

Chapter 3

Radio Frequency Communications

At a Glance

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Lecture Notes

Overview

Chapter 3 introduces students to the different components that make up a radio communications system. The ways in which a radio signal can be influenced, either by active or passive devices, or by environmental conditions, is also discussed. Organizations that form standards applicable to wireless communications and network communications in general are detailed. Finally, the use of unregulated radio frequency bands is explored.

Chapter Objectives

After reading this chapter and completing the exercises, the student will be able to:

- List the basic components of a radio system
- Describe the factors that affect the design of a radio system
- Discuss why standards are beneficial and list the major telecommunications standards organizations
- Explain the radio frequency spectrum

Teaching Tips

Components of a Radio System

Filters

1. Explain how an RF signal filter works to remove unwanted signals based on a signal's frequency.
2. Introduce the three different types of RF filters, and explain how each functions:
 - a. Low-pass (uses maximum frequency threshold)
 - b. Bandpass (uses a minimum and maximum threshold, called a passband)
 - c. High-pass (uses a maximum threshold)
3. Describe harmonics as stray signals that are created during the modulation process, which require filtering.
4. Explain to students that filters are commonly used in transmitters to filter out harmonic oscillations that occur from modulation of a signal.
5. Define an intermediate frequency (IF) signal as the output from the modulation process, and describe how a filter removes unwanted frequencies from this signal.

Teaching Tip

Both DSL services and cable services make use of filter devices. With DSL, the filter is typically a low-pass filter that keeps phone services from interfering with

	DSL frequencies. Filters used for cable services are usually high pass or bandpass filters.
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Mixers

1. Mixers should be described as a device that combines two signals to create a single output signal. Show students the standard mixer symbol.
2. Explain sidebands as the sum and difference of two input frequencies, and show how a lower and upper sideband exists with the frequency carrier at the center.
3. Demonstrate how a mixer can take an input frequency and output a specific desired frequency.

Amplifiers

1. Introduce amplifiers as devices that increase the amplitude of a radio frequency signal, and show the symbol used for an amplifier.
2. Explain that amplifiers are necessary to make up for the losses in signal when passing through other passive devices, such as filters and mixers.
3. Note that because an amplifier requires electricity to increase a signal's strength, it is considered an active device.

Antennas

1. Show students the standard symbol used for an antenna, and explain that both a transmitter and a receiver require an antenna.

Design of a Radio System

Multiple Access

1. Provide a basic overview on how multiple wireless devices can make use of the same frequency.
2. Introduce the Frequency Division Multiple Access (FDMA) standard, which uses small frequency bands created by the division of the bandwidth of a channel.
3. Discuss the issue of crosstalk, which occurs when one signal on a specific frequency bleeds into another frequency.

4. Time Division Multiple Access (TDMA) can be explained as a standard that attempts to address crosstalk issues by using time slots. Note what advantages TDMA has in comparison to FDMA.
5. Describe Code Division Multiple Access (CDMA) as a standard commonly used by cellular phones that uses direct sequence spread spectrum in addition to a digital spreading code, or PN code.
6. Elaborate on how the PN code is used to identify unique transmissions in a frequency range. Explain how the PN code ensures that an unintended receiver of a transmission will ignore the transmission.
7. Point out the following advantages of CDMA in comparison to TDMA:
 - a. Can carry three times the amount of data
 - b. Harder to eavesdrop due to spread spectrum
 - c. Eavesdropper must know exact chip and PN code

Transmission Direction

1. Explain simplex transmission as a one way signal transmission between two or more points.
2. Half-duplex transmission can be explained as two way transmission that functions one way at a time, such as with CB radios or walkie-talkies.
3. Describe full-duplex transmission as two way communication that can occur simultaneously between devices.
4. Students should understand how full-duplex wireless devices commonly make use of separate sending and receiving frequencies.

Teaching Tip

Many Ethernet based radios are capable of full duplex transmission, but utilize aggregated bandwidth. In other words, an Ethernet radio with full duplex and 300 Mbps throughput is capable of utilizing 150 Mbps for transmit, and 150 Mbps for receive. Some radios can redistribute this allocation based on utilization.

Switching

1. Discuss the process of switching, and explain that it involves the moving or “switching” of a signal between wires or frequencies.
2. Define circuit switching as switching that involves the creation of a direct circuit between points.

