大学计算机教育丛书（影印版）

DIGITAL AND ANALOG COMMUNICATION SYSTEMS

FIFTH EDITION

数字与模拟通信系统

第5版

LEON W. COUCH II

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Abbreviations

ac	alternating current
ADC	analog-to-digital conversion
ADM	adaptive delta modulation
AM	amplitude modulation
ANSI	American National Standards Institute
APLL	analog phase-locked loop
ASCII	American Standard Code for Information Interchange
ATM	Asynchronous transfer mode
AT&T	American Telephone and Telegraph
AWGN	additive white Gaussian noise
BER	bit error rate
BISYNC	binary synchronous communication protocol
BPSK	binary phase shift keying
CATV	cable antenna television system
CCITT	Consultative Committee for International Telephone and Telegraph
CDMA	code-division multiple access
CFT	continuous Fourier transform
CMOS	complementary metal oxide conductor
CO	central telephone office
CRT	cathode ray tube
dB	decibel
dc	direct current
DCE	data communications equipment
DFT	discrete Fourier transform
DM	delta modulation
DPCM	differential pulse code modulation
DSB-SC	double-sideband suppressed carrier
DTE	data terminal equipment
EIRP	effective isotropic radiated power
EIA	Electronics Industries Association
ERP	effective radiated power
FCC	Federal Communications Commission (United States)
FDM	frequency-division multiplexing
FET	field effect transistor
FFT	fast Fourier transform
FM	frequency modulation
FSK	frequency shift keying
HDLC	high-level data link control protocol
HDTV	high-definition television
HF	high frequency
IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate frequency
IMD	intermodulation distortion
ISDN	integrated service digital network
ISI	intersymbol interference
ISO	International Organization for Standardization
ITU	International Telecommunications Union of the United Nations
LED	light-emitting diode

LO	local oscillator
LOS	line of sight
LPF	low-pass filter
LSSB	lower single sideband
MAP	maximum a posteriori (criterion)
MPSK	*M*-ary phase shift keying
MQAM	*M*-ary quadrature amplitude modulation
MSK	minimum-shift keying
NBFM	narrowband frequency modulation
NCS	National Communications System of the federal government
NRZ	nonreturn-to-zero
OOK	on-off keying
OQPSK	offset quadrature phase shift keying
OSI	open system interconnection protocol model
PAM	pulse amplitude modulation
PCM	pulse code modulation
PD	phase detection
PDF	probability density function
PEP	peak envelope power
PLL	phase-locked loop
PM	phase modulation
PPM	pulse position modulation
PSD	power spectral density
PSK	phase shift keying
PTM	pulse time modulation
PWM	pulse width modulation
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift
rms	root-mean-square
RT	remote telephone terminal
RZ	return-to-zero
SAW	surface acoustics wave
SDLC	synchronous data link control protocol
S/N or SNR	signal-to-noise ratio
SS	spread spectrum (system)
SSB	single sideband
TDM	time-division multiplexing
TDMA	time-division multiplex access
TELCO	telephone company
THD	total harmonic distortion
TTL	transistor transistor logic
TV	television
TVRO	TV receive only terminal
TWT	traveling-wave tube
UHF	ultra high frequency
USSB	upper single sideband
VCO	voltage-controlled oscillator
VF	voice frequency
VHF	very high frequency
VSB	vestigial sideband
WBFM	wideband frequency modulation

出版前言

我们的大学生、研究生毕业后，面临的将是一个国际化的信息时代。他们将需要随时查阅大量的外文资料；会有更多的机会参加国际性学术交流活动；接待外国学者；走上国际会议的讲坛。作为科技工作者，他们不仅应有与国外同行进行口头和书面交流的能力，更为重要的是，他们必须具备极强的查阅外文资料获取信息的能力。有鉴于此，在国家教委所颁布的“大学英语教学大纲”中有一条规定：专业阅读应作为必修课程开设。同时，在大纲中还规定了这门课程的学时和教学要求。有些高校除开设“专业阅读”课之外，还在某些专业课拟进行英语授课。但教、学双方都苦于没有一定数量的合适的英文原版教材作为教学参考书。为满足这方面的需要，我们挑选了 7 本计算机科学方面最新版本的教材，进行影印出版。首批影印出版的 6 本书受到广大读者的热情欢迎，我们深受鼓舞，今后还将陆续推出新书。希望读者继续给予大力支持。Prentice Hall 公司和清华大学出版社这次合作将国际先进水平的教材引入我国高等学校，为师生们提供了教学用书，相信会对高校教材改革产生积极的影响。

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PREFACE

Continuing the tradition of the first to fourth editions of this book, this new edition provides the latest up-to-date treatment of digital and analog communication systems. It includes a significant number of new study-aid examples and homework problems, many of which require solutions via a personal computer. It is written as a textbook for junior or senior engineering students and is also appropriate for an introductory graduate course or as a modern technical reference for practicing electrical engineers. It covers *practical aspects* of communication systems developed from a sound *theoretical basis*.

THE THEORETICAL BASIS

- Representation of digital signals
- Representation of analog signals
- Magnitude and phase spectra
- Fourier analysis
- Modulation theory
- Random variables
- Probability density
- Random processes

- Orthogonal function theory
- Power spectral density
- Linear systems
- Nonlinear systems
- Intersymbol interference
- Calculation of (SNR)
- Calculation of BER
- Optimum systems
- Block codes
- Convolutional codes

THE PRACTICAL APPLICATIONS

- PAM, PCM, DPCM, DM, PWM, and PPM baseband signaling
- OOK, BPSK, QPSK, MPSK, MSK, and QAM bandpass digital signaling
- AM, DSB-SC, SSB, VSB, PM, and FM bandpass analog signaling
- Time-division multiplexing and the standards used
- Digital line codes and spectra
- Circuits used in communication systems
- Bit synchronizers
- Frame synchronizers
- Carrier synchronizers
- Frequency-division multiplexing and the standards used
- Telecommunication systems
- Telephone systems
- ISDN
- Satellite communication systems
- Effective input-noise temperature and noise figure
- Link budget analysis
- SNR at the output of analog communication systems
- BER for digital communication systems
- Fiber optic systems
- Spread spectrum systems
- Cellular radio telephone systems
- Television systems
- Technical standards for AM, FM, TV, HDTV, and CATV
- Computer communication systems
- Protocols for computer communications
- Technical standards for computer communications
- Math tables
- Study-aid examples
- More than 550 homework problems with selected answers
- More than 60 computer-solution homework problems with solution templates
- Extensive references
- Emphasis on design of communication systems

Many of the equations and homework problems are marked with a personal computer symbol, 💻, which indicates that there is a MATLAB and MATHCAD solution for this equation or problem on an available floppy disk or via Internet, **http:www.eel.ufl.edu/~lcouc**.

This book is an outgrowth of my teaching of graduate as well as undergraduate communication courses at the University of Florida and is tempered by my experiences an amateur radio operator (K4GWQ). I believe that the reader does not fully understand the technical material unless he or she has the opportunity to work on problems. Consequently, more than 550 problems have been included. (Personal computer solutions are provided for more than 60 of these problems on a floppy disk.) Some of them are easy, so that the beginning student will not become frustrated, and some are difficult enough to challenge the more advanced students. All the problems are designed to provoke thought about, and understanding of, communication systems.

This book is written to be applicable to many different course structures. Some of these are summarized in the accompanying table.

Course Length	Chapters Covered	Course Title and Comments
Short Courses		
3 days	1, 3 (partially), 7 (partially)	Digital Communications and Coding
3 days	3, 8	Telecommunications
3 days	4, 5	Modulation, Transmitters, and Receivers
3 days	1, 8	Survey of Communication Systems
3 days	Appendix B	Probability and Random Variables
3 days	6	Random Processes
1 day	8	Case Studies of Communication Systems
Undergraduate		
1 term	1, 2 (rapidly), 3–5, 8	Introduction of Digital and Analog Communication Systems (deterministic approach)
1 term	1, Appendix B, 6–8	Noise in Digital and Analog Communication Systems (a course in probability, random variables, random processes, and applications to communication systems)
1 term	1, Appendix B, 3,6, 7-1 to 7-8	Noise in Digital Communication Systems
1 term	1, 2 (rapidly), 3–5, 7	Digital and Analog Communication Systems (prior course in random processes required)
Two terms		
1st term	1, 2 (rapidly), 3–5	Communication I—Introduction to Communication Systems
2nd term	Appendix B, 6–8	Communication II—Performance of Communication Systems in Noise
Graduate		
1 term	1, Appendix B, 6–8	Introduction to Communication Systems (some undergraduate knowledge of communications required)

I appreciate the help of the many persons who contributed to this book and the helpful comments that have been provided by the reviewers, in particular Marvin Siegel, Department of Electrical Engineering, University of Michigan, and J. B. O'Neal, North Carolina State University. I also appreciate the assistance of my colleagues at the University of Florida. I thank my wife, Dr. Margaret Couch, who typed the original and revised manuscripts.

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LIST OF SYMBOLS

There are not enough symbols in the English and Greek alphabets to allow the use of each letter only once. Consequently, some symbols may be used to denote more than one entity, but their use should be clear from the context. Furthermore, the symbols are chosen to be generally the same as those used in the associated mathematical discipline. For example, in the context of complex variables, x denotes the real part of a complex number (i.e., $c = x + jy$), whereas in the context of statistics x might denote a random variable.

