

CRC

---

HANDBOOK  
OF  
ENGINEERING  
TABLES

---

# The Electrical Engineering Handbook Series

*Series Editor*

**Richard C. Dorf**

University of California, Davis

## Titles Included in the Series

*The Handbook of Ad Hoc Wireless Networks*, Mohammad Ilyas

*The Avionics Handbook*, Cary R. Spitzer

*The Biomedical Engineering Handbook, Second Edition*, Joseph D. Bronzino

*The Circuits and Filters Handbook, Second Edition*, Wai-Kai Chen

*The Communications Handbook, Second Edition*, Jerry Gibson

*The Computer Engineering Handbook*, Vojin G. Oklobdzija

*The Control Handbook*, William S. Levine

*The CRC Handbook of Engineering Tables*, Richard C. Dorf

*The Digital Signal Processing Handbook*, Vijay K. Madisetti and Douglas Williams

*The Electrical Engineering Handbook, Second Edition*, Richard C. Dorf

*The Electric Power Engineering Handbook*, Leo L. Grigsby

*The Electronics Handbook*, Jerry C. Whitaker

*The Engineering Handbook*, Richard C. Dorf

*The Handbook of Formulas and Tables for Signal Processing*, Alexander D. Poularikas

*The Handbook of Nanoscience, Engineering, and Technology*, William A. Goddard, III,  
Donald W. Brenner, Sergey E. Lyshevski, and Gerald J. Iafrate

*The Handbook of Optical Communication Networks*, Mohammad Ilyas and  
Hussein T. Mouftah

*The Industrial Electronics Handbook*, J. David Irwin

*The Measurement, Instrumentation, and Sensors Handbook*, John G. Webster

*The Mechanical Systems Design Handbook*, Osita D.I. Nwokah and Yidirim Hurmuzlu

*The Mechatronics Handbook*, Robert H. Bishop

*The Mobile Communications Handbook, Second Edition*, Jerry D. Gibson

*The Ocean Engineering Handbook*, Ferial El-Hawary

*The RF and Microwave Handbook*, Mike Golio

*The Technology Management Handbook*, Richard C. Dorf

*The Transforms and Applications Handbook, Second Edition*, Alexander D. Poularikas

*The VLSI Handbook*, Wai-Kai Chen

## Forthcoming Titles

*The Electrical Engineering Handbook, Third Edition*, Richard C. Dorf

*The Electronics Handbook, Second Edition*, Jerry C. Whitaker

*The Engineering Handbook, Second Edition*, Richard C. Dorf

CRC

---

HANDBOOK  
OF  
ENGINEERING  
TABLES

---

EDITOR-IN-CHIEF  
RICHARD C. DORF  
*University of California, Davis*



**CRC PRESS**

---

Boca Raton London New York Washington, D.C.

## Library of Congress Cataloging-in-Publication Data

---

CRC handbook of engineering tables / edited by Richard C. Dorf.

p. cm. — (Electrical engineering handbook series)

Includes index.

ISBN 0-8493-1587-5 (alk. paper)

1. Engineering—Tables. I. Dorf, Richard C. II. Series.

TA151.C76 2003

620'.002'1—dc21

2003055215

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage or retrieval system, without prior permission in writing from the publisher.

All rights reserved. Authorization to photocopy items for internal or personal use, or the personal or internal use of specific clients, may be granted by CRC Press LLC, provided that \$1.50 per page photocopied is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA. The fee code for users of the Transactional Reporting Service is ISBN 0-8493-1587-5/04/\$0.00+\$1.50. The fee is subject to change without notice. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

The consent of CRC Press LLC does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from CRC Press LLC for such copying.

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

**Trademark Notice:** Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

Visit the CRC Press Web site at [www.crcpress.com](http://www.crcpress.com)

---

© 2004 by CRC Press LLC

No claim to original U.S. Government works

International Standard Book Number 0-8493-1587-5

Library of Congress Card Number 2003055215

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

Printed on acid-free paper

# Preface

---

## Purpose

The purpose of the *CRC Handbook of Engineering Tables* is to provide in a single volume a ready reference for the practicing engineer in industry, government, and academia. The tables and figures provided in this book include data and information from all fields of engineering in a comprehensive format. This information is organized into five sections: Electrical and Computer Engineering; Civil and Environmental Engineering; Chemical Engineering, Chemistry and Material Science; Mechanical Engineering; and General Engineering and Mathematics. The 450 tables and figures are compiled from 51 books and are inclusive of most ready available, important data widely used by the engineering practitioner.

## Locating Your Topic

Two avenues of access to information are provided. A complete table of contents is provided at the front of the book. An index is provided at the end of the book. The *CRC Handbook of Engineering Tables* provides answers to most engineering data with reference to the original source. The reader may find it valuable to refer to the original source for a fuller discussion of the underlying theory. We hope that this handbook will be ready at hand to provide data on engineering methods, devices, materials, chemistry, and mathematics.

## Acknowledgement

The handbook was compiled with the generous help of the editors and authors of the original sources and I am grateful for their assistance. I wish to acknowledge the diligent help of my editor, Nora Konopka, and my editorial project development supervisor, Helena Redshaw.

