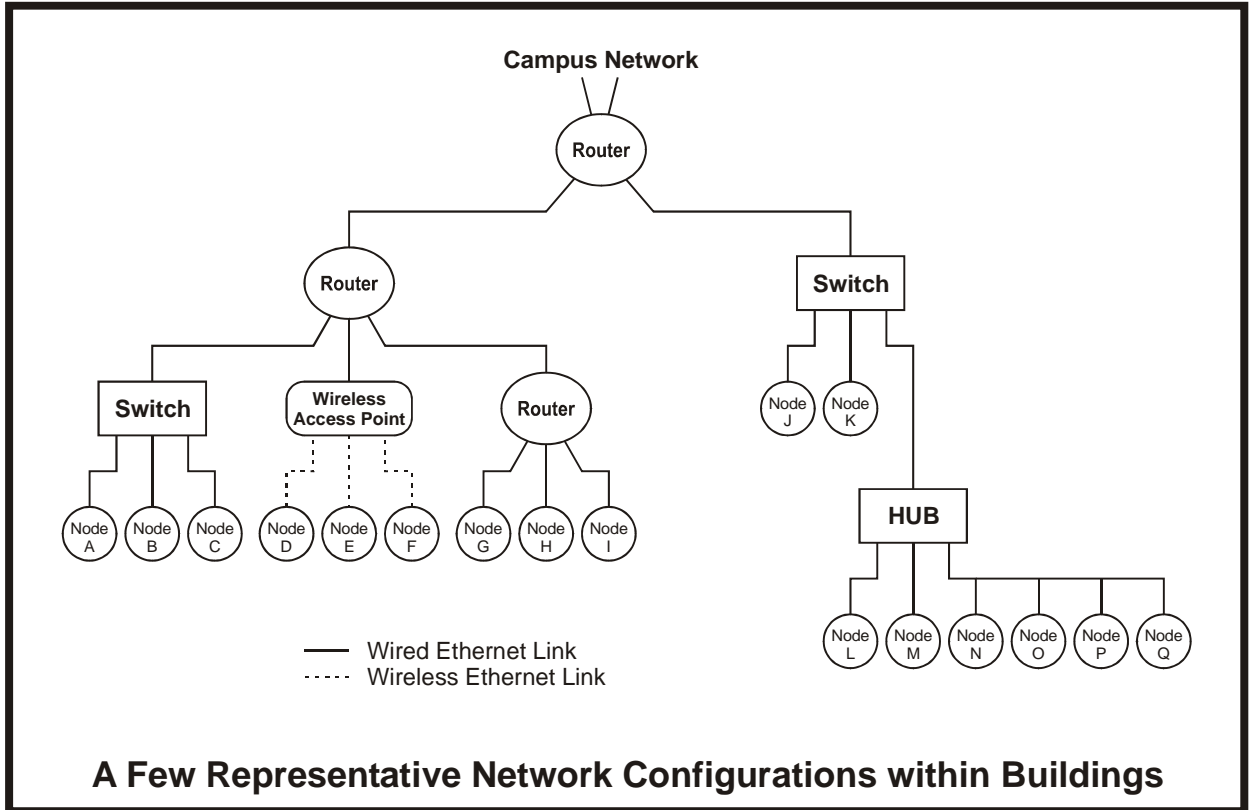


Figure 40 – Wired/Wireless Network Configurations

**Aspects of Digital Communication**  
**Chapter Error Control**

**Chapter 5. Error Control**

Redundancy - Any information added to a message or collection of information for the purpose of ensuring the integrity of the communication or the storage of that information.

**5.1. Error prevention**

1. Improve the media of information exchange/storage
2. Improve transmitter/receiver
3. Slow down transmissions /decrease storage density

**5.2. Error detection**

1. Parity
  - 1.1. Even/odd/none(parity bit = 0)/none (parity bit = 1)
  - 1.2. Vertical (lateral) parity
  - 1.3. Horizontal (longitudinal)
  - 1.4. Longitudinal Redundancy Character (LRC)
2. Checksums
3. Cyclic Redundancy character (CRC)

$$\frac{M \cdot 2^n}{G} = Q + \frac{R}{G}$$

where M is the message to be sent treated as a single binary number, n is the number of bits in the CRC character, G is a n + 1 bit number, (the divisor or generator polynomial), Q is the quotient which is discarded, and R is the remainder of the division. The CRC is the least significant n bits of R. The CRC is appended to the message.

**Aspects of Digital Communication**  
**Chapter Error Control**

Standard Generator Polynomials

Name	Symbolic Representation	Binary Value
CRC-16	$X^{16} + X^{15} + X^2 + 1$	1 1000 0000 0000 0101
CRC-CCITT	$X^{16} + X^{12} + X^5 + 1$	1 0001 0000 0010 0001
CRC-32	$X^{32} + X^{26} + X^{23} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$	1 0000 0100 1000 0001 0001 1101 1011 0111

4. Signature analysis

**5.3. Error correction**

1. Retransmission
  - 1.1. Complete (echo)
  - 1.2. Upon error detection
2. Horizontal - Vertical parity correlation
3. Hamming codes
4. Hagelbarger codes
5. Bose-chaudhuri codes

# Aspects of Digital Communication

## Chapter Error Control

CEM 924 MagTape 17-MAY-1992

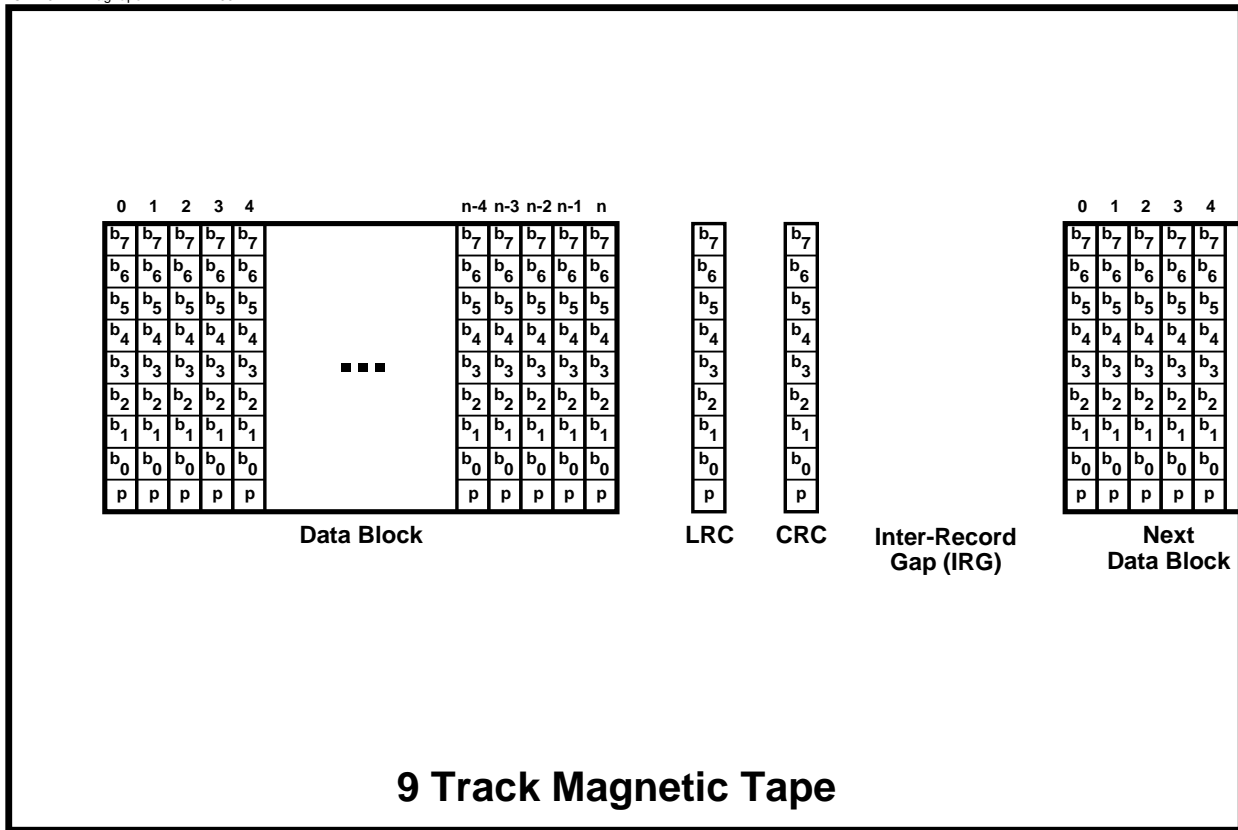


Figure 1 9 Track Magnetic Tape

## Aspects of Digital Communication Chapter Error Control

### 5.4. Examples

Message: ABCDEF

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	A	0100 0001	101	65	41	0100 0001	101	65	41	1100 0001	301	193	C1
2	B	0100 0010	102	66	42	0100 0010	102	66	42	1100 0010	302	194	C2
3	C	0100 0011	103	67	43	1100 0011	303	195	C3	0100 0011	103	67	43
4	D	0100 0100	104	68	44	0100 0100	104	68	44	1100 0100	304	196	C4
5	E	0100 0101	105	69	45	1100 0101	305	197	C5	0100 0101	105	69	45
6	F	0100 0110	106	70	46	1100 0110	306	198	C6	0100 0110	106	70	46

LRC (Even)	0000 0111	7	7	7	1000 0111	207	135	87	1000 0111	207	135	87
LRC (Odd)	1111 1000	370	248	F8	0111 1000	170	120	78	0111 1000	170	120	78
Checksum	1001 0101	225	149	95	0001 0101	25	21	15	0001 0101	25	21	15
CRC	1100 0110	306	198	C6	1010 0110	246	166	A6	1000 0110	206	134	86

Message: ACCDEF

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	A	0100 0001	101	65	41	0100 0001	101	65	41	1100 0001	301	193	C1
2	C	0100 0011	103	67	43	1100 0011	303	195	C3	0100 0011	103	67	43
3	C	0100 0011	103	67	43	1100 0011	303	195	C3	0100 0011	103	67	43
4	D	0100 0100	104	68	44	0100 0100	104	68	44	1100 0100	304	196	C4
5	E	0100 0101	105	69	45	1100 0101	305	197	C5	0100 0101	105	69	45
6	F	0100 0110	106	70	46	1100 0110	306	198	C6	0100 0110	106	70	46

LRC (Even)	0000 0110	6	6	6	0000 0110	6	6	6	0000 0110	6	6	6
LRC (Odd)	1111 1001	371	249	F9	1111 1001	371	249	F9	1111 1001	371	249	F9
Checksum	1001 0110	226	150	96	1001 0110	226	150	96	1001 0110	226	150	96
CRC	1010 0110	246	166	A6	0111 0110	166	118	76	0101 0110	126	86	56

## Aspects of Digital Communication Chapter Error Control

Message: ABCDFE

	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	A	0100 0001	101	65	41	0100 0001	101	65	41	1100 0001	301	193	C1
2	B	0100 0010	102	66	42	0100 0010	102	66	42	1100 0010	302	194	C2
3	C	0100 0011	103	67	43	1100 0011	303	195	C3	0100 0011	103	67	43
4	D	0100 0100	104	68	44	0100 0100	104	68	44	1100 0100	304	196	C4
5	F	0100 0110	106	70	46	1100 0110	306	198	C6	0100 0110	106	70	46
6	E	0100 0101	105	69	45	1100 0101	305	197	C5	0100 0101	105	69	45

LRC (Even)	0000 0111	7	7	7	1000 0111	207	135	87	1000 0111	207	135	87
LRC (Odd)	1111 1000	370	248	F8	0111 1000	170	120	78	0111 1000	170	120	78
Checksum	1001 0101	225	149	95	0001 0101	25	21	15	0001 0101	25	21	15
CRC	1110 0101	345	229	E5	1000 0101	205	133	85	1010 0101	245	165	A5

Message: 530 ml. benzene

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	5	0011 0101	65	53	35	0011 0101	65	53	35	1011 0101	265	181	B5
2	3	0011 0011	63	51	33	0011 0011	63	51	33	1011 0011	263	179	B3
3	0	0011 0000	60	48	30	0011 0000	60	48	30	1011 0000	260	176	B0
4		0010 0000	40	32	20	1010 0000	240	160	A0	0010 0000	40	32	20
5	m	0110 1101	155	109	6D	1110 1101	355	237	ED	0110 1101	155	109	6D
6	l	0110 1100	154	108	6C	0110 1100	154	108	6C	1110 1100	354	236	EC
7	.	0010 1110	56	46	2E	0010 1110	56	46	2E	1010 1110	256	174	AE
8		0010 0000	40	32	20	1010 0000	240	160	A0	0010 0000	40	32	20
9	b	0110 0010	142	98	62	1110 0010	342	226	E2	0110 0010	142	98	62
10	e	0110 0101	145	101	65	0110 0101	145	101	65	1110 0101	345	229	E5
11	n	0110 1110	156	110	6E	1110 1110	356	238	EE	0110 1110	156	110	6E
12	z	0111 1010	172	122	7A	1111 1010	372	250	FA	0111 1010	172	122	7A
13	e	0110 0101	145	101	65	0110 0101	145	101	65	1110 0101	345	229	E5
14	n	0110 1110	156	110	6E	1110 1110	356	238	EE	0110 1110	156	110	6E
15	e	0110 0101	145	101	65	0110 0101	145	101	65	1110 0101	345	229	E5

LRC (Even)	0110 0100	144	100	64	1110 0100	344	228	E4	0110 0100	144	100	64
LRC (Odd)	1001 1011	233	155	9B	0001 1011	33	27	1B	1001 1011	233	155	9B
Checksum	1100 0110	306	198	C6	0100 0110	106	70	46	1100 0110	306	198	C6
CRC	1100 0101	305	197	C5	0110 0101	145	101	65	0110 0101	145	101	65

## Aspects of Digital Communication Chapter Error Control

Message: 350 ml. benzene

Ind	Char	No Parity				Even Parity				Odd Parity						
		Binary		Oct	Dec	Hex	Bin		Oct	Dec	Hex	Bin		Oct	Dec	Hex
1	3	0011	0011	63	51	33	0011	0011	63	51	33	1011	0011	263	179	B3
2	5	0011	0101	65	53	35	0011	0101	65	53	35	1011	0101	265	181	B5
3	0	0011	0000	60	48	30	0011	0000	60	48	30	1011	0000	260	176	B0
4		0010	0000	40	32	20	1010	0000	240	160	A0	0010	0000	40	32	20
5	m	0110	1101	155	109	6D	1110	1101	355	237	ED	0110	1101	155	109	6D
6	l	0110	1100	154	108	6C	0110	1100	154	108	6C	1110	1100	354	236	EC
7	.	0010	1110	56	46	2E	0010	1110	56	46	2E	1010	1110	256	174	AE
8		0010	0000	40	32	20	1010	0000	240	160	A0	0010	0000	40	32	20
9	b	0110	0010	142	98	62	1110	0010	342	226	E2	0110	0010	142	98	62
10	e	0110	0101	145	101	65	0110	0101	145	101	65	1110	0101	345	229	E5
11	n	0110	1110	156	110	6E	1110	1110	356	238	EE	0110	1110	156	110	6E
12	z	0111	1010	172	122	7A	1111	1010	372	250	FA	0111	1010	172	122	7A
13	e	0110	0101	145	101	65	0110	0101	145	101	65	1110	0101	345	229	E5
14	n	0110	1110	156	110	6E	1110	1110	356	238	EE	0110	1110	156	110	6E
15	e	0110	0101	145	101	65	0110	0101	145	101	65	1110	0101	345	229	E5

LRC (Even)	0110	0100	144	100	64	1110	0100	344	228	E4	0110	0100	144	100	64
LRC (Odd)	1001	1011	233	155	9B	0001	1011	33	27	1B	1001	1011	233	155	9B
Checksum	1100	0110	306	198	C6	0100	0110	106	70	46	1100	0110	306	198	C6
CRC	0000	0101	5	5	5	1010	0101	245	165	A5	1010	0101	245	165	A5

## Aspects of Digital Communication

### Chapter Error Control

Message: !"#%&'()\*+,-./0123456789:;<=>?

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1		0010 0000	40	32	20	1010 0000	240	160	A0	0010 0000	40	32	20
2	!	0010 0001	41	33	21	0010 0001	41	33	21	1010 0001	241	161	A1
3	"	0010 0010	42	34	22	0010 0010	42	34	22	1010 0010	242	162	A2
4	#	0010 0011	43	35	23	1010 0011	243	163	A3	0010 0011	43	35	23
5	\$	0010 0100	44	36	24	0010 0100	44	36	24	1010 0100	244	164	A4
6	%	0010 0101	45	37	25	1010 0101	245	165	A5	0010 0101	45	37	25
7	&	0010 0110	46	38	26	1010 0110	246	166	A6	0010 0110	46	38	26
8	'	0010 0111	47	39	27	0010 0111	47	39	27	1010 0111	247	167	A7
9	(	0010 1000	50	40	28	0010 1000	50	40	28	1010 1000	250	168	A8
10	)	0010 1001	51	41	29	1010 1001	251	169	A9	0010 1001	51	41	29
11	*	0010 1010	52	42	2A	1010 1010	252	170	AA	0010 1010	52	42	2A
12	+	0010 1011	53	43	2B	0010 1011	53	43	2B	1010 1011	253	171	AB
13	,	0010 1100	54	44	2C	1010 1100	254	172	AC	0010 1100	54	44	2C
14	-	0010 1101	55	45	2D	0010 1101	55	45	2D	1010 1101	255	173	AD
15	.	0010 1110	56	46	2E	0010 1110	56	46	2E	1010 1110	256	174	AE
16	/	0010 1111	57	47	2F	1010 1111	257	175	AF	0010 1111	57	47	2F
17	0	0011 0000	60	48	30	0011 0000	60	48	30	1011 0000	260	176	B0
18	1	0011 0001	61	49	31	1011 0001	261	177	B1	0011 0001	61	49	31
19	2	0011 0010	62	50	32	1011 0010	262	178	B2	0011 0010	62	50	32
20	3	0011 0011	63	51	33	0011 0011	63	51	33	1011 0011	263	179	B3
21	4	0011 0100	64	52	34	1011 0100	264	180	B4	0011 0100	64	52	34
22	5	0011 0101	65	53	35	0011 0101	65	53	35	1011 0101	265	181	B5
23	6	0011 0110	66	54	36	0011 0110	66	54	36	1011 0110	266	182	B6
24	7	0011 0111	67	55	37	1011 0111	267	183	B7	0011 0111	67	55	37
25	8	0011 1000	70	56	38	1011 1000	270	184	B8	0011 1000	70	56	38
26	9	0011 1001	71	57	39	0011 1001	71	57	39	1011 1001	271	185	B9
27	:	0011 1010	72	58	3A	0011 1010	72	58	3A	1011 1010	272	186	BA
28	;	0011 1011	73	59	3B	1011 1011	273	187	BB	0011 1011	73	59	3B
29	<	0011 1100	74	60	3C	0011 1100	74	60	3C	1011 1100	274	188	BC
30	=	0011 1101	75	61	3D	1011 1101	275	189	BD	0011 1101	75	61	3D
31	>	0011 1110	76	62	3E	1011 1110	276	190	BE	0011 1110	76	62	3E
32	?	0011 1111	77	63	3F	0011 1111	77	63	3F	1011 1111	277	191	BF

LRC (Even)	0000 0000	0	0	0	0000 0000	0	0	0	0000 0000	0	0	0
LRC (Odd)	1111 1111	377	255	FF	1111 1111	377	255	FF	1111 1111	377	255	FF
Checksum	1111 0000	360	240	F0	1111 0000	360	240	F0	1111 0000	360	240	F0
CRC	1110 1111	357	239	EF	0110 1111	157	111	6F	0011 1111	77	63	3F

