



# Contemporary Communication Systems

using **MATLAB®**

and  
**Simulink®**

**Second Edition**

**John G. Proakis**  
**Masoud Salehi**  
**Gerhard Bauch**

# Contents

## 1 Signals and Linear Systems 1

- 1.1 Preview 1
- 1.2 Fourier Series 1
  - 1.2.1 Periodic Signals and LTI Systems 13
- 1.3 Fourier Transforms 18
  - 1.3.1 Sampling Theorem 23
  - 1.3.2 Frequency-Domain Analysis of LTI Systems 28
- 1.4 Power and Energy 32
- 1.5 Lowpass Equivalent of Bandpass Signals 36

## 2 Random Processes 45

- 2.1 Preview 45
- 2.2 Generation of Random Variables 45
- 2.3 Gaussian and Gauss–Markov Processes 50
- 2.4 Power Spectrum of Random Processes and White Processes 57
- 2.5 Linear Filtering of Random Processes 62
- 2.6 Lowpass and Bandpass Processes 68
- 2.7 Monte Carlo Simulation of Digital Communication Systems 74

## 3 Analog Modulation 81

- 3.1 Preview 81
- 3.2 Amplitude Modulation (AM) 81
  - 3.2.1 DSB-AM 82
  - 3.2.2 Conventional AM 91
  - 3.2.3 SSB-AM 98
- 3.3 Demodulation of AM Signals 103
  - 3.3.1 DSB-AM Demodulation 103
  - 3.3.2 SSB-AM Demodulation 109
  - 3.3.3 Conventional AM Demodulation 114
- 3.4 Angle Modulation 119

## 4 Analog-to-Digital Conversion 132

- 4.1 Preview 132
- 4.2 Measure of Information 132
  - 4.2.1 Noiseless Coding 133
- 4.3 Quantization 138
  - 4.3.1 Scalar Quantization 139
  - 4.3.2 Vector Quantization 148
  - 4.3.3 Pulse-Code Modulation 155
  - 4.3.4 Uniform PCM 155

## 5 Baseband Digital Transmission 173

- 5.1 Preview 173

<b>5.2</b>	<b>Binary Signal Transmission</b>	<b>173</b>
5.2.1	Optimum Receiver for the AWGN Channel	174
5.2.2	Other Binary Signal Transmission Methods	184
5.2.3	Signal Constellation Diagrams for Binary Signals	193
<b>5.3</b>	<b>Multiamplitude Signal Transmission</b>	<b>194</b>
5.3.1	Signal Waveforms with Four Amplitude Levels	194
5.3.2	Optimum Receiver for the AWGN Channel	197
5.3.3	Signal Waveforms with Multiple Amplitude Levels	203
<b>5.4</b>	<b>Multidimensional Signals</b>	<b>206</b>
5.4.1	Multidimensional Orthogonal Signals	207
5.4.2	Biorthogonal Signals	216
<b>6</b>	<b>Digital Transmission Through Bandlimited Channels</b>	<b>226</b>
6.1	Preview	226
6.2	The Power Spectrum of a Digital PAM Signal	226
6.3	Characterization of Bandlimited Channels and Channel Distortion	231
6.4	Characterization of Intersymbol Interference	240
6.5	Communication System Design for Bandlimited Channels	247
6.5.1	Signal Design for Zero ISI	247
6.5.2	Signal Design for Controlled ISI	252
6.5.3	Precoding for Detection of Partial Response Signals	257
6.6	Linear Equalizers	260
6.6.1	Adaptive Linear Equalizers	268
6.7	Nonlinear Equalizers	273
<b>7</b>	<b>Digital Transmission via Carrier Modulation</b>	<b>281</b>
7.1	Preview	281
7.2	Carrier-Amplitude Modulation	281
7.2.1	Demodulation of PAM Signals	284
7.3	Carrier-Phase Modulation	287
7.3.1	Phase Demodulation and Detection	290
7.3.2	Differential Phase Modulation and Demodulation	296
7.4	Quadrature Amplitude Modulation	303
7.4.1	Demodulation and Detection of QAM	304
7.4.2	Probability of Error for QAM in an AWGN Channel	306
7.5	Carrier-Frequency Modulation	311
7.5.1	Frequency-Shift Keying	311
7.5.2	Demodulation and Detection of FSK Signals	313
7.5.3	Probability of Error for Noncoherent Detection of FSK	318
7.6	Multicarrier Modulation and OFDM	322
7.7	Synchronization in Communication Systems	328
7.7.1	Carrier Synchronization	328
7.7.2	Clock Synchronization	334
<b>8</b>	<b>Channel Capacity and Coding</b>	<b>344</b>
8.1	Preview	344
8.2	Channel Model and Channel Capacity	344
8.2.1	Channel Model	345
8.2.2	Channel Capacity	345

8.3	Channel Coding	356
8.3.1	Linear Block Codes	358
8.3.2	Convolutional Codes	372
<b>9</b>	<b>Spread Spectrum Communication Systems</b>	<b>391</b>
9.1	Preview	391
9.2	Direct-Sequence Spread Spectrum Systems	392
9.2.1	Signal Demodulation	394
9.2.2	Probability of Error	396
9.2.3	Two Applications of DS Spread Spectrum Signals	397
9.3	Generation of PN Sequences	403
9.4	Frequency-Hopped Spread Spectrum	409
9.4.1	Probability of Error for FH Signals	410
9.4.2	Use of Signal Diversity to Overcome Partial-Band Interference	415
<b>10</b>	<b>Simulink Tutorial on Digital Modulation Methods</b>	<b>422</b>
10.1	Preview	422
10.2	Short Introduction to Simulink	423
10.2.1	Example: BPSK Transmission	423
10.3	Start the Tutorial	430
10.4	Pulse Shaping	431
10.4.1	Theory	432
10.4.2	Experiments	437
10.5	Binary Phase-Shift Keying (BPSK)	443
10.5.1	Binary Phase Shift Keying with NRZ Rectangular Pulses	445
10.5.2	Binary Phase Shift Keying with Raised-Cosine Pulses	451
10.5.3	Binary Phase Shift Keying with Square-Root Raised-Cosine Pulses	454
10.6	Quadrature Phase-Shift Keying (QPSK)	457
10.6.1	Quadrature Phase-Shift Keying with Square-Root Raised-Cosine Pulses	457
10.6.2	Phase and Frequency Offset	461
10.7	Offset-QPSK	466
10.7.1	Theory	466
10.7.2	Experiments	467
10.8	Minimum Shift Keying (MSK)	471
10.8.1	Theory	471
10.8.2	Experiments	471
10.9	16-ary Quadrature Amplitude-Shift Keying (16-QAM)	477
10.9.1	16-QAM with Square-Root Raised-Cosine Pulses	477
10.9.2	16-QAM with Raised-Cosine Pulses	481
<b>Bibliography</b>	<b>485</b>	
<b>Index</b>	<b>486</b>	