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ELECTRICAL ENGINEERING

DICTIONARY

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Phillip A. Laplante

CHAPMAN & HALL/**CRC***netBASE*

Product Manager: *Karen Feinstein*
Project Editor: *Ibrey Woodall*
Packaging design: *Jonathan Pennell*

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Preface

One can only appreciate the magnitude of effort required to develop a dictionary by actually experiencing it. Although I had written nine other books, I certainly did not know what I was getting into when in January of 1996 I agreed to serve as Editor-in-Chief for this project. Now, after 2 1/2 years I understand.

Unlike other books that I have written, creating this dictionary was more a test of will and stamina and an exercise in project management than mere writing. And although I have managed organizations of up to 80 academics, nothing is more like “herding cats” than motivating an international collection of almost 200 distinguished engineers, scientists, and educators scattered around the globe almost entirely via email. Yet, I think there is no other way to undertake a project like this. I still marvel at how Noah Webster must have managed to construct his English Dictionary without the benefits of modern communication.

But this project, as much as it is a monument to individual will, is really the collaborative work of many brilliant and dedicated men and women. This is their dictionary and your dictionary.

Phillip A. Laplante, PE, Ph.D.
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Media, Pennsylvania

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Foreword

How was the dictionary constructed?

As I knew this project would require a divide-and-conquer approach with fault-tolerance, I sought to partition the dictionary by defining areas that covered all aspects of Electrical Engineering. I then matched these up to IEEE defined interest areas to ensure that complete coverage was provided. This created a great deal of overlap, which was intentional. I knew that terms needed to be defined several different ways, depending on usage and I needed to ensure that every term would be defined at least once.

The mapping of the Dictionary's areas to the IEEE interest areas are as follows:

Power systems • Power Engineering • Power Electronics	Circuits and systems • Circuits and Systems • Instruments and Measurements
Electric motors and machines • Power Engineering • Power Electronics	Control systems • Control Systems • Robotics and Automation
Digital electronics, VLSI, hardware description language • Consumer Electronics • Electronic Devices • Industrial Electronics • Instruments and Measurements	Electromagnetics • Electromagnetic Compatibility • Magnetics
Microelectronics and solid state devices • Industrial Electronics • Instruments and Measurements	Computer engineering (processors) • Computer
RF, radio, and television • Broadcast Technology	Computer engineering (I/O and storage) • Computer
Communications and information processing • Communications • Information Theory • Systems, Man, and Cybernetics • Reliability	Microwave systems • Antennas and Propagation • Microwave Theory and Techniques
Signal and image processing • Signal Processing • Systems, Man, and Cybernetics	Electro-optical and lightwave systems • Lasers and Electro-Optics
	Illumination
	Properties of materials • Dielectrics and Electrical Insulation
	Packaging • Components, Packaging, and • Manufacturing Technology

Note that Software Engineering was not included as an area, and most software terms have been omitted. Those that were included were done so because they relate to some aspect of assembly language programming or low-level control, or artificial intelligence and robotics. For those interested in software engineering terms, CRC's

forthcoming *Comprehensive Dictionary of Computer Science, Engineering and Technology* will include those terms.

Several other IEEE interest areas were not explicitly assigned to area editors. However, after discussing this fact with the Editorial Board, it was decided that relevant terms of a general nature would be picked up and terms that were not tagged for the dictionary from these areas were probably too esoteric to be included.

These interest areas encompass:

Aerospace and Electronic Systems	Geosience and Remote Sensing
Education	Industry Applications
Engineering in Medicine and Biology	Nuclear and Plasma Science
Engineering Management	Oceanic Engineering
Professional Communications	Ultrasonic, Ferroelectrics, and Frequency Control
Social Implications of Technology	Vehicular Technology

Given the Area Editor structure, constructing the dictionary then consisted of the following steps:

1. Creating a terms list for each area
2. Defining terms
3. Cross-checking terms within areas
4. Cross-checking terms across areas
5. Compiling and proofing the terms and definitions
6. Reviewing compiled dictionary
7. Final proofreading

The first and most important task undertaken by the area editors was to develop a list of terms to be defined. A terms list is a list of terms (without definitions), proper names (such as important historical figures or companies), or acronyms relating to Electrical Engineering. What went into each terms list was left to the discretion of the area editor based on the recommendations of the contributing authors. However, lists were to include all technical terms that relate to the area (and subareas). Technical terms of a historical nature were only included if it was noted in the definition that the term is “not used” in modern engineering or that the term is “historical” only. Although the number of terms in each list varied somewhat, each area’s terms list consisted of approximately 700 items.

Once the terms lists were created, they were merged and scrutinized for any obvious omissions. These missing terms were then assigned to the appropriate area editor. At this point the area editors and their contributing authors (there were 5 to 20 contributing authors per area) began the painstaking task of term definition. This process took many months. Once all of the terms and their definitions were collected, the process of converting, merging, and editing began.

The dictionary included contributions from almost 200 contributors from 17 countries. Although authors were provided with a set of guidelines to write terms definitions, they were free to exercise their own judgment and to use their own style.

As a result, the entries vary widely in content from short, one-sentence definitions to rather long dissertations. While I tried to provide some homogeneity in the process of editing, I neither wanted to tread on the feet of the experts and possibly corrupt the meaning of the definitions (after all, I am not an expert in any of the representative areas of the dictionary) nor did I want to interfere with the individual styles of the authors. As a result, I think the dictionary contains a diverse and rich exposition that collectively provides good insights into the areas intended to be covered by the dictionary. Moreover, I was pleased to find the resultant collection much more lively, personal, and user-friendly than typical dictionaries.

Finally, we took advantage of the rich CRC library of handbooks, including *The Control Handbook*, *Electronics Handbook*, *Image Processing Handbook*, *Circuits and Filters Handbook*, and *The Electrical Engineering Handbook*, to pick up any definitions that were missing or incomplete. About 1000 terms were taken from the CRC handbooks. We also borrowed, with permission from IEEE, about 40 definitions that could not be found elsewhere or could not be improved upon.

Despite the incredible support from my area editors, individual contributors, and staff at CRC Press, the final task of arbitrating conflicting definitions, rewording those that did not seem descriptive enough, and identifying missing ones was left to me. I hope that I have not failed you terribly in my task.

How to use the dictionary

The dictionary is organized like a standard language dictionary except that not every word used in the dictionary is defined there (this would necessitate a complete embedding of an English dictionary). However, we tried to define most non-obvious technical terms used in the definition of another term.

In some cases more than one definition is given for a term. These are denoted (1), (2), (3), ..., etc. Multiple definitions were given in cases where the term has multiple distinct meanings in differing fields, or when more than one equivalent but uniquely descriptive definition was available to help increase understanding. In a few cases, I just couldn't decide between two definitions. Pick the definition that seems to fit your situation most closely. The notation 1., 2., etc. is used to itemize certain elements of a definition and are not to be confused with multiple definitions.

Acronym terms are listed by their expanded name. Under the acronym the reader is referred to that term. For example, if you look up "RISC" you will find "See reduced instruction set computer," where the definition can be found. The only exceptions are in the cases where the expanded acronym might not make sense, or where the acronym itself has become a word (such as "laser" or "sonar").

While I chose to include some commonly used symbols (largely upon the recommendations of the contributors and area editors), this was not a principle focus of the dictionary and I am sure that many have been omitted.

Finally, we tried to avoid proprietary names and tradenames where possible. Some have crept in because of their importance, however.

Acknowledgments

A project of this scope literally requires hundreds of participants. I would like to take this moment to thank these participants both collectively and individually. I thank, in no particular order:

- The editorial board members and contributors. Although not all participated at an equal level, all contributed in some way to the production of this work.
- Ron Powers, CRC President of Book Publishing, for conceiving this dictionary, believing in me, and providing incredible support and encouragement.
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Finally to my wife Nancy and children Christopher and Charlotte for their incredible patience and endurance while I literally spent hundreds of hours to enable the birth of this dictionary. This achievement is as much theirs as it is mine.

Please accept my apologies if anyone was left out — this was not intentional and will be remedied in future printings of this dictionary.

How to Report Errors/Omissions

Because of the magnitude of this undertaking and because we attempted to develop new definitions completely from scratch, we have surely omitted (though not deliberately) many terms. In addition, some definitions are possibly incomplete, weak, or even incorrect. But we wish to evolve and improve this dictionary in subsequent printings and editions. You are encouraged to participate in this collaborative, global process. Please send any suggested corrections, improvements, or new terms to be added (along with suggested definitions) to me at p.laplace@ieee.org or plaplace@pit.edu. If your submission is incorporated, you will be recognized as a contributor in future editions of the dictionary.

Editor-in-Chief

Phil Laplante is the President of Pennsylvania Institute of Technology, a two-year, private, college that focuses on technology training and re-training. Prior to this, he was the founding dean of the BCC/NJIT Technology and Engineering Center in Southern New Jersey. He was also Associate Professor of Computer Science and Chair of the Mathematics, Computer Science and Physics Department at Fairleigh Dickinson University, New Jersey. In addition to his academic career, Dr. Laplante spent almost eight years as a software engineer designing avionics systems, a microwave CAD engineer, a software systems test engineer, and a consultant.

He has written dozens of articles for journals, newsletters, magazines, and conferences, mostly on real-time computing and image processing. He has authored 10 other technical books and edits the journal, *Real-Time Imaging*, as well as two book series including the CRC Press series on Image Processing.

Dr. Laplante received his B.S., M.Eng., and Ph.D. in Computer Science, Electrical Engineering, and Computer Science, respectively, from Stevens Institute of Technology and an M.B.A. from the University of Colorado at Colorado Springs.

He is a senior member of IEEE and a member of ACM and numerous other professional societies, program committees, and advisory boards. He is a licensed professional engineer in New Jersey and Pennsylvania.

Dr. Laplante is married with two children and resides in Pennsylvania.

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Contributors

James T. Aberle
Arizona State University
Tempe, AZ

Giovanni Adorni
Università di Parma
Parma, Italy

Ashfaq Ahmed
Purdue University
West Lafayette, IN

A. E. A. Almaini
Napier University
Edinburgh, Scotland

Earle M. Alexander IV
San Rafael, CA

Jim Andrew
CISRA
North Ryde, Australia

James Antonakos
Broome County Community College
Binghamton, NY

Eduard Ayguade
Barcelona, Spain

Bibhuti B. Banerjee
Dexter Magnetic Materials
Fremont, CA

Partha P. Banerjee
University of Alabama
Huntsville, AL

Ishmael (“Terry”) Banks
American Electric Power Company
Athens, OH

Walter Banzhaf
University of Hartford
Hartford, CT

Ottis L. Barron
University of Tennessee at Martin
Martin, TN

Robert A. Bartkowiak
Penn State University at Lehigh Valley
Fogelsville, PA

Richard M. Bass
Georgia Institute of Technology
Atlanta, GA

Michael R. Bastian
Brigham Young University
Provo, UT

Jeffrey S. Beasley
New Mexico State University
Las Cruces, NM

Lars Bengtsson
Halmsted University
Halmsted, Sweden

Mi Bi
Tai Seng Industrial Estate
Singapore

Edoardo Biagioni
SCS
Pittsburgh, PA

David L. Blanchard
Purdue University Calumet
Hammond, IN

Wayne Bonzyk
Colman, SD

R. W. Boyd
University of Rochester
Rochester, NY

M. Braae
University of Cape Town
Rondebosch, South Africa

Doug Burges
University of Wisconsin
Madison, WI

Nick Buris
Motorola
Schaumburg, IL

Jose Roberto Camacho
Universidade Federal de Uberlândia
Uberlândia, Brazil

Gerard-Andre Capolino
University of Picardie
Amiens, France

Lee W. Casperson
Portland State University
Portland, OR

Antonio Chella
University of Palermo
Palermo, Italy

C. H. Chen
University of Massachusetts
N. Dartmouth, MA

Zheru Chi
Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

Shamala Chickamenahalli
Wayne State University
Detroit, MI

Christos Christodoulou
University of Central Florida
Orlando, FL

Badrul Chowdhury
University of Wyoming
Laramie, Wyoming

Dominic J. Ciardullo
Nassau Community College
Garden City, NY

Andrew Cobb
New Albany, IN

Christopher J. Conant
Broome County Community College
Binghamton, NY

Robin Cravey
NASA Langley Research Center
Hampton, VA

George W. Crawford
Penn State University
McKeesport, PA

John K. Daher
Georgia Institute of Technology
Atlanta, GA

Fredrik Dahlgren
Chalmers University of Technology
Gothenburg, Sweden

E. R. Davies
University of London
Surrey, England

Ronald F. DeMara
University of Central Florida
Orlando, FL

William E. DeWitt
Purdue University
West Lafayette, IN

Alex Domijan
University of Florida
Gainesville, FL

Bob Dony
University of Guelph
Guelph, Ontario, Canada

Tom Downs
University of Queensland
Brisbane, Australia

Marvin Drake
The MITRE Corporation
Bedford, MA

Lawrence P. Dunleavy
University of South Florida
Tampa, FL

Scott C. Dunning
University of Maine
Orono, ME

Andrzej Dzielinski
ISEP
Warsaw University of Technology
Warsaw, Poland

Jack East
University of Michigan
Ann Arbor, MI

Sandra Eitnier
San Diego, CA

Samir El-Ghazaly
Arizona State University
Tempe, AZ

Irv Englander
Bentley College
Waltham, MA

Ivan Fair
Technical University of Nova Scotