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We anticipate that, in the near future, we will witness a replacement of the current analog AM and FM radio and television broadcast by digital transmission systems. The development of sophisticated, high-speed digital communication systems has been accelerated by concurrent developments in inexpensive high speed integrated circuits IC and programmable digital signal processing chips. All of these technological developments point to a continuation in the trend toward increased use of digital communications as a means for transmitting information.

OVERVIEW OF THE TEXT

It is assumed that students using this book have a basic understanding of linear system theory, both continuous and discrete, including a working knowledge of Fourier series and Fourier transform techniques. Chapter 2 provides a review of basic material on signals and systems and establishes the necessary notation used in subsequent chapters. It is also assumed that students have had a first course in probability. Such courses are currently required in many undergraduate electrical engineering and computer engineering programs. Chapter 4 provides a review of probability and random processes to the extent that is necessary for a first course in communications. Chapter 3 treats modulation and demodulation of analog signals. This treatment includes amplitude modulation AM, frequency modulation FM, and phase modulation PM. Radio and television broadcasting and mobile radio cellular systems are discussed as examples of analog communication systems. Chapter 5 continues the treatment of analog communication systems by analyzing the effect of additive noise in the demodulation of AM, FM, and PM signals. The phase-locked loop, which is used for estimating the phase of a sinusoidal carrier in both analog and digital communication systems is also described in Chapter 5.

The chapter concludes with a treatment of the effect of transmission losses and the characterization of noise sources in communication systems. A logical beginning in the introduction of digital communication systems analysis and design is the characterization of information sources and source encoding. Chapter 6 is devoted to this topic. In this chapter we introduce the reader to the modeling of information sources, both discrete and continuous analog, and the basic mathematical concepts of entropy and mutual information. Our discussion of source encoding for discrete sources includes the Huffman coding algorithm and the Lempel-Ziv algorithm. For the case of analog sources, we treat both scalar and vector quantization and describe the common waveform coding techniques, namely, PCM, DPCM, and DM. We also describe the LPC-based source modeling method. As practical examples of the source coding methods described in this chapter we cite the digital speech transmission systems in the telephone plant, the digital audio recording systems as embodied in the compact disc CD player and the JPEG image coding standard. Digital modulation and demodulation techniques are described in Chapter 7. Binary and nonbinary modulation methods are described based on a geometric representation of signals, and their error rate performance is evaluated and compared. This chapter also describes symbol synchronization methods for digital communication systems. Chapter 8 treats digital transmission through bandlimited AWGN channels. In this chapter we derive the power spectral density of linearly modulated baseband signals and consider the problem of signal design for a bandlimited channel. We show that the effect of channel distortion is to introduce intersymbol interference ISI, which can be eliminated or minimized by proper signal design.

The use of linear and nonlinear adaptive equalizers for reducing the effect of ISI is also described. Chapter 9 treats the topic of channel coding and decoding. The capacity of a communication channel is first defined, and the capacity of the Gaussian channel is determined. Linear block codes and convolutional codes are introduced and appropriate decoding algorithms are described. The benefits of coding for bandwidth constrained channels are also described. The final section of this chapter presents three practical applications of coding. The last chapter of this book treats topics in wireless communications. First, we consider the characterization of fading multipath channels and describe the effects of such channels on wireless digital

communication systems. The design of signals that are effective in mitigating this type of channel distortion is also considered. Second, we describe the class of continuous phase modulated signals, which are especially suitable for digital communication in wireless channels. Finally, we treat the class of spread spectrum signals, which are suitable for multiuser wireless communication systems.

EXAMPLES AND HOMEWORK PROBLEMS

We have included a large number of carefully chosen examples and homework problems. The text contains over 180 worked out examples and over 480 problems. Examples and problems range from simple exercises to more challenging and thought provoking problems. A Solutions Manual is available free to all adopting faculty, which is provided in both typeset form and as a diskette formatted in LATEX. Solutions are not available for sale to students. This will enable instructors to print out solutions in any configuration easily.

COURSE OPTIONS

This book can serve as a text in either a one or two semester course in communication systems.

