DigiPoints Volume 1

Leader Guide

Module 2 – Modem Overview

Summary

Modems are the interface between digital computers and the communications network. It is the modem that makes the sending of digital data possible between distant points. This module discusses how modems perform the various tasks needed to get data on and off of the network.

Outcomes

One of the potential advantages the cable telecommunications industry has is the ability to carry data signals at speeds significantly higher than what can be attained on telephony networks. This has the potential to be a valuable revenue source. It is important to build a foundation of knowledge about modems, modulation techniques, and the standards in place to provide these services. The data communications environment uses both switched and private line modems. Although similar in operations, there are differences. The cable modem will compete with both of these devices. It is important to build a foundation of knowledge about modems, modulation techniques, and the standards that are in place.

Module Objectives

Upon successful completion of this module, the student should be able to:

- Explain the differences between DTE and DCE.
- List the three basic tasks of a modem.
- Be able to categorize a modem in terms of switched or private line, synchronous or asynchronous, etc.
- Identify an RS232 connector.
- Explain the steps involved in setting up a communications link between modems.
- Explain the purpose of the Hayes Command Set.
- Explain the difference between private line and switched modems.
- State and define the common features of private line modems.
- Describe how a digital termination differs from an analog termination.
- Describe the functions that the CSU and the DSU perform.
- Describe what a null modem does.
- Identify and describe four different modulation techniques.

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- Explain the difference between QAM, 16 QAM, and 64 QAM signals.
- State four standards used on telephony modems to increase line speeds.
- Compare and contrast cable modems with telephony modems.

Prerequisites

Students should have read Chapter 2 of *DigiPoints, Volume 1*.

Length

2–2 ½ hours

Materials/Preparation for Instructor

- One workbook per student
- Visual Aids
- Instructor should read Chapter 2 of *DigiPoints, Volume 1*.

Supplies/Equipment

- Dry erase board with markers and eraser
- Easel flip chart
- Masking tape
- Pointing tool, e.g., laser or pointer
- Tent cards for students' names

Audience

The intended audience will be mid- to senior-level technicians or other associates who are seeking an understanding of digital basics.

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Module Outline

This is an introductory level module that will provide a review of the following topics:

Objectives 1
Introduction 2
Modem Basics 3
Other Modems 13
Modulation Techniques 23
Cable Modems and RF Modulators vs. Telephony Modems 34
Summary 35
Appendix 36

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Objectives

EXPLAIN

REFER TO WB 2.1

Tell students that when they have completed this module, they will be able to accomplish these objectives.

- Explain the differences between DTE and DCE.
- List the three basic tasks of a modem.
- Be able to categorize a modem in terms of switched or private line, synchronous or asynchronous, etc.
- Identify an RS232 Connector.
- Explain the steps involved in setting up a communications link between modems.
- Explain the purpose of the Hayes Command Set.
- Explain the difference between private line and switched modems.
- State and define the common features of private line modems.
- Describe how a digital termination differs from an analog termination.
- Describe the functions that the CSU and the DSU perform.
- Describe what a null modem does.
- Identify and describe four different modulation techniques.
- Explain the difference between QAM, 16 QAM, and 64 QAM signals.
- State four standards used on telephony modems to increase line speeds.
- Compare and contrast cable modems with telephony modems.

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Introduction

DISCUSS

Ask students to describe their understanding of what a modem is.

Most students have heard the term, but don't realize the technology behind making a modem communicate on a network.

This opening discussion will set the foundation for building on their existing understanding.

Write responses on the board or flip chart. Tell students this module will go into depth regarding how a modem allows communication through a network.

REFER TO WB 2.2
ASK

Where does the word "modem" originate?

It is a contraction of **MO**dulation/**DEM**odulation.

Write on easel:

MODEM

- Modems are devices that convert discrete digital signals to a continuous analog signal, and vice versa, so that digital information can be transmitted on a telecommunications network.
- The purpose of a modem is to:
  - ◊ Allow the transmission of a computer's digital data (information) to another computer or terminal using the telephone network…or, today, a cable TV network.
  - ◊ The modem makes this possible by converting the digital signals of a computer to a continuous analog signal.

Modem Basics

DISCUSS VA 2.1
REFER TO WB 2.3

Why Do We Have Modems?

When a person decides to make a telephone call to someone across the street or across the country, certain things must be in place.

A telephone is needed at both ends. And for the telephones to work, they must be connected to the local telephone companies' networks.

Finally, the local networks must be connected together.

The decision to make the call comes from the person making the call. Once started, the telephone and the telephone network put the call through to the far end.

The person on the other end answers and information passes between the two people. The telephones and the networks keep the call up until the people involved decide it is time to terminate the call.

This VA shows the same thing for machines communicating with each other.

The place of the person is taken by the computer. The modem takes the place of the telephone. The network can be the same for either a data or a voice call.

This is how a computer would be connected to a network.

