PRINCIPLES OF COMMUNICATION SYSTEMS

Second Edition

Herbert Taub

Donald L. Schilling

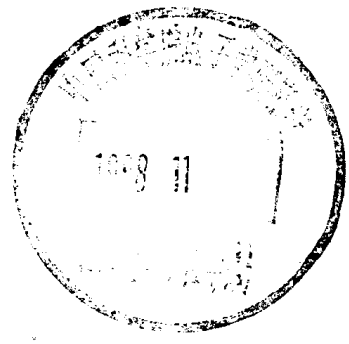
PRINCIPLES OF COMMUNICATION SYSTEMS

Second Edition

Herbert Taub

Donald L. Schilling

Professors of Electrical Engineering
The City College of New York



McGraw-Hill Book Company

New York St. Louis San Francisco Auckland Bogotá Hamburg
Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

This book was set in Times Roman.
The editor was Sanjeev Rao;
the cover was designed by John Hite;
the production supervisor was Marietta Breitwieser.
Project supervision was done by Santype International Limited.
R. R. Donnelley & Sons Company was printer and binder.

PRINCIPLES OF COMMUNICATION SYSTEMS

234567890 DOCDOC 89876

ISBN 0-07-062955-2

Library of Congress Cataloging in Publication Data

Taub, Herbert, 1918–
Principles of communication systems.

(McGraw-Hill series in electrical engineering. Communications and signal processing)
Includes bibliographies.
1. Telecommunication systems. I. Schilling, Donald L. II. Title. III. Series
TK5101.T28 1986 621.38 85-11638
ISBN 0-07-062955-2 (text)
ISBN 0-07-062956-0 (solutions manual)

PRINCIPLES OF COMMUNICATION SYSTEMS

McGraw-Hill Series in Electrical Engineering

Consulting Editor
Stephen W. Director, Carnegie-Mellon University

Circuits and Systems
Communications and Signal Processing
Control Theory
Electronics and Electronic Circuits
Power and Energy
Electromagnetics
Computer Engineering
Introductory
Radar and Antennas
VLSI

Previous Consulting Editors

Ronald M. Bracewell, Colin Cherry, James F. Gibbons, Willis W. Harman, Hubert Heffner, Edward W. Herold, John G. Linvill, Simon Ramo, Ronald A. Rohrer, Anthony E. Siegman, Charles Susskind, Frederick E. Terman, John G. Truxal, Ernst Weber, and John R. Whinnery

Communications and Signal Processing

Consulting Editor
Stephen W. Director, Carnegie-Mellon University

Antoniou: *Digital Filters: Analysis and Design*
Candy: *Signal Processing: The Model-Based Approach*
Carlson: *Communications Systems: An Introduction to Signals and Noise in Electrical Communication*
Cherin: *An Introduction to Optical Fibers*
Cooper and McGillem: *Modern Communications and Spread Spectrum*
Davenport: *Probability and Random Processes: An Introduction for Applied Scientists and Engineers*
Drake: *Fundamentals of Applied Probability Theory*
Guiasu: *Information Theory with New Applications*
Keiser: *Optical Fiber Communications*
Melsa and Cohn: *Decision and Estimation Theory*
Papoulis: *Probability, Random Variables, and Stochastic Processes*
Papoulis: *Signal Analysis*
Papoulis: *The Fourier Integral and Its Applications*
Peebles: *Probability, Random Variables, and Random Signal Principles*
Proakis: *Digital Communications*
Schwartz: *Information Transmission, Modulation, and Noise*
Schwartz and Shaw: *Signal Processing*
Shooman: *Probabilistic Reliability: An Engineering Approach*
Smith: *Modern Communication Circuits*
Taub and Schilling: *Principles of Communication Systems*
Viterbi and Omura: *Principles of Digital Communication and Coding*

PREFACE

The first edition of this text was intended to serve as a one-semester text for a senior-level or first-year graduate course in communications. This second edition can be used as a two-semester course in which the Instructor has great latitude in the selection of topics. As in the previous edition, consistent with the level of presentation, every effort has been made to ensure that the material included represents the present state of the art and current expectations of the direction of future developments. Accordingly, although analog communication systems are accorded a full and complete treatment, the emphasis is placed on digital systems, and chapters are provided in telephone switching, computer communications and spread spectrum.

This book is an outgrowth of courses, both undergraduate and graduate, given at The City College of New York, and also to engineering personnel at the many Government Agencies, Services and Corporations to whom we have presented this material. Thus, for the undergraduate student and beginning graduate students the book provides the excitement of the communications field as well as the background required for advanced study in communication systems. The practicing engineer will find it of service to update his knowledge in the field.