3. Packet switching should be explained as using packets that are sent on a network, with each packet possibly using different paths to reach a destination. Students should be aware of the advantages of packet switching, such as better bandwidth utilization and increased error correction.

Signal Strength

1. Emphasize the importance of signal strength in maintaining wireless communications.
2. Describe electromagnetic interference (EMI), or noise, and list some typical sources of interference.
3. Define the signal-to-noise ratio (SNR) as a measurement of signal strength in comparison to background noise. Students should understand that amplifiers and signal filters can assist in improving SNR, as can the use of FHSS.
4. Point out to students the typical causes of attenuation, which results in a loss of signal strength, such as solid objects.
5. Describe the problem caused by multipath distortion, which can cause interference when a transmitted signal is received from multiple different reflected paths.
6. Explain how a directional antenna can be used to minimize multipath distortion by focusing electromagnetic waves into specific direction.
7. Point out other methods of reducing the effects of multipath distortion, such as the use of a powerful amplifier, or using separate frequencies for the same signal.

Quick Quiz 1

1. The output from the modulation process is known as which of the following?
 - A. crosstalk
 - B. attenuation
 - C. intermediate frequency (IF)
 - D. harmonicsAnswer: C
2. True or False: Crosstalk is a desirable effect that occurs when one frequency increases the signal strength of neighboring frequencies.
Answer: False
3. Which multiple access wireless technology utilizes a digital spreading code to identify unique transmissions in a specific frequency range?
 - A. FDMA
 - B. CDMA

- C. TDMA
- D. RDMA

Answer: B

4. Select the device below that removes unwanted RF signals by setting a maximum frequency threshold, allowing all signals below the threshold to pass.
- A. Low pass filter
 - B. High pass filter
 - C. Pass band filter
 - D. Mid-range filter

Answer: A

5. Which of the following is a way of minimizing multipath distortion?
- A. Using a single receiver radio
 - B. Using an omnidirectional antenna
 - C. Using a low-power amplifier
 - D. Using directional antennas

Answer: D

Understanding Standards

The Need for Standards

1. Stress the need for standardization, which helps to ensure compatibility between devices from different vendors.

Advantages and Disadvantages of Standards

1. Explain that devices would most likely not be interoperable without standards, and explain how standards help to create competition between vendors.
2. Elaborate on the problem of proprietary devices being phased out, and point out how standards can provide alternatives or a clear migration path.
3. Students should understand that international standards can be a disadvantage in that they can create overseas competition. Note also that standards can often produce competing standards that attempt to address a specific issue or shortcoming, while also creating incompatibility.

Teaching Tip

Before the 802.11n standard was completed, several manufacturers created “Draft-n” devices, which were based on early drafts of the 802.11n standard. These devices often had compatibility issues between different equipment vendors, which typically limited the available throughput on the network.

Types of Standards

1. Explain a de facto standard as an unofficial standard that is common practice within a specific industry.
2. De jure standards can be explained as official standards that are controlled by a specific organization or body.
3. Describe how standards are typically created, and introduce students to the use of Requests for Comments (RFCs), which are draft documents.
4. Explain that one problem with de jure standards is that standards can take a considerable amount of time to be completed.
5. Describe a consortia as an industry sponsored organization that promotes a specific technology, and use the World Wide Web Consortium (W3C) consisting of Microsoft, Netscape, Sun / Oracle, and IBM as an example.

Teaching Tip

RFCs are freely available to anyone who is interested in reading them. Many RFCs that describe how the Internet and networks function in general are archived on <http://www.ietf.org>

Telecommunications Standards Organizations

1. Describe the American National Standards Institute (ANSI) as a standards organization that creates standards for different industries within the United States.
2. The Telecommunications Industries Association (TIA) should be noted as an ANSI affiliated organization consisting of vendors in telecommunications, electronic components, consumer electronics, and electronic information.
3. Introduce the Internet Engineering Task Force (IETF) as a large community that focuses on the development and standardization of telecommunications protocols. Note that the IETF was formalized by the Internet Architecture Board (IAB).
4. The Internet Society (ISOC) should be described an organization consisting of experts that often oversee the construction of policies and standards made by other boards.
5. Describe the Institute of Electrical and Electronics Engineers (IEEE) as an organization that establishes standards for the IT industry as a whole, in addition to telecommunications standards.

6. Explain the role of the European Telecommunications Standards Institute (ETSI) in the development of standards for use in Europe.
7. Discuss the International Telecommunication Union (ITU) as an organization that sets standards for all member nations, and note that the ITU-T subsidiary focuses on telecommunications, while ITU-R focuses on RF-based communications.
8. The International Organization for Standardization (ISO) can be discussed as than organization that establishes standards in a wide variety of fields.

Regulatory Agencies

1. Discuss the role of the Federal Communications Commission (FCC) in regulating and licensing radio frequency usage.
2. Stress the importance of using properly licensed frequencies for the transmission of wireless signals.

Radio Frequency Spectrum

1. Define the radio frequency spectrum as the range of radio frequencies that exist, starting at 10 KHz and moving up to over 30 GHz, and explain how the spectrum is divided into 450 different bands.
2. List the following radio frequency band acronyms, and note some common uses of each band:
 - a. Very Low Frequency (VLF)
 - b. Low Frequency (LF)
 - c. Medium Frequency (MF)
 - d. High Frequency (HF)
 - e. Very High Frequency (VHF)
 - f. Ultra High Frequency (UHF)
 - g. Super High Frequency (SHF)
 - h. Extremely High Frequency (EHF)
3. Explain how international spectrum allocations established by the ITU can affect the United States.
4. Describe the license exempt spectrum, or unregulated bands, as bands that do not require special licensing for use, and are available to mobile or fixed devices.
5. List the unregulated bands established by the ITU-R:
 - a. Industrial, Scientific and Medical (ISM) band
 - b. Unlicensed National Information Infrastructure (U-NII)
 - c. Unlicensed Personal Communications Systems
 - d. Millimeter Wave

6. Discuss the use of adaptive array processing which uses an array of antenna elements that can deliver RF signals to specific users instead of radiating signals out in all directions.

Quick Quiz 2

1. What type of network uses small units of data that can be sent independently through the network?

Answer: packet switched

2. True or False: A de facto standard is an official standard that is ratified by a standards producing organization or body.

Answer: False

3. Which organization is an international organization that has two separate subsidiaries responsible for the creation of telecommunications and radio frequency standards?

Answer: International Telecommunication Union (ITU)

4. Which of the following is specifically used to describe a loss of signal strength?

- A. Noise
- B. Signal-to-Noise Ratio
- C. Attenuation
- D. Distortion

Answer: C

5. Which type of transmission allows communication to occur in two directions, but only one direction at a time?

- A. Half-duplex
- B. Full-duplex
- C. Simplex
- D. Multiplex

Answer: A

Class Discussion Topics

1. Have students discuss the importance of standards in networking technology and in communications in general. Students can evaluate how standards have helped to shape commonly used devices such as cellular phones or mobile devices.
2. Start a class discussion on the importance of unlicensed bands being available for public use. Get students to discuss whether wireless networks (such as those that exist in homes and small offices) would be possible if FCC licensing were required to operate such devices.

Additional Projects

1. Have students research the requirements for licensing a specific frequency for use from the FCC. Different services exist, and depending on intended use, the forms or requirements may change drastically.
2. Give students time to research different RFCs on the ietf.org website, and give a list of example RFCs that describe TCP/IP communication and various upper layer protocols.

Additional Resources

1. United States Frequency Allocations map:
<http://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf>
2. Additional information on how CDMA is used with cellular phones:
http://www.pcmag.com/encyclopedia_term/0,1237,t=CDMA&i=39462,00.asp

Key Terms

- **adaptive array processing** A radio transmission technique that replaces a traditional antenna with an array of antenna elements.
- **American National Standards Institute (ANSI)** A clearinghouse for standards development in the United States.
- **amplifier** A component that increases a signal's intensity.
- **attenuation** A loss of signal strength.
- **band** A range of radio frequencies. Frequency bands are defined by each country's regulatory agencies, such as the FCC in the United States, and each range is allocated for a specific radio communications purpose.
- **bandpass filter** A filter that passes all signals that are between the maximum and minimum threshold.
- **circuit switching** A switching technique in which a dedicated and direct physical connection is made between two transmitting devices—for example, between two telephones during a call.
- **Code Division Multiple Access (CDMA)** A technique that uses spread spectrum technology and unique digital codes to send and receive radio transmissions.
- **consortia** Industry-sponsored organizations that have the goal of promoting a specific technology.
- **crosstalk** Signals from close frequencies that may interfere with other signals.
- **de facto standards** Common practices that the industry follows for various reasons.
- **de jure standards** Standards that are controlled by an organization or body.
- **directional antenna** An antenna that radiates the electromagnetic waves in one direction only. As a result, it can help reduce or eliminate the effect of multipath distortion if there is a clear line of sight between the two antennas.
- **electromagnetic interference (EMI)** Interference with a radio signal; also called noise.