- Both ends of the communications path would be connected similarly.
    - ◊ Each end could have a terminal, computer or some other type of machine.
    - ◊ Computer #2 would have to have a modem too.
- The computer is communicating with the modem via a digital signal.
    - ◊ The modem converts the digital signal to an analog signal.
- The modem is communicating through the network with the modem at the other end of the link via an analog signal.

- The second modem sends messages to the first modem using an analog signal.
  - ◊ The first modem converts the analog signal received from the network to a digital signal that the computer can recognize.

ASK

What type of signal is being passed between the computer and the modem?

Answer:

- ◊ *A digital signal*

ASK

What is the modem doing?

Answer:

- ◊ *Converting the digital pulse stream from the computer to an analog signal, and converting the analog signal from the network into a digital signal.*

DISCUSS VA 2.2

When the computer industry began in the late 1940s:

- It was estimated that there was only a worldwide demand for 6-9 computers.
- The first business computers were housed in corporate locations in secure, environmentally controlled environments.
- They were operated and maintained by staffs of systems engineers and programmers.
- The machines were programmed in "machine language", which required the programmer to tell the machine everything…such as designating a precise location on the disc when putting something into memory.
- Jobs were submitted to these "masters of the machine."
  - ◊ Key punch operators would produce the cards needed to program the computer and to input data.
  - ◊ Results, usually paper printouts, would be mailed to the user.

DISCUSS VA 2.3
REFER TO WB 2.4

- Submitting jobs by "hand" is not an efficient way of getting information to or from the machines.
- It is especially inefficient if the "user" is not in the same building…or city…or state…or country.
- Insurance claim reps, brokers, service reps, etc. all need access to information.
- Getting it to them directly from the computer would be more efficient.
- The remote user was set up on a dumb terminal in order to communicate with the centrally located computer.

ASK

What happens if the connection to the network is lost, the network fails, or the computer has problems?

Answer:

◊ *The people at the remote sites cannot do their jobs. Without the computer, or the connection to it, the remote location(s) are off line.*

◊ *If a task required a connection to the main computer…or some other computer…the task could not be completed until the computer or network was operational.*

ASK

What happens if the local access line to your home is cut?

Answer:

◊ *The machines and people at your location cannot communicate remotely.*

EXPLAIN VA 2.4
REFER TO WB 2.5

What is a Modem?

- The modem is connected between the computer, the Data Terminal Equipment (DTE) and the communications network.
- The modem is a piece of Data Circuit-Terminating Equipment. It is commonly known as Data Communications Equipment (DCE).
- The modem is in the first layer of the OSI Model. The physical layer.

Write on easel
DTE

DCE

OSI = Open Systems Interconnection.
It will be covered in detail in a subsequent session.

What does the modem do?

Answer:

◊ *It lets machines communicate over long distances like a telephone lets people talk.*

What is a DTE? Give an example.

Answer:

◊ *Data Terminal Equipment*
◊ *PC, mainframe*

DISCUSS VA 2.5
REFER TO WB 2.6

Modem Tasks

The four basic tasks common to all modems are:

- Handle the initial setup of the connection. This is sometimes called "handshaking."
- Convert the digital signals from the machine into a form suitable for the transmission over the physical circuit to which it is attached.
- Convert signals received from the line to a digital, machine readable format.
- Send and receive information over the circuit to which it is attached.

As users became more sophisticated, so did the requirements for modems. These tasks are built into more sophisticated modems.

- Protect the network facilities from harmful voltages or signals from the DTE side of the modem.

◊ This is typically handled by other external devices such as a data access arrangement (DAA), which is a transformer isolating the network from the equipment and vice versa.

- Automatically initiate and accept calls.
  - ◊ The computer starts the process, but the modem can handle the "routines" in setting up and completing the call.
- Error detection and correction. The correction may consist of little more than requesting a re-send. It is important because it relieves the computer of this responsibility.
- Identify and report equipment failures. The equipment can report on itself. Systems are also designed to a have modems report on other modems in the network.
  - ◊ One feature available is for the technician to use the modem that he/she is working at to show the indicator lights of the far end modem. In other words, the technician can "see", remotely, what indicator lights are on and off at the far end.

ASK

Why is it important to electrically isolate the network from the equipment?

Answer:

◊ *To avoid having harmful voltages entering the DTE from the network and to prevent harmful voltages from the DTE entering the network.*

ASK

What task can a sophisticated modem perform that will speed maintenance and repair?

Answer:

◊ *Identify and report problems. Sophisticated units can identify type of problem and location of the problems. There are also units that allow the user to remotely "look" at modems up and downstream.*

EXPLAIN VA 2.6
REFER TO WB 2.7

These descriptors are used to identify and categorize modems.