## Aspects of Digital Communication

### Chapter Error Control

Message: @ABCDEFGHIJKLMN OPQRSTUVWXYZ[\]^\_

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	@	0100 0000	100	64	40	1100 0000	300	192	C0	0100 0000	100	64	40
2	A	0100 0001	101	65	41	0100 0001	101	65	41	1100 0001	301	193	C1
3	B	0100 0010	102	66	42	0100 0010	102	66	42	1100 0010	302	194	C2
4	C	0100 0011	103	67	43	1100 0011	303	195	C3	0100 0011	103	67	43
5	D	0100 0100	104	68	44	0100 0100	104	68	44	1100 0100	304	196	C4
6	E	0100 0101	105	69	45	1100 0101	305	197	C5	0100 0101	105	69	45
7	F	0100 0110	106	70	46	1100 0110	306	198	C6	0100 0110	106	70	46
8	G	0100 0111	107	71	47	0100 0111	107	71	47	1100 0111	307	199	C7
9	H	0100 1000	110	72	48	0100 1000	110	72	48	1100 1000	310	200	C8
10	I	0100 1001	111	73	49	1100 1001	311	201	C9	0100 1001	111	73	49
11	J	0100 1010	112	74	4A	1100 1010	312	202	CA	0100 1010	112	74	4A
12	K	0100 1011	113	75	4B	0100 1011	113	75	4B	1100 1011	313	203	CB
13	L	0100 1100	114	76	4C	1100 1100	314	204	CC	0100 1100	114	76	4C
14	M	0100 1101	115	77	4D	0100 1101	115	77	4D	1100 1101	315	205	CD
15	N	0100 1110	116	78	4E	0100 1110	116	78	4E	1100 1110	316	206	CE
16	O	0100 1111	117	79	4F	1100 1111	317	207	CF	0100 1111	117	79	4F
17	P	0101 0000	120	80	50	0101 0000	120	80	50	1101 0000	320	208	D0
18	Q	0101 0001	121	81	51	1101 0001	321	209	D1	0101 0001	121	81	51
19	R	0101 0010	122	82	52	1101 0010	322	210	D2	0101 0010	122	82	52
20	S	0101 0011	123	83	53	0101 0011	123	83	53	1101 0011	323	211	D3
21	T	0101 0100	124	84	54	1101 0100	324	212	D4	0101 0100	124	84	54
22	U	0101 0101	125	85	55	0101 0101	125	85	55	1101 0101	325	213	D5
23	V	0101 0110	126	86	56	0101 0110	126	86	56	1101 0110	326	214	D6
24	W	0101 0111	127	87	57	1101 0111	327	215	D7	0101 0111	127	87	57
25	X	0101 1000	130	88	58	1101 1000	330	216	D8	0101 1000	130	88	58
26	Y	0101 1001	131	89	59	0101 1001	131	89	59	1101 1001	331	217	D9
27	Z	0101 1010	132	90	5A	0101 1010	132	90	5A	1101 1010	332	218	DA
28	[	0101 1011	133	91	5B	1101 1011	333	219	DB	0101 1011	133	91	5B
29	\	0101 1100	134	92	5C	0101 1100	134	92	5C	1101 1100	334	220	DC
30	]	0101 1101	135	93	5D	1101 1101	335	221	DD	0101 1101	135	93	5D
31	^	0101 1110	136	94	5E	1101 1110	336	222	DE	0101 1110	136	94	5E
32	_	0101 1111	137	95	5F	0101 1111	137	95	5F	1101 1111	337	223	DF

LRC (Even)	0000 0000	0	0	0	0000 0000	0	0	0	0000 0000	0	0	0
LRC (Odd)	1111 1111	377	255	FF	1111 1111	377	255	FF	1111 1111	377	255	FF
Checksum	1111 0000	360	240	F0	1111 0000	360	240	F0	1111 0000	360	240	F0
CRC	0111 1111	177	127	7F	1111 1111	377	255	FF	1010 1111	257	175	AF

## Aspects of Digital Communication Chapter Error Control

Message: `abcdefghijklmnopqrstuvwxyz{|}~

Ind	Char	No Parity				Even Parity				Odd Parity			
		Binary	Oct	Dec	Hex	Bin	Oct	Dec	Hex	Bin	Oct	Dec	Hex
1	`	0110 0000	140	96	60	0110 0000	140	96	60	1110 0000	340	224	E0
2	a	0110 0001	141	97	61	1110 0001	341	225	E1	0110 0001	141	97	61
3	b	0110 0010	142	98	62	1110 0010	342	226	E2	0110 0010	142	98	62
4	c	0110 0011	143	99	63	0110 0011	143	99	63	1110 0011	343	227	E3
5	d	0110 0100	144	100	64	1110 0100	344	228	E4	0110 0100	144	100	64
6	e	0110 0101	145	101	65	0110 0101	145	101	65	1110 0101	345	229	E5
7	f	0110 0110	146	102	66	0110 0110	146	102	66	1110 0110	346	230	E6
8	g	0110 0111	147	103	67	1110 0111	347	231	E7	0110 0111	147	103	67
9	h	0110 1000	150	104	68	1110 1000	350	232	E8	0110 1000	150	104	68
10	i	0110 1001	151	105	69	0110 1001	151	105	69	1110 1001	351	233	E9
11	j	0110 1010	152	106	6A	0110 1010	152	106	6A	1110 1010	352	234	EA
12	k	0110 1011	153	107	6B	1110 1011	353	235	EB	0110 1011	153	107	6B
13	l	0110 1100	154	108	6C	0110 1100	154	108	6C	1110 1100	354	236	EC
14	m	0110 1101	155	109	6D	1110 1101	355	237	ED	0110 1101	155	109	6D
15	n	0110 1110	156	110	6E	1110 1110	356	238	EE	0110 1110	156	110	6E
16	o	0110 1111	157	111	6F	0110 1111	157	111	6F	1110 1111	357	239	EF
17	p	0111 0000	160	112	70	1111 0000	360	240	F0	0111 0000	160	112	70
18	q	0111 0001	161	113	71	0111 0001	161	113	71	1111 0001	361	241	F1
19	r	0111 0010	162	114	72	0111 0010	162	114	72	1111 0010	362	242	F2
20	s	0111 0011	163	115	73	1111 0011	363	243	F3	0111 0011	163	115	73
21	t	0111 0100	164	116	74	0111 0100	164	116	74	1111 0100	364	244	F4
22	u	0111 0101	165	117	75	1111 0101	365	245	F5	0111 0101	165	117	75
23	v	0111 0110	166	118	76	1111 0110	366	246	F6	0111 0110	166	118	76
24	w	0111 0111	167	119	77	0111 0111	167	119	77	1111 0111	367	247	F7
25	x	0111 1000	170	120	78	0111 1000	170	120	78	1111 1000	370	248	F8
26	y	0111 1001	171	121	79	1111 1001	371	249	F9	0111 1001	171	121	79
27	z	0111 1010	172	122	7A	1111 1010	372	250	FA	0111 1010	172	122	7A
28	{	0111 1011	173	123	7B	0111 1011	173	123	7B	1111 1011	373	251	FB
29		0111 1100	174	124	7C	1111 1100	374	252	FC	0111 1100	174	124	7C
30	}	0111 1101	175	125	7D	0111 1101	175	125	7D	1111 1101	375	253	FD
31	~	0111 1110	176	126	7E	0111 1110	176	126	7E	1111 1110	376	254	FE

LRC (Even)	0111 1111	177	127	7F	1111 1111	377	255	FF	0111 1111	177	127	7F
LRC (Odd)	1000 0000	200	128	80	0000 0000	0	0	0	1000 0000	200	128	80
Checksum	0111 0001	161	113	71	1111 0001	361	241	F1	0111 0001	161	113	71
CRC	0101 1110	136	94	5E	0111 1110	176	126	7E	1111 1110	376	254	FE

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**Chapter 6. Elements of Digital Communication**

**6.1. ISO - OSI**

**Table 11 - ISO-OSI Model**

International Standards Organization Open Systems Interconnect Model

OSI Layer	Name	Description
1	Physical Layer	Provides a virtual pipe for passing streams of bits between any pair of nodes.
2	Data Link Layer	Uses Physical Layer bit pipe to send/receive error free frames or packets.
3	Network Layer	performs flow control and routing of packets through the network.
4	Transport Layer	Assembles/disassembles messages into packets. Multiplex multiple sessions using the same path through the network. Provide reliable end to end communication for the sessions. Provide gateways between different subnets.
5	Session Layer	Directory assistance for lower levels, helps locate the service to which the communication is to connect. Load balancing between peer servers. Deals with access rights.
6	Presentation Layer	Encryption/decryption, data compression, code conversion.
7	Application Layer	What is left. High level programs. User interfaces. User is not part of the official model.
8	<i>User</i>	Not included in the official model
9	<i>Bureaucracy</i>	Unofficial. Whatever it takes to get all parties who wish to communicate to adhere to the above seven standards.

Aspects of Digital Communication  
Chapter Elements of Digital Communication

CEMCF OSI 1 10-MAY-1992

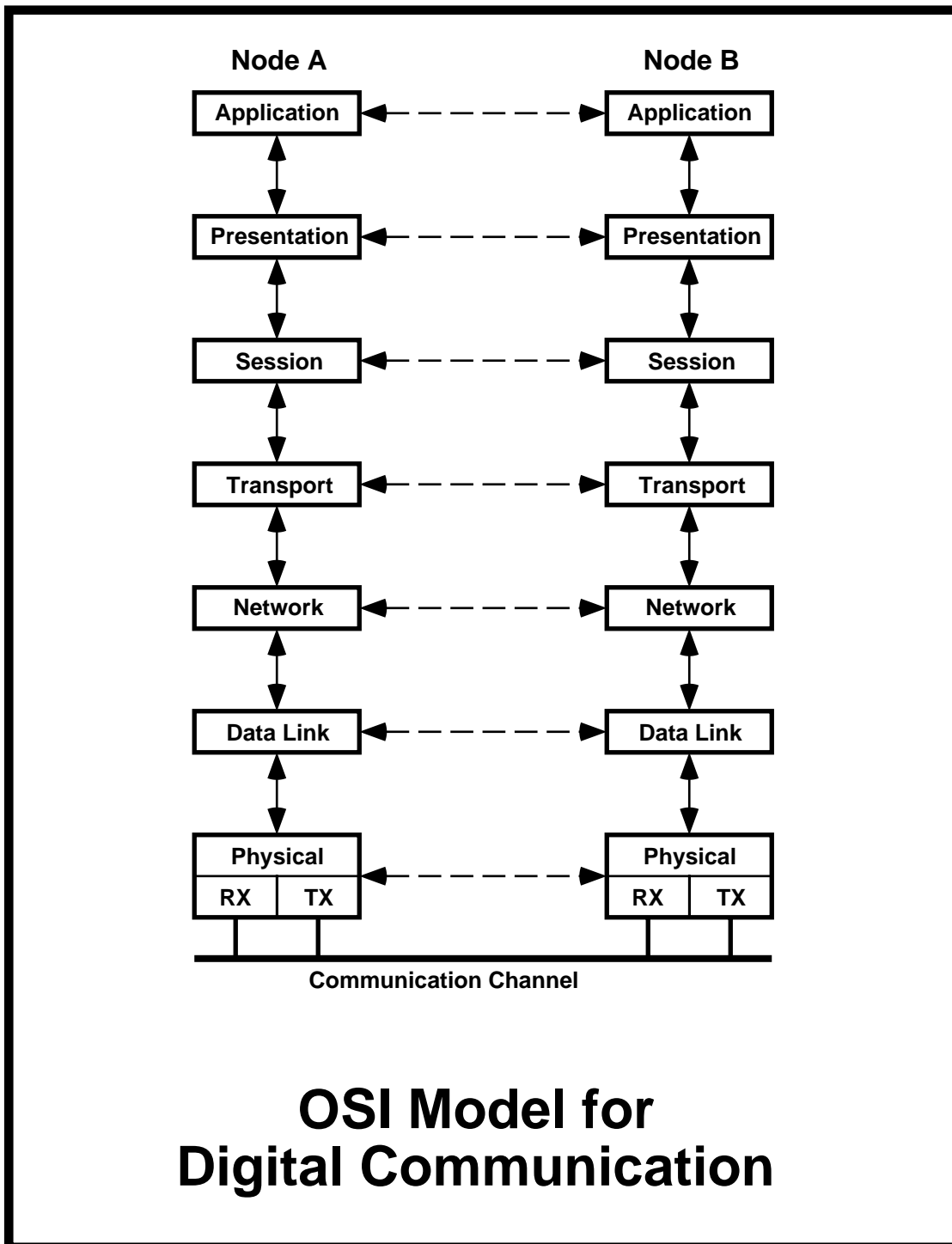


Figure 41 - OSI Model: Protocol Stacks

# Aspects of Digital Communication

## Chapter Elements of Digital Communication

CEMCF OSI 1a 19-MAY-1992

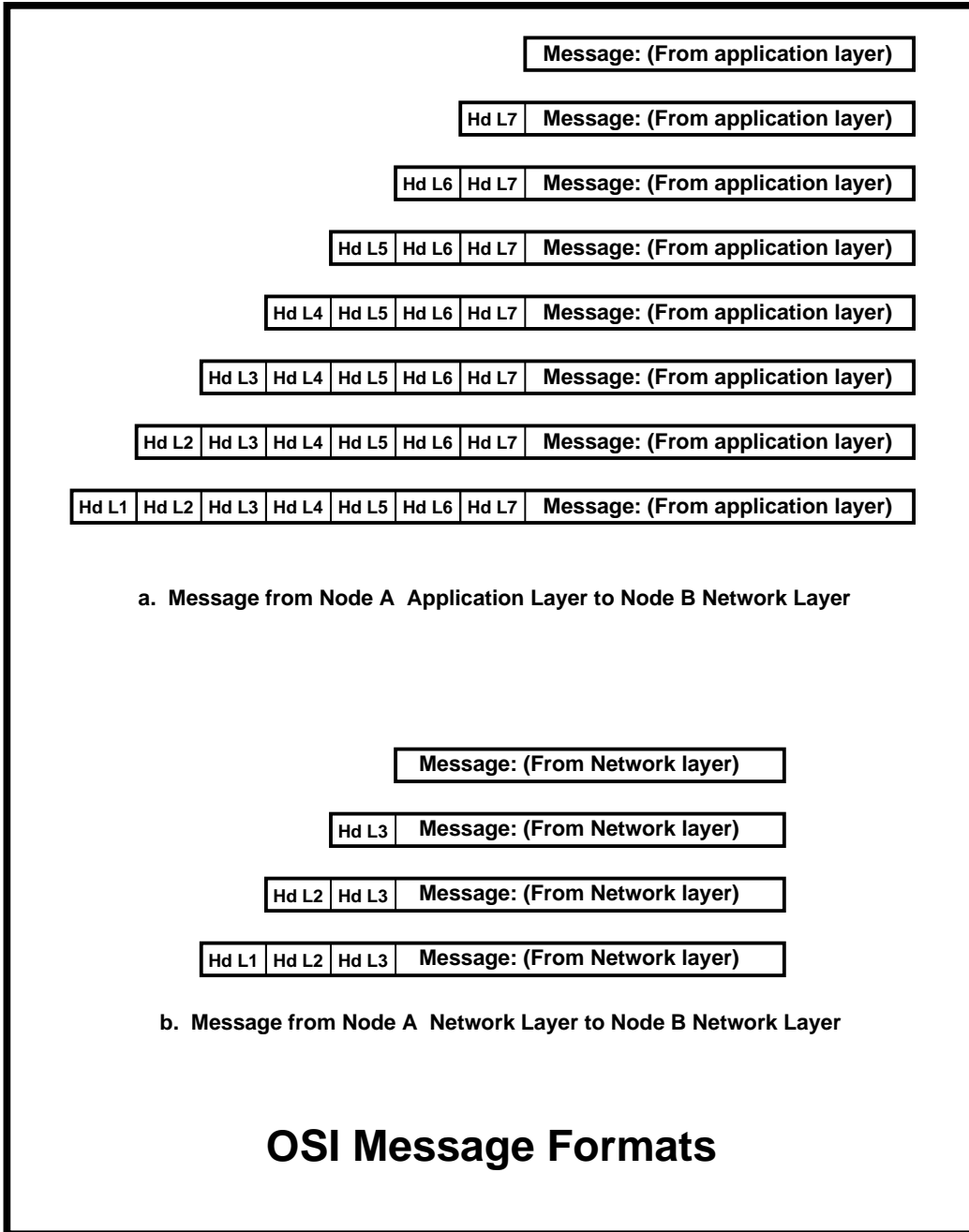
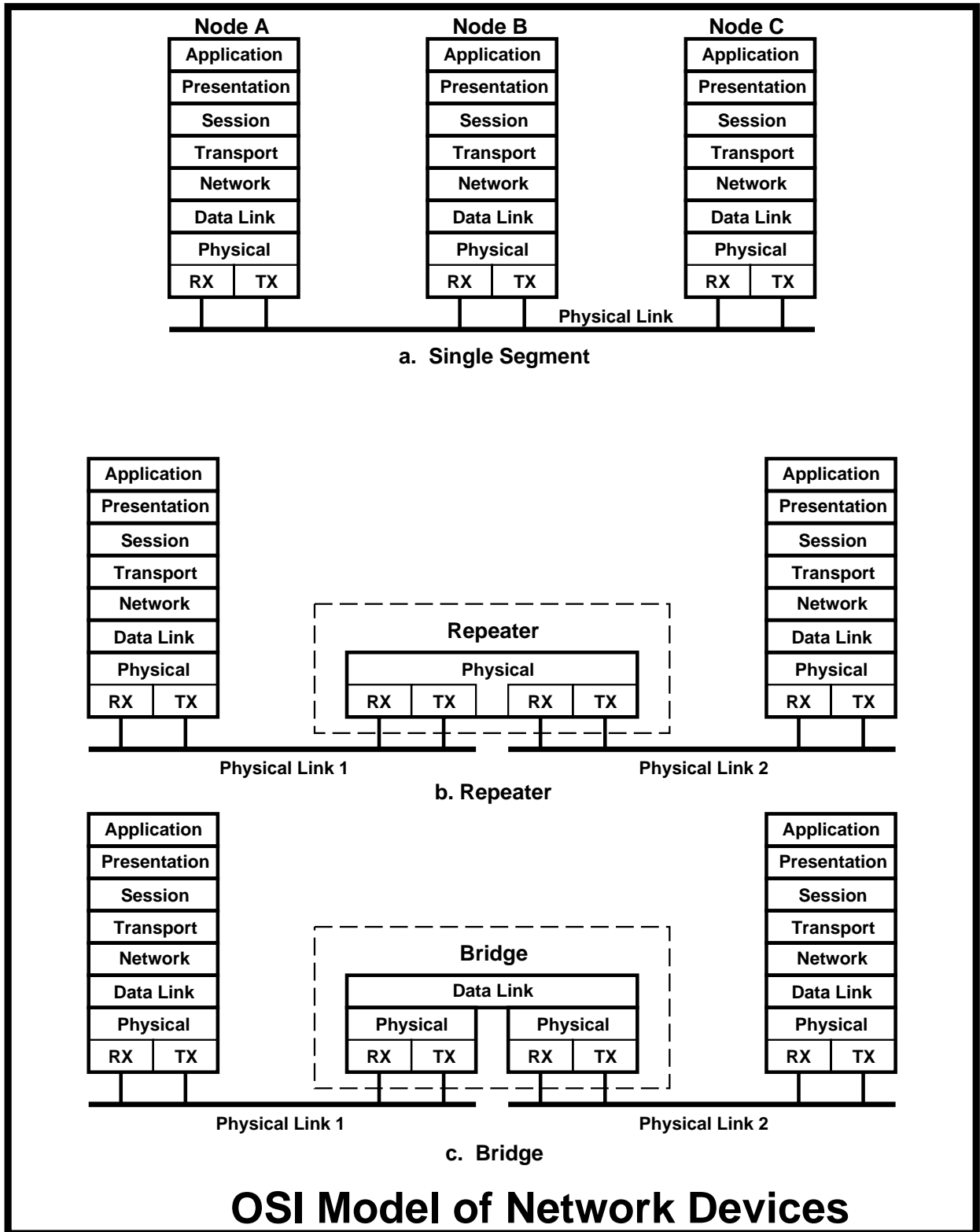


Figure 42 - OSI Message Formats

# Aspects of Digital Communication

## Chapter Elements of Digital Communication

CEMCF OSI 2 19-MAY-1992

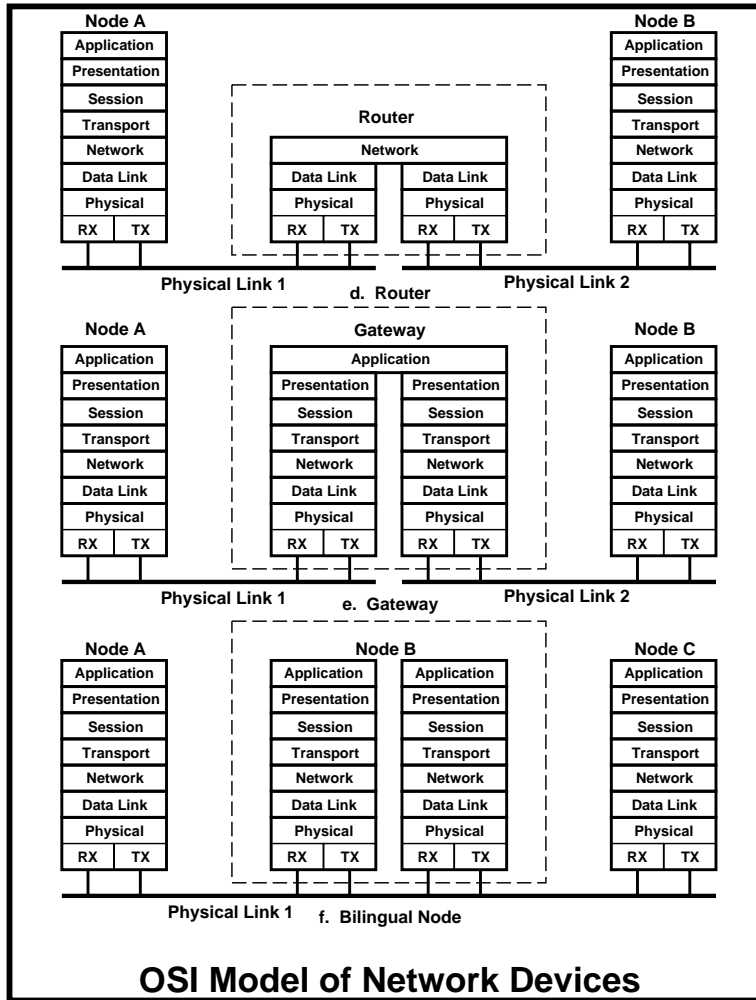


# Aspects of Digital Communication

## Chapter Elements of Digital Communication

**Figure 43 - OSI Model of Network Devices**

CEMCF OSI 3 19-MAY-1992



**Figure 44 - OSI Model of Network Devices Cont.**

# Aspects of Digital Communication

## Chapter Elements of Digital Communication

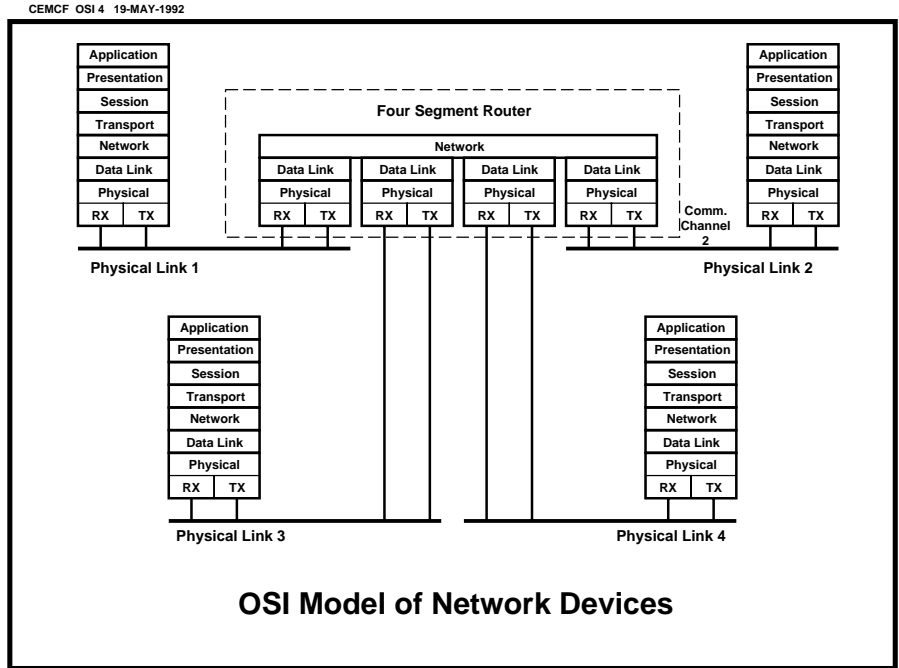


Figure 45 - OSI Model of Network Devices Cont.

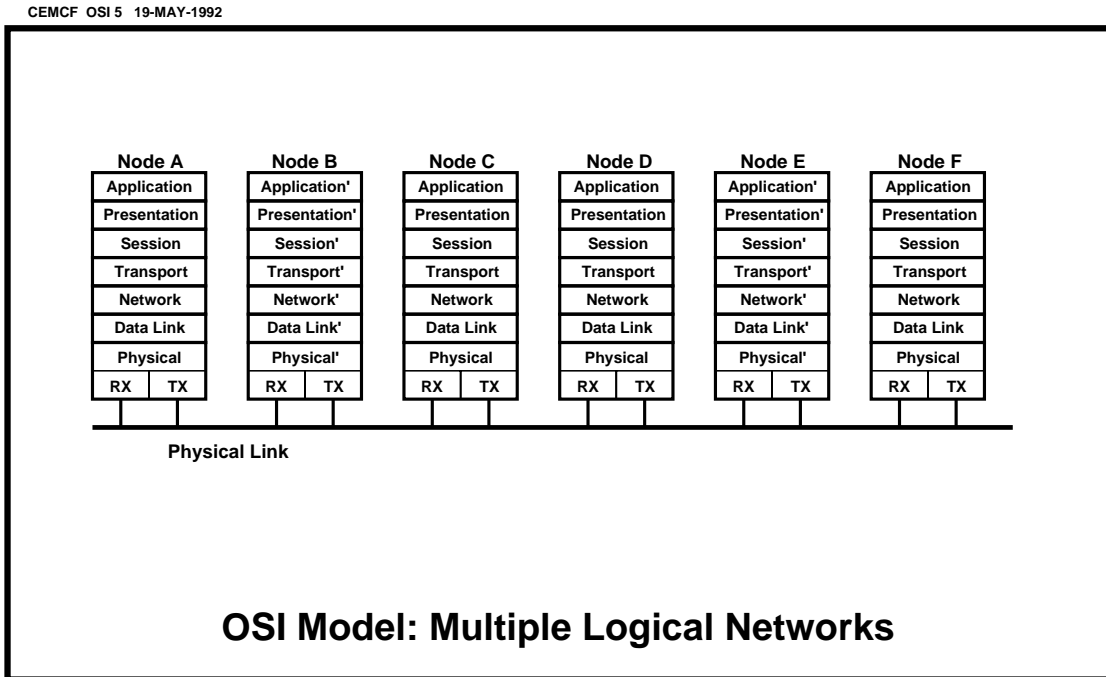


Figure 46 - OSI Model: Multiple Logical Networks

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

CEMCF OSI 6 19-MAY-1992

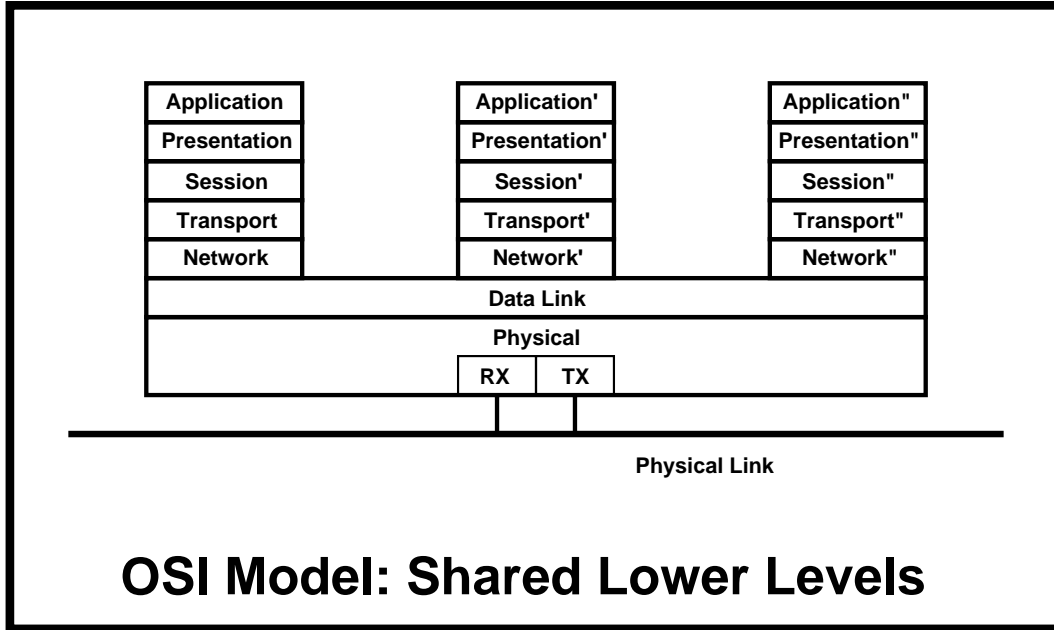


Figure 47 - OSI Model: Shared Lower Levels

CEMCF OSI 7 19-MAY-1992

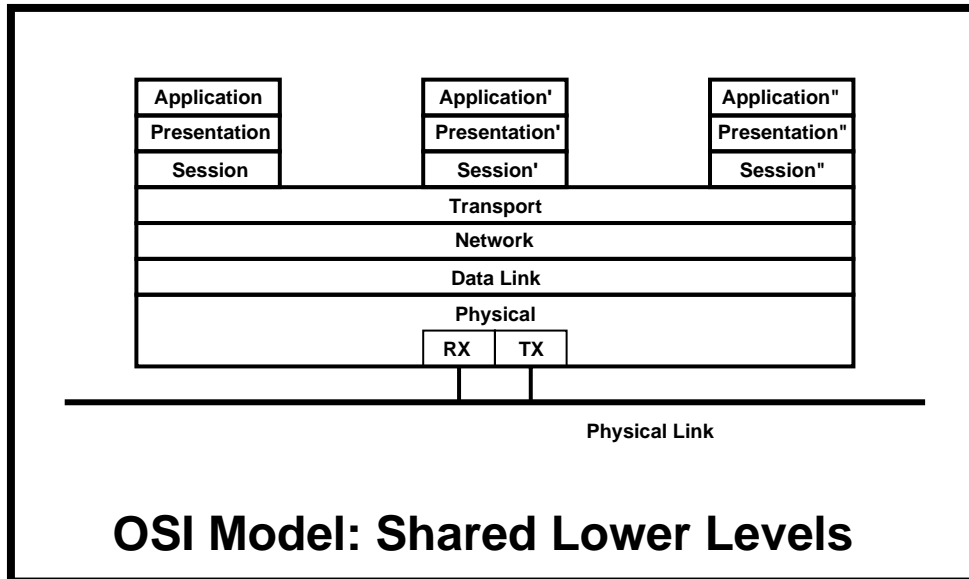


Figure 48 - OSI Model: Shared Lower Levels Cont.

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**6.2. Physical Layer**

**6.2.1. Parallel**

This category is not often considered in formal discussions of communication, mostly because there is very little standardization and the distances possible are too short for the majority of communication links.

1. Computer bus
  - 1.1. Unibus
  - 1.2. Q-bus
  - 1.3. S-100
  - 1.4. VME
  - 1.5. Multibus (Intel)
  - 1.6. IBM PC Bus (PC, ISA(AT), EISA, Microchannel, Vesa, Local, PCI)
  - 1.7. Nu Bus
  - 1.8. SCSI
  - 1.9. PCI
4. Parallel Communication links (DRV-11, etc.)
5. CAMAC
6. IEEE 488 Interface Bus [Hewlett Packard's Instrument bus (HP-IB)]

**6.2.2. Serial - Point to Point Links**

1. Communication Channels - Transmitter Interface / Receiver Interface
  - 1.1. Copper, Current Loop - Current switch/solenoid, optoisolator, or other current sensors
  - 1.2. Copper Twisted Pairs, Voltage - line driver/line receiver, optoisolator
    - 1.2.1. Interface Standard: RS-232C

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

- 1.2.2. Interface Standard: RS-442A
- 1.2.3. Interface Standard: RS-443A
- 1.2.4. Interface Standard: RS-449
- 1.3. Copper, Coax, Voltage - line driver/line receiver, optoisolator
- 1.4. Copper, DDD network (Phone Company) - "Mo"/"dem"
- 1.5. Fiber optic - Led, Laser/Photodiode
- 1.6. Infrared, in air - Led, Laser/Photodiode
- 1.7. Visible, in air - Led, Laser/Photodiode
- 1.8. Microwave, radiowave - transmitter/receiver
- 2. Organization
  - 2.1. Simplex
  - 2.2. Half duplex
  - 2.3. Full duplex
- 3. Device Implementation
  - 3.1. Physical Controller Functions
    - 3.1.1. Baud rate generator
    - 3.1.2. Parallel/serial serial/parallel converter
    - 3.1.3. Modem control logic
  - 3.2. Construction
    - 3.2.1. Discrete components (Obsolete)
    - 3.2.2. General purpose logic (Obsolete)
    - 3.2.3. UART
    - 3.2.4. USART and other high function IC's

**6.2.2.1. RS-232 Details**

**Table 12 - RS-232 (Revision C) - Signal Definitions**

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

RS-232 (Revision C) - Electrical Industry Association (EIA)  
Standard for Interface between  
Data Terminal and Data Communication Equipment

Signal Definitions (with assignments for DB-25 Connector)

PIN	EIA	CCITT	Description	Abbrev	DTE ↔ DCE
			Grounds		↔
1	AA	101	Protective ground	PG	G
7	AB	102	Signal ground/Common return	SG	G
			Data Lines		
2	BA	103	Transmitted data	TD	→
3	BB	104	Received Data	RD	←
			Modem Control		
4	CA	105	Request to Send	RTS	→
5	CB	106	Clear to Send	CTS	←
6	CC	107	Data Set Ready	DSR	←
20	CD	108.2	Data Terminal Ready	DTR	→
22	CE	125	Ring Indicator	RI	←
8	CF	109	Received Line Signal Detector (Carrier Detect)	CD	←
21	CG	110	Signal Quality Detector		←
23	CH	111	Data Signal Rate Selector (DTE)		→
23	CI	112	Data Signal Rate Selector (DCE)		←
			Timing (Synchronous only)		
24	DA	113	Transmitter Signal Element Timing (DTE)		→
15	DB	114	Transmitter Signal Element Timing (DCE)		←
17	DD	115	Receiver Signal Element timing (DCE)		←
14	SBA	118	Secondary Transmitted Data		→
16	SBB	119	Secondary Received Data		←
			Data (Synchronous only)		
14	SBA	118	Secondary Transmitted Data		→
16	SBB	119	Secondary Received Data		←
			Modem Control (Synchronous only)		
19	SCA	120	Secondary Request to Send		→
13	SCB	121	Secondary Clear to Send		←
12	SCF	122	Secondary Received Line Signal Detector		←

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

Pin            Signal  
 9,10          Reserved for testing  
 11, 18, 25   Unassigned

**Table 13 - Pin Assignments for DB-9 (Zenith, IBM)**

DB-9	DB-25	EIA	Signal
1	8	CF	Carrier Detect (CD)
2	3	BB	Receive Data (RD)
3	2	BA	Transmit Data (TD)
4	20	CD	Data Terminal Ready (DTR)
5	1,7	AA,AB	Ground
6	6	CC	Data Set Ready (DSR)
7	4	CA	Request to Send (RTS)
8	5	CB	Clear to Send (CTS)
9	22	CE	Ring Indicate (RI)

DCE    Digital Communication equipment - modems  
 DTE    Digital Terminal Equipment - Terminals, computers, printers

**Table 14 - RS-232 (Revision C) - Voltage Levels**

Voltage Levels:
$15V < hi < 5V$
$-5V < lo < -15V$

## Aspects of Digital Communication

### Chapter Elements of Digital Communication

**Table 15 - RS-232 (Revision C) - Brief Signal Definitions**

Signal	Name	Description
CA	Request to Send	(From DTE) Full Duplex: Indicates the DCE should prepare to transmit data. Half Duplex: ON state Indicates that the DCE should prepare to transmit data to the communication link. OFF state Indicates that the DCE should prepare to receive data from the communication link.
CB	Clear to Send	(From DCE) When ON and CA, CC, and CD are ON, indicates that data will be transmitted from BA to the communication link.
CC	Data Set Ready	(From DCE) Local data set (modem) is connected to the communication link and ready to operate.
CD	Data Terminal Ready	(From DTE) Data terminal is ready to receive or transmit data.

