Problem-Based Learning

in Communication

Systems Using MATLAB®

and Simulink

KWONHUE CHOI HUAPING LIU







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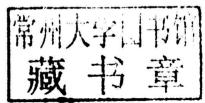
PROBLEM-BASED LEARNING IN COMMUNICATION SYSTEMS USING MATLAB AND SIMULINK

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Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-1-119-06034-5

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

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IEEE Press

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PREFACE

THE CHALLENGES OF LEARNING AND TEACHING COMMUNICATIONS

Many digital communication topics taught in the traditional way require understanding mathematical expressions and algorithmic procedures to learn abstract concepts. The majority of existing textbooks facilitate teaching this way with systematic and thorough explanation of communication theories and concepts, mainly via mathematical models and algorithmic procedures. This is the natural outcome when computers and software were not so universally accessible decades ago as they are today. However, most students find such a way of learning digital communications ineffective and often frustrating. And even if they are able to follow the instructors in the classroom, their understanding of the concepts is often superficial. The accessibility of powerful software like MATLAB/Simulink and the Internet to students could be exploited to revolutionize the teaching of math intensive subjects such as digital communications. Through decades of classroom experience, we have learned that students' learning becomes significantly more effective if they are led to "construct" the system themselves and observe waveforms and statistics at various stages of the system or algorithm, a process called "active" learning here.

However, given the tools and texts available on the market to the instructors, implementing this active learning process is by no means easy. First, the majority of the textbooks are optimized for instruction in the traditional way. Some recent textbooks provide problems that involve the use of MATLAB/Simulink or similar software and codes or computer models to perform certain simulation. Readers can replicate these codes/models and conduct simulation, which would certainly reinforce some aspects they have learned. Such an approach is still far short of encouraging active learning

by students. Second, there are some existing hardware training kits designed for educational purposes that can be used for labs/experiments of communications classes. However, these training kits are often expensive and cover only a limited number of topics of communications. Additionally, students need to learn hardware design skills such as DSP programming and VHDL to be able to use such a tool.

UNIQUE FEATURES OF THIS BOOK

This book is written to encourage active learning of communication theories and systems by its readers. Toward this goal, major communication concepts and algorithms are examined through carefully designed MATLAB/Simulink projects. Each project implements the simulation construction and execution steps or sequences that match how an actual communications system or algorithm works. These steps progressively explore the intermediate results between steps that students can "see" and comprehend what happens behind theories and mathematical expressions. The bulk of MATLAB simulation codes or Simulink models for these projects are provided. This ensures that students will be able to complete even complex projects such as Viterbi decoding, multiple-input multiple-output (MIMO) detection, and orthogonal frequency division multiplexing (OFDM) demodulation.

However, important parameters and codes lines or model blocks that are critical for learning the algorithm or communications process are left out for students to complete. This makes mechanically executing a certain completed code without understanding the technical details impossible. Step-by-step instructions are designed for each problem. Readers can conveniently check the results of each intermediate step and compare the various parameter choices and their effects and are thus led to actively figure out the intended answers and build up a complete system/algorithm.

Summarizing it, this book is written with the following three main goals in mind:

- The framework of the codes/models provided in the book efficiently guides students through the simulation and actively engages students in learning the materials.
- The codes/blocks provided minimize the amount of time students need to complete their simulations and ensure that they will be able to complete even complex projects without getting lost in the middle and giving up.
- 3. In completing the main algorithm/concept-specific incomplete parts, students will effectively be internalizing the theories.

In Chapters 4, 7, 9, 10, 11, 13, 20, 22, 23, and 30, students will learn how to convert constructed waveforms in simulations into electric signals and then to listen to those signals if they are audio signals, or observe the eye-patterns, scatter plots, or signal trajectories by using an oscilloscope for digitally modulated signals. In Chapters 13 and 30, students are encouraged to complete actual wireless communications in the band near-ultrasonic frequencies, requiring only a mobile phone and a PC with a microphone. We have found that all such present-day projects that embrace student

interests can motivate them to explore more intensely how communication systems work.

Although, students are not required to know MATLAB/Simulink to use this book, Chapter 1 provides carefully designed projects that enable students to self-learn the MATLAB/Simulink skills needed for the rest of the projects in this book. All that a student needs are access to MATLAB, a headphone and an oscilloscope for some projects.