**Richard C. Dorf**

Davis, California

[rcdorf@ucdavis.com](mailto:rcdorf@ucdavis.com)

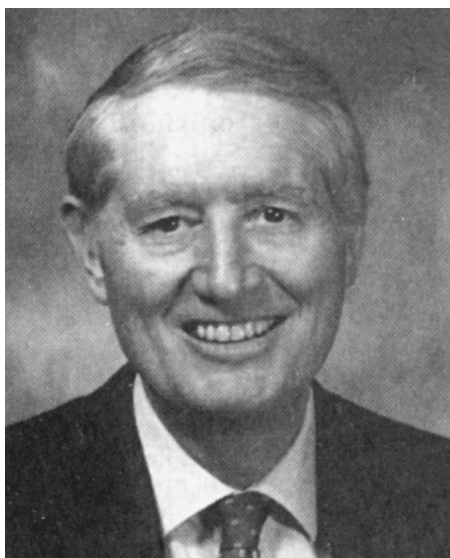
# Dedication

---

I wish to dedicate this book to the memory of my mother and father, Marion Fraser Dorf and William Carl Dorf.

# Editor-in-Chief

---



**Richard C. Dorf**, professor of electrical and computer engineering at the University of California, Davis, teaches graduate and undergraduate courses in electrical engineering in the fields of circuits and control systems. He earned a Ph.D. in electrical engineering from the U.S. Naval Postgraduate School, an M.S. from the University of Colorado, and a B.S. from Clarkson University. Highly concerned with the discipline of engineering and its wide value to social and economic needs, he has written and lectured internationally on the contributions and advances in engineering and their value to society.

Professor Dorf has extensive experience with education and industry and is professionally active in the fields of robotics, automation, electric circuits, and communications. He has served as a visiting professor at the University of Edinburgh, Scotland; the Massachusetts Institute of Technology; Stanford University; and the University of California, Berkeley.

A Fellow of The Institute of Electrical and Electronics Engineers, Dr. Dorf is widely known to the profession for his *Modern Control Systems*, 10th Edition (Prentice Hall 2004) and *Introduction to Electric Circuits*, 6th Edition (Wiley 2004). He is the Editor-in-Chief of the *Electrical Engineering Handbook*, 2nd Edition (CRC Press 1997), the *Technology Management Handbook* (CRC Press 1999), and the *Engineering Handbook*, 2nd Edition (CRC Press 2004).

# Original Source Page

---

*Material from the following titles appears in the CRC Handbook of Engineering Tables*

AC Power Systems Handbook, Second Edition, Jerry C. Whitaker, Technical Press  
Avionics Handbook, Cary R. Spitzer, AvioniCon, Inc.  
Biomedical Engineering Handbook, Second Edition, Joseph D. Bronzino, Trinity College and Biomedical Engineering Alliance for Connecticut  
Circuits and Filters Handbook, Second Edition, Wai-Kai Chen, University of Illinois  
Civil Engineering Handbook, Second Edition, Wai-Fai Chen, University of Hawaii, and J. Y. Richard Liew, National University of Singapore  
Communications Handbook, Second Edition, Jerry D. Gibson, Southern Methodist University  
Comprehensive Dictionary of Electrical Engineering, Philip A. Laplante, Pennsylvania Institute of Technology  
Computer Engineering Handbook, Vojin G. Oklobdzija, University of California  
Concrete Construction Engineering Handbook, Edward G. Nawy, Rutgers University  
Control Handbook, William E. Levine, University of Maryland  
CRC Handbook of Tables for Applied Engineering Science, Ray E. Bolz, Worcester Polytechnic Institute, and George L. Tuve, Case Institute of Technology  
CRC Handbook of Mechanical Engineering, Frank Kreith, University of Colorado  
CRC Materials Science and Engineering Handbook, James F. Shackelford and William Alexander, University of California  
CRC Standard Mathematical Tables and Formulae, 31st Edition, Daniel Zwillinger, Rensselaer Polytechnic Institute  
Digital Color Imaging Handbook, Gaurav Sharma, Xerox Corporation  
Digital Signal Processing Handbook, Vijay K. Madisetti and Douglas B. Williams, Georgia Institute of Technology  
Earthquake Engineering Handbook, Wai-Fai Chen, University of Hawaii, and Charles Scawthorn  
Electric and Hybrid Vehicles: Design Fundamentals, Iqbal Husain, University of Akron  
Electric Power Engineering Handbook, Leo L. Grigsby, Auburn University  
Electrical Engineering Handbook, Second Edition, Richard C. Dorf, University of California  
Electronic Packaging Handbook, Glenn R. Blackwell, Purdue University  
Electronics Handbook, Jerry C. Whitaker, Technical Press  
Engineering Handbook, Richard C. Dorf, University of California  
Environmental Engineers' Handbook, Second Edition, David H. F. Liu, J.T. Baker, Inc., and Béla G. Lipták, Liptak Associates  
Fuel Cell Technology Handbook, Gregory Hoogers, Trier University of Applied Sciences  
Handbook of Ad hoc Wireless Networks, Mohammad Ilyas, Florida Atlantic University  
Handbook of Antennas in Wireless Communications, Lal Chand Godara, University of New South Wales



Handbook of Chemistry and Physics, 83rd Edition, David R. Lide, National Institute of Standards and Technology

Handbook of Formulas and Tables for Signal Processing, Alexander Poularikas, The University of Alabama in Huntsville