An important consideration in the design of the course is whether or not the students have had a prior course in probability and random processes. Another important consideration is whether or not analog modulation and demodulation techniques are to be covered. Here, we outline three scenarios. Through these media we are able to communicate nearly instantaneously with people on different continents, transact our daily business, and receive information about various developments and events of note that occur all around the world. Electronic mail and facsimile transmission have made it possible to rapidly communicate written messages across great distances.

Can you imagine a world without telephones, radio, and TV. Yet, when you think about it, most of these modern day communication systems were invented and developed during the past century. Here, we present a brief historical review of major developments within the last two hundred years that have had a major role in the development of modern communication systems.

1.1 HISTORICAL REVIEW

Telegraphy and Telephony. One of the earliest inventions of major significance to communications was the invention of the electric battery by Alessandro Volta in 1799. This invention made it possible for Samuel Morse to develop the electric telegraph, which he demonstrated in 1837. The first telegraph line linked Washington with Baltimore and became operational in May 1844. Morse devised the variable length binary code given in Table 1.1, in which letters of the English alphabet were represented by a sequence of dots and dashes code words. This cable failed after about four weeks of operation. A second cable was laid a few years later and became operational in July 1866.

Telephony came into being with the invention of the telephone in the 1870s. Alexander Graham Bell patented his invention of the telephone in 1876, and in 1877 established the Bell Telephone Company.

Early versions of telephone communication systems were relatively simple and provided service over several hundred miles. Significant advances in the quality and range of service during the first two decades of the twentieth century resulted from the invention of the carbon microphone and the induction coil.

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Section 1.1 Historical Review 3

The invention of the triode amplifier by Lee De Forest in 1906 made it possible to introduce signal amplification in telephone communication systems and, thus, to allow for telephone signal transmission over great distances. For example, transcontinental telephone transmission became operational in 1915.

Two world wars and the Great Depression during the 1930s must have been a deterrent to the establishment of transatlantic telephone service. It was not until 1953, when the first transatlantic cable was laid, that telephone service became available between the United States and Europe.

Automatic switching was another important advance in the development of telephony. The first automatic switch, developed by Strowger in 1897, was an electromechanical step by step switch. This type of switch was used for several decades. With the invention of the transistor, electronic digital switching became economically feasible. After several years of development at the Bell Telephone Laboratories, a digital switch was placed in service in Illinois in June 1960.

During the past thirty years there have

been numerous significant advances in telephone communications. Fiber optic cables are rapidly replacing copper wire in the telephone plant and electronic switches have replaced the old electromechanical systems.

Wireless Communications. The development of wireless communications stems from the works of Oersted, Faraday, Gauss, Maxwell, and Hertz. In 1820, Oersted demonstrated that an electric current produces a magnetic field.

On August 29, 1831, Michael Faraday showed that an induced current is produced by moving a magnet in the vicinity of a conductor. Thus, he demonstrated that a changing magnetic field produces an electric field. With this early work as background, James C. Maxwell in 1864 predicted the existence of electromagnetic radiation and formulated the basic theory that has been in use for over a century. Guglielmo Marconi is credited with the development of wireless telegraphy. Marconi demonstrated the transmission of radio signals at a distance of approximately 2 kilometers in 1895. Two years later, in 1897, he patented a radio telegraph system and established the Wireless Telegraph and Signal Company. On December 12, 1901, Marconi received a radio signal at Signal Hill in Newfoundland, which was transmitted from Cornwall, England, a distance of about 1700 miles.

The invention of the vacuum tube was especially instrumental in the development of radio communication systems. The vacuum diode was invented by Fleming in 1904 and the vacuum triode amplifier was invented by De Forest in 1906, as previously indicated. The invention of the triode made radio broadcast possible in the early part of the twentieth century. Amplitude modulation AM broadcast was initiated in 1920 when radio station KDKA, Pittsburgh, went on the air. From that date, AM radio broadcasting grew rapidly across the country and around the world. The superheterodyne AM radio receiver, as we know it today, was invented by Edwin Armstrong during World War I. Another significant development in radio communications was the invention of Frequency modulation FM, also by Armstrong. In 1933, Armstrong built and demonstrated the first FM communication system. However, the use of FM was slow to develop compared with AM broadcast.