- Switched: Used on the switched telephony network.
- Non-switched: Used on private networks
- Full Duplex: Indicates simultaneous two-way transmission. This can be done by having transmit and receive connections on two different pairs of wires, which is known as a 4-wire connection. Assigning the incoming and outgoing messages to different frequency ranges can also provide full duplex service.
- Half Duplex: Indicates two way transmission, but in only one direction at a time. This is the typical 2-Wire circuit.
- Analog: For converting digital signal information from the machine to an analog signal for transmission on an analog network.
- Digital: Interfaces a digital machine with a digital network, i.e. ISDN.
- Asynchronous: Character by character transmission where each character contains both start and stop bits so that the respective terminals are synchronized.
- Synchronous: A data transmission method where the receiving and transmitting terminals are kept in time with each other via either an external clock or a clock signal embedded in the data itself.

ASK

If you were going to buy a modem for the PC you have sitting at home today, what adjectives would be used to describe it?

Answer:

◊ *Switched, full duplex, analog, and asynchronous.*

ASK

How could it operate in a full duplex state with only 2 wires?

Answer:

◊ *Two different sets of frequencies for sending and receiving.*

DISCUSS VA 2.7
REFER TO WB 2.8

How Does a Modem Work?

Two things must be considered:

- The physical connection between the DTE and the modem, and
- The protocols that the modem utilizes to talk to other modems.

Standards bodies have determined these.

For the type of modem we are discussing, the most obvious physical aspect is the RS-232 serial port found on it.

- This is a "D" shaped connector with 25 pins (DB-25).
- This is a common physical shape, and not every 25 pin "D" shaped plug will be an RS-232 interface.
- What makes the connector RS-232 is how the pins are wired.

DISCUSS VA 2.8
REFER TO WB 2.9

All 25 pins are defined for use in many situations. It is the way that the PINS are wired that makes this an RS-232 connector.

DO NOT go through every PIN. The table is for reference.

Other interfaces using the DB-25 pin connector include:

- EIA RS 449 – an RS 232 with extended range
- CCITT V.35

The signals on each pin on the RS-232 are digital and are transmitted serially, that is, one at a time.

ASK

Which pin is used to by the DTE to signal to the DCE that it is in the ready state?

Answer:

◊ *PIN 20*

Have the students refer to the table

ASK

Which pin is used by the DCE to signal to the DTE that it is on-line, has data carrier detect, and is prepared to receive data?

Answer:

◊ *PIN 8*

ASK

Which layer of the OSI Model is the RS232 connector?

Answer:

◊ *Layer 1, the physical layer*

ASK

Are there interfaces other than the RS-232 that use this connector?

Answer:

◊ *Yes*

DISCUSS VA 2.9
REFER TO WB 2.10 AND WB 2.11

- The RS-232 is a large connector.
- PC manufactures have gone to a DB-9 serial connector to save room on the computer.
  - ◊ It requires a converter to go from a 25 pin to a 9 pin connection.
- Look at the two versions of a RS232 that IBM uses:
  - ◊ The IBM 25 Pin RS-232C
  - ◊ The IBM 9 Pin RS-232C

Show examples of 25 and 9 pin RS232 plugs.

Why are there two different connectors?

Answer:

◊ *These are two different RS232C standards.*

◊ *The connector with fewer pins takes up less space on the back of the computer. This is especially important for laptops and other small computer devices, such as PDAs.*

Let the students refer to the table to answer this.

Point out that the RS–232 interface is not just ONE interface. There are variations. Look at name and suffix.

EXERCISE:

2 students in front of class.

Directions: Scenario: Student 1 is sitting at home watching TV. Student 2 is calling student 1 to deliver "personal" information.

This means that the student needs to confirm who is at the far end. Have them set up a conversation between themselves.

The objective is to show how a data call and a voice call are similar.

Make signs on 8.5 X 11 paper indicating the commands.

Direct the students to hold up the cards and explain the sequencing as they do this. Provide an envelope to the sender for the information to be passed once the communications link is established.

Point out the dialing, sending, receiving, acknowledging, agreeing, and actual transmission of information.

Time: 5 to 10 minutes.

EXPLAIN VA 2.10
REFER TO WB 2.12

- These are the steps taken by two modems in setting up and exchanging information.
  - ◊ First step is S dials up remote T.
  - ◊ Second, T answers and goes into data mode.
  - ◊ Third, T sends mark tone to S to let S know that T is ready. S goes into data mode.
  - ◊ Fourth, S sends mark tone to T.
  - ◊ Fifth, data sent between S & T.
- Modems should be ready to transmit data in 5 seconds.

ASK

Where does the data come?

Answer:

- ◊ *The data comes from the computer.*

ASK

What device controls the transmission of the data?

Answer:

◊ *The computer, the DTE device, would take control of the modems at each end of the connection. The modems handle the communications link, the computers provide and ultimately receive the data.*

ASK

How long does it take to complete the sequence of tasks setting up the connection?

Answer:

◊ *Should be done in 5 seconds or less.*

EXPLAIN VA 2.11
REFER TO WB 2.13

A commonly used set of instructions is known as the Hayes Command Set. These commands are received by the modem (DCE) from the computer (DTE). The basic format for a Hayes command is:

AT _____

A partial list of commands can be found in *DigiPoints, Volume 1*, Chapter 2. The most common one used is:

ATDT*telephone number*

- AT - is the preface to all the commands. It tells the modem to pay attention.

The next set of characters are the command, for example:

◊ **M1** – turn on modem's speaker, or
◊ **M0** – turn speaker off.

- All Hayes Commands are in CAPITALS.
- Lower case letters are not recognized.
- In many computer environments, the user does not have to remember the command set.

The user is prompted for a telephone number, the number of rings, whether or not to have the speaker on, etc. The command set is utilized in the software, but the interface with the user has been made easier to use.

Other Modems

EXPLAIN VA 2.12
REFER TO WB 2.14

Private Line Modems

Private networks are different from public networks in that all the facilities are dedicated to the "owner" of the private network.

- All the equipment on the private network may be owned and operated by one company.
- A company may have a combination of owned and leased equipment and lines. In this case, everything is still being dedicated to that one customer.
- In today's environment, there are true private networks, as described above, and virtual private networks (VPN).
- A VPN is a private network in which the "owner" of that network is sharing equipment and services with other clients. The separation of the networks is done via software.
- It can not be determined just by looking at them, if networks are traditional private networks or VPNs.

It is important to understand that the "owner" has rights to use specific equipment and services as if those items were privately owned and operated. Both types of networks have:

- Locations that could contain modems, computers and/or terminals.
- Non-switched, or private line modems, that are used in private networks.
- Modems connected to lines that form a private network for the organization.
- Modems permanently connected to the communication lines and to the modems located at the remote ends.
- Modems operating on the same principles as the dial up modems discussed in Module 1.

- Because these modems are permanently connected to one another, and the organizations that utilize them spend large amounts of money to transmit information:
  - ◊ The organizations that have private networks demand more capabilities than is available on dial up modems.
  - ◊ Example 1, the FAA Network is a private network. If it goes down planes are delayed.
  - ◊ Example 2 is the FED WIRE, which is used by financial institutions to move money around the country.

ASK

How is a private network different from a dial-up network?

Answer:

- ◊ *The modems are always connected to the network on a private network.*

ASK

How does a private network modem differ from a modem found on a dial-up network?

Answer:

- ◊ *These networks are always connected. Since the modems are always connected, these modems can be designed to have more functionality.*

ASK

Name some private networks with which you are familiar.

Answer:

- ◊ *We have identified the FAA and the FED Wire. Others that could be mentioned: Networks found at universities; military network; state and federal government networks; police networks, etc.*

DISCUSS VA 2.13
REFER TO WB 2.15

Private Network Modems

Private network modems are more sophisticated than dial up modems because:

- Network down time can be very expensive.
  - ◊ Modems must monitor the system and report deterioration of service quality as it is detected.
- It is also important for these systems to continue operating under less than proper conditions.
  - ◊ Private line modems have been designed to automatically adjust to deteriorating conditions in order to keep the data flowing between points.

Some of the more common enhanced features and capabilities found on Private Line Modems and Private Networks are:

- MNP Error Control:
  - ◊ MNP - Microcom Network Protocol.
  - ◊ It is a widely used technique to detect and request retransmission of frames with errors.
  - ◊ It is used on asynchronous lines.
- Diagnostics:
  - ◊ Software provided with the modem
  - ◊ Provides diagnostic capability and real time display of this information on either the modem or a control panel/screen.
  - ◊ They also provide information about the communications line.
- Loop Back:
  - ◊ The ability to locally and remotely loop back the modem and look down the line (analog signals) or back towards the DTE (digital signals)
  - ◊ Enhances the ability to isolate and correct problems.
- Adaptive Line Rate:
  - ◊ This feature allows the modem to “sense” the line conditions.
  - ◊ Adjusts the transmission rate to the maximum possible at a given time.

- Adaptive Inbound Rate:
  - ◊ Similar to the Adaptive Line Rate.
  - ◊ Utilized on circuits that have multiple drops/termination points.
  - ◊ Each modem on the line has its own conversation with the host computer.
  - ◊ It can happen that a particular segment of the circuit can be having problems.
  - ◊ If this would occur on a network without this feature, ALL the drops/modems would have to reduce their speed to the slowest speed of transmission on the circuit.
  - ◊ With this capability, each modem is able to transmit at the fastest supportable speed between that modem and the computer.
  - ◊ An entire circuit is not degraded because of a problem at one location.
- Modem Sharing:
  - ◊ This feature allows multiple low speed channels to share one higher speed channel.
  - ◊ For example, perhaps 4 - 4800 bps channels could be concentrated onto one 19.2 kbps line.
- Signal Constellation Generator:
  - ◊ Provides a modem's signals at externally available test points.
  - ◊ Allows a technician to look at the signals with external test equipment.
- Reverse Channel Capability:
  - ◊ Common in half-duplex applications.
  - ◊ It amounts to a small upstream channel using a narrow band of frequencies to send information to the transmitting end.
  - ◊ This is how some cable modems work.

- Network Management:
  - ◊ These are systems that collect information on modems and other devices on the network, e.g., concentrators, terminals, etc.
  - ◊ By collecting this information and sending it back to a centralized point, it is possible to monitor the performance of an entire network at one centralized point.
  - ◊ This monitoring can be done by either the host processor or, as is more common, by an adjunct processor specifically set up for this task.
  - ◊ By employing Network Management software, it is possible to continuously monitor the health of the network, circuits, and specific items of equipment.
  - ◊ Problems can be addressed before total failure occurs.
  - ◊ Chronic problems can be monitored in an attempt to identify the causes of recurring failures.

ASK

What is reverse channel capability?

Let the students discuss these questions.

Answer:

- ◊ *This is typically found on half duplex systems. It provides the end terminal a way to send information upstream to the transmitting equipment. This is done by allocating a narrow band of frequencies to the receiving end for upstream signaling.*

ASK

What is the advantage of having modems with the Adaptive Inbound Rate feature?

Answer:

- ◊ *An entire circuit is not degraded because of a problem at one location.*
- ◊ *Each modem on the line has its own conversation with the host computer.*
- ◊ *It can happen that a particular segment of the circuit can be having problems.*
- ◊ *If this would occur on a network without this feature, all the drops/modems would have to reduce their speed to the slowest speed of transmission on the circuit.*
- ◊ *With this capability, each modem is able to transmit at the fastest supportable speed between that modem and the computer.*

ASK

Briefly describe the difference between diagnostics and network management.

Are they mutually exclusive?

Students need not answer completely, but should know basic difference.

Answer:

- ◊ *First, they are not mutually exclusive.*
- ◊ *Different information is provided.*

- ◊ *Diagnostics is the:*
  - – Software provided with the modem
  - – –Provides diagnostic capability and real time display of this information on either the modem or a control panel/screen.
- ◊ *These internal diagnostic capabilities can provide information about the communications line too.*
- ◊ *Network Management provides details beyond the simple diagnostics to include:*
  - – Information on modems and other devices on the network, e.g., concentrators, terminals, etc.
  - – Collecting this information and sending it back to a centralized point, it is possible to monitor the performance of an entire network at one centralized point.
  - – Monitoring can be done by either the host processor or, as is more common, by an adjunct processor specifically set up for this task.
  - – Network Management software makes it possible to continuously monitor the health of the network, circuits, and specific items of equipment.
  - – Problems are addressed before total failure occurs
  - – Chronic problems can be monitored in an attempt to identify the causative factor in recurring failures.

DISCUSS VA 2.14
REFER TO WB 2.16

Null Modem

- This is needed when attempting to connect co-located DTE devices, such as PCs, together.
  - ◊ The DTE devices normally communicate through the DCE devices.
  - ◊ The short distance involved does not require a modem.
  - ◊ An asynchronous adapter known as a "null modem" or "null modem cable" is used.
- Why can the two DTE devices NOT be connected together?
  - ◊ Because both devices would deliver their respective outputs to the same pin, i.e., 2 to 2, 3 to 3, etc.
  - ◊ The null modem adapters are put on the DTE equipment to cross connect the transmit and receive pins of each device.

ASK

When is a modem not a modem?

Answer:

- ◊ *When it is a null modem*

ASK

How does the null modem actually work?

Answer:

- ◊ *The null modem is attached to each DTE device's RS-232 connector.*
- ◊ *The DCE is bypassed. Because PIN 2 of DTE(1) and PIN 2 of DTE(2) cannot talk to one another directly.*
- ◊ *The null modem cross connects PIN 2 of DTE(1) to the appropriate PIN of DTE(2). All the sending pins must be cross-connected to their respective receiving pins.*

ASK

Give an example of where a null modem might be used.

Answer:

- ◊ *To connect collocated PCs*

DISCUSS VA 2.15
REFER TO WB 2.17

Digital Terminations – DSU and CSU

Not all DCE devices are modems that convert DTE digital signals to analog signals.

- It is also possible to take the DTE digital signal and prepare it for transmission via a digital network.
  - ◊ The DTE's digital signal, as it originates from the machine, cannot go directly onto a digital network.
  - ◊ It must be prepared for that network.
- That is the task of a different type of DCE device. Sometimes it is referred to as a digital modem.
  - ◊ The proper nomenclature for these devices is to call them either a CSU (Channel Service Unit) or a DSU (Data Service Unit).
  - ◊ These are the physical network interfaces between the customer and the network service provider
- The CSU provides electrical isolation of the customer's equipment and the service provider's network.
  - ◊ Voltage from the customer's DTE does not go directly onto the provider's network and vice versa.
- The DSU, includes a CSU in it,
  - ◊ Does what the CSU does plus it provides a properly formed digital pulse that is compatible with the service provider's network.
  - ◊ Timing of these pulses is also provided.