THE STRUCTURE OF THIS BOOK

The 30 chapters of this book cover MATLAB/Simulink basics (Chapter 1), basic signals and systems (Chapters 2–8), analog communications (Chapters 9–13), probability and random signals (Chapters 14–15), basics of digital communication techniques (Chapters 16–24), and wireless communication techniques (Chapters 25–30).

The majority of these chapters are structured as follows.

Aims: Summarize the topics and goals of the chapter.

Prelab: The theoretical background for the topic, if necessary; prerequisite problem sets for students to become familiar with the required MATLAB functions and features for the chapter.

Main lab: Problems for the main topic.

Further studies: Problems for advanced topics, if there are any.

A user's guide is provided at the beginning of the book, where the problem numbers corresponding to the prelab, main lab, and further studies of all chapters are tabulated.

To minimize the time students would otherwise have to spend on nonessential (in terms of learning core concepts and algorithms) but necessary and time-consuming tasks, MATLAB code script (incomplete m-files), Simulink models (incomplete mdl/.slx files), and data files (.mat files) are provided so that students can easily access the core materials.

HOW TO EFFICIENTLY USE THIS BOOK

Teaching with this book:

 As a supplementary textbook (mainly for assigning labs and projects) for undergraduate- and junior-level graduate communications and wireless communications classes as well as undergraduate signal and systems classes. A content-mapping table of the sections of this book with the sections of four widely adopted existing textbooks that cover essentially the same materials is provided. As the main textbook for the aforementioned courses. While this book is not written to compete with existing communications theory and system textbooks, it is all-inclusive in that it covers, all major topics of communications.

With option 1, instructors can conveniently make lab assignments using the content-mapping table to choose appropriate projects from this book to reinforce student's learning experience. Because the projects in this book are designed to guide students step by step toward more complex projects, instructors need only spend minimal time and effort to cover all the material in class.

With option 2, instructors can use their own lecture notes to summarize the theory parts of the chapters/sections of this book that they plan to teach in class. For graduate classes, such class presentations may not be needed, since graduate students should be able to search for additional information, if needed. Students should nevertheless follow through the projects and write reports.

These uses of the book will reduce the amount of work that the instructors need to put into the class presentations, but the students still gain a thorough understanding of each concept through active learning. Instructors can customize the different chapters for different courses. For example, when this book is used for an undergraduate signals and systems class, Chapters 1–7 would be ideal, plus some materials on z-transform (for most curricula, students should have learned Laplace transform before taking signals and systems). In the first two to three weeks, students could complete Chapter 1 by themselves while the instructor focuses on basic signals and system properties. When the instructor is ready to start teaching signals and systems in both time and frequency domains, filter design, and sampling and reconstruction, students will then have all the MATLAB/Simulink skills needed to work on the corresponding projects. For an analog communications class, Chapters 1 and 8-13 should be covered. For a junior-level digital communications course, Chapters 1 and 14-24 may be covered. For a junior-level graduate wireless communications course (provided that students have taken digital communications), some or all of Chapters 1 and 25-30 can be covered.

SUPPLEMENTS

The following supplements are available from the companion website:

All MATLAB code or Simulink model samples and templates (incomplete m-files and incomplete .mdl/.slx models) and data files (.mat files).

Correction table for each edition if found.

Content-mapping table of the sections of this book with the sections of widely adopted existing textbooks if updated.

ACKNOWLEDGMENTS

This book has gone through many revisions over the past 12 years to make it a useful tool for instructors and effective guide for students learning communications systems. The writing of the book would have been impossible without the tremendous help from many of our colleagues and students. In particular, we thank Dr. Bong-seok Kim for checking every technical detail and Ms. Sahar Amini for proofreading the manuscript.

Our editor, Mary Hatcher, has very competently steered us through this project. We especially appreciate her steadfast support of our book and patience in guiding us through the publication process.

Huaping Liu is also extremely grateful to his wife Catherine and sons Frank, Ethan, Raymond, and Andrew for their endurance and not making demands on his time during the writing of this book. He also offers special thanks to two of his sons, Ethan and Raymond, for giving him many useful writing tips and for helping him revise the writing of chapters.

NOTATION AND LIST OF SYMBOLS

[WWW]: Sections or problems that require a data file or problems for which a script-file (m-file) is provided from the companion website (http://www.wiley.com/go/choi_problembasedlearning).

[T]: Theory-based sections or problems that do not require MATLAB or Simulink.

[A]: Advanced problems or materials.

m-file: MATLAB script-files

Terms using this style and font: MATLAB/Simulink-related terms, for example, variable/parameter/function/block/file name.

LIST OF ACRONYMS

AM amplitude modulation

AWGN additive white Gaussian noise

BER bit error rate

CLT central limit theory CNR carrier-to-noise ratio

CP cyclic prefix

CSI channel state information

DSB-LC double side-band with a large carrier DSB-SC double side-band-suppressed carrier

EGC equal gain combining ESD energy spectral density

FDM frequency division multiplexing

ICI inter-carrier interference
IFFT inverse Fast Fourier transform
ISI inter-symbol interference
LSSB lower single-side band
MIMO multiple input multiple output

ML maximum likelihood

MLD maximum likelihood detection (or decoding)

MPSK M-ary phase shift keying MRC maximum ratio combining

NBFM narrowband FM NUS near ultrasonic

OFDM orthogonal frequency division multiplexing

OQPSK offset QPSK

xxii LIST OF ACRONYMS

OSIC ordered successive interference cancellation

PAM pulse amplitude modulation

PD phase detector

PDF probability density function

PLL phase locked loop PSD power spectral density

OAM quadrature amplitude modulation

QM quadrature multiplexing

OPSK quadrature phase shift keying

SD spatial diversity

SDC selection diversity combining

SIC successive interference cancellation

SM spatial multiplexing

SRRC square-root raised cosine

SSB single-side band

STBC space time block code
USSB upper single-side band
VCO voltage controlled oscillator

WSS wide-sense stationary

ZF zero forcing

CONTENT-MAPPING TABLE WITH MAJOR EXISTING TEXTBOOKS

NOTE: Mapping table for newer versions of the major textbooks will be updated on the companion website.

PART I. COMMUNICATION SYSTEM

	Corresponding Sections of Widely Adopted Existing Textbooks				
Chapter	Introduction to Communication Systems by Ferrell G. Stremler, 3rd ed. Addison Wesley, 1990.	Introduction to Analog and Digital Communication by S. Haykin and M. Moher, 2nd ed. John Wiley & Sons 2007			
2	2.5~2.7	_			
3	2.12, 2.13, 2.15, 3.3, 3.9	2.1~2.3, 2.5			
4	3.2, 3.5, 3.6, 3.15, 3.17	2.6			
5	3.5~3.9	2.3			
6	2.19, 3.11~3.13	2.7			
7	3.15, 3.16	5.1~5.2			
8	4.1~4.7.1	2.8			
9	5.1, 5.2	3.1~3.3			
10	5.3	3.5, 3.9			
11	5.4	3.6, 3.8			
12	6.1, 6.2	4.1~4.2, 4.4			
13	6.7.2, 6.7.3	4.8			

PART II. DIGITAL COMMUNICATION

	Corresponding Sections of Widely Adopted Existing Textbooks			
Chapter	Digital Communications: Fundamentals and Applications by B. Sklar, 2nd ed. PHIPE, 2002	Digital Communications by J. G. Proakis, 5th ed. McGraw-Hill, 2008		
14	1.1~1.5	2.3		
15	1.4~1.5.5	2.3, 2.7-1		
16	3.1~3.2.1	2.3, 4.2-1		
17, 18	3.1.3, 3.2.5.3, 4.2.6, 4.3.1	4.2, 5.1~5.1-1		
19	4.3.2	2.2, 2.3, 4.2-2		
20	3.2.3, 3.4.2	9.2~9.2-3		
21	4.1~4.4.2, 4.7.1	3.2-2, 4.2-2		
22	4.4.3~4.8.3, 9.8.1, 9.8.2.1	3.2-2, page 124 (OQPSK)		
23	9.8.3, 9.5.1	3.2-3		
24	7.1~7.4	8.1~8.1-1, 8.2~8.2-1, 8.3, 8.4		
25	15.5.4	13.1, 13.4		
26		11.2, 13.6		
27		11.2, 13.6		
28		15.4		
29		15.1~15.2		
30		11.2, 13.6		