#### 6.2.2.2. Connectors

Figure 2 RS-232C - Connectors

#### 6.2.2.3. Typical Practices

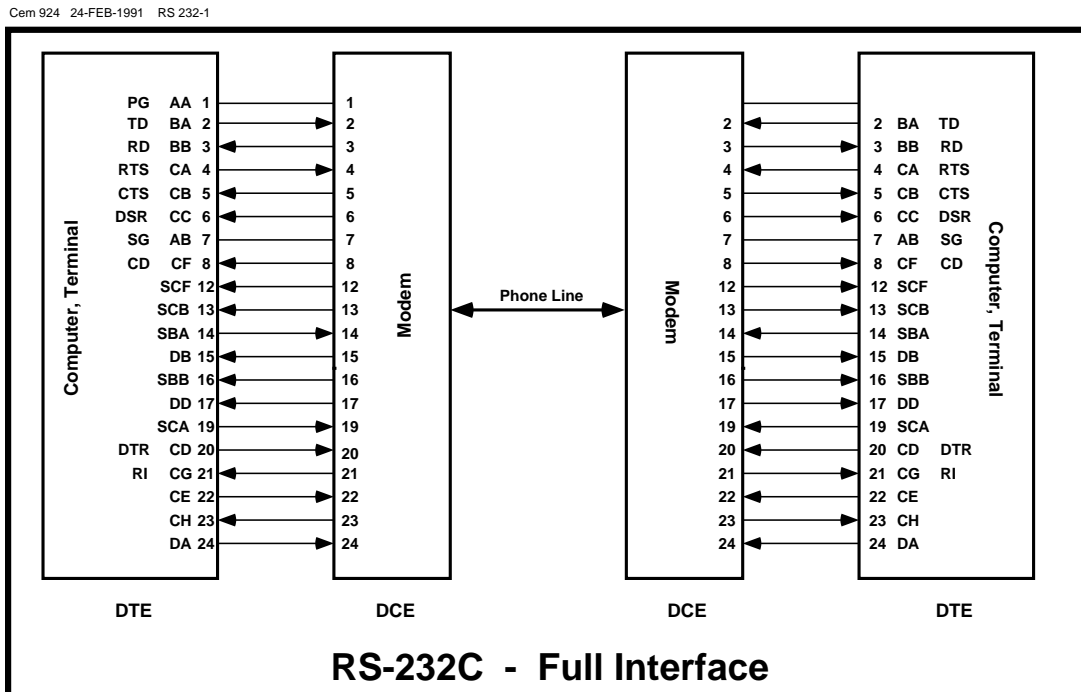


Figure 49 - RS-232C - Full Implementation

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

Cem 924 24-FEB-1991 RS 232-2

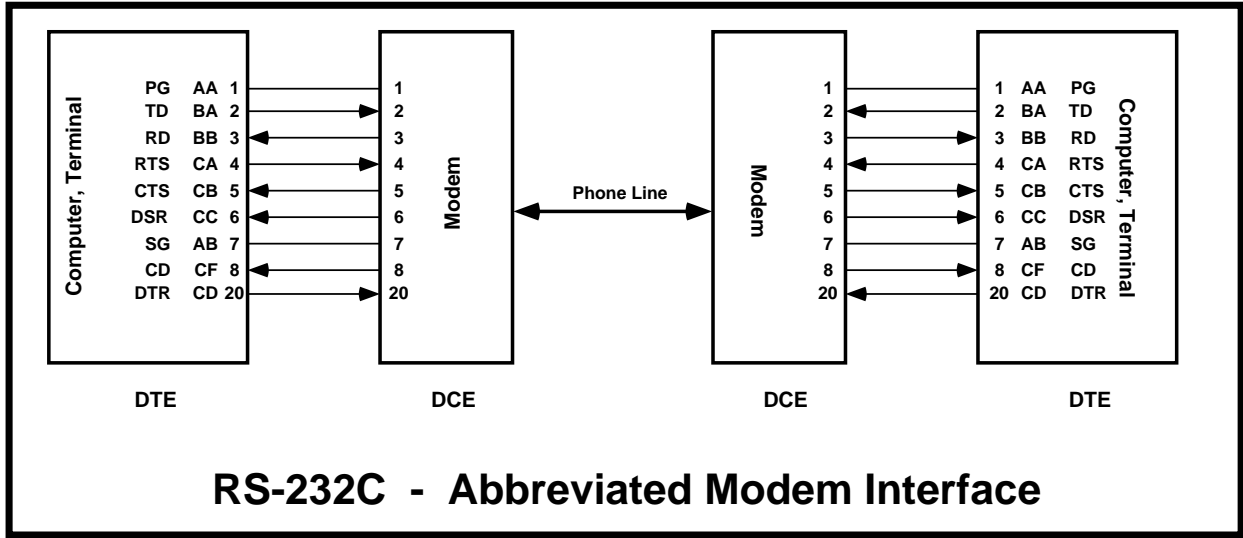


Figure 50 - RS-232C - Typical Modem Implementation

Cem 924 RS 232-3 23-FEB-93

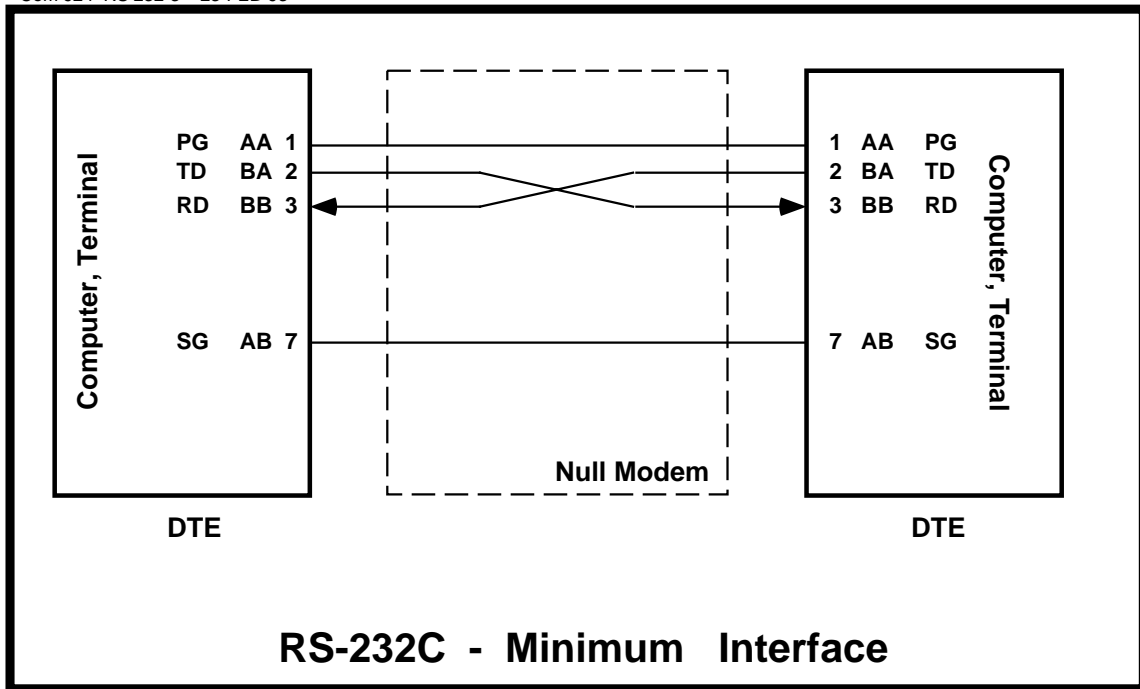


Figure 51 - RS-232C - Simple Terminal Implementation

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

Software Flow Control: XON/XOFF or ETX/STX

Cem 924 RS 232-4 23-MAR-1993

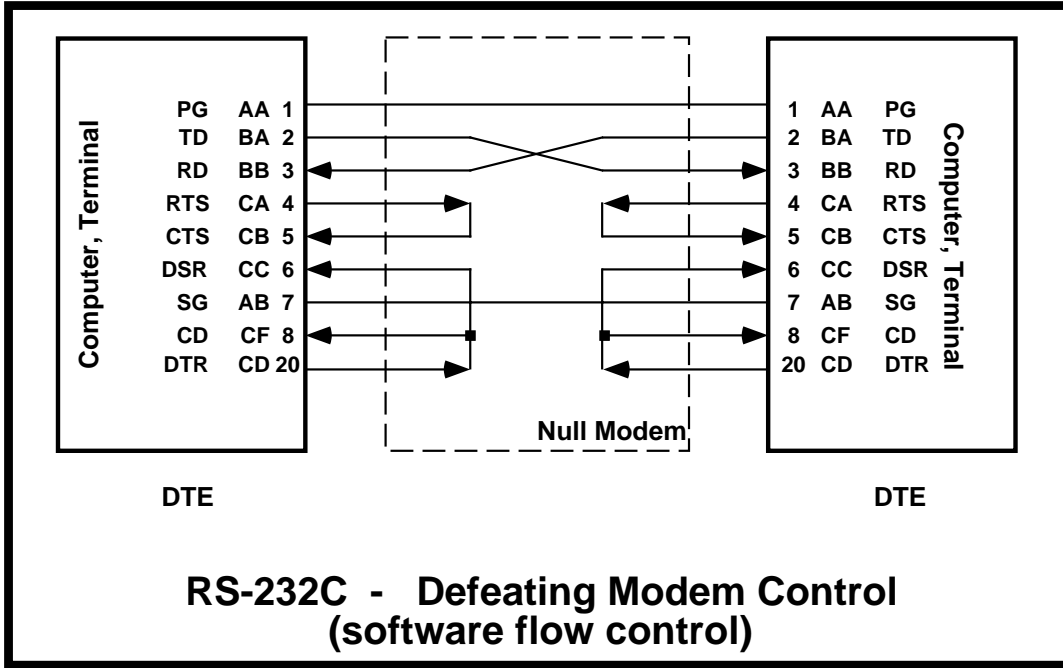


Figure 52 - RS-232C - Defeating Modem Control (Software flow control)

Software Flow Control: XON/XOFF or ETX/STX

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

Cem 924 RS 232-5 23-MAR-1993

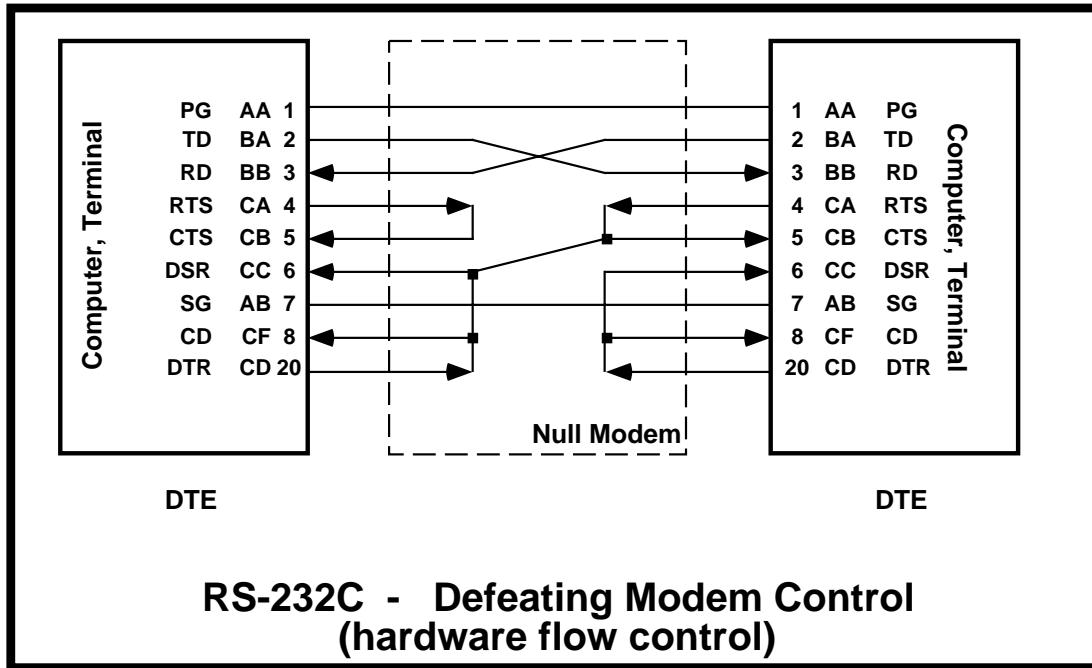


Figure 53 - RS-232C - Defeating Modem Control (Hardware flow control)

**6.2.2.4. Other methods**

As an example, the Okidata Microline 92 Printer user's manual indicates at least 10 methods with various combinations of the modem control signals that can be used for flow control between two devices.

**6.2.2.5. Transfer Times**

The two tables included in this section contain the time required to transfer various volumes of information via asynchronous serial communication as a function of the communication rate. This information can be used to estimate the feasibility of using a particular transfer rate in a particular application, e.g. down line loading a floppy full of information at the beginning of a class hour. The tables are based on the assumption that there is no dead time between the characters and the only overhead is the start and stop bits. These very unrealistic assumptions lead to the theoretical lower limit of transfer times. Actual transfer times for a particular environment could easily be twice as long.

Table 16 contains the shortest possible times for various volumes of information characteristic of graphics displays. Column 1(BAUD) gives the transfer rate in expressed in baud or bits per second. Column 2(CPS) gives the transfer rate in characters per second. This is based on the assumption of one start bit and one stop bit per character and

## **Aspects of Digital Communication**

### **Chapter Elements of Digital Communication**

no dead time between frames. Column 3(LPM) gives the transfer rate in lines per minute. This rate is based on 135 characters per line which is characteristic of many line printers. Column 4(PPM) gives the transfer rate in pages per minute and assumes a page consists of 60 lines of 70 characters. Notice that the transfer rates are the same for the four columns, but the units are different. Thus, 9600 bits per seconds corresponds to 426.67 lines per minute and also to 13.71 pages per minute. The remaining columns give the time required to transfer the volume of information at the head of the column. Table 16 shows the times to transfer a screen full of image. 24x80x8 represents the information to represent a simple alphanumeric screen containing 24 lines of 80 characters each represented by one byte. The remaining columns represent displays that are n pixels per line by m lines by the number of bits used to store the intensity/color of each pixel.

Table 17 contains the shortest possible times required to transfer various volumes of information characteristic of disk storage. Note that 363 K, 730K, and 1.4M correspond to the size of the various floppy disks common at this time.

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**Table 16 - Transfer times for Displays**

Transfer Rate				Transfer Time for Indicated Displays				
BAUD	CPS	LPM	PPM	Alpha	MGA	VGA	SVGA(Enh.)	Titan
				24 x 80 x 8	720 x 350 x 1	720 x 400 x 16	1024 x 768 x 8	1280 x 1024 x 32
100	10	4.44	0.14	3.2 mn	52.5 mn	16 hr	21.83 hr	6.07 dy
300	30	13.33	0.43	1.07 mn	17.5 mn	5.33 hr	7.28 hr	2.02 dy
1200	120	53.33	1.71	16 sc	4.38 mn	1.33 hr	1.82 hr	12.14 hr
1400	140	62.22	2	13.71 sc	3.75 mn	1.14 hr	1.56 hr	10.4 hr
2800	280	124.44	4	6.86 sc	1.88 mn	34.29 mn	46.79 mn	5.2 hr
3375	337.5	150	4.82	5.69 sc	1.56 mn	28.44 mn	38.81 mn	4.32 hr
4200	420	186.67	6	4.57 sc	1.25 mn	22.86 mn	31.19 mn	3.47 hr
4800	480	213.33	6.86	4 sc	1.09 mn	20 mn	27.29 mn	3.03 hr
6750	675	300	9.64	2.84 sc	46.67 sc	14.22 mn	19.41 mn	2.16 hr
7000	700	311.11	10	2.74 sc	45 sc	13.71 mn	18.71 mn	2.08 hr
8400	840	373.33	12	2.29 sc	37.5 sc	11.43 mn	15.6 mn	1.73 hr
9600	960	426.67	13.71	2 sc	32.81 sc	10 mn	13.65 mn	1.52 hr
11900	1190	528.89	17	1.61 sc	26.47 sc	8.07 mn	11.01 mn	1.22 hr
13500	1350	600	19.29	1.42 sc	23.33 sc	7.11 mn	9.7 mn	1.08 hr
14400	1440.00	640	20.57	1.33 sc	21.88 sc	6.67 mn	9.10 mn	1.01 hr
19200	1920	853.33	27.43	1 sc	16.41 sc	5 mn	6.82 mn	45.51 mn
38400	3840	1706.67	54.86	500 ms	8.2 sc	2.5 mn	3.41 mn	22.76 mn
56000	5600	2488.89	80	342.86 ms	5.63 sc	1.71 mn	2.34 mn	15.6 mn
100000	10000	4444.44	142.86	192 ms	3.15 sc	57.6 sc	1.31 mn	8.74 mn
1000000	100000	44444.45	1428.57	19.2 ms	315 ms	5.76 sc	7.86 sc	52.43 sc

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**Table 17 - Transfer Times for Disk Volumes**

Transfer Rate				Transfer Times for indicated number of Bytes					
Baud	CPS	LPM	PPM	66 x 80	363K	730K	1.4M	10M	100M
100	10	4.44	0.14	8.8 mn	10.08 hr	20.28 hr	1.69 dy	1.65 wk	16.53 wk
300	30	13.33	0.43	2.93 mn	3.36 hr	6.76 hr	13.5 hr	3.86 dy	5.51 wk
1200	120	53.33	1.71	44 sc	50.42 mn	1.69 hr	3.37 hr	23.15 hr	1.38 wk
3375	337.5	150	4.82	15.64 sc	17.93 mn	36.05 mn	1.2 hr	8.23 hr	3.43 dy
4200	420	186.67	6	12.57 sc	14.4 mn	28.97 mn	57.84 mn	6.61 hr	2.76 dy
4800	480	213.33	6.86	11 sc	12.6 mn	25.35 mn	50.61 mn	5.79 hr	2.41 dy
6750	675	300	9.64	7.82 sc	8.96 mn	18.02 mn	35.99 mn	4.12 hr	1.71 dy
7000	700	311.11	10	7.54 sc	8.64 mn	17.38 mn	34.71 mn	3.97 hr	1.65 dy
8400	840	373.33	12	6.29 sc	7.2 mn	14.48 mn	28.92 mn	3.31 hr	1.38 dy
9600	960	426.67	13.71	5.5 sc	6.3 mn	12.67 mn	25.31 mn	2.89 hr	1.21 dy
13500	1350	600	19.29	3.91 sc	4.48 mn	9.01 mn	18 mn	2.06 hr	20.58 hr
14400	1440.00	640	20.57	3.67 sc	4.20 mn	8.45 mn	16.87 mn	1.93 hr	19.29 hr
19200	1920	853.33	27.43	2.75 sc	3.15 mn	6.34 mn	12.65 mn	1.45 hr	14.47 hr
38400	3840	1706.67	54.86	1.38 sc	1.58 mn	3.17 mn	6.33 mn	43.4 mn	7.23 hr
56000	5600	2488.89	80	942.86 ms	1.08 mn	2.17 mn	4.34 mn	29.76 mn	4.96 hr
100000	10000	4444.44	142.86	528 ms	36.3 sc	1.22 mn	2.43 mn	16.67 mn	2.78 hr
1000000	100000	44444.45	1428.57	52.8 ms	3.63 sc	7.3 sc	14.58 sc	1.67 mn	16.67 mn

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**6.2.2.6. References**

"Data Communications, Computer Networks, and Open Systems," Fred Halsall, Addison-Wesley, 1992.

"Data Networks", Dimitri Bertsekas, Robert Gallager, Prentice-Hall, 1987.

"Technical Aspects of Data Communication", John E. MaNamara, Digital Press, 1977.

"Data Communications Handbook", Alan J. Weissberger, Signetics, 1978.

**6.2.3. Serial - Multiaccess**

1. Examples
  - 1.1. Satellite Channels
  - 1.2. Multi-drop
  - 1.3. Multitap bus
  - 1.4. Packet Radio
2. Medium Access (to communication medium) Control
  - 2.1. Carrier Sense Multiple Access with Collision Detection(CSMA/CD) (IEEE 802.3)
  - 2.2. Token Busses (IEEE 802.4)
  - 2.3. Token Rings (IEEE 802.5)

**6.3. Data Link Layer**

**6.3.1. Codes used for information exchange (character sets)**

1. ASCII - American Standard Code for Information Interchange
2. BCDIC - Binary Coded Decimal Interchange Code (Obsolete)
3. EBCDIC - Extended Binary Coded Decimal Interchange Code
4. Hollerith (punched cards) (Obsolete)
5. Baudot
6. CDC Display Code
7. Morse

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**6.3.2. Framing**

1. Asynchronous Characters
2. Fixed Length packets
3. Byte Count
4. Byte oriented Packets
5. Bit Oriented Packets

**6.4. Network Layer**

**6.4.1. Geographical Classification**

1. Local Area Networks (LAN)
2. Extended Local Area Networks
3. Campus Wide Networks
4. Metropolitan Area Networks (MAN)
5. Wide Area Networks (WAN) - Usually involve phone companies.

**6.4.2. Topological Classification**

1. Collections of Point to Point Links (Routed)
  - 1.1. General mesh
  - 1.2. Abbreviated mesh
  - 1.3. Tree
  - 1.4. Star
  - 1.5. Ring (closed bus)
  - 1.6. Star Configured ring
2. Multiaccess - Bus (multidrop, party line)
3. Mixed

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

**6.4.3. Routing issues**

1. Throughput/average packet delay - flow control
2. Best path for a message
3. Virtual Circuits/Datagrams
4. Centralized/distributed
5. Adaptive/static to load conditions
6. Topology changes - Hello, routing, and keep alive messages

**6.4.4. Addressing**

**6.5. Network Management**

3. Address Space management
4. Topology maintenance
5. Link maintenance
6. Node maintenance (Hardware/Software service and updates, configuration control)
7. Traffic monitoring
8. Accounts maintenance
9. Accounting usage
10. Mail maintenance (Dead Letter office, forwarding, Address resolution, Mailbox management, Storage management)
11. Security

**6.6. Security**

1. Physical - protection of the equipment
2. Physical - Allowing access only to legitimate users
3. Viruses, Worms, Trojan Horses
4. Flooding network with messages

**Aspects of Digital Communication**  
**Chapter Elements of Digital Communication**

5. Fraud
6. Flames - Inflammatory messages

**6.7. Sociological issues**

1. Intrusion "I haven't used a computer yet and, by gosh, I am not going to use electronic mail!"
2. Privacy

## **Chapter 7. Data Representations and Compression**

A typical activity in the development of a scientific area or topic is seeking an appropriate and efficient representation for the information involved. Appropriate representation promotes easier understanding and more facile manipulation of the concepts and information. The development of computer and communication technology has included continual attempts to optimize the way things are represented and, hence, stored, communicated, or printed. Practical considerations often dictate that efficient representations of information be chosen to conserve scarce resources such as disk and memory. These considerations impact everyone from the user who must consider how to manage his data and documents, to the programmer who must choose structures for programs and data, to the file system designers, to the designers of systematic compression facilities.

Often, compromises must be made in representations. For a given set of information the most efficient representation may be too obscure. On the other extreme, the ultimate representation with respect to clarity may be too costly in space. Another approach is to have a translation facility that translates back and forth between the verbose but understandable form and the cryptic but condensed form. Still, the cost of such translation in terms of time and computer resources has to be factored into any choice of representation.

### **7.1. Forms of digital information**

#### **7.1.1. Logical Variables**

1. Single bit
2. One Byte (treated as a single binary variable)
3. One Byte (treated as 8 binary variables)
4. Two Byte (treated as a single binary variable)
5. Two Byte (treated as 16 binary variables)

#### **7.1.2. Binary numbers**

1. Size
  - 1.1. Nibble --- 4 bit numbers
  - 1.2. Byte --- 8 bit numbers
  - 1.3. Word --- 8,12,16,18,24,32,36,60,64 bit numbers

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

2. Type
  - 2.1. Unsigned
  - 2.1. Sign Magnitude
  - 2.2. Signed -- One's compliment
  - 2.3. Signed -- Two's compliment
  - 2.4. Modulo N excess

**7.1.3. Floating Point numbers**

smmmmmmm....SEEEE....

1. Unnormalized
2. Normalized (with/without "hidden bit")

**7.1.4. Machine Level Programs**

**7.1.5. Coded "text"**

1. High level programs
2. Encoded numerical data
3. Alphanumeric data
  - 3.1. Literature
  - 3.2. Letters
  - 3.3. Manuscripts

**7.2. Specific Representations**

**7.2.1. Textual Information**

In the early days of computing, information was often stored on Hollerith (IBM) cards. These cards had a fixed size and held 80 characters of information. When these cards were processed, this intrinsic record size was maintained. Furthermore, when disk storage first became generally available, text files were often stored using fixed length records of 80 characters. Figure 54 is one simple short example of a typical text file, a FORTRAN program, as viewed on paper or CRT screen. Figure 55 shows the TEST2.FOR file as stored in fixed length records. In this example, the delimiters ">" and "<" are used to

## Aspects of Digital Communication

### Chapter Data Representations and Compression

show the actual records of the file and are not actually part of the file. For ease of illustration in this example, the record length was set to 70 characters.

```

          PROGRAM MAIN
C=====
C
C
C   Title: TEST2.FOR
C
C   T V Atkinson
C   Department of Chemistry
C   Michigan State University
C   East Lansing, MI 48824
C
C   DATE: 15-JAN-85
C
C-----
C
C   This routine demonstrates calling sequences.
C
C=====
C
C   WRITE (5,10)
10  FORMAT (' Program MAIN is running, about to call subroutine
SUB1 '
C
C   CALL SUB1
C   WRITE (5,20)
20  FORMAT (' Returned from SUB1 to MAIN, about to call SUB2')
C   CALL SUB2
C   WRITE (5,30)
30  FORMAT (' Returned from SUB2, all done ...')
C   CALL EXIT
C   END
```

**Figure 54 - Text File: Regular View**

## Aspects of Digital Communication

### Chapter Data Representations and Compression

```
|>          PROGRAM MAIN
<|
|>C=====
<|
|>C
<|
|>C          Title: TEST2.FOR
<|
|>C
<|
|>C          T V Atkinson
<|
|>C          Department of Chemistry
<|
|>C          Michigan State University
<|
|>C          East Lansing, MI 48824
<|
|>C
<|
|>C          DATE: 15-JAN-85
<|
|>C
<|
|>C-----
<|
|>C
<|
|>C          This routine demonstrates calling sequences.
<|
|>C
<|
|>C=====
<|
|>C
<|
|>          WRITE (5,10)
<|
|>10          FORMAT (' Program MAIN is running, about to call subroutine
SUB1'<|
|>          CALL SUB1
<|
|>          WRITE (5,20)
<|
|>20          FORMAT (' Returned from SUB1 to MAIN, about to call SUB2')
<|
|>          CALL SUB2
<|
|>          WRITE (5,30)
<|
|>30          FORMAT (' Returned from SUB2, all done ...')
<|
|>          CALL EXIT
<|
|>          END
<|
```

**Figure 55 - Text File : Fixed Length Records, Blank Filled**

This file contains 2016 characters and would typically be stored in that number of bytes of disk space.