Symbols

a_n	a constant
a_n	quadrature Fourier series coefficient
A_c	level of modulated signal of carrier frequency f_c
A_e	effective area of an antenna
b_n	quadrature Fourier series coefficient
B	baseband bandwidth

B_p	bandpass filter bandwidth
B_T	transmission (bandpass) bandwidth
c	a complex number where $c = x + jy$
c	a constant
c_n	complex Fourier series coefficient
C	channel capacity
C	capacitance
°C	degrees Celsius
dB	decibel
D	dimensions/s, symbols/s ($D = N/T_0$), or baud rate
D_f	frequency modulation gain constant
D_n	polar Fourier series coefficient
D_p	phase modulation gain constant
e	error
e	the natural number, 2.7183
E	modulation efficiency
E	energy
$\mathscr{E}(f)$	energy spectral density (ESD)
E_b/N_0	energy per bit/noise power spectral density ratio
f	frequency (Hz)
$f(x)$	probability density function (PDF)
f_c	carrier frequency
f_i	instantaneous frequency
f_0	a (frequency) constant; the fundamental frequency of a periodic wavefonn
f_s	sampling frequency
F	noise figure
$F(a)$	cumulative distribution function (CDF)
$g(t)$	complex envelope
$\tilde{g}(t)$	corrupted complex envelope
G	power gain
$G(f)$	power transfer function
h	Planck's constant, 6.2×10^{-34} joule-s
$h(t)$	impulse response of a linear network
$h(x)$	mapping function of x into $h(x)$
H	entropy
$H(f)$	transfer function of a linear network
i	an integer
I_j	information in the jth message
j	the imaginary number $\sqrt{-1}$
j	an integer
k	Boltzmann's constant, 1.38×10^{-23} joule/K
k	an integer
$k(t)$	complex impulse response of a bandpass network
K	number of bits in a binary word that represents a digital message

K	degrees Kelvin (°C + 273)
l	an integer
ℓ	number of bits per dimension or bits per symbol
L	inductance
L	number of levels permitted
m	an integer
m	mean value
$m(t)$	message (modulation) waveform
$\tilde{m}(t)$	corrupted (noisy received) message
M	an integer
M	number of messages permitted
n	an integer
n	number of bits in message
$n(t)$	noise waveform
N	an integer
N	number of dimensions used to represent a digital message
N	noise power
N_0	level of the power spectral density of white noise
$p(t)$	an absolutely time-limited pulse waveform
$p(t)$	instantaneous power
$p(m)$	probability density function of frequency modulation
P	average power
P_e	probability of bit error
$P(C)$	probability of correct decision
$P(E)$	probability of message error
$\mathcal{P}(f)$	power spectral density (PSD)
$Q(z)$	integral of Gaussian function
$Q(x_k)$	quantized value of the kth sample value, x_k
$r(t)$	received signal plus noise
R	data rate (bits/s)
R	resistance
$R(t)$	real envelope
$R(\tau)$	autocorrelation function
$s(t)$	signal
$\tilde{s}(t)$	corrupted signal
S/N	signal power/noise power ratio
t	time
T	a time interval
T	absolute temperature (Kelvin)
T_b	bit period
T_e	effective input-noise temperature
T_0	duration of a transmitted symbol or message
T_0	period of a periodic waveform
T_0	standard room temperature (290 K)

T_s	sampling period
u_{ij}	covariance
$v(t)$	a voltage waveform
$v(t)$	a bandpass waveform or a bandpass random process
$w(t)$	a waveform
$W(f)$	spectrum (Fourier transform) of $w(t)$
x	an input
x	a random variable
x	real part of a complex function or a complex constant
$x(t)$	a random process
y	an output
y	an output random variable
y	imaginary part of a complex function or a complex constant
$y(t)$	a random process
α	a constant
β	a constant
β_f	frequency modulation index
β_p	phase modulation index
δ	step size of delta modulation
δ_{ij}	Kronecker delta function
$\delta(t)$	impulse (Dirac delta function)
ΔF	peak frequency deviation (Hz)
$\Delta\theta$	peak-phase deviation
ϵ	a constant
ϵ	error
η	spectral efficiency [(bits/sec)/Hz]
$\theta(t)$	phase waveform
λ	dummy variable of integration
λ	wavelength
$\Lambda(r)$	likelihood ratio
π	3.14159
ρ	correlation coefficient
σ	standard deviation
τ	independent variable of autocorrelation function
τ	pulse width
$\varphi_j(t)$	orthogonal function
ϕ_n	polar Fourier series coefficient
ω_c	radian carrier frequency, $2\pi f_c$
$\equiv$	mathematical equivalence
$\triangleq$	mathematical definition of a symbol

Defined Functions

$J_n(\cdot)$	Bessel function of the first kind nth order
$\ln(\cdot)$	natural logarithm

$\log(\cdot)$	base 10 logarithm
$\log_2(\cdot)$	base 2 logarithm
$Q(z)$	integral of a Gaussian probability density function
$\mathrm{Sa}(z)$	$(\sin z)/z$
$u(\cdot)$	unit step function
$\Lambda(\cdot)$	triangle function
$\Pi(\cdot)$	rectangle function

Operator Notation

$\mathrm{Im}\{\cdot\}$	imaginary part of
$\mathrm{Re}\{\cdot\}$	real part of
$\overline{[\cdot]}$	ensemble average
$\langle[\cdot]\rangle$	time average
$[\cdot] * [\cdot]$	convolution
$[\cdot]^*$	conjugate
$\underline{/[\cdot]}$	angle operator or angle itself, see (2-108)
$\lvert[\cdot]\rvert$	absolute value
$\hat{[\cdot]}$	Hilbert transform
$\mathcal{F}[\cdot]$	Fourier transform
$\mathcal{L}[\cdot]$	Laplace transform
$[\cdot] \cdot [\cdot]$	*dot product*

CONTENTS