Handbook of Lasers, Marvin J. Weber, Lawrence Berkeley National Laboratory, University of California

Handbook of Nanoscience, Engineering, and Technology, William A. Goddard III, California Institute of Technology, Donald W. Brenner, North Carolina State University, Sergey Edward Lyshevski, Rochester Institute of Technology, and Gerald J. Iafrate, North Carolina State University

Handbook of Photonics, Mool C. Gupta, Eastman Kodak Company

Handbook of Structural Engineering, Wai-Fai Chen, Purdue University

Image Processing Handbook, Third Edition, John C. Russ, North Carolina State University

Industrial Electronics Handbook, J. David Irwin, Auburn University

Instrument Engineers' Handbook: Process Software and Digital Networks, Third Edition, Béla G. Lipták, Lipták Associates

Laws and Models: Science, Engineering, and Technology, Carl W. Hall, Consultant

Measurement, Instrumentation and Sensors Handbook, John G. Webster, University of Wisconsin — Madison

Mechanical Systems Design Handbook, Osita D. I. Nwokah and Yildirim Hurmuzlu, Southern Methodist University

Mechatronics Handbook, Robert H. Bishop, The University of Texas at Austin

MEMS Handbook, Mohamed Gal-el-Hak, University of Notre Dame

Ocean Engineering Handbook, Ferial El-Hawary, BH Engineering Systems, Ltd.

Optical Communications Handbook, Mohammad Ilyas, Florida Atlantic University

Power Electronics Handbook, Timothy L. Skvarenina, Purdue University

Resource Handbook of Electronics, Jerry C. Whitaker, Technical Press

RF and Microwave Handbook, Mike Golio, Motorola Corporation

RF Transmission Systems Handbook, Jerry C. Whitaker, Technical Press

Technology Management Handbook, Richard C. Dorf, University of California

Telecommunications Handbook, Kornel Terplan and Patricia Morreale, Stevens Institute of Technology

VLSI Handbook, Wai-Kai Chen, University of Illinois

Wind and Solar Power Systems, Mukund R. Patel, U.S. Merchant Marine Academy

# Table of Contents

---

## SECTION 1 Electrical and Computer Engineering

---

Parameters and Characteristics of Discrete Capacitors.....	1-7
Electrical Properties of Common Insulating Liquids.....	1-8
Types of Systemwide Protection Equipment Available to Facility Managers and the AC Line Abnormalities That Each Approach Can Handle .....	1-8
Comparison of System Grounding Methods.....	1-9
Typical Resistivity of Common Soil Types .....	1-9
Specifications of Standard Cooper Wire.....	1-10
Parameters of Some First-Generation Cellular Standards .....	1-11
Parameters of Some Second-Generation Cellular Standards.....	1-11
Comparison of Satellite Systems as a Function of Orbit.....	1-12
Summary of Transmission Media Characteristics.....	1-12
CSDB Physical Characteristics.....	1-12
Sensor Data Required for Full Flight Regime Operation.....	1-13
Categorization of Fault-Tolerant Software Techniques .....	1-14
The Discipline of Biomedical Engineering.....	1-15
Hematocytes .....	1-16
Plasma.....	1-17
Arterial System .....	1-18
Venous System.....	1-19
Main Endocrine Glands and the Hormones They Produce and Release .....	1-20
Typical Lung Volumes for Normal, Healthy Males .....	1-20
Molecular Masses, Gas Constants, and Volume Fractions for Air and Constituents .....	1-21
Conductivity Values for Cardiac Bidomain .....	1-21
Schematic of Energy Transformations Leading to Muscular Mechanical Work.....	1-22
Typical Values and Estimates for Young's Modulus $E$ .....	1-22
Properties of Bone, Teeth, and Biomaterials.....	1-23
Biomedical Signals .....	1-23
Amplitudes and Spectral Range of Some Important Biosignals .....	1-24
Representative Thermal Property Values .....	1-25
Summary of Several Types of Wavelet Bases for $L^2(R)$ .....	1-25
Debye Temperature and Resistivity of Nonmagnetic Metals.....	1-26
Comparison of Capacitor Dielectric Constants .....	1-26
$\nu'$ Index of Various Capacitors.....	1-26
Capacitors.....	1-27

Inductor Qualifiers and Attributes.....	1-28
Inductance $L_0$ of Various Air Inductors Dimensionally Similar but Having the Same Number of Turns.....	1-29
Basic Characteristics of Magnetic Materials Essential for Inductor Applications .....	1-30
Ideal Op Amp Types .....	1-31
The Four Possible Op Amp Configurations .....	1-31
ITRS Microprocessor Roadmap .....	1-31
Properties of the Relative Sensitivity.....	1-32
Portion of the Electromagnetic Spectrum.....	1-32
The General Arrangement of the Frequency Spectrum that is Applied to Satellite Communications and Other Radiocommunications Services .....	1-33
The Primary Strengths of Satellite Communications .....	1-33
Access Time .....	1-34
Active Filter .....	1-34
Algorithm .....	1-34
Address .....	1-34
Antenna .....	1-34
Appropriate Technology .....	1-34
Attenuation.....	1-34
Automation .....	1-34
Base .....	1-34
Bayesian Theory.....	1-34
Binary-Coded Decimal .....	1-34
Bit.....	1-34
Boundary Condition.....	1-34
Broadcasting.....	1-35
Bus .....	1-35
Byte .....	1-35
Cache .....	1-35
Capacitance .....	1-35
Causal System.....	1-35
Central Processing Unit .....	1-35
Channel .....	1-35
Chaos .....	1-35
Circuit.....	1-35
Code.....	1-35
Computer .....	1-36
Conductivity.....	1-36
Dielectric .....	1-36
Electric Field.....	1-36
Electromagnetic Energy.....	1-36
Ethernet .....	1-36
Gate.....	1-36
Ground .....	1-36
Hologram .....	1-36
Laser.....	1-36