- Other advantages of digital terminations:
  - ◊ Both the CSU and DSU can provide diagnostic testing and loop backs.
  - ◊ There is no analog to digital to analog conversion,
  - ◊ These digital line terminations are typically less expensive than modems.
  - ◊ While the typical modem can operate up to 53 kbps today, the digital lines typically start at 56 kbps and go higher, such as 1.544 Mbps.

ASK

How does the "digital modem" differ from the analog modems discussed earlier?

Answer:

- ◊ *The digital modem does not do an analog to digital to analog conversion.*

ASK

What is the difference between a DSU and a CSU?

Answer:

- ◊ *The CSU is a line isolation device. The DSU has that capability, plus other functions:*
- ◊ *It provides properly formed and timed digital pulses.*

Modulation Techniques

DISCUSS VA 2.16
REFER TO WB 2.18

Digital Signals on Analog Lines

- Computer output is a digital signal, a series of voltages representing 1s and 0s.
- Networks were originally designed to handle analog information.
    - ◊ The need is to convert the digital signals into analog signals.
- There is also the need to put multiple conversations onto one actual signal path.
- The process used is call modulation.
- The common modulation techniques used are:
    - ◊ Frequency
    - ◊ Amplitude
    - ◊ Phase
    - ◊ Multibit

DICUSSS VA 2.17
REFER TO WB 2.19

Frequency Modulation

- Frequency modulation, FM
  - ◊ Assigns one discreet frequency to a 1 bit, and
  - ◊ A second frequency is assigned to a 0 bit.
  - ◊ It is a simple technique that allows for inexpensive, easy to build devices which consume little power and are relatively insensitive to noise.
  - ◊ FM when applied to data is also known as Frequency Shift Keying or FSK.
- With only two states, only one bit can be sent at a time using this technique.
  - ◊ Each character must have a signal indicating when that character begins and ends.
  - ◊ This requirement for start and stop bits puts a large overhead requirement for each character.
  - ◊ This limits the number of characters per second that can be transmitted on a given line.
  - ◊ FM modems were adequate at data speeds of 1200 bps or less.
  - ◊ These modems are unacceptable in an environment that demands higher transfer rates.

ASK

What is the limiting factor with FM modulation?

Answer:

- ◊ *One bit is sent at a time. Each character must have start & stop bits. This adds significant overhead.*

EXPLAIN VA 2.18
REFER TO WB 2.20

Amplitude Modulation

Amplitude Modulation, AM

- The amplitude of the sine wave is changed, not the frequency.
- There must always be an amplitude on the line so that the receiving equipment knows that there is signal present.
  - ◊ A 1 is represented by one amplitude, and
  - ◊ A 0 is represented by another non-zero amplitude
- Modems using AM techniques are much more susceptible to noise than are FM modems, and
- These modems use more power.
  - ◊ Pure AM modems are rare;
  - ◊ This technique is used in conjunction with other modulation techniques, such as multibit modulation.

ASK

- AM when applied to data is also known as Amplitude Shift Keying or ASK.

Why is a zero amplitude NOT used to represent a 0 bit?

Answer:

- ◊ *There are constraints in using "nothing" to represent something. The far end modem could detect a loss of carrier signal and disconnect if a string of zeros arrived.*

DISCUSS VA 2.19
REFER TO WB 2.21

Phase Modulation, PM

- Uses the starting point of the sine wave carrier to code 1s and 0s onto the sine waves.
- A way of implementing PM is to change the phase of the carrier whenever a 1 bit is transmitted.
    - ◊ In this coding scheme, a 1 bit will cause a change in the phase, and
    - ◊ A 0 bit will cause the carrier to maintain the same phase, that is, no change.
    - ◊ It is the change to the 1 bit that causes the phase change.
- PM is also known as Phase Shift Keying, PSK.

EXPLAIN

Multibit Modulation

Write on board:
Bandwidth constraints

- All systems have bandwidth constraints.
- For example: the telephony network was designed for voice conversation, 0 – 4000 Hz.

Telephony limit 4 kHz

- Shannon's Law
  - ◊ In order to define frequency, amplitude, or the phase of a sine wave, it is necessary to have AT LEAST one-half (½) of the cycle before changing to a different phase.

Shannon's Law: frequency amplitude phase

- To get the maximum number of changes in a given unit of time, the sine wave used must be the highest frequency feasible for that particular media.
  - ◊ This will allow for the highest speed modem.

Use highest frequency possible

Multibit

- Techniques were created to get MORE information on the highest frequency allowed for that medium.
  - ◊ The set of techniques used to do this is known as multibit modulation
  - ◊ Two of the multibit techniques are:
  - ◊ QAM – Quadrature Amplitude Modulation and
  - ◊ QPSK – Quadrature Phase Shift Keying

QAM

QPSK

DISCUSS VA 2.20
REFER TO WB 2.22

QPSK

The concept behind QPSK is to use more than just two phase shifts to code digital information.

