Introduction to Communication Systems
- a Multimedia Workbook

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Preface

This workbook is to support a first course in analog and digital communications. Having completed a basic course in signals and systems, an average undergraduate student should be able to complete five or six of the chapters in a one-semester course (40 hours). The workbook is intended to be compact and to accompany a comprehensive text on communication systems from authors such as L.W. Couch, S. Haykin, B.P Lathi, or F.G. Stremler.

There is a fresh approach to several topics including phase and frequency modulation, PCM oversampling, and asynchronous multiplexing. A short review of signal theory is included. Features of the workbook are:

1. A focus on physical implementation with illustrations and examples that include numeric quantities with units. Signals are real functions of time with amplitudes expressed in peak, peak-to-peak and rms voltages as well as dBm and dBV.
2. Images are used extensively; mathematical expressions are often placed in the illustrations.
3. Noise is introduced early so the discussion of phase and frequency modulation can include noise mitigation as well as spectral properties.
4. The workbook contains self-checking drill problems, example problems and references to interactive virtual experiments. End-of-chapter problems range from simple drill questions to those that require synthesis. Each chapter is reasonably self-contained and there are few references to other chapters.
5. The multimedia CD contains laboratory images to impart physical reality to the text, illustrations, and mathematical descriptions. The CD allows students to experience the sounds of aliasing and quantizing noise, to see the spectral occupancy of common broadcast signals.
6. There has been special effort to provide a physical understanding of noise and to “keep the student’s feet on the ground”. The CD allows students to hear the sounds of noise while observing the spectrum and time waveforms.
7. Virtual experiments require interpretation of information presented on oscilloscope and spectrum analyzer screens. This is intended as preparation for the workplace where an engineer must interpret results from laboratory measurements.

NOTES TO INSTRUCTORS

Opinions differ as to the optimal order of topics. According to one viewpoint, a study of communication requires an initial mastery of signal analysis, information theory, probability theory, and random processes. In a second viewpoint, students should be initially motivated by a study of successful communication systems with theory introduced as required and with specialized topics and theoretical details covered in an elective follow-on course. This workbook attempts to follow the second viewpoint.

Although newly designed communication systems rarely use analog carrier modulation, this topic has been placed first partly because this is tradition in most engineering programs and partly because modulation is a basic process required for digital communications and signal processing. An instructor that wishes to emphasize digital systems may skip Chapter 3 and then review analog carrier modulation as an introduction to digital carrier modulation in Chapter 8.
Sections and sub-sections that are not essential to an undergraduate communication course have been noted with an asterisk.

Web browser-based virtual laboratories and virtual simulations are provided on CD to augment the printed material in Chapters 2, 3, 4, 5, 6 and 8. The material is suited for demonstration using a classroom computer projector. Students can use their own CD for review and to download MATLAB code as a “jump start” for more comprehensive simulations.

Workbook illustrations, examples and problems include units. In practice, an engineer’s solutions and design values must include not only a number but also the units. Without appropriate units, a calculation result might be a silly as “the distance to the airport is 15 kg and the average speed is 20 nanoseconds”. Some end-of-chapter problems are slightly beyond the material provided in the workbook and will require an unfamiliar solution method. This is an attempt to stimulate the student’s innovative thinking and to model the working environment where solutions are required for totally new problems. Problem solutions are available to instructors in image format.

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1 Introduction

Information is conveyed in the form of messages. For example, instructions on how to build a house would represent information. A message signal might take the form of text, spoken instructions or a motion picture on construction techniques. In this workbook we investigate systems to communicate message signals.

1.1 Signal Properties

Initially, we begin with a study of message signals themselves. Signals may be characterized by their waveform, voltage, average power and by their amplitude probability density. Signals are also characterized by their spectrum or spectral density.

1.2 Elements of a Communication System

A communication system is the combination of circuits and devices put together to accomplish the transmission of information from one point to another. There are many different types of information sources and there are different forms for messages. In general, messages may be classified as analog or digital. Analog messages (such as speech, music, temperature, ...) are represented by continuous-time variables while discrete messages (such as text or numeric data) are represented by discrete symbols.

Often the message produced by an information source is not suitable for transmission and therefore an input transducer must be used. For example, a microphone converts speech (i.e. the message signal) from a pressure wave to an electrical voltage and the message is represented by an analog waveform. In other examples, the analog signal voltage is proportional to temperature, pressure or light intensity. In a digital signal, discrete values of voltage represent various states of the message source. For example, a computer keyboard can generate more than 100 discrete symbols.

A transmitter is used to couple the message signal to the transmission medium (i.e. the channel). The transmitter may simply filter, amplify and couple the signal to the medium or it may impose the message signal on a higher frequency carrier wave. The message signal is used to modulate the carrier wave. Use of the higher frequency carrier facilitates wireless radio transmission.

The channel includes the transmission medium and it may introduce noise and distortion. Example channels are coaxial cable, twisted wire, optical fiber or the free space between transmitting and receiving radio antennas.

The receiver extracts the message signal from the received signal and then converts it to a form suitable for the output transducer. The extraction process usually includes amplification, filtering and demodulation.

The output transducer completes the communication system by converting the electric signal to the form desired by the user. Examples of output transducers are loudspeakers, meters, television screens and computer display screens.
1.3 **Modern Communication Systems are Digital**

Communication systems of all types have “gone digital” and the primary advantage is maintenance of signal integrity during storage or transmission. With the application of error correcting codes, the original message may be almost perfectly recovered even though some of the stored or transmitted information (say 1%) is corrupted. Digital transmission can span great distances through the use of regenerative repeaters spaced along the transmission path. The repeater corrects almost all errors in the received signal and re-transmits a “perfect” replica of the original message. Inherently analog signals, such as speech, are converted to digital form and, in this manner, we eliminate the accumulation of noise that is normal in analog transmission systems. One disadvantage is that digital transmission usually requires more bandwidth than an analog system.

The first significant application of digital transmission began in 1962 when the ATT Bell System installed the first T1 transmission system between telephone switching centers in Chicago. The system gave a 12-fold increase in transmission capacity on the wire pairs and it yielded high quality transmission with good noise performance when compared with analog transmission. The cost advantage of digital transmission has improved greatly with the advance of very large integrated circuit (VLSI) technology and virtually all of telephone transmission and switching has become digital. Only the subscriber access line remains analog, however, even that portion is being overlaid with digital subscriber line (DSL) access to the Internet.

New communication system designs use digital technology, and the use of analog systems is rapidly declining. Examples of legacy analog systems are AM and FM radio, cassette tape, vinyl recordings, analog television broadcast and VHS recording. These analog systems are being supplanted by superior digital technologies such as compact disc (CD) and .mp3 music recording, digital cable and satellite TV, Internet video, and DVD recording. Furthermore, the analog demodulation found in radio equipment is being replaced by direct A/D down-conversion and DSP “software radio” techniques. Analog techniques remain dominant for optical wavelength division systems and for signal processing at microwave frequencies.