Node .....1-36

Noise .....1-36

Permeability .....1-36

Port .....1-36

Random Signal .....1-36

Resolution.....1-36

Sensor .....1-36

Traveling Wave .....1-37

Waveguide.....1-37

Cost of Selected Memory Devices.....1-37

4-Bit Fractional Two's Complement Numbers.....1-38

DFT Parameters .....1-38

Typical Underdamped Unit-Step Response of a Control System.....1-39

Sequences Corresponding to Various z-Transform Pole Locations.....1-40

Transfer Functions of Dynamic Elements and Networks .....1-43

Block Diagram Transformations .....1-47

Transfer Function Plots for Typical Transfer Functions .....1-48

Fraction of Area Occupied by the Eight Primaries of the Neugebauer Model.....1-56

Characterization vs. Calibration.....1-56

Block Diagram of the Hardware Components Used in a Typical Digital Camera.....1-57

Some Basic DTFT Pairs .....1-57

Properties of the DTFT .....1-58

Properties of the DFT .....1-59

Summary of the Four Types of Linear-Phase FIR Filters .....1-60

Basic Parameters for Three Classes of Acoustic Signals.....1-60

CD and DAT Bit Rates.....1-61

Summary of the Functionalities and Characteristics of the Existing Standards.....1-61

EV and ICEV Efficiencies from Crude Oil to Traction Effort.....1-62

Nominal Energy Density of Sources .....1-62

Specific Energy of Batteries .....1-62

USABC Objectives for EV Battery Packs .....1-63

Properties of EV and HEV Batteries .....1-63

Fuel Cell Types .....1-63

Summary of Power Devices.....1-64

Wind Power Installed Capacity .....1-65

Comparison of Five Fuel Cell Technologies .....1-65

Distributed Generation Technology Chart .....1-66

Basic Fuel Cell Operation.....1-66

Usual Operating Conditions for Transformers.....1-67

Resistivity and Temperature Coefficient of Some Materials .....1-67

Most Commonly Found Relays for Generator Protection.....1-67

Appliances and Sectors under Direct Utility Control, U.S. — 1983 .....1-68

Typical Characteristics of Integrated Circuit Resistors .....1-68

Speech Coder Performance Comparisons .....1-69

Surface Mount Substrate Material .....1-69

Emissivities of Some Common Materials.....1-69

Thermal Conductivities of Typical Packaging Materials at Room Temperature .....1-70

Relative Permeability,  $\mu_r$ , of Some Diamagnetic, Paramagnetic, and Ferromagnetic Materials.....1-71

“Hard” and “Soft” Magnetic Materials.....1-71

Standard Rectangular Waveguides.....1-72

Material Parameters for Several Semiconductors.....1-73

Absorption Loss Is a Function of Type of Material and Frequency.....1-74

Filters Provide a Variety of Frequency Characteristics.....1-75

Radar Bands .....1-76

Typical Acoustic Properties.....1-77

Ferroelectric, Piezoelectric, and Electrostrictive Materials.....1-77

Material Parameters for Type I Superconductors.....1-78

Material Parameters for Conventional Type II Superconductors.....1-78

Spontaneous Polarizations and Curie Temperatures for a Range of Ferroelectrics .....1-78

Pyroelectric Properties of Selected Materials .....1-79

Electrical Properties of a Number of Representative Insulating Liquids .....1-79

Electrical and Physical Properties of Some Common Solid Insulating Materials .....1-80

Physical and Chemical Transduction Principles.....1-82

Electrical Properties of Metals Used in Transmission Lines .....1-83

Typical Synchronous Generate Parameters.....1-83

Excitation Methods and Voltage Current Characteristics for DC Generators .....1-84

Complex Envelope Functions for Various Types of Modulation .....1-85

Protected Service Signal Intensities for Standard Broadcasting (AM) .....1-86

Coding Gains with BPSK and QPSK .....1-87

Comparison of Orbit and Link Parameters for LEO, MEO, and GEO for the Particular Case  
of Circular Orbits (eccentricity,  $e_c = 0$ ) and for Elevation Angle ( $el = 10$ ) .....1-87

Partial List of Satellite Frequency Allocations .....1-88

Specifications of TDMA and CDMA Systems.....1-88

Switching Algebra Summary .....1-89

Binary-to-Decimal Conversion .....1-89

DFs of Single-Valued Nonlinearities .....1-90

Illuminance Categories and Illuminance Values for Genetic Types of Activities in Interiors.....1-92

Representative Transducers.....1-92

Worldwide Radio Navigation Aids.....1-93

Classifications of Chemical Biomedical Sensors.....1-93

Approximate Ultrasonic Attenuation Coefficient, Speed, and Characteristics Impedance for  
Water and Selected Tissues at 3.5 MHz.....1-94