## Aspects of Digital Communication

### Chapter Data Representations and Compression

Notice that a large fraction of this file is "<SPACE>" characters or white space. This practice was quickly seen to be undesirable and spurred the development of variable length records. By not storing the blanks at the end of the lines (i.e. the trailing blanks), a great deal of space can be saved. In order for this to be done, some type of record separator or a byte count mechanism must be added to the file structure. Figure 56 illustrates how the file will be stored using variable length records. Again, the delimiters ">" and "<" are being used here for clarity and would not be stored.

```
|>          PROGRAM MAIN<|
|>C-----|
|====<|
|>C<|
|>C          Title: TEST2.FOR<|
|>C<|
|>C          T V Atkinson<|
|>C          Department of Chemistry<|
|>C          Michigan State University<|
|>C          East Lansing, MI 48824<|
|>C<|
|>C          DATE: 15-JAN-85<|
|>C<|
|>C-----|
|----<|
|>C<|
|>C          This routine demonstrates calling sequences.<|
|>C<|
|>C-----|
|====<|
|>C<|
|>          WRITE (5,10)<|
|>10        FORMAT (' Program MAIN is running, about to call subroutine
SUB1')<|
|>          CALL SUB1<|
|>          WRITE (5,20)<|
|>20        FORMAT (' Returned from SUB1 to MAIN, about to call
SUB2')<|
|>          CALL SUB2<|
|>          WRITE (5,30)<|
|>30        FORMAT (' Returned from SUB2, all done ...')<|
|>          CALL EXIT<|
|>          END<|
```

**Figure 56 - Text File: Variable Record Links**

As you can see, there is no difference in the appearance of this file. However, the file now contains only 746 bytes not counting the new variable record overhead, byte counts or record separators. This file contains 28 records, so the size would be increased by 28 or 56 bytes depending on whether one or two byte record separators or byte counts were used.

#### 7.2.2. Tokens

Another compression technique consists of translating keywords into a shorter symbolic form. For example, TEST2.FOR will be translated according to Table 18. This particular translation table contains only the keywords found in TEST2.FOR. In general, the

## Aspects of Digital Communication

### Chapter Data Representations and Compression

translation table would contain all the keywords of the particular language. We are assuming that the number of keywords is small enough to allow mapping into appropriate 2 character symbols. In cases of larger translation tables symbols of three or more characters would be required.

**Table 18 - Token Translation Table**

Token	Keyword
\$1	CALL
\$2	END
\$3	EXIT
\$4	FORMAT
\$5	PROGRAM
\$6	WRITE

Figure 57 shows the results of this translation. The file has also been striped of comments and is 264 bytes long.

```
> $1 MAIN<|
> $6 (5,10)<|
>10 $4 (' Program MAIN is running, about to call subroutine
SUB1'<|
> $6 (5,20)<|
>20 $4 (' Returned from SUB1 to MAIN, about to call SUB2')<|
> $1 SUB2<|
> $6 (5,30)<|
>30 $4 (' Returned from SUB2, all done ...')<|
> $1 $3<|
```

**Figure 57 - Text File: Tokens**

The version using tokens will require less storage, as the symbols are significantly shorter than the corresponding keyword. This technique was commonly practiced in the TRS-80, VIC-20, and other small machines from the early days of microcomputers when storage space and memory were extremely limited.

#### 7.2.3. Storage of Numerical Data

Scientific computing provides another example of how representation can provide savings in memory and disk space. As an example, consider a generalized simple 3 x 3 matrix shown in Table 19.

**Table 19 - Array Storage: Generalized 3x3 Matrix**

A(1,1)	A(1,2)	A(1,3)
A(2,1)	A(2,2)	A(2,3)
A(3,1)	A(3,2)	A(3,3)

Such a matrix of numbers would be stored in one of the two ways shown in Figure 58.

# Aspects of Digital Communication

## Chapter Data Representations and Compression

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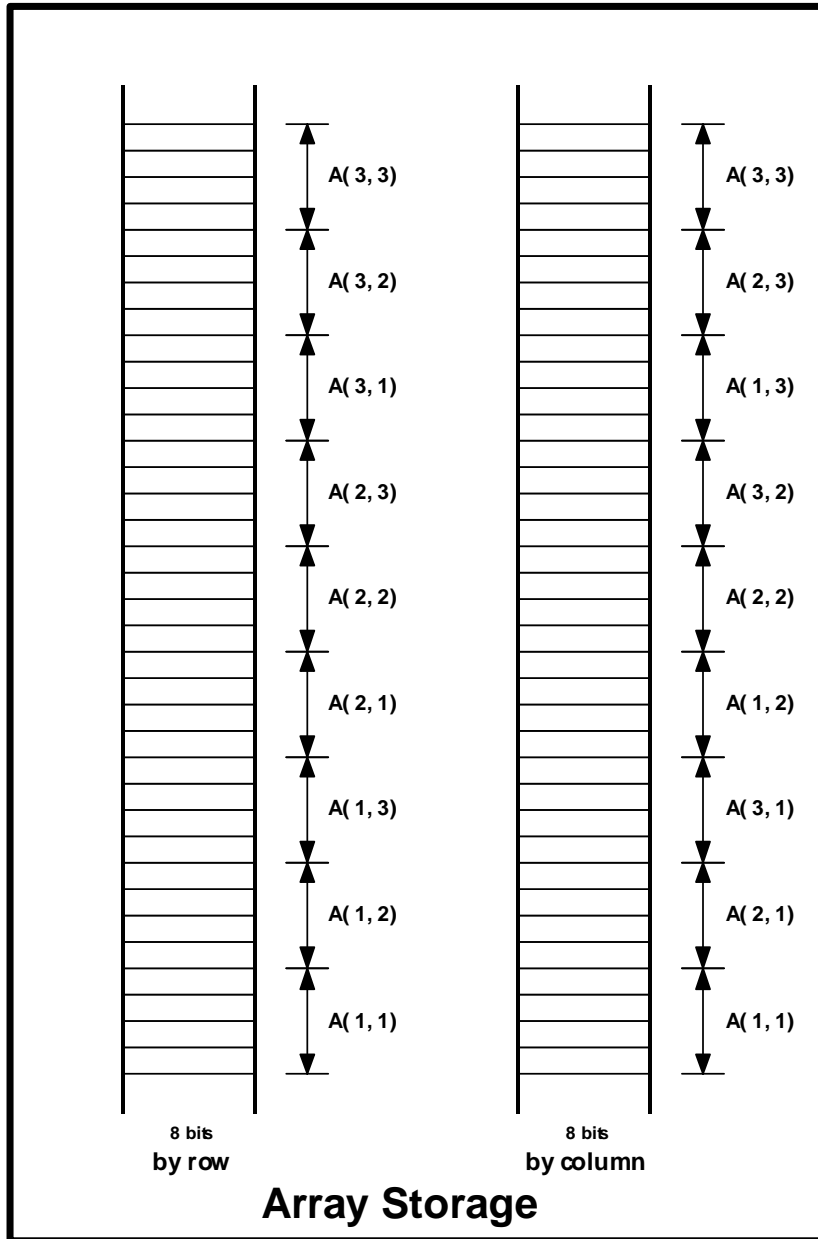


Figure 58 - Array Storage

Table 20 is an example of such a matrix, with 32 bit floating point elements.

Table 20 - Example 3x3 Array

1.0	0.0	3.1516
0.0	2.0	0.0
0.0	0.0	4.0

## Aspects of Digital Communication

### Chapter Data Representations and Compression

This example matrix would be stored as shown in Table 21 if all elements are stored. The columns marked Value (Binary) and Value(Hex) show how the matrix would be stored in memory. This matrix requires 36 bytes of storage.

**Table 21 - Array Storage: All Elements Stored**

Index	Byte	Value (Decimal)	Value (Binary)	Value (Hex)
1,1	0	0.10000000E+01	0000 0000 0000 0000 0100 0000 1000 0000	4080
1,2	4	0.00000000E+00	0000 0000 0000 0000 0000 0000 0000 0000	0
1,3	8	0.31415901E+01	0000 1111 1101 0000 0100 0001 0100 1001	FD04149
2,2	12	0.00000000E+00	0000 0000 0000 0000 0000 0000 0000 0000	0
2,2	16	0.20000000E+01	0000 0000 0000 0000 0100 0001 0000 0000	4100
2,3	20	0.00000000E+00	0000 0000 0000 0000 0000 0000 0000 0000	0
3,1	24	0.00000000E+00	0000 0000 0000 0000 0000 0000 0000 0000	0
3,2	28	0.00000000E+00	0000 0000 0000 0000 0000 0000 0000 0000	0
3,3	32	0.40000000E+01	0000 0000 0000 0000 0100 0001 1000 0000	4180

#### 7.2.3.1. Sparse Matrix

Another approach would be to store only non-zero elements. This requires storing the indices as well as the data as shown in Table 22. This technique has long been used to store very large matrices with few non-zero elements (sparse matrices). Special algorithms have been developed for performing multiplication, inversion, transposition, and other matrix operations without the need to explicitly expand the matrix back to full size.

**Table 22 - Array Storage: Non-Zero Elements Stored**

Index	Byte	Value (Decimal)	Value (Binary)	Value (Hex)
1,1	0	1	0000 0000 0000 0001	1
	2	1	0000 0000 0000 0001	1
	4	0.10000000E+01	0000 0000 0000 0000 0100 0000 1000 0000	4080
2,2	8	2	0000 0000 0000 0010	2
	10	2	0000 0000 0000 0010	2
	12	0.20000000E+01	0000 0000 0000 0000 0100 0001 0000 0000	4100
3,3	16	3	0000 0000 0000 0011	3
	18	3	0000 0000 0000 0011	3
	20	0.40000000E+01	0000 0000 0000 0000 0100 0001 1000 0000	4180
1,3	24	1	0000 0000 0000 0001	1
	26	3	0000 0000 0000 0011	3
	28	0.31415901E+01	0000 1111 1101 0000 0100 0001 0100 1001	FD04149

This representation would require 32 bytes of storage, only a modest savings of space. As the size of and the sparseness of the matrix grows, the savings in space become much more dramatic.

#### 7.2.4. Graphical representations

The representation and visualization of 2D and 3D objects, i. e. graphics, is a major concern in the computer industry. Often graphical representation will provide a more appropriate and efficient method of storing and presenting information. This is a very

## Aspects of Digital Communication

### Chapter Data Representations and Compression

complicated subject<sup>1</sup>. Methods for representing 2D and 3D objects are required. 3D objects usually must be represented, i.e. projected, in 2D. Recreating the color of an object in the presentation is a major topic. In addition, there is a wide variation in the nature, e. g. resolution, color characteristics, speed, etc. of the devices and mechanisms used to present an image that can be viewed by the human. Some aspects of this large area of endeavor will be covered in this section.

#### 7.2.4.1. Full bitmap

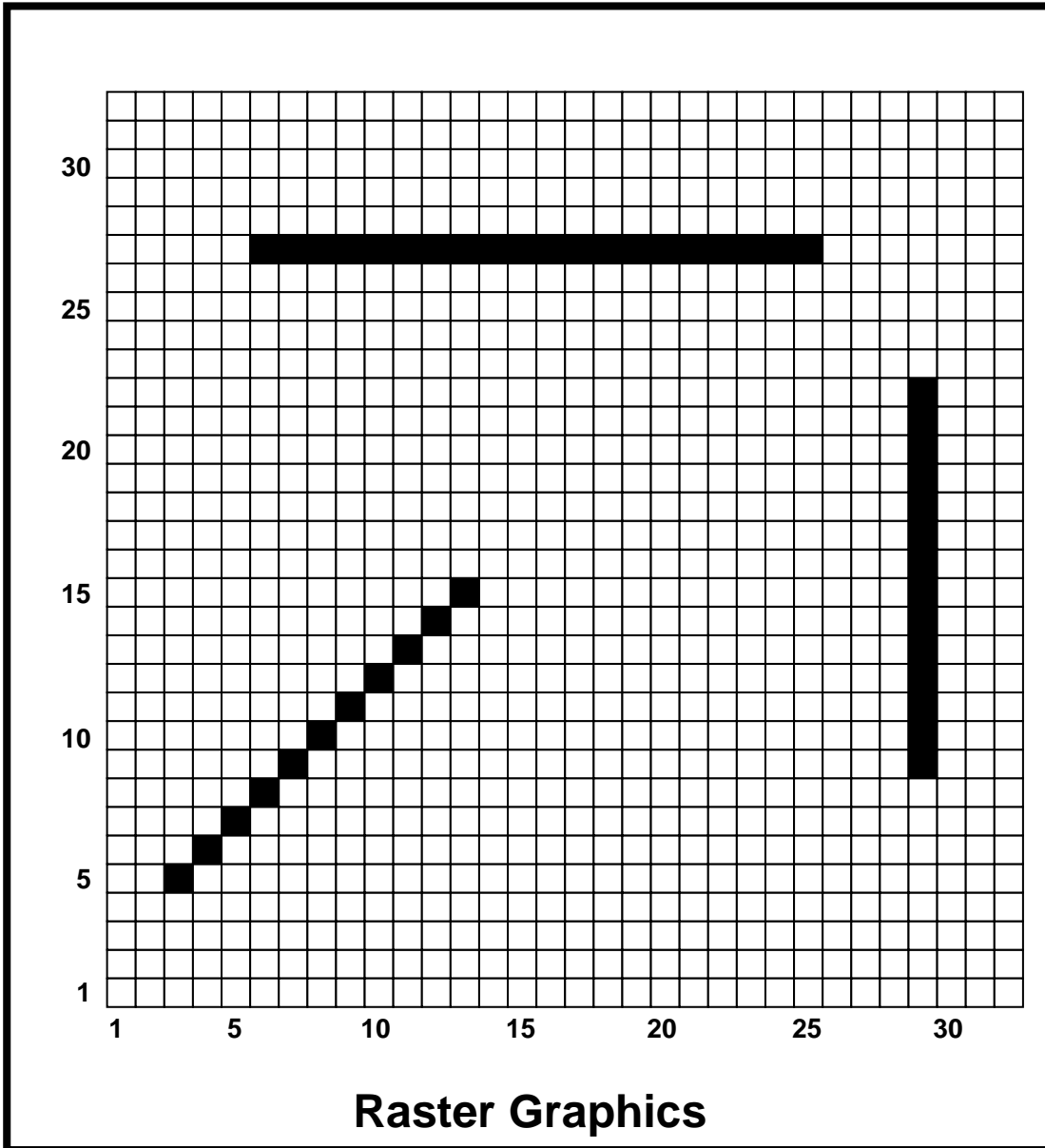
The vast majority of modern graphical output devices, e.g. CRT, liquid crystal, and other displays, ink jet, laser, and other printers, are raster devices. In such cases, the image is represented by a collection of picture elements (pixels) arranged in a two-dimensional array (raster) as shown in Table 23. In such representations, graphical elements, e.g. lines, circles... are a set of pixels that are turned "on", against a background of pixels that are "off". In this particular example (32 x 32), a line between 3,5 and 13,15 is thus a set of 11 "darkened" pixels.

---

<sup>1</sup> "Computer Graphics: Principles and Practicies," 2<sup>nd</sup> edition, James D. Foley, Andries van Dam, Steven K. Feiner, John F. Hughes, Addison-Wesley, 1993.

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

Cem 924 DataRep2 24-FEB-1991



**Table 23 - Raster Graphics Device**

Notice that horizontal lines and vertical lines are "cleaner" than those at an angle. In this example the pixels have two states, on or off. In general, each pixel can have multiple states such as gray scale or color.

**7.2.4.2. Grayscale**

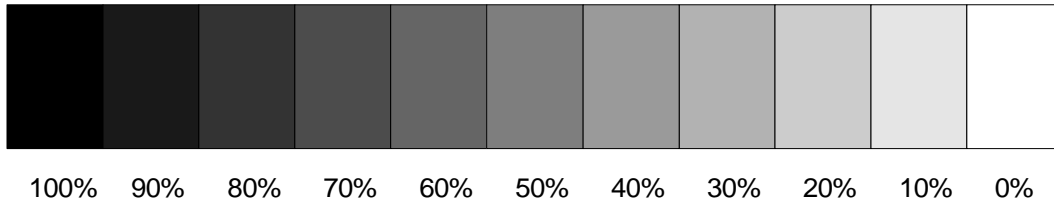
**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**



**Figure 59 - Abraham Lincoln (120 pixels per inch)**



**Figure 60 - Abraham Lincoln (16 pixels/inch)**



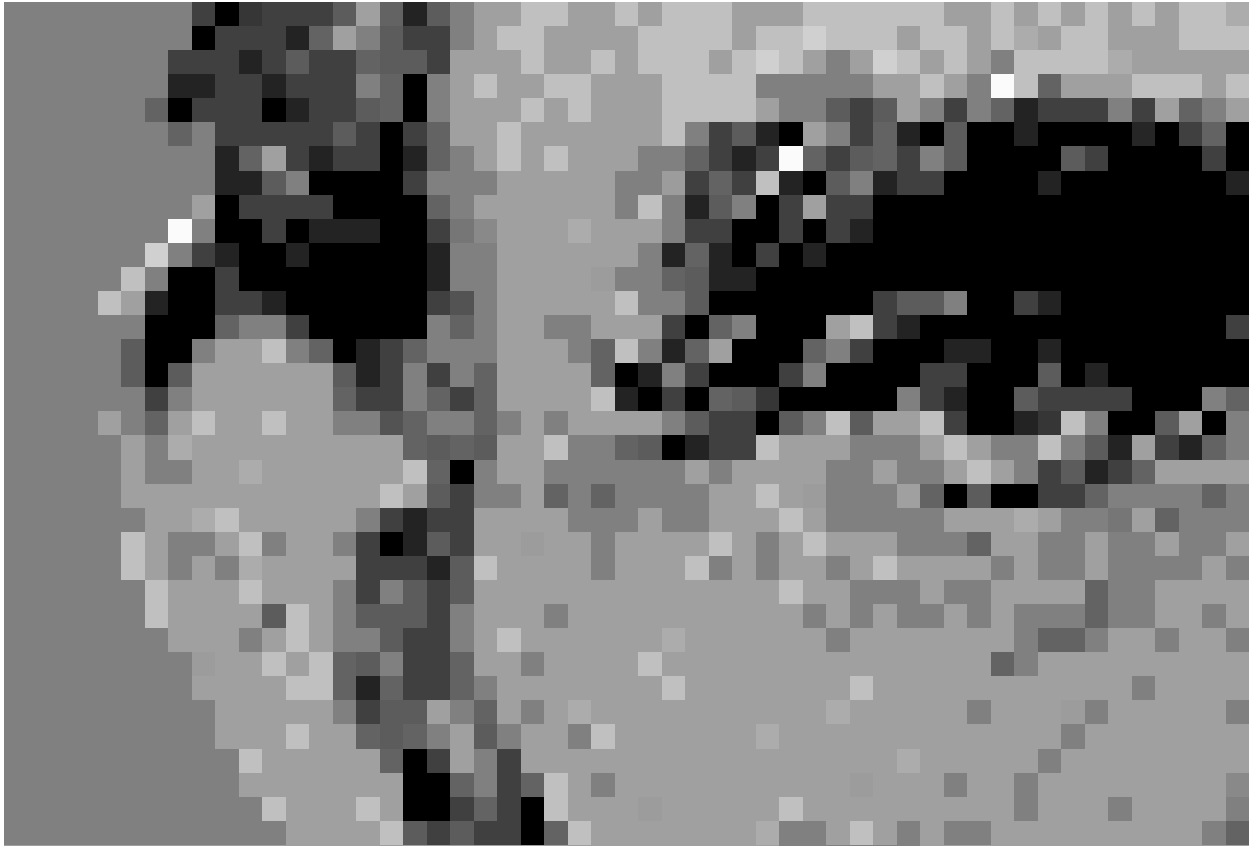
**Grayscale (%Black)**

**Figure 61 - Grayscale**



**Figure 62 - Abraham Lincoln Detail (120 pixels per inch)**

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**



**Figure 63 - Abraham Lincoln Detail (120 pixels per inch magnified)**

#### **7.2.4.3. Halftone**

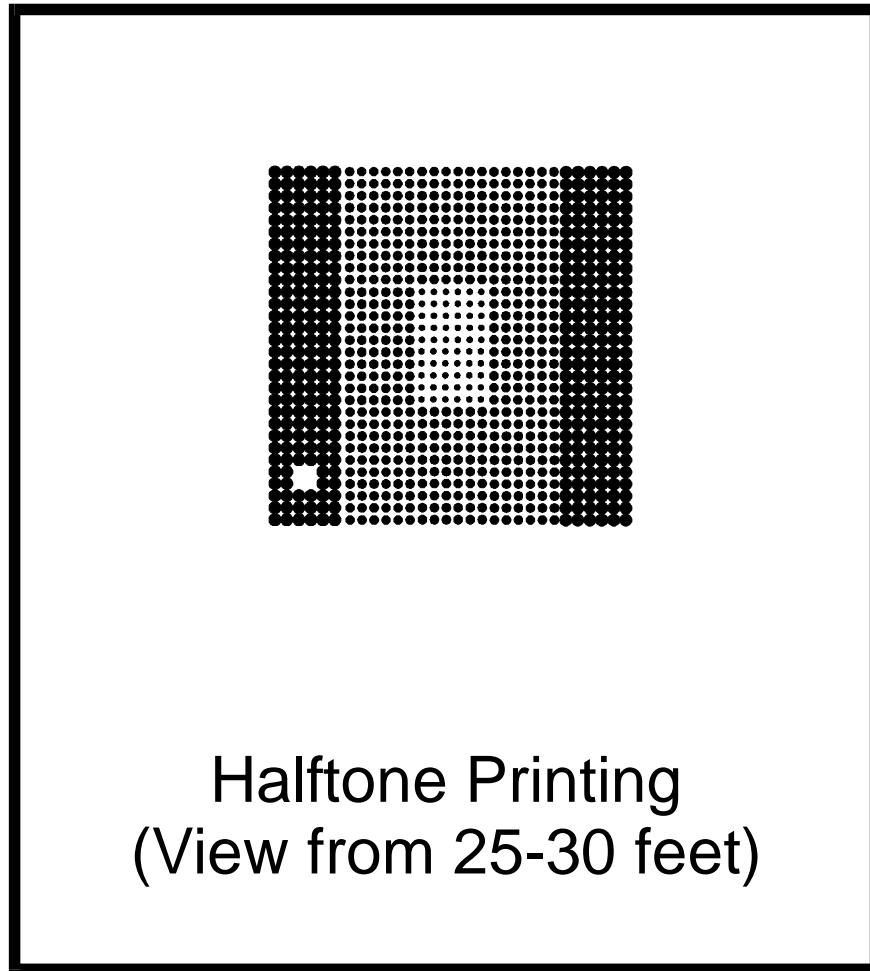
When a newspaper or magazine is printed, areas of ink of one color, e. g. black, or areas of ink of one of a few colors, e. g. cyan, magenta, yellow, and black, are placed on the paper. The resultant image on the paper is either black and white or four colors. To accommodate images of grayscale or more than four colors, the printing industry has traditionally used a technique called “halftone.”