- **European Telecommunications Standards Institute (ETSI)** A standards body that develops telecommunications standards for use throughout Europe.
- **Federal Communications Commission (FCC)** The primary U.S. regulatory agency for telecommunications.
- **filter** A component that is used to either accept or block a radio frequency signal.
- **Frequency Division Multiple Access (FDMA)** A radio transmission technique that divides the bandwidth of the frequency into several smaller frequency bands.
- **full-duplex transmission** Transmissions in which data flows in either direction simultaneously.
- **guard band** Frequency space in which no signal is transmitted. Intended to prevent interference between two transmitters using adjacent channels.
- **half-duplex transmission** Transmission that occurs in both directions but only one way at a time.
- **high-pass filter** A filter that passes all signals that are above a maximum threshold.
- **harmonics** Stray oscillations that result from the process of modulating a wave and that fall outside the range of frequencies used for transmission. Harmonics also occur when a signal goes through a mixer and must be filtered out at several points before the signal is finally fed to the antenna for transmission.
- **Industrial, Scientific and Medical (ISM) band** An unregulated radio frequency band approved by the FCC in 1985.
- **Institute of Electrical and Electronics Engineers (IEEE)** A standards body that establishes standards for telecommunications.
- **intermediate frequency (IF)** The output signal that results from the modulation process.
- **International Organization for Standardization (ISO)** An organization to promote international cooperation and standards in the areas of science, technology, and economics.
- **International Telecommunication Union (ITU)** An agency of the United Nations that sets international telecommunications standards and coordinates global telecommunications networks and services.
- **Internet Architecture Board (IAB)** The organization responsible for defining the overall architecture of the Internet, providing guidance and broad direction to the IETF. The IAB also serves as the technology advisory group to the Internet Society and oversees a number of critical activities in support of the Internet.
- **Internet Engineering Task Force (IETF)** A standards body that focuses on the lower levels of telecommunications technologies.
- **Internet Society (ISOC)** A professional-membership organization of Internet experts that comments on policies and practices and oversees a number of other boards and task forces dealing with network policy issues.
- **license exempt spectrum** Unregulated radio frequency bands that are available in the United States to any users without a license.
- **low-pass filter** A filter that passes all signals that are below a maximum threshold.
- **mixer** A component that combines two inputs to create a single output.
- **multipath distortion** What occurs when the same signal reflects and arrives at the receiver's antenna from several different directions and at different times.
- **noise** Interference with a signal.

- **official standards** *See de jure standards.*
- **packet** A smaller segment of the transmitted signal.
- **packet switching** Data transmission that is broken into smaller units.
- **passband** A minimum and maximum threshold that spells out which range of frequencies will pass through a filter.
- **PN code** Pseudo random code; a code that appears to be a random sequence of 1s and 0s but actually repeats itself. Used in CDMA cellular telephone technology.
- **radio frequency (RF) communications** All types of radio communications that use radio frequency waves.
- **radio frequency spectrum** The entire range of all radio frequencies that exist.
- **sidebands** The sum and the differences of the frequency carrier that serve as buffer space around the frequency of the transmitted signal.
- **signal-to-noise ratio (SNR)** The measure of signal strength relative to the background noise.
- **simplex transmission** Transmission that occurs in only one direction.
- **switching** Moving a signal from one wire or frequency to another.
- **Telecommunications Industries Association (TIA)** A group of more than 600 companies that manufacture or supply the products and services used in global communications.
- **Time Division Multiple Access (TDMA)** A transmission technique that divides the bandwidth into several time slots.
- **Unlicensed National Information Infrastructure (U-NII)** An unregulated band approved by the FCC in 1996 to provide for short-range, high-speed wireless digital communications.
- **unregulated bands** *See license exempt spectrum.*