Parasitics in Various Electronic Packages.....1-94

Wiring Board Material Properties.....1-94

Interconnect Models .....1-95

Dielectric Constants and Wave Velocities within Various PCB Materials.....1-97

Wire Ampacity and Size .....1-97

Parameters for Multimode and Single-Mode Fiber .....1-97

Standard Optical Cable Color Coding.....1-98

Common Tests for Optical Fiber.....1-98

Common Tests for Optical Cable Design .....1-99

Cable Interconnects.....1-99

The Electromagnetic Spectrum .....	1-100
Properties of Magnetic Materials and Magnetic Alloys .....	1-101
Units .....	1-102
Summary of Capacitor Properties.....	1-102
Frequency Response Magnitude Functions for Butterworth LP Prototype Filters.....	1-103
Frequency Response Magnitude Functions for Chebyshev LP Prototype Filters .....	1-103
Op-amp Circuits .....	1-104
Operating Characteristics of Common Battery Types .....	1-108
Example Fourier Transform Pairs .....	1-109
Advantages and Disadvantages of Satellites.....	1-110
Satellites Frequency Allocations .....	1-110
Typical Uplink and Downlink Satellite Frequencies (GHz).....	1-110
Frequency Allocations for FSS (Below ~30 GHz) .....	1-110
Characteristics of Satellite PCS Systems .....	1-111
Table of Laplace Operations .....	1-111
Table of Laplace Transforms.....	1-112
Properties of Fourier Transform .....	1-132
Table of Fourier Transforms ( $x = t$ ; $y = w$ ) .....	1-133
Examples of Display Transfer Functions .....	1-157
Common Fourier Transforms .....	1-157
Common Laplace Transforms .....	1-158
Important Properties of Laplace Transforms .....	1-158
Representation Values of Absolute Seebeck Thermoelectric Coefficients of Some Materials	
Used in Industrial Electronic Circuits .....	1-159
Power Definitions (Single-Phase Circuits).....	1-159
Power Definitions (Three-Phase Circuits).....	1-160
Summary of Describing Differential Equations for Ideal Elements .....	1-160
Properties of the Wave Types for Time-of-Flight Measuring .....	1-161
Comparison of Strain Sensors.....	1-162
Pressure-Sensing Elements .....	1-163
Permittivity (Dielectric Constants of Materials Used in Capacitors).....	1-164
The Key Elements of Mechatronics.....	1-164
Mechanical Process and Information Processing Develop Towards Mechatronic Systems.....	1-165
Generalized Through and Across Variables for Processes with Energy Flow.....	1-165
Power and Energy Variables for Mechanical Systems .....	1-165
Mechanical Dissipative Elements .....	1-166
Typical Coefficient of Friction Values .....	1-166
Mechanical Potential Energy Storage Elements (Integral Form).....	1-167
Mechanical Kinetic Energy Storage Elements (Integral Form) .....	1-167
Resistance of Copper Wire .....	1-168
Type of Sensors for Various Measurement Objectives .....	1-168
Type of Actuators and Their Features.....	1-170
Performance of Two Deep-Sea Armored Coaxes .....	1-171
Past and Projected Future Growth of Data and Voice Traffic .....	1-172
Nominal Geographical Spans of Access, Metro-Core/Regional, and Long-Haul Networks.....	1-172
ITU-T-Approved Band Assignment in the Low Attenuation Window of the Silica Fibers .....	1-173

Fiber Optics Chemical Sensors.....1-174

Typical Components of Various Glass Systems .....1-175

Thyristor Symbol and Volt-Ampere Characteristics .....1-175

Triac Symbol and Volt-Ampere Characteristics.....1-176

GTO Symbol and Turn-Off Characteristics .....1-176

Power MOSFET Circuit Symbol .....1-177

Total Elongation at Failure of Selected Polymers .....1-177

Tensile Strength of Selected Wrought Aluminum Alloys .....1-178

Density of Selected Materials, mg/m<sup>2</sup> .....1-178

Applications in the Microwave Bands.....1-179

The Electromagnetic Spectrum .....1-180

Typical Luminance Values .....1-180

Resistivity of Selected Ceramics .....1-181

Properties of Magnetic Materials and Magnetic Alloys .....1-181

Thermal Conductivity of Common Materials.....1-182

Relative Thermal Conductivity of Various Materials As a Percentage of the Thermal  
Conductivity of Copper .....1-182

Variation of Electrical and Thermal Properties of Common Insulators As a Function of  
Temperature .....1-182

Common Op-Amp Circuits .....1-183

Electromagnetic Frequency Spectrum and Associated Wavelengths .....1-187

Modulation Schemes, Glossary of Terms.....1-187

Radar Bands .....1-188

Thermal Conductivities of Typical Metals (W/m K) at Room Temperature .....1-189

Thermal Coefficient of Linear Expansion of Some of the Materials Used in Microwave and RF  
Packaging Applications (at Room Temperature, in 10<sup>-6</sup>/K) .....1-189

Properties of Some Typical Engineering Insulating Materials.....1-190

Selected Material Properties of Semiconductor for Microwave and RF Applications.....1-190