To achieve grayscale images, the image is divided into a matrix of black dots (See Figure 64). The radius of each dot is a function of the image at that point. When viewed from the appropriate distance, the human eye integrates the dots and “sees” an area of the appropriate grayscale intensity.

To achieve more than 4 colors, the matrix of dots will have alternating dots for the four colors, CMYK. The radius of each dot is a function of the intensity of that color at that point of the image.

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

halftone2.cdr 21-Mar-1997

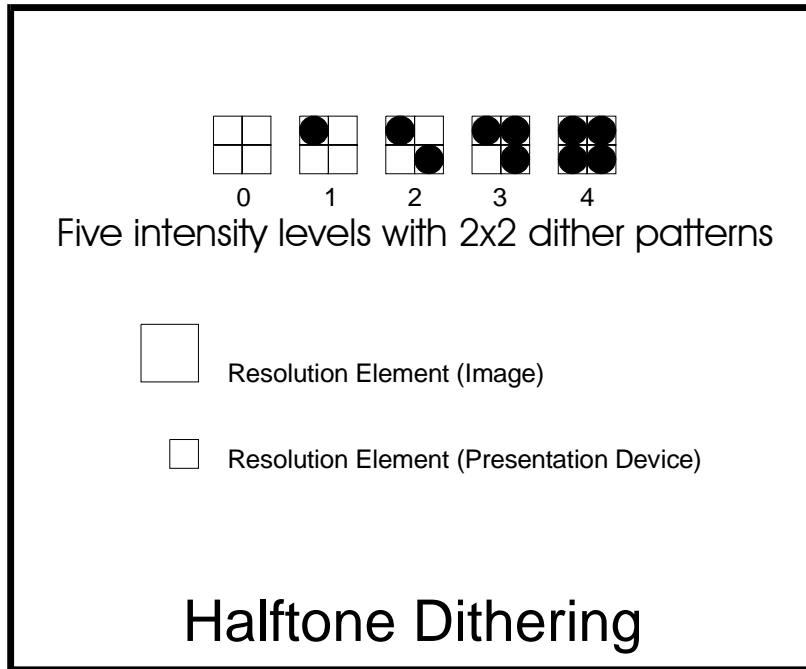


**Figure 64 - Halftone (Grayscale)**

The halftone technique as practiced by the printing industry requires a plate to be made for each page. Printers and other raster devices also can only put areas of a single color, black, or areas of one of four colors, CMYK, down on the writing surface. However, they can not create dots of different radius. The so called “halftone dithering” technique (See Figure 65 and Figure 66) provide an alternative method of creating images of multiple grayscales or colors for these devices. Notice that the resolution of the image is less than the resolution of the presentation device.

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

2x2dithering 21-Mar-1997



**Figure 65 - Halftone Dithering 2x2**

# Aspects of Digital Communication

## Chapter Data Representations and Compression

3x3dither.cdr 21-Mar-1997

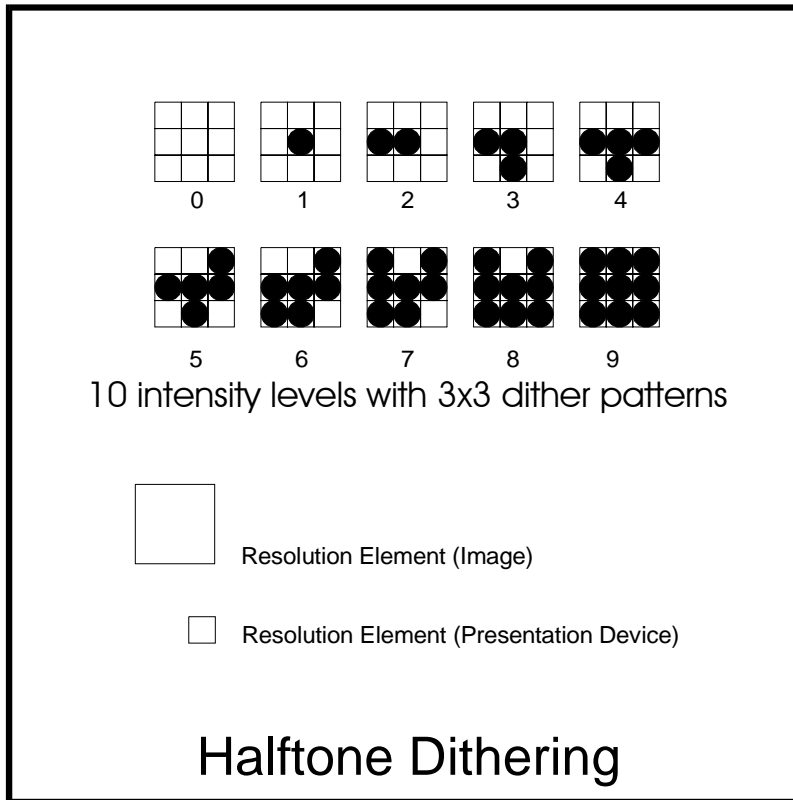
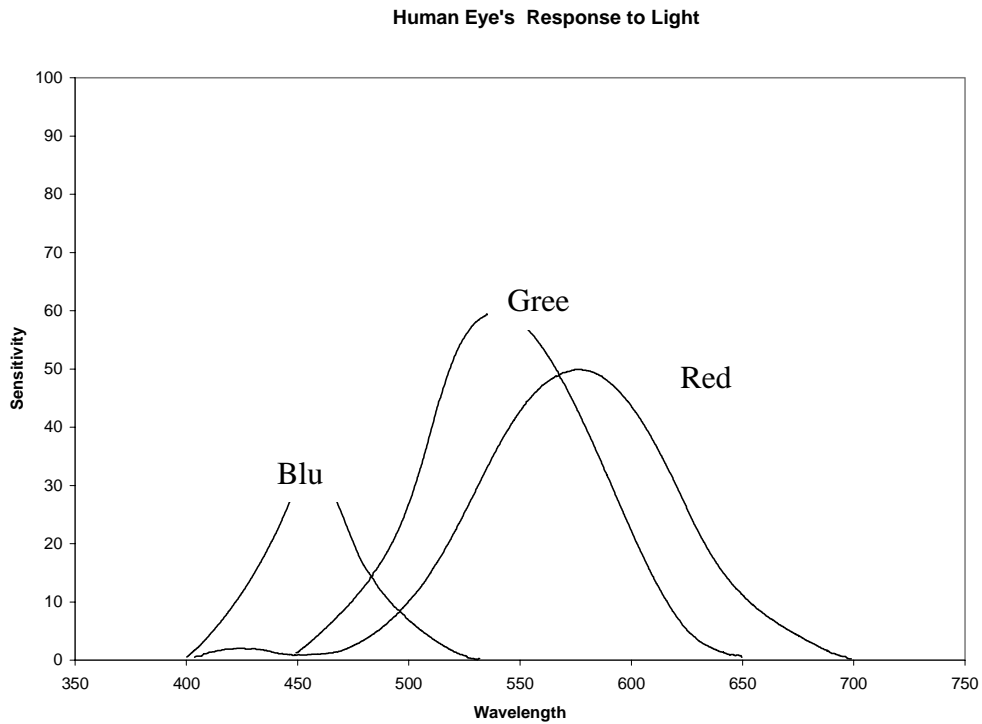


Figure 66 - Halftone Dithering 3x3

#### 7.2.4.4. Color

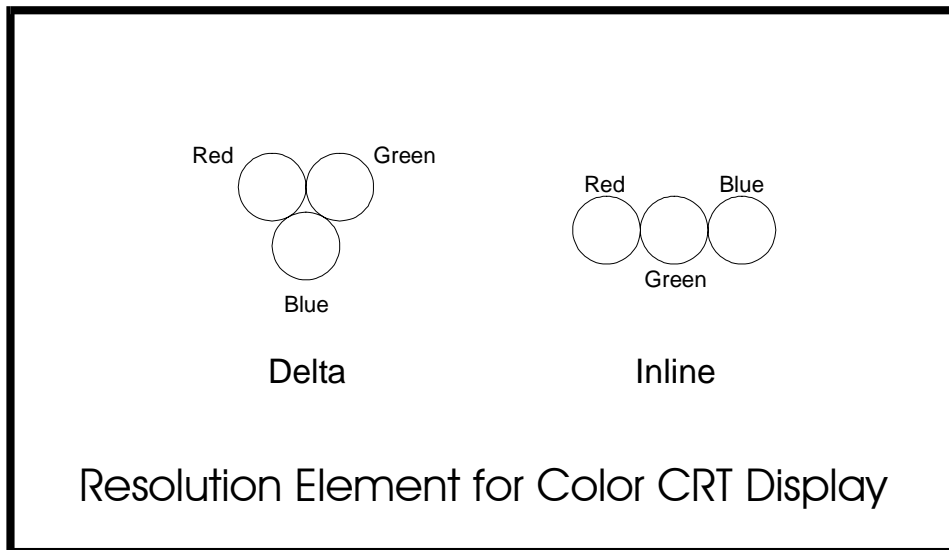
Figure 67 shows the response of the human eye to different colors of light. The three responses are for three different sets of cones that respond to light differently. The three sets of cones are sensed separately by the brain and determine the “color” perceived for each point of the image. This phenomenon is the basis of the tri-stimulus theory of color perception. For the human eye, all colors can be achieved by placing varying intensities of the three basic colors in close proximity of each other (See Figure 68). The human eye can resolve about 256 different levels of gray or each of the three basic colors. Thus an 8 bit grayscale is usually sufficient. A 24 bit tri-color representation usually is called “true color.”

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**



**Figure 67 - The Response of the Human Eye to Light**

rgb.cdr 21-Mar-1997



**Figure 68 - Resolution Element for Color CRT**

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**Table 24 - Information Content by Resolution (1 Bit/Pixel)**

Image Size	Width	Length	Units	W/L	L/W	Area Sq. In.	Resolution in Lines per Inch				
							100	300	600	1200	2700
							Bytes	Bytes	Bytes	Bytes	Bytes
A (ANSI)	8.5	11	in.	0.77	1.29	93.50	115.49 K	1.04 M	4.16 M	16.63 M	84.19 M
B	11	17	in.	0.65	1.55	187.00	230.98 K	2.08 M	8.32 M	33.26 M	168.38 M
C	17	22	in.	0.77	1.29	374.00	461.96 K	4.16 M	16.63 M	66.52 M	336.77 M
D	22	34	in.	0.65	1.55	748.00	923.91 K	8.32 M	33.26 M	133.04 M	673.53 M
E	34	44	in.	0.77	1.29	1496.00	1.85 M	16.63 M	66.52 M	266.09 M	1.35 G
A4 (Inter. Std.)	210	297	mm	0.71	1.41	96.67	119.41 K	1.07 M	4.30 M	17.19 M	87.05 M
A3	297	420	mm	0.71	1.41	193.35	238.82 K	2.15 M	8.60 M	34.39 M	174.10 M
A2	420	594	mm	0.71	1.41	386.69	477.64 K	4.30 M	17.19 M	68.78 M	348.20 M
A1	594	841	mm	0.71	1.42	774.31	956.41 K	8.61 M	34.43 M	137.72 M	697.22 M
A0	841	1189	mm	0.71	1.41	1549.92	1.91 M	17.23 M	68.92 M	275.68 M	1.40 G
Photographs	1	1	in	1.00	1.00	1.00	1.24 K	11.12 K	44.47 K	177.87 K	900.44 K
	2.25	2.25	in	1.00	1.00	5.06	6.25 K	56.28 K	225.11 K	900.44 K	4.56 M
	3	5	in	0.60	1.67	15.00	18.53 K	166.75 K	667.00 K	2.67 M	13.51 M
	4	6	in	0.67	1.50	24.00	29.64 K	266.80 K	1.07 M	4.27 M	21.61 M
	5	7	in	0.71	1.40	35.00	43.23 K	389.08 K	1.56 M	6.23 M	31.52 M
	8	10	in	0.80	1.25	80.00	98.81 K	889.33 K	3.56 M	14.23 M	72.04 M

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**Table 25 - Information Content by Resolution (8 Bit/Pixel)**

Size	Width	Length	Units	W/L	L/W	Area Sq.In.	Resolution in Lines per Inch				
							100	300	600	1200	2700
							Bytes	Bytes	Bytes	Bytes	Bytes
A (ANSI)	8.5	11	in.	0.77	1.29	93.50	923.91 K	8.32 M	33.26 M	133.04 M	673.53 M
B	11	17	in.	0.65	1.55	187.00	1.85 M	16.63 M	66.52 M	266.09 M	1.35 G
C	17	22	in.	0.77	1.29	374.00	3.70 M	33.26 M	133.04 M	532.17 M	2.69 G
D	22	34	in.	0.65	1.55	748.00	7.39 M	66.52 M	266.09 M	1.06 G	5.39 G
E	34	44	in.	0.77	1.29	1496.00	14.78 M	133.04 M	532.17 M	2.13 G	10.78 G
A4 (Inter. Std.)	210	297	mm	0.71	1.41	96.67	955.27 K	8.60 M	34.39 M	137.56 M	696.39 M
A3	297	420	mm	0.71	1.41	193.35	1.91 M	17.19 M	68.78 M	275.12 M	1.39 G
A2	420	594	mm	0.71	1.41	386.69	3.82 M	34.39 M	137.56 M	550.24 M	2.79 G
A1	594	841	mm	0.71	1.42	774.31	7.65 M	68.86 M	275.45 M	1.10 G	5.58 G
A0	841	1189	mm	0.71	1.41	1549.92	15.32 M	137.84 M	551.36 M	2.21 G	11.16 G
Photographs	1	1	in	1.00	1.00	5.06	50.02 K	450.22 K	1.80 M	7.20 M	36.47 M
	2.25	2.25	in	0.69	1.44	7.31	72.26 K	650.32 K	2.60 M	10.41 M	52.68 M
	3	5	in	0.60	1.67	15.00	148.22 K	1.33 M	5.34 M	21.34 M	108.05 M
	4	6	in	0.67	1.50	24.00	237.15 K	2.13 M	8.54 M	34.15 M	172.89 M
	5	7	in	0.71	1.40	35.00	345.85 K	3.11 M	12.45 M	49.80 M	252.12 M
	8	10	in	0.80	1.25	80.00	790.51 K	7.11 M	28.46 M	113.83 M	576.28 M

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**Table 26 - Information Content by Resolution (24 Bit/Pixel)**

Image Type	Width	Length	Units	W/L	L/W	Area	Resolution in Lines per Inch				
							100	300	600	1200	2700
							Bytes	Bytes	Bytes	Bytes	Bytes
A (ANSI)	8.5	11	in.	0.77	1.29	93.50	2.77 M	24.95 M	99.78 M	399.13 M	2.02 G
B	11	17	in.	0.65	1.55	187.00	5.54 M	49.89 M	199.57 M	798.26 M	4.04 G
C	17	22	in.	0.77	1.29	374.00	11.09 M	99.78 M	399.13 M	1.60 G	8.08 G
D	22	34	in.	0.65	1.55	748.00	22.17 M	199.57 M	798.26 M	3.19 G	16.16 G
E	34	44	in.	0.77	1.29	1496.00	44.35 M	399.13 M	1.60 G	6.39 G	32.33 G
A4 (Inter. Std.)	210	297	mm	0.71	1.41	96.67	2.87 M	25.79 M	103.17 M	412.68 M	2.09 G
A3	297	420	mm	0.71	1.41	193.35	5.73 M	51.58 M	206.34 M	825.36 M	4.18 G
A2	420	594	mm	0.71	1.41	386.69	11.46 M	103.17 M	412.68 M	1.65 G	8.36 G
A1	594	841	mm	0.71	1.42	774.31	22.95 M	206.58 M	826.34 M	3.31 G	16.73 G
A0	841	1189	mm	0.71	1.41	1549.92	45.95 M	413.52 M	1.65 G	6.62 G	33.49 G
Photographs	1	1	in.	1.00	1.00	1.00	29.64 K	266.80 K	1.07 M	4.27 M	21.61 M
	2.25	2.25	in.	1.00	1.00	5.06	150.07 K	1.35 M	5.40 M	21.61 M	109.40 M
	2.25	3.25	in.	0.69	1.44	7.31	216.77 K	1.95 M	7.80 M	31.22 M	158.03 M
	4	5	in.	0.80	1.25	20.00	592.89 K	5.34 M	21.34 M	85.38 M	432.21 M
	5	7	in.	0.71	1.40	35.00	1.04 M	9.34 M	37.35 M	149.41 M	756.37 M
	8	10	in.	0.80	1.25	80.00	2.37 M	21.34 M	85.38 M	341.50 M	1.73 G
35 mm negative	24	35	mm	0.69		1.30	38.60 K	347.37 K	1.39 M	5.56 M	28.14 M

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**Table 27 - Storage Volumes of Video Images**

Process	Image Size				Size of Single Image			Video clip (24 fps)		Video clip (60 fps)	
	Horiz	Vert	Aspect Ratio	Pixels	1 Bit/pixel	8 bits/pixel	24 bits/pixel	1 second	90 min	1 second	90 min
	lines	lines	horiz/vert		bytes	bytes	bytes	bytes	bytes	bytes	bytes
Movies (50 lines/mm)											
Movies (Traditional) 35 mm	1750	1316	1.33	2302632	281.08 K	2.28 M	6.83 M	163.82 M	884.65 G	409.56 M	2.21 T
Movies (wide screen) 35 mm	1750	1061	1.65	1856061	229.26 K	1.83 M	5.50 M	132.05 M	713.08 G	330.13 M	1.78 T
Movies (Cinemascope) 35 mm	1750	745	2.35	1303191	160.97 K	1.29 M	3.86 M	92.72 M	500.67 G	231.79 M	1.25 T
Movies (Cinemascope) 70 mm	3500	1577	2.22	5518018	681.57 K	5.45 M	16.36 M	392.59 M	2.12 T	981.47 M	5.30 T
35 mm negative	1750	1200	1.46	2100000	259.39 K	2.08 M	6.23 M				
NTSC TV	425	512	0.83	217600	26.88 K	215.02 K	645.06 K	15.48 M	83.60 G	38.70 M	209.00 G
HDTV	1920	1080	1.78	2073600	256.13 K	2.05 M	6.15 M	147.53 M	796.66 G	368.82 M	1.99 T
Monitors (1997)	640	480	1.33	307200	37.94 K	303.56 K	910.67 K	21.86 M	118.02 G	54.64 M	295.06 G
	800	600	1.33	480000	59.29 K	474.31 K	1.42 M	34.15 M	184.41 G	85.38 M	461.03 G
	1024	768	1.33	786432	97.14 K	777.11 K	2.33 M	55.95 M	302.14 G	139.88 M	755.35 G
	1152	864	1.33	995328	122.94 K	983.53 K	2.95 M	70.81 M	382.39 G	177.03 M	955.99 G
	1280	1024	1.25	1310720	161.90 K	1.30 M	3.89 M	93.25 M	503.57 G	233.13 M	1.26 T
Monitors (Traditional)											
Raster Example from this text	32	32	1.00	1024	0.13 K	1.01 K	3.04 K	72.85 K	393.41 M	182.13 K	983.53 M
Monochrome (MGA)	720	350	2.06	252000	31.13 K	249.01 K	747.04 K	17.93 M	96.82 G	44.82 M	242.04 G
Color (CGA)	640	200	3.20	128000	15.81 K	126.48 K	379.45 K	9.11 M	49.18 G	22.77 M	122.94 G
EGA	750	350	2.14	262500	32.42 K	259.39 K	778.16 K	18.68 M	100.85 G	46.69 M	252.12 G
VGA	720	400	1.80	288000	35.57 K	284.58 K	853.75 K	20.49 M	110.65 G	51.23 M	276.62 G
Super VGA	800	600	1.33	480000	59.29 K	474.31 K	1.42 M	34.15 M	184.41 G	85.38 M	461.03 G
Enhanced Super VGA	1024	768	1.33	786432	97.14 K	777.11 K	2.33 M	55.95 M	302.14 G	139.88 M	755.35 G
Titan	1280	1024	1.25	1310720	161.90 K	1.30 M	3.89 M	93.25 M	503.57 G	233.13 M	1.26 T
Onyx											

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**7.2.4.5. Partial Storage of the Pixels of an Image**

A graphical element could also be represented by the set of points that are "on". In the above case, the diagonal line of Table 28 could also be represented by the set of 11 points. This technique is never done.