Considerable thought and effort were devoted to the pedagogy of presentation and to the clarity of presentation. Great care has been exercised in the development of approximately 600 homework problems. These problems serve to elucidate the text, in some cases to extend the discussion, and are an integral and important part of the book.

The introductory chapters cover the mathematical background required for the remainder of the text. It is assumed that the reader has had some previous exposure to the elementary notions of spectral analysis including such topics as Fourier series and the Fourier transform. Spectral analysis is a mathematical tool of such wide applicability that we have judged it rather unlikely that the senior engineering student, employing the text, will not have had some experience with the subject. Hence Chap. 1, which deals with spectral analysis, is intended for the

most part as a review and to refresh the students' knowledge. Certain more advanced topics, such as the concepts of power spectral density, the correlation between waveforms and representation of signals by orthogonal functions are dealt with more fully.

The importance of probabilistic concepts in the analysis of communication systems cannot be overemphasized. A discussion of communications that does not take into account the presence of noise omits a basic and essential feature. On the other hand, it is all too easy to devote so much time to an introduction to probabilistic concepts that, within the constraint of a single semester, hardly any time remains to cover the subject of communications itself. We believe that we have steered a reasonable and effective middle course. All of the background in random variables and processes required in this text is included in a single chapter (Chap. 2).

The discussion of communication systems begins in Chap. 3, where amplitude-modulation systems are covered, and Chap. 4, which presents angle-modulation systems. Chapter 5 discusses the sampling theorem, the concept of quantization and pulse-code-modulation systems as well as other analog to digital conversion techniques such as adaptive delta-modulation, encoders and linear predictive coding. This chapter also considers $T1$, $T2$, etc. hierarchy, multiplexing, signaling and synchronization. Chapter 6 discusses transmission of quantized and coded messages by means of M-ary phase-shift keying, quadrature AM, M-ary frequency-shift keying as well as some of the newer modulation techniques such as MSK and Tamed FM. In these four chapters (3 through 6), communication systems are discussed without reference to the manner in which noise affects their performance. We concentrate instead on comparing spectrum and relative complexity. We have found that such an initial presentation, excluding considerations of noise, is pedagogically very effective.

A mathematical representation of noise, using the concepts introduced in Chap. 2, is presented in Chap. 7. In Chaps. 8 and 9 the discussion of AM and FM is extended to the analysis of the influence of noise on system performance.

Chapter 10 discusses the subject of threshold and threshold extension in frequency modulation. The phase-locked loop, carrier synchronization, and bit synchronization, extremely important components in any communication system, are here discussed.

Chapters 11 and 12 discuss the performance of digital communication systems in the presence of noise. The matched-filter concept is studied, and the notion of probability of error is introduced as a criterion for system comparison. In Chap. 11, using the Union Bound, the student is shown how to calculate the error rate of the systems described in Chap. 6 and is shown how to compare the performance of such systems. Chapter 12 is concerned with the SNR of PCM and DM systems.

The underlying unity of the theory of communication systems is presented in Chap. 13 which includes a discussion of information theory and coding for error correction and detection. Although the presentation is introductory, we believe it is more extensive and complete than comparable discussions in other intro-

ductory texts. Block codes including BCN and Reed–Solomon codes are considered as well as convolutional coding and sequential and Viterbi algorithm decoding. In addition, we include here a discussion of trellis decoded modulation, a new modulation technique.

Chapter 14 serves to provide an overall view of a communication system. Sources of noise are discussed and concepts such as noise figure, noise temperature, and path loss are introduced.

Chapters 15, 16 and 17 are new to this text and are not usually found in senior/first year graduate level texts. Chapter 15, Telephone Switching, is an introduction to telephone switching, covering Strowger, Crossbar and Digital Switching.. Chapter 16, Computer Communications, provides insight to the reasons that makes this area so fascinating. Topics, such as, Design considerations, ARPANET, Packet Radio (ALOHA and CSMA), as well as Protocols are introduced. Finally Chap. 17 looks at Spread Spectrum applications.

We are pleased to acknowledge our indebtedness to Dr. Adam Lender who reviewed the entire manuscript. His most gracious encouragement .and very valued constructive criticism are most sincerely appreciated. In addition, we would like to thank Mr. David Monela for his criticism of the text and for his preparation of the Solutions Manual. Particular thanks is also due to Professors S. Davilorici, L. Milstein, R. L. Pickholtz and T. Saadarvi for reading and criticizing selected portions of this text. Their contributions were invaluable. We express our appreciation to Mrs. Joy Rubin of the Electrical Engineering Department at The City College, Miss Victoria Benzinqu and Mrs Annalisle Speckeritch for their most skillful service in the preparation of the manuscript. We also thank all of our colleagues and students for their assistance.

Herbert Taub
Donald L. Schilling

CONTENTS