Channel Designations for VHF and UHF Television Stations in the U. S. ....1-191

Radar Frequency Bands .....1-192

Common-Carrier Microwave Frequencies Used in the U.S. ....1-192

Comparison of Amplitude Modulation Techniques .....1-193

Representative Specifications for Various Types of Flexible Air-Dielectric Coaxial Cable.....1-193

Four Drives of Change in Telecommunications.....1-194

Summary and Comparison of Second-Generation TDMA-Based System Parameters.....1-194

Some Milestones for Multimedia .....1-195

Comparison of Interconnect Characteristics for Al and Cu.....1-195

Comparison of High-Permittivity Constant Materials for DRAM Cell Capacitors .....1-195

Summary of Some Architectures and Applications Possible from a Molecular Computing  
System .....1-196

Comparison of Selected Important Semiconductors of Major SiC Polytypes with Silicon  
and GaAs.....1-196

MEMS Processing Technologies .....1-197

Materials Properties of LPCVD Deposited MEMS Materials.....1-198

Wafer Bonding Techniques .....1-198

Microrelays .....1-199

Electronic Packaging Requirements .....1-200

Thermal and Electrical Properties of Materials Used in Packaging .....1-200

Some Properties of Ceramic Packaging Materials.....1-201

Interconnect Technologies .....1-201

Voltage Buffer Performance.....1-201

Embedded Memory Technologies and Applications.....1-202

Recent High-Speed ADC Applications .....1-202

Microprocessor Statistics .....1-203

Comparing Electrical Parameters for BJT/HBT vs. FET .....1-203

Status of Conventional and Renewable Power Sources.....1-204

Benefits of Using Renewable Electricity.....1-204

Electromagnetic Radiation and Stable Elementary Particles .....1-205

Electromagnetic Frequency Spectra .....1-206

Dynamic Response of RCL System to a Step-Change Input .....1-207

Amplitude Response — Second-Order System .....1-208

Phase Response — Second-Order System .....1-209

Frequency-Response Approximations and Corrections .....1-210

Corrections to the Log Magnitude and Phase Diagram .....1-211

Block and Signal-Flow Diagrams .....1-212

Block-Diagram Manipulations.....1-213

Signal-Flow Diagrams.....1-215

Root Loci.....1-218

Transfer Function Plots for Typical Transfer Function.....1-224

**SECTION 2    Civil and Environmental Engineering**

---

Properties of Dressed Lumber .....2-3

Beam Formulas .....2-4

Phases in the Value Engineering Job Plan .....2-5

Maximum Contaminant Concentrations Allowable in Drinking Water (Action Levels) .....2-6

National Ambient Air Quality Standards.....2-10

Standard Normal Probability .....2-11

Typical Values of Elastic Modulus and Poisson's Ratio for Granular Soils.....2-12

Representative Applications and Controlling Functions of Geotextiles .....2-13

Physical Properties of Water in SI Units.....2-14

Physical Properties of Air at Standard Atmospheric Pressure in English Units .....2-14

Physical Properties of Common Liquids at Standard Atmospheric Pressure in SI Units .....2-15

Physical Properties of Common Gases at Standard Sea-Level Atmosphere and 68°F in English  
Units .....2-15

Typical Physical Properties of and Allowable Stresses for Some Common Materials (in U.S.  
Customary System Units).....2-16

Typical Physical Properties of and Allowable Stresses for Some Common Materials (in SI  
System Units).....2-17



Probability Distribution Types .....2-18

Typical Compound Composition of Ordinary Portland Cement .....2-19

Properties of Some Lightweight Concretes.....2-19

Mechanical Properties of Hardened Concrete.....2-20

ACI 318 Maximum Chloride-Ion Content for Corrosion Protection.....2-21

Properties of Typical Air-Entraining Admixtures.....2-21

Total Target Air Content for Concrete.....2-21

Beam Formulas for One-, Two-, and Three-Span Conditions .....2-22

Theoretical Maximum Load Ratios on Floor and Prop for Various Shore/Reshore Combinations .....2-23

Selected Earthquakes Since 1900 (Fatalities Greater than 1,000) .....2-23

Selected U.S. Earthquakes.....2-26

Earthquake Loss Process.....2-28

Earthquake Risk Management Decision Process.....2-29

Principle Elemental Components of Structural Steel .....2-30

Three Levels of Analysis in the EIA Process.....2-30

Public Participation in Environmental Impact Assessment.....2-31

Priority Chemicals Targeted in the 33/50 Project for the Industrial Sector Pollution Prevention  
Strategy.....2-32

Main Membrane Separation Processes: Operating Principles and Application.....2-32

Summary of NAAQs.....2-33

National Emission Standards for Hazardous Air Pollutants.....2-33

Molecular and Aerosol Particle Diameters .....2-37

Radon Risk Evaluation Chart.....2-38

Mechanical Characteristics of Sound Waves.....2-38

Representative Sound Pressures and Sound Levels .....2-39

Typical Wastewater Flow Rates from Residential Sources.....2-39

Estimated Distribution of World's Water .....2-40

Currently Developed Types of Fuel Cells and Their Characteristics and Applications.....2-40