**Table 28 - Set of Visible Pixels**

3, 5	9, 11
4, 6	10, 12
5, 7	11, 13
6, 8	12, 14
7, 9	13, 15
8, 10	

**7.2.4.6. Parametric Representation of Graphics Primitives**

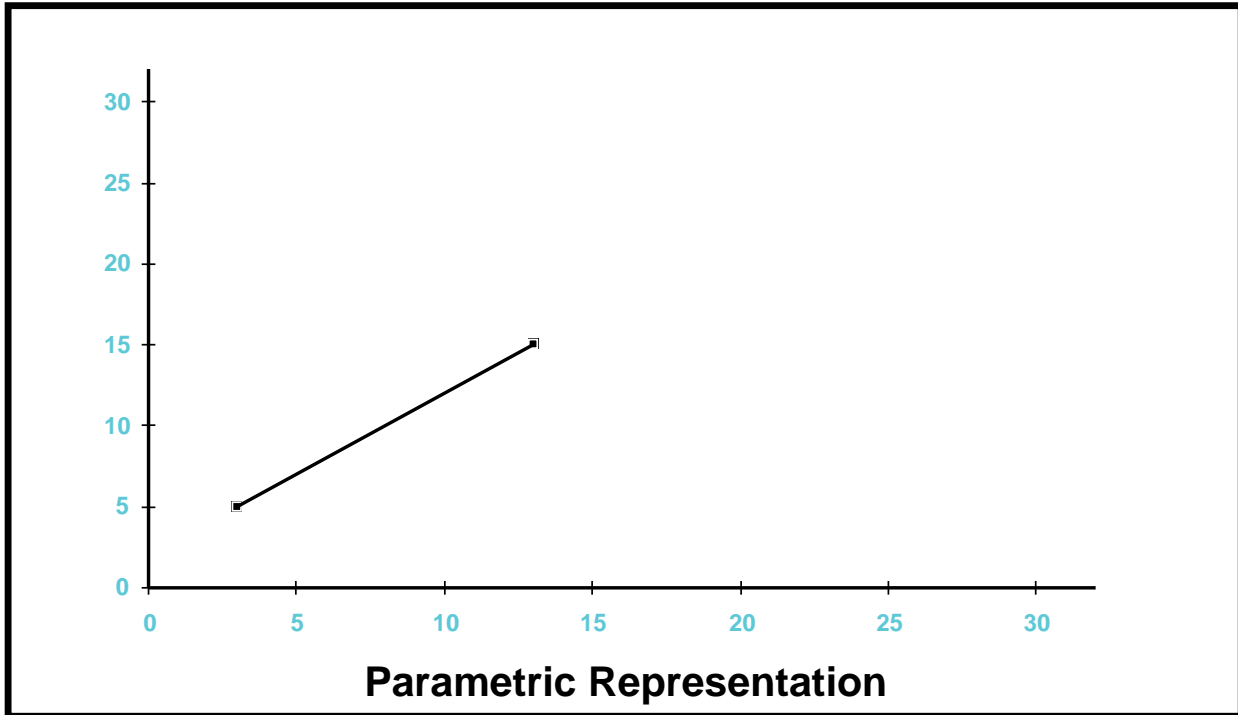
Graphical elements can also be represented parametrically. For example, lines can be described by the following equation.

$$y = mx + b$$

where  $m$  is the slope and  $b$  is the  $y$ -intercept. Thus, a line segment can actually be described by the four parameters:  $m$ ,  $b$ , minimum value of  $x$ , maximum value of  $x$ . Alternatively, the line could be represented by the four parameters  $x_{min}$ ,  $y_{min}$ ,  $x_{max}$ ,  $y_{max}$ , i.e. the coordinates of the end points of the segment. A circle can be represented by three parameters, the coordinates of the center, and the radius.

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

CEM 924 DATAREP4 16-MAY-1992



**Figure 69 - A Simple Graphical Element: Line**

**7.2.4.7. Object Oriented Representations**

A higher level representation of graphical images utilizes graphical objects. Each type of graphical object is a well defined combination of primitive graphical elements such as lines, circles, and other simple constructions. A given object can be fully described by a small set of parameters. Figure 70 shows one simple example of a graphical object, a solid arrow. The arrow can be fully described using the five parameters position (A and B), and the dimensions C, D, E.

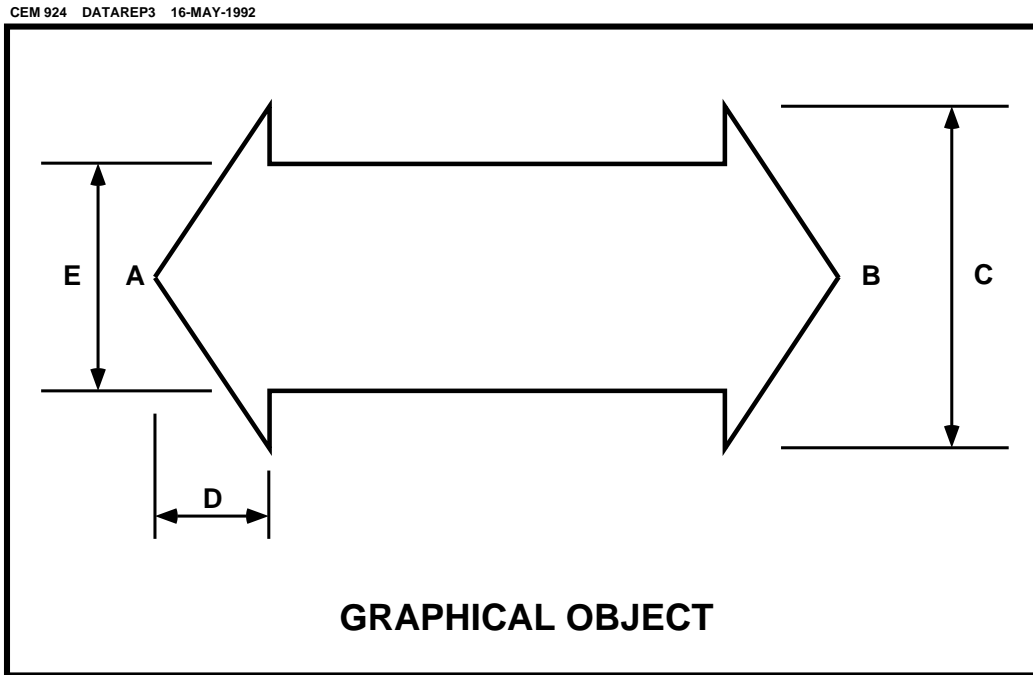


Figure 70 – A Graphical Object: Solid Arrow

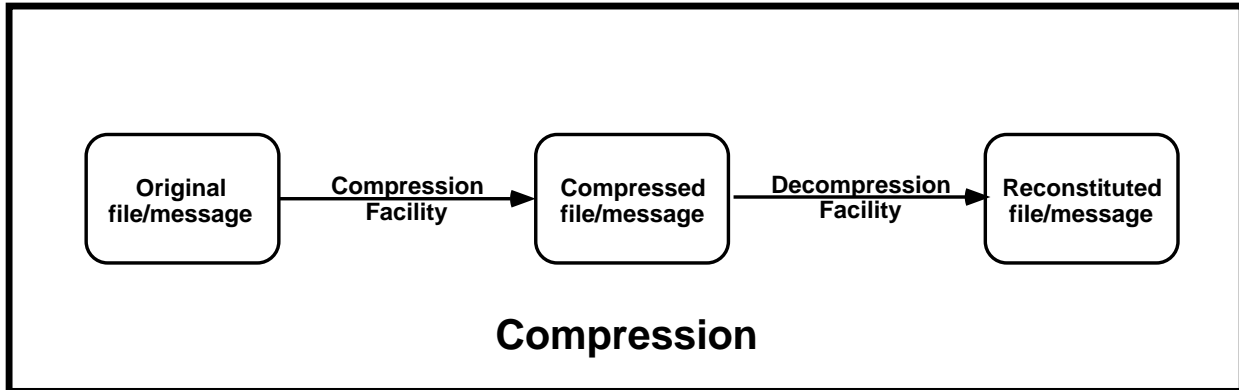
### 7.3. Systematic Compression, Decompression

A more systematic approach would be to have a facility such as that below where arbitrary files could be compressed and reconstituted at will. This has been an area of active research. The reference gives a good insight into this area and extends the Ziv-Lempel (LV) algorithm for adaptive compression. In this particular algorithm, a single pass is made through the file and a translation table is constructed of unique strings of bytes (characters) that occur. These strings are replaced with the corresponding symbol, which are of fixed length. The translation table is stored or transmitted with the compressed data.

This is an extension of the token approach discussed in the section textual information. The differences are that a symbol table for translation is constructed for each file or message. Furthermore, the symbol table is transmitted/stored with the compressed file.

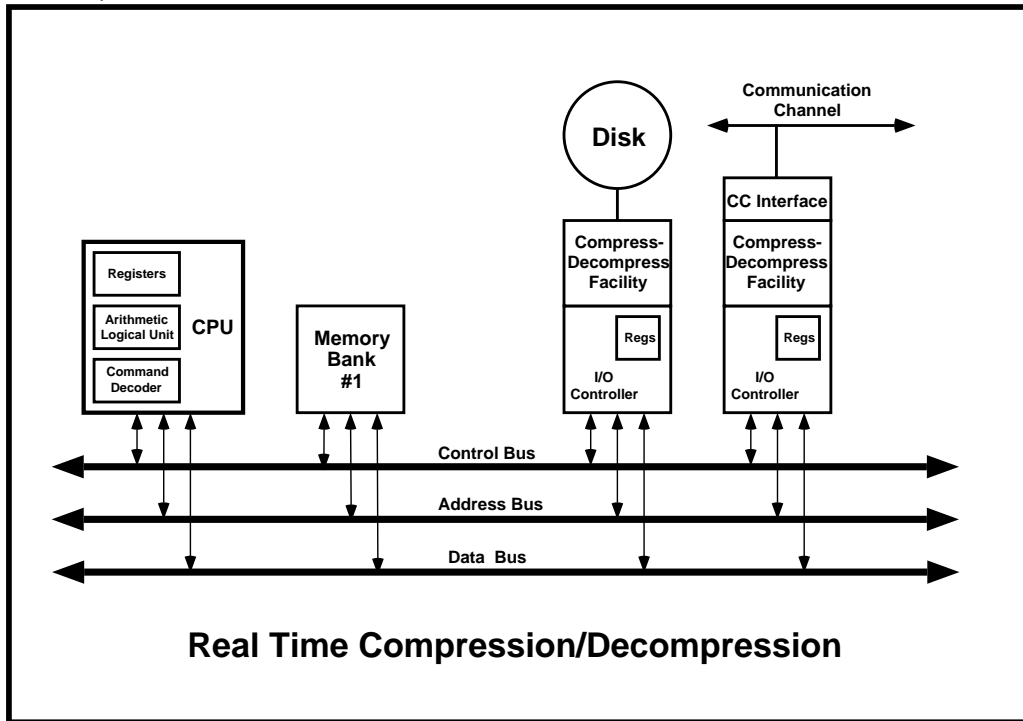
**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

CEM 924 DATAREP5 16-MAY-1992



**Figure 71 - Compression Facility**

CEM 924 Compress2 19-MAY-1992



**Figure 72 - Real Time Compression Facilities**

The results of any such techniques depend on the contents of the files being compressed. Indeed for a given algorithm, if the file containing certain sequences of bytes and of short length may even be expanded by the procedure rather than compressed. Table 29 from reference<sup>2</sup> shows some representative results.

<sup>2</sup>"A Technique for High-Performance Data Compression", T A Welch, Computer, 8, June 1984.

**Aspects of Digital Communication**  
**Chapter Data Representations and Compression**

**Table 29 - Compression Results fo LZ Compression**

Data File Type	Compression Ratio
English Text	1.8
Cobol Files	2 to 6
Floating Point Arrays	1.0
Formatted Scientific Data	2.1
System Log Data	2.6
Program Source Code	2.3
Object Code	1.5

## Chapter 8. Real Networks

MACAddress.cdr 1-Apr-1997

T.V. Atkinson - Department of Chemistry - Michigan State University

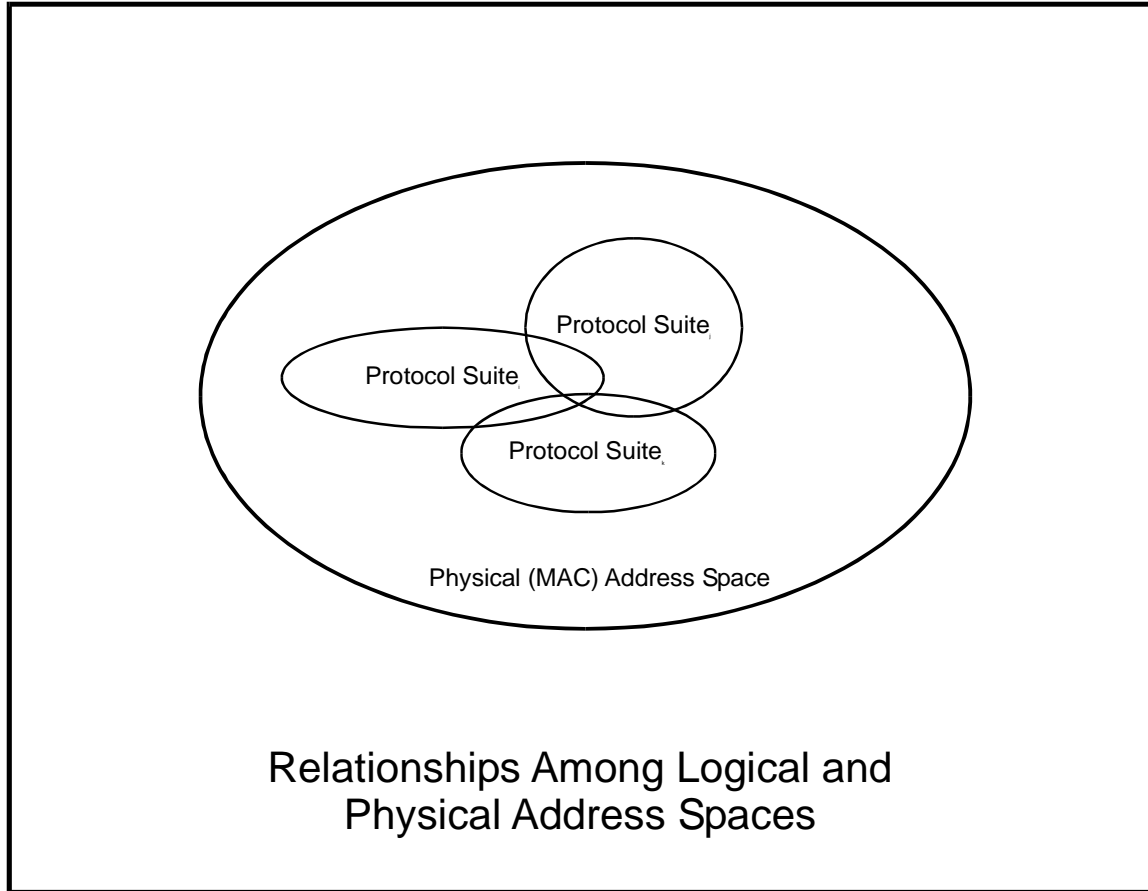
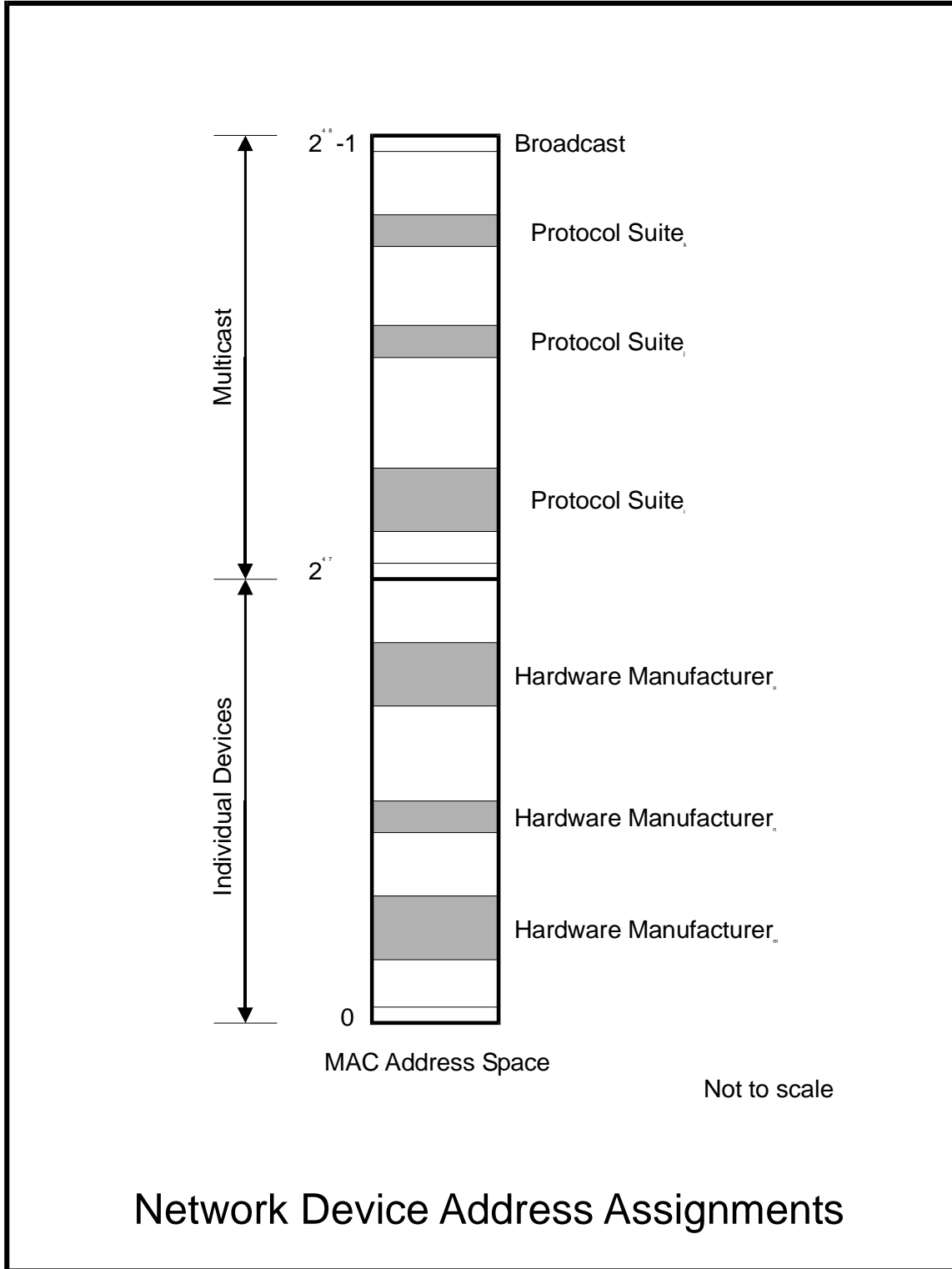


Figure 73 - Logical and Physical Addresses

Aspects of Digital Communication  
Chapter Real Networks

MACAddress.cdr 1-Apr-1997

T V Atkinson - Department of Chemistry - Michigan State University



Network Device Address Assignments

Figure 74 - MAC Address Space

# Aspects of Digital Communication

## Chapter Real Networks

### 8.1. TCP/IP

TCPIP.cdr 12-APR-1997

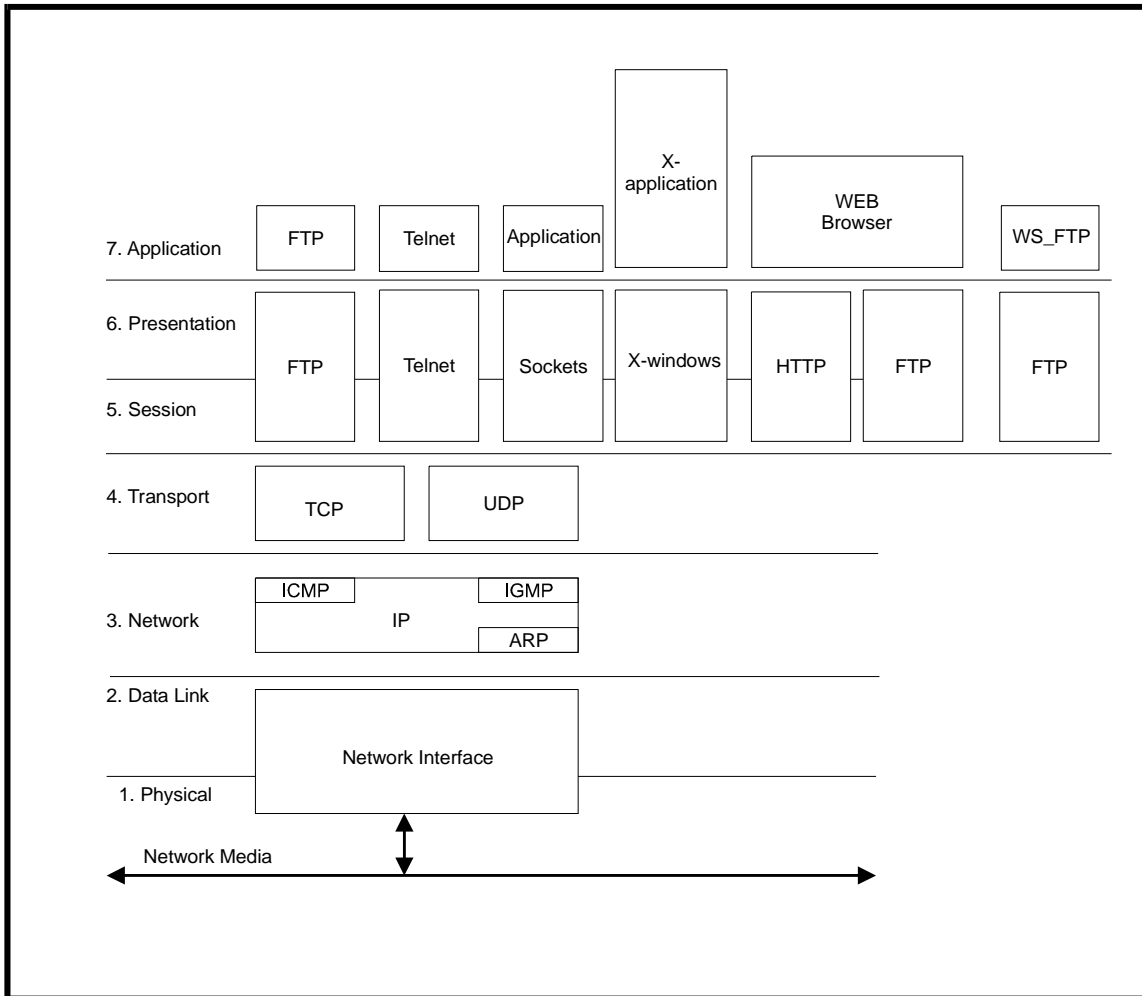


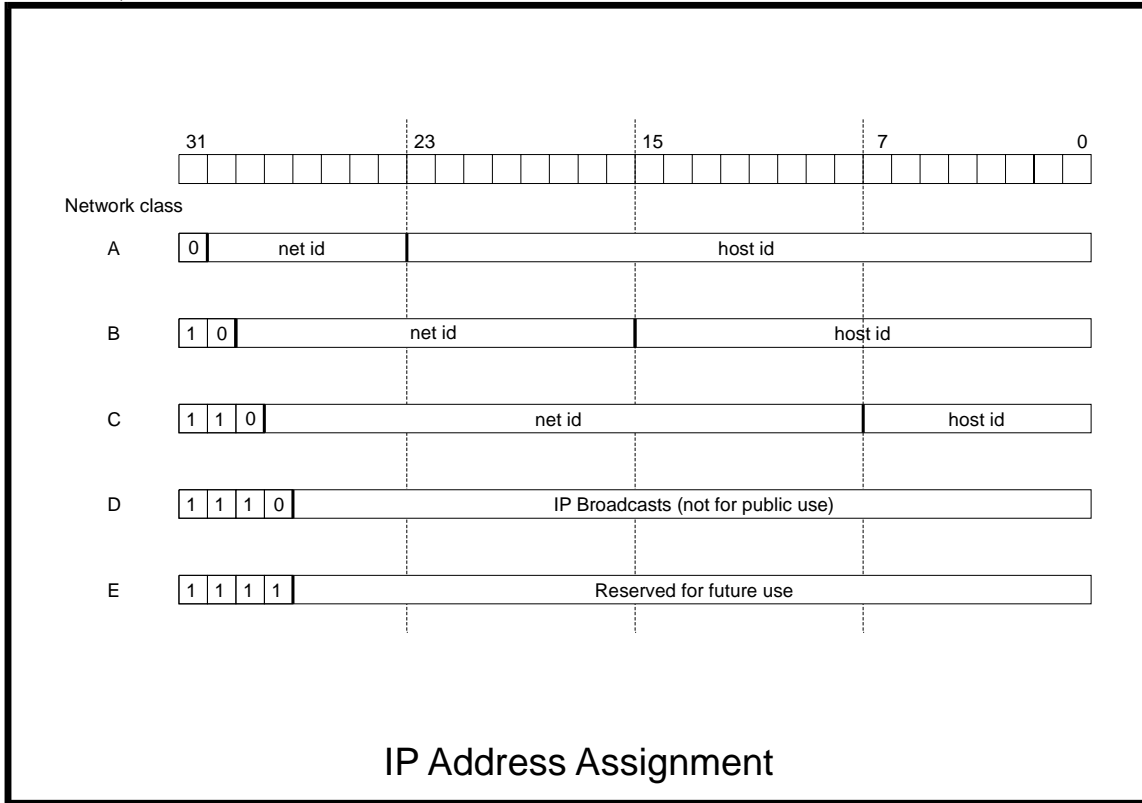
Figure 75 - TCP/IP Protocols

# Aspects of Digital Communication

## Chapter Real Networks

### 8.1.1. IPv4 Addresses

IPClasses.cdr 12-Apr-1997



**Figure 76 - IP Network Address Assignments**

“Dotted Decimal” Notation      d.d.d.d where “d” is a 8 bit binary number expressed in digital.

**Table 30 - IP Network Address Assignment**

Net Class	Number of network bits	First available net id	Last available net id	Number of nets available	Number of hosts available
A	7	1	126	126	16 777 214
B	14	128.1	191.254	16 382	65 534
C	21	192.0.1	223.255.254	2 097 150	254
D		224.0.0.0	239.255.255.254		
E		240.0.0.0	255.255.255.254		

**Aspects of Digital Communication**  
**Chapter Real Networks**

**Table 31 - IP Reserved Addresses**

Address	Discussion
127.x.x.x	where “x” is any number. Used for local loopback software tests
Net id =0, any class	my current network
Net id is all 1’s	
Host id =0	Any class, any network id
Host id = all 1’s	Network broadcast address
0.0.0.0	
255.255.255.255	Broadcast to all nodes on my network

**Table 32 - MSU Significant IP Addresses and Masks**

Binary	Hexadecimal	Dotted Decimal	Domain Name
0010 0011 0000 1000 0001 1001 0010 0111	23 08 19 27	35.8.25.39	argus.cem.msu.edu cem.msu.edu
0010 0011 0000 1000 0001 1000 0101 1011	23 08 18 5b	35.8.24.91	slater.cem.msu.edu www.cem.msu.edu
0010 0011 0000 1000 0001 1001 0100 1100	23 08 19 4c	35.8.25.76	poohbah.cem.msu.edu WINS Server
0010 0011 0000 1000 0000 0010 0010 1001	23 08 02 29	35.8.2.41	serv1.cl.msu.edu DNS server
0010 0011 0000 1000 0000 0010 0010 1010	23 08 02 2a	35.8.2.42	serv2.cl.msu.edu DNS server
0010 0011 0000 1000 0000 0010 0010 1011	23 08 02 2b	35.8.2.43	Serv3.cl.msu.edu DNS server
1111 1111 1111 1000 0000 0010 0010 1001	ff f8 00 00	255.248.0.0	Net mask
0010 0011 0000 1000 0000 0000 0000 0000	23 08 00 00	35.8.0.0	Broadcast address
0010 0011 0000 1000 0000 0010 0000 0011	23 08 02 03	35.8.2.3	gateway
0010 0011 0000 1000 0000 0010 0001 1001	23 08 02 19	35.8.2.25	WINS server
0010 0011 0000 1000 0000 0010 0100 0101	23 08 02 45	35.8.2.69	WINS server

**Aspects of Digital Communication**  
**Chapter Real Networks**

**8.1.2. IPv6 Addresses**

128 bits

Notation  $x:x:x:x:x:x:x$  where “x” is a 16 bit number represented in hexadecimal.  
 Leading zeros suppressed

**Table 33 - IPv6 Addressing Examples**

Actual	Preferred Notation	Alternative
FACE:1234:5678:ABCD:D023:3523:BBBB:1000	FACE:1234:5678:ABCD:D023:3523:BBBB:1000	
FACE:0000:0000:0000:0000:3523:BBBB:1000	FACE:0:0:0:0:3523:BBBB:1000	FACE::3523:BBBB:1000
0000:0000:0000:0000:0000:3523:BBBB:1000	0:0:0:0:0:3523:BBBB:1000	::3523:BBBB:1000

Notation  $x:x:x:x:x:d.d.d.d$  where “x” is a 16 bit number represented in hexadecimal, “d” is a 8 bit number expressed in decimal. Leading zeros suppressed.

**Table 34 - IPv6/IPv4 Addressing Examples**

IPv4	Actual	Preferred Notation	Alternative 1	Alternative 2
35.8.25.39	0000:0000:0000:0000:0000:0000:2308:1927	0:0:0:0:0:0:2308:1927	::2308:1927	0:0:0:0:0:0:35.8.25.39
35.8.2.3	0000:0000:0000:0000:0000:0000:2308:0203	0:0:0:0:0:0:2308:0203	::2308:0203	0:0:0:0:0:0:35.8.2.3
35.8.24.91	0000:0000:0000:0000:0000:0000:2308:185b	0:0:0:0:0:0:2308:185b	::2308:185b	0:0:0:0:0:0:35.8.24.91

## Chapter 9. Human-Machine interface

### Terminals, Workstations, and Terminal Emulation

Terminal is the last piece of hardware in the interface between the human user and the digital system. Thus, the "terminal" is the terminating equipment that sits at the boundary between the system and the user.

#### 9.1. Unit Record Equipment

These earliest examples of input and output devices include the keypunch, line printers, and other early "unit record" equipment.

#### 9.2. Early Terminals

Frieden: Flexiwriter

Teletype: ASR 33, ASR 35

DEC: Decwriter, Decwriter II

##### 9.2.1. Specific Example: TeleTYpe (TTY) (Current loop)

CEMCOMPFAC TTY 31-AUG-1992

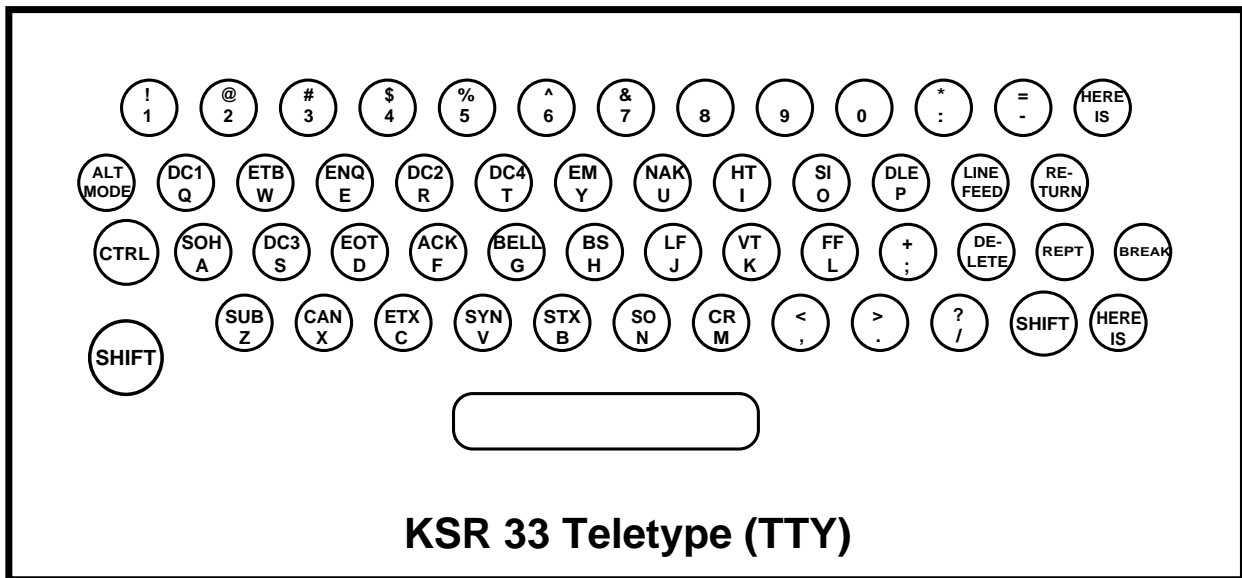


Figure 77 - Teletype (TTY) Keyboard

##### 9.2.1.1. Input (Keyboard)

Input is defined with respect to the CPU, thus input is information flowing from the TTY to the computer system.

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

**Table 35 - TTY Input from Keyboard**

Key struck	Action
A-Z	Transmit corresponding ASCII code
0-9	Transmit corresponding ASCII code
!"_#\$%&/	Transmit corresponding ASCII code
()*+,-./	Transmit corresponding ASCII code
@:;<=>?[^	Transmit corresponding ASCII code

**Table 36 - TTY Input from Keyboard 2**

Key struck	Action
BREAK	Line break - Hold communication line open for $t_d$
HERE IS	Transmit Answerback message (20 bytes)
DELETE	Transmit ASCII rubout
CTRL	Select Control meaning of Alphanumeric keys
RETURN	Transmit ASCII carriage return
LINE FEED	Transmit ASCII line feed
ESC	Transmit ASCII escape
REPEAT	Repeatedly transmit struck key
SHIFT	Select second meaning for the alpha keys
SPACE	Transmit ASCII space

**9.2.1.2. Output**

Output is defined with respect to the CPU, thus output is information flowing from the computer system to the TTY to .

**Table 37 - TTY Output**

Code received	Action (relative to current print head position)
A-Z	Print ASCII character and advance 1 character position
0-9	Print ASCII character and advance 1 character position
!"_#\$%&/	Print ASCII character and advance 1 character position
()*+,-./	Print ASCII character and advance 1 character position
@:;<=>?[^	Print ASCII character and advance 1 character position
Bell	Ring the bell
Carriage Return	Return print head to left margin
Line Feed	Advance paper one line
Space	Advance print head one position
Form Feed	Advance paper to the top of next page
Break	Print mechanism chatters but does not print or advance

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

**9.3. "CRT" Terminals**

IBM: 3270

DEC: VT52, VT100, VT220, VT320

Tectronix: 4010, 4006, 4014, 42xx

Lear Siegler: ADM-3

Hazeltine:

**9.3.1. Specific Example: VT100**

CEMCOMPFAC VT100 31-AUG-1992

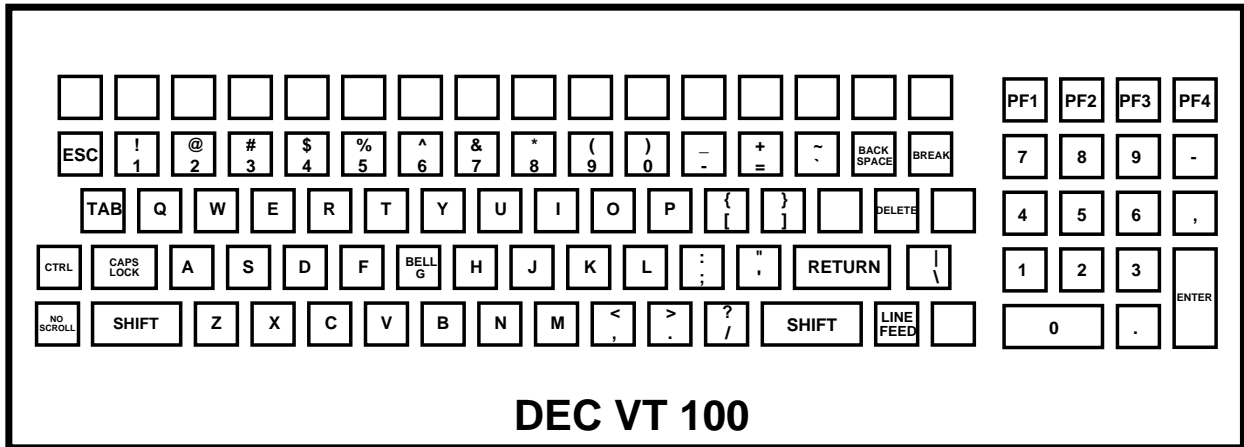


Figure 78 - DEC VT100 Keyboard

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

**9.3.1.1. Input (Keyboard)**

**Table 38 - TTY Input from Keyboard**

Key struck	Action
A-Z	Transmit corresponding ASCII code
a-z	Transmit corresponding ASCII code
0-9	Transmit corresponding ASCII code
Punctuation	Transmit corresponding ASCII code
BACKSPACE	Transmit ASCII backspace
BREAK	Hold comm. line in space state for 0.2333 sec
<SHIFT/BREAK>	Hold comm. line in space state for 3.5 sec. Drop DTR
<CTRL/BREAK>	Transmit Answerback message (20 bytes) to CPU
DELETE	Transmit ASCII rubout
CTRL	Select Control meaning of Alphanumeric keys
RETURN	Transmit ASCII carriage return
LINE FEED	Transmit ASCII line feed
ESC	Transmit ASCII escape
SHIFT	Select second meaning for the alpha keys
SPACE	Transmit ASCII space
SET-UP	Set terminal in special local set-up mode

**Table 39 - TTY Input from Keyboard**

Keypad keys (Causes the following codes to be transmitted upon being struck.

**Table 40 - VT100 Input from Keypad**

Key	Transmitted String
PF1	<ESC> O P
PF2	<ESC> O Q
PF3	<ESC> O R
PF4	<ESC> O S

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

**Table 41 - VT100 Input from Keypad**

Key	NUM mode	Application mode
0	0	<ESC> O p
1	1	<ESC> O q
2	2	<ESC> O r
3	3	<ESC> O s
4	4	<ESC> O t
5	5	<ESC> O u
6	6	<ESC> O v
7	7	<ESC> O w
8	8	<ESC> O x
9	9	<ESC> O y
.	.	<ESC> O n
	,	<ESC> O l
-	-	<ESC> O m
ENTER	<CR>	<ESC> O M

Table 1 VT100 Input from Curser Keys

**Table 42 - VT100 Input from Curser Keys**

Up	<ESC> [ A	<ESC> O A
Down	<ESC> [ B	<ESC> O B
Right	<ESC> [ C	<ESC> O C
Left	<ESC> [ D	<ESC> O D

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

**9.3.1.2. Output ASCII Set**

**Table 43 - VT100 Output**

Code received	Action (relative to current cursor position)
A-Z	Print ASCII character and advance 1 character position
a-z	Print ASCII character and advance 1 character position
0-9	Print ASCII character and advance 1 character position
Punctuation	Print ASCII character and advance 1 character position
Bell	Ring the bell
Carriage Return	Return cursor position to left margin
Line Feed	Advance cursor position one line
Space	Advance cursor position one position
Form Feed	Advance paper to the top of next page
HT	Move cursor position to next tab stop
BS	Move Cursor position back on position
ENQ	Transmit answerback message to computer
FF	Treated as line feed
VT	Treated as line feed
SO	Select G1 Character set
S1	Select G0 Character set

**9.3.1.3. Output Control Sequences**

The following are just a few control sequences that can be sent to the terminal from the driving software.

- Position cursor (to relative or absolute position)
- Clear screen
- Clear parts of screen
- Transmit the position of the cursor
- Change character types
- Set character attributes: blinking, bold, etc
- Transmit status of terminal

**9.4. Workstations**

**9.4.1. User Interface Input devices**

- Keyboard
- Keypad
- Mouse
- Track ball
- Switches
- Knobs

**Aspects of Digital Communication**  
**Chapter Human-Machine interface**

Touch screens  
Voice  
Digitizers

**9.4.2. User Interface Output devices**

Monitor  
Lights  
Sound  
Voice

**9.4.3. Examples**

IBM PC (Monochrome)  
IBM PC (CGA)  
IBM PC (EGA)  
IBM PC (PGA)  
IBM PC (VGA)  
MAC (Monochrome)  
MAC (Color)  
VAXstations (VWS)  
VAXstation (DECwindows)  
SUN (X-Windows)  
CGS, PHIGS, ...

**9.5. Terminal Emulation**

**9.6. Real Workstation Terminal Emulation (Communication) Programs**

VT100  
DEC Keyboard xxxx  
Zenith PC Keyboard xxxx  
    PATHWORKS/DOS sethost  
    FTP Software tnvt  
    ms-kermit  
MAC Keyboard xxx  
    PATHWORKS/MAC sethost  
    PROComm  
Zenith Z29