- In QPSK, four (4) phase shifts, or angles are used.
- With 4 phase shifts there are 4 sets of numbers that can be encoded.
  - ◊ Two bits can be encoded with each phase shift.
  - ◊ In the binary system, those four numbers are 00, 01, 10, and 11.
  - ◊ With constant amplitude, QPSK has 4 unique states.

ASK

What does Shannon's Law state?

Answer:

- ◊ *In order to define frequency, amplitude, or the phase of a sine wave, it is necessary to have AT LEAST one-half (½) of the cycle before changing to a different phase.*

ASK

How does this affect the frequency chosen for a particular medium?

Answer:

- ◊ *Pick the highest frequency that can be transmitted on that medium to maximize the line rate, i.e., the speed of transmission.*

ASK

Why?

Answer:

- ◊ *Since ½ of the cycle is needed, the more cycles that are available, the more information that can be sent.*

ASK

What is multibit modulation and how does it work?

Answer:

◊ *Multibit modulation uses phase shifts to indicate changes in state. There can be more than 2 phase shifts used. For example, with QPSK the phase shifts can be at 0º, 90º, 180º, and 270º. Four different states allow the encoding of four sets of bits: 00, 01, 10, and 11.*

DISCUSS VA 2.21
REFER TO WB 2.23

QAM

QAM is an extension of the QPSK concept.

- The phase angle is changed, and
- The signal has multiple amplitudes.
- 16 QAM is an example of a QAM signal that has:
  - ◊ 4 phase angles, and
  - ◊ Each phase angle has 4 possible amplitudes.
  - ◊ It is called 16QAM because there are 16 possible states for the signal.

DISCUSS VA 2.22
REFER TO WB 2.24

This is a graphical representation of 16QAM.

What would 64QAM look like?

Answer:

- ◊ *8 phase angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) and 8 amplitudes for each phase angle.*

Let the students discuss this.

Have a student sketch one quadrant of this on the easel. The appendix has a sketch of how this could look.

How many bits are in each state of a 64 QAM signal?

Answer:

- ◊ *63 Base 10 = 111111 Base 2.*
- ◊ *Reasoning: 000 000 is one state. The other 63 states are handled with 6 bits.*
- ◊ *1 1 1 1 1 1 is*
  32+16+8+4+2 +1 = 63
  63 + 0 makes for 64 states.

It may be necessary to Review the Base 2 to Base 10 conversions from Module 1

What would 256QAM look like?

Answer:

- ◊ *The square root of 256 is 16.*
- ◊ *There would be 16 phase angles (22.5^o between each angle), and*
- ◊ *16 distinct amplitudes for each phase angle.*

How many bits are in each state?

Answer:

- ◊ *255 Base 10 = 1111 1111 Base2*
- ◊ *1 1 1 1 1 1 1 1*
- ◊ *128+64+32+16+8+4+2+1=255*
- ◊ *8 bits in each state.*

DISCUSS VA 2.23
REFER TO WB 2.25

Increased Speeds Through New Standards

- To improve the transmission rate over telephony networks, using twisted copper pairs, the V.x standards were established by the ITU.
- The more common ones in use are V.32, V.32bis, V.34, V.42bis, and V.90.
- The V.32 standard was developed to achieve modem speeds up to 9600 bits per second.
    - ◊ V.32 specifies synchronous, full duplex operation over two wire switched circuits.
    - ◊ An error correcting modulation technique called Trellis-coded modulation is used to overcome noise problems on dial-up lines.
- V.32bis allows modems to operate over copper pair at 14.4 Kilobits per second.
    - ◊ This standard specifies an optional "fall forward" feature that eliminates the need for reestablishing connections to regain high-speed operation as line conditions improve.
- V.34 currently provides a higher data rate over copper pair by applying adaptive intelligence.
    - ◊ Adaptive intelligence is the ability to sense the characteristics of the communications environment at any given moment and to shift resources accordingly for optimum performance.
    - ◊ Once a connection is made, a V.34 modem automatically selects and combines an optimum set of modulation tools, adapting as the condition of the telephone line varies.

ITU= International Telecommunications Union

- ◊ Tools include:
  - – Improved handshake procedures at sign-on,
  - – Line probing to determine proper filtering, power levels, and carrier frequency,
  - – Improved equalizing of different carrier frequencies,
  - – Enhanced Trellis coding for better error correction, and
  - – A fast tracking, or synchronization process, on initial connection establishment.
- ◊ To accommodate these higher bit rates, a new physical level interface has been specified to replace the RS-232 standard. Because of the large base of RS-232 interfaces on computer equipment, however, at least one version of the V.34 interface is backward compatible with RS 232.

ASK

- V.42bis standard can be used with V.34 type modems to improve performance.
  - ◊ Data compression technique
  - ◊ Replaces strings of 0s or 1s with special codes
  - ◊ Replace common strings, such as the one representing “the” with a shorter code.

What is the advantage of using the V.42bis standard?

Answer:

- ◊ *Through the use of data compression techniques, more information can be transmitted.*

Cable Modems and RF Modulators vs. Telephony Modems

DISCUSS VA 2.24
REFER TO WB 2.26

Cable Modems

Cable modems are inherently faster than telephony modems.

- Same modulation techniques are used, but
- Cable modems use higher frequencies and therefore have the ability to carry more bits per second.
- Telephony modems operate up to 56 kbps today
- Commercial cable modems are available at speeds up to 10 mbps.
- Standards are important to make cable modem usage widespread.
    - ◊ Consider FAX machines. If you have a fax machine, you can connect to another fax machine anywhere in the world.
    - ◊ CableLabs and SCTE are working to further advance standards for cable modems.

ASK

What makes cable modems faster than telephony modems?

Answer:

- ◊ *Cable modems operate on a medium that has a higher potential bandwidth.*

REFER TO WB 2.27 THROUGH WB 2.29

Summary

Have students answer the study questions at the end of Module 2. Review the answers.

Answers in Appendix

APPENDIX

Answers to the questions at end of student workbooks.

1. What is a modem?

   A device used to convert discrete digital signals from a computer or business machine to a continuous analog signal (and vice versa) so that information can be transmitted on a telecommunications network.

2. What is the purpose of a modem? What does it allow the user to do?

   A modem is a peripheral device to the computer that allows machines to talk to each other. It has three basic tasks:
   - *Set up the connection*
   - *Convert digital signals from the computer into a form suitable for transmission over the physical circuit to which it is attached and convert line signals back into digital signals for the computer.*
   - *Send and receive information over the circuit to which it is attached.*

3. Define the following terms:

   DTE - Data Terminal Equipment.- Equipment which originates and receives data over a communications channel.

   DCE - Data Circuit Terminating Equipment or Data Communications Equipment - Equipment that establishes a connection to a network, interfaces with the DTE, and terminates the connection when transmission is finished. A modem is an example of DCE.

   Asynchronous - Data transmission method that requires a start and stop bit to be associated with each word that is transmitted.

   Synchronous - Data transmission method where the receiving and transmitting terminals are kept in time with each other via an external clock or a clock signal embedded in the data itself.

   Full Duplex - Circuit over which information can be sent in both directions simultaneously

   Half Duplex - Circuit over which information can be sent in only one direction at a time.

DAA - Data Access Arrangement. Transformer that isolates the network and the customer from each other

4. What is the physical interface between the computer and the modem?

The modem is connected to the computer via an RS-232 serial port.

5. What is the physical interface between the modem and the telephone line?

The modem is connected to the telephone line via an RJ-11 jack.

6. Explain why two PCs cannot be directly connected together to transfer information. What device is used to make it possible to effect a connection between two PCs? How does it do this?

A direct connection is not possible because both devices would deliver their respective outputs to the same pin. For communication to occur, leads such as transmit and receive must be cross-connected. A null modem accomplishes the connection of two PCs without a modem by providing the required cross-connections.

7. What are the three basic modulation methods, and how do they work?

The three modulation methods are frequency modulation, amplitude modulation, and phase modulation. Frequency modulation operates by assigning one frequency to a 1 bit, and a second frequency to a 0 bit. Amplitude modulation (AM) uses a fixed frequency sine wave carrier, but changes the amplitude of that carrier to code 0s and 1s. Phase modulation (PM) uses the timing of the starting point of the sine wave carrier to code 1s and 0s.

8. How do QAM and QPSK differ?

QPSK uses more than one phase shift to code digital information. The Q in QPSK indicates that quad, or four, phase angles are being used. QAM changes the amplitude of the signal as well as the phase angle.

9. What is the purpose of the V.34 and V.42bis standards for telephony modems?

V.34 applies adaptive intelligence, or the ability to sense the characteristics of its communications environment at any given moment and to shift resources accordingly for optimum performance. Many V.34 modems use the V.42bis data compression standard to further improve the effective data rate.

10. What is the major difference between the modulation techniques used for telephony modems and cable modems?

Cable modems differ from telephony modems in that the transmission speed of a cable modem is higher, different protocols, or rules for data transfer, may be used to define the data transmission, and the media connecting to the cable modem is coax rather than twisted pair. Currently, QAM technology is the modulation scheme used to send data downstream and QPSK is used in the upstream links for a cable modem, whereas a telephony modem typically uses one type of modulation in both directions.

11. Describe phase, frequency, and amplitude of a sine wave.

The amplitude of the sine wave is the maximum height of the waveform. The frequency is the number of times per second that the sine wave repeats itself. The phase is the relationship of the starting time of the sine wave to some reference sine wave.

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