Hydrogen Storage Properties for a Range of Metal Hydrides .....2-41

Typical Gas Composition of Biogas from Organic Household Waste .....2-41

Performance of Different Battery Types .....2-42

Thermodynamic Data for Selected Chemical Compounds.....2-42

Shear Force and Bending Moment Diagrams for Beams with Simple Boundary Conditions  
Subjected to Selected Loading Cases .....2-43

Shear Force and Bending Moment Diagrams for Built-Up Beams Subjected to Typical Loading  
Cases.....2-46

Typical Loading on Plates and Loading Functions .....2-48

Typical Loading and Boundary Conditions for Rectangular Plates .....2-50

Typical Loading and Boundary Conditions for Circular Plates .....2-51

Frequencies and Mode Shapes of Beams in Flexural Vibration .....2-52

Fundamental Frequencies of Portal Frames in Asymmetrical Mode of Vibration.....2-53

Basic Weld Symbols .....2-54

Strength of Welds.....2-55

Reinforcing Bar Dimensions and Weights.....2-56

Eurocode 4 Maximum Width-to-Thickness Ratios for Steel Webs.....2-56

Mechanical Properties of Steels Referred to in the AISI 1996 Specification.....2-57

Some Nominal Properties of Aluminum Alloys.....2-59

Minimum Mechanical Properties.....2-59

Steel Plate Materials .....2-60

Mechanical Properties of Common Design Materials .....2-61

Properties of Sections .....2-61

Components of the Atmosphere.....2-63

Sound Transmission Through Partition Walls .....2-64

Sound-Absorption Coefficients .....2-65

**SECTION 3    Chemical Engineering, Chemistry  
                    and Materials Science**

---

International System of Units (SI) .....3-3

Conversion Factors.....3-11

Periodic Table of Elements .....3-23

Properties of Semiconductors .....3-24

Solid State Lasers.....3-45

III-V Material Systems with Important Optoelectronic Applications.....3-46

Energy Gap and Lattice Parameters for Cubic Group IV, III-V, and II-VI Semiconductors .....3-47

Important Parameters of Semiconductors of Interest for Conventional Electronics and  
    Emerging High Temperature Electronics .....3-47

Properties of GaN(a), AlN (b), and InN(c) .....3-48

List of Ferroelectric Materials and Their Crystal Growth Methods .....3-49

General Physical Properties of Ferroelectric Materials .....3-50

Applications of the Ferroelectric Thin Films.....3-51

The Principal Photometric Units .....3-52

Dielectric Constants of Common Materials.....3-52

Characteristics of Coaxial Cables .....3-52

Dry Saturated Steam: Temperature Table .....3-53

Properties of Superheated Steam .....3-55

Properties of Water at Various Temperatures from 40 to 540°F (44 to 282.2°C) .....3-59

Atomic Mass of Selected Elements.....3-60

Solid Density of Selected Elements .....3-62

Thermal Conductivity of Metals (Part 1) .....3-63

Thermal Conductivity of Metals (Part 2) .....3-64

Thermal Conductivity of Metals (Part 3) .....3-65

Thermal Conductivity of Metals (Part 4) .....3-66

General Properties of Refrigerants.....3-68

Thermodynamic Properties of Saturated Mercury .....3-70

Properties of Rare-Earth Metals.....3-71

Products of Powder Metallurgy.....3-72

Fiber-Reinforced Metals.....3-73

Properties of Commercial Plastics .....3-74

Rubbers and Elastomers .....3-85

Electrical Properties of Various Kinds of Glass .....3-87

Properties of the Chemical Elements.....3-88

Additional Properties of the Chemical Elements .....3-90

Available Stable Isotopes of the Elements.....3-93

Energy Absorption Mass Attenuation Coefficient In  $\text{cm}^2/\text{g}$ .....3-96

Gamma-Ray Absorption Cross Section In  $\text{cm}^{-1}$  .....3-97

Removal Cross Sections for Various Materials .....3-98

Diffusion of Gases and Vapors into Air .....3-99

Speed of Sound in Water and Steam ( $\text{m}\cdot\text{s}^{-1}$ ) .....3-100

Dynamic Viscosity of Water and Steam ( $\text{mPa}\cdot\text{s}$ ) .....3-101

**SECTION 4   Mechanical Engineering**

---

Basic Mechanical Properties .....4-3

Symbols and Definitions for Selected Properties .....4-4

Heating Values in  $\text{kJ}/\text{kg}$  of Selected Hydrocarbons at  $25^\circ\text{C}$ .....4-4

Some Fuel Properties of Four Different Biomass Types .....4-5

Physical Properties of Selected Ceramics.....4-5

Steel Pipe Sizes .....4-6

Commercial Copper Tubing.....4-7

Summary of Definitions .....4-8

CAPP System Characteristics and Their Effects .....4-9

System's View of the Injection Molding Process .....4-10

Magnitude of Process Variation by Machine Input .....4-11

Visualization of Accuracy, Repeatability, and Resolution .....4-11

Anthropomorphic Robot with Frame Assignment .....4-12

Denavit-Hartenberg Parameters of the Anthropomorphic Robot .....4-12

Basic Grip and Trigger Concepts.....4-13

Examples of Specialization of Robot Designs .....4-13

Typical Arm and Wrist Configurations of Industrial Robots .....4-14

From Industrial Robots to Service Robots — The Evolution of Machine Intelligence .....4-15

Scale of Things, in Meters .....4-16

Metals .....4-17

Molecular and Continuum Flow Models.....4-17

Knudsen Number Regimes.....4-18

The Operation Range for Typical MEMS and Nanotechnology Applications Under Standard  
    Conditions Spans the Entire Knudsen Regime .....4-18

Classification of Microrobots According to Size and Fabrication Technology .....4-19

Classification of Microrobots by Functionality.....4-19

Thermal Conductivity, Coefficient of Thermal Expansion, Cost Estimates, and Scaling Trends of  
    Current and Potential Substrate Materials.....4-20

Tools for Soft Computing.....4-20

Saturated Steam, Water, and Ice — SI Units .....4-21

Viscosity and Thermal Conductivity of Steam and Water — SI Units.....4-23

Properties of Gases.....4-24

Mechanical Properties of Metals and Alloys.....4-34

Thermal Properties of Pure Metals — Metric Units.....4-46

Terms and Units for Radiant Energy and Illumination.....4-48

Blackbody Radiation.....4-49

Thermodynamic Nonflow Process Equations .....4-50

Thermodynamic Cycle Efficiencies .....4-51

Heat of Fusion of Some Inorganic Compounds.....4-52

Conservation Equations of a Viscous, Heat-Conducting Fluid.....4-59

Energy Conversions .....4-65

Helical Steel Springs.....4-66

Ultrasonic Energy and Applications .....4-68

Mechanical Components .....4-69

Pneumatic Compensating Components .....4-71

Dynamic Elements and Networks.....4-73

Properties of Saturated Water and Steam (Temperature).....4-76

Properties of Saturated Water and Steam (Pressure) .....4-81

Thermal Conductivity of Water and Steam ( $\text{mW}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ ) .....4-87

**SECTION 5    General Engineering and Mathematics**

---

Constants — Types of Numbers.....5-3

Decimal Multiples and Prefixes.....5-4

Powers of 10 in Hexadecimal Scale.....5-4

Factorials .....5-5

Prime Numbers.....5-7

Reliability.....5-7

Conversion: Metric to English.....5-7

Conversion: English to Metric.....5-7

Interpretations of Powers of 10.....5-8

Typical Values for Coefficients of Static Friction .....5-8

Properties of Plane Areas.....5-9

Moments of Inertia of Homogeneous Solids .....5-10

Dynamic Viscosity of Liquids.....5-14

Resistor Color Code.....5-14

The Problem of Total Cost Visibility.....5-15

Trigonometry .....5-15

Series.....5-19

Differential Calculus .....5-26

Integral Calculus .....5-30

Special Functions .....5-35

Moore's Laws.....5-44

Approximate Current Densities in Electrons per Second per Square Nanometer Calculated from  
Experimental Data for Selected Molecular Electronic and Macroscopic Metal Devices .....5-44

Comparison of Memory Technologies for the Year 2011 .....5-45

Size and Scale of Naturally Occurring Structures as Compared With Human-Made Structures .....5-45

Trends in Miniaturization of Integrated Circuits in the Last 25 Years.....5-46

Civilizations, Technology Periods (Ages), and Historical Revolutions as a Function of Time .....5-47

Abbreviations .....5-48

Boiling Point Law, General .....5-49

Hall Effect.....5-50

Ideal Mixtures, Law of .....5-50

Large Numbers, Law of.....5-51

Maxwell Electromagnetic Field Equations.....5-51

Moore Law.....5-51

Newton Laws of Motion.....5-52

Normal Law.....5-53

Photoelectric Effect, Laws of .....5-54

Shannon Law or Formula or Theorem.....5-54

Skin Effect .....5-55

Snell Law.....5-55

Thermodynamics, Laws of.....5-56

Young Modulus, E.....5-57

Types of Manufacturing — Characteristics and Examples.....5-58

Coefficient of Friction — Identical Metals.....5-59

Coefficient of Friction — Identical Alloy Pairs .....5-60

Coefficient of Friction — Dissimilar Metals .....5-61

Coefficient of Friction — Single Crystals.....5-62

Coefficients of Friction — Non-Metals .....5-63

Coefficient of Friction — Lubricating Powders .....5-64

Coefficients of Static and Sliding Friction.....5-64

The Greek and Russian Alphabets .....5-66

Units and Their Conversion.....5-67

International System (SI) Metric Units.....5-69

Conversions to SI Units .....5-72

Fundamental Physical Constants.....5-81

Numerical Constants .....5-83

Mathematical Constants .....5-85

Derivatives .....5-86

Facts from Algebra .....5-89

Integrals — Elementary Forms .....5-90

Series.....5-92

Tables of Statistical Probability .....5-100

Ordinates and Areas for Normal or Gaussian Probability Distribution .....5-102

Student's *t*-Distribution.....5-105

Chi-Square Distribution .....5-106

F-Distribution .....5-107

Binomial Distribution — Cumulative Probabilities:  $P$  .....5-111

Poisson Distribution — Cumulative Probabilities:  $P$  .....5-113

Critical Values for the Sign Test .....5-116

Factors for Computing Control Limits.....5-117

Number Systems and Change of Base .....5-120

Binary, Octal, and Decimal Numbers .....5-122

Octal-Decimal Integer Conversion.....5-124

Boolean Theorems .....5-128

Applications and Functions of Two Variables .....5-129