It was not until the end of World War II that FM broadcast gained in popularity and developed commercially.

The first television system was built in the United States by V. K. Zworykin and demonstrated in 1929. Commercial television broadcasting began in London in 1936 by the British Broadcasting Corporation BBC. Five years later the Federal Communications Commission FCC authorized television broadcasting in the United States.

The Past Fifty Years. The growth in communications services over the past fifty years has been phenomenal. The invention of the transistor in 1947 by Walter Brattain, John Bardeen, and William Shockley; the integrated circuit in 1958 by Jack Kilby and Robert Noyce; and the laser by Townes and Schawlow in 1958, have made possible the development of smallsize, lowpower, lowweight, and highspeed electronic circuits which are used in the construction of satellite communication systems, wideband microwave radio systems, and lightwave communication systems using fiber optic cables. A satellite named Telstar I was launched in 1962 and used to relay TV signals between Europe and the United States. Commercial satellite communication services began in 1965 with the launching of the Early Bird satellite.

Currently, most of the wireline communication systems are being replaced by fiber optic cables which provide extremely high bandwidth and make possible the transmission of a wide variety of information sources, including voice, data, and video. Cellular radio has been developed to provide telephone service to people in automobiles, buses, and trains. Highspeed communication networks link computers and a variety of peripheral devices literally around the world.

Today we are witnessing a significant growth in the introduction and use of personal communications services, including voice, data, and video transmission. Satellite and fiber optic networks provide highspeed communication services around the world.

Indeed, this is the dawn of the modern telecommunications era. There are several historical treatments in the development of radio and telecommunications covering the past century. In general, a communication system can be represented by the functional block diagram shown in Figure 1.1. The information generated by the source may be of the form of voice speech source, picture image source, or plain text in some particular language, such as English, Japanese, German, French, etc. Otherwise, there would be no need to transmit the message. A transducer is usually required to convert the output of a source into an electrical signal that is suitable for transmission. For example, a microphone serves as the transducer that converts an acoustic speech signal into an electrical signal, and a video camera converts an image into an electrical signal. At the destination, a similar transducer is required to convert the electrical signals that are received into a form that is suitable for the user; e.g., acoustic signals, images, etc. The heart of the communication system consists of three basic parts, namely, the transmitter, the channel, and the receiver. The functions performed by these three elements are described next.

The Transmitter. The transmitter converts the electrical signal into a form that is suitable for transmission through the physical channel or transmission medium. For example, in radio and TV broadcast, the Federal Communications Commission FCC specifies the frequency range for each transmitting station. Hence, the transmitter must translate the information signal to be transmitted into the appropriate frequency range that matches the frequency allocation assigned to the transmitter. Thus, signals transmitted by multiple radio stations do not interfere with one another.

Similar functions are performed in telephone communication systems where the electrical speech signals from many users are transmitted over the same wire. In general, the transmitter performs the matching of the message signal to the channel by a process called modulation. Usually, modulation involves the use of the information signal to systematically vary either the amplitude, frequency, or phase of a sinusoidal carrier. For example, in AM radio broadcast, the information signal that is transmitted is contained in the amplitude variations of the sinusoidal carrier, which is the center frequency in the frequency band allocated to the radio transmitting station. This is an example of amplitude modulation. In FM radio broadcast, the information signal that is transmitted is contained in the frequency variations of the sinusoidal carrier. This is an example of frequency modulation. Phase modulation PM is yet a third method for impressing the information signal on a sinusoidal carrier.

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Introduction Chapter 1

In general, carrier modulation such as AM, FM, and PM is performed at the transmitter, as indicated above, to convert the information signal to a form that matches the characteristics of the channel. Thus, through the process of modulation, the information signal is translated in frequency to match the allocation of the channel. The choice of the type of modulation is based on several factors, such as the amount of bandwidth allocated, the types of noise and interference that the signal encounters in transmission over the channel, and the electronic devices that are available for signal amplification prior to transmission. In any case, the modulation process makes it possible to accommodate the transmission of multiple messages from many users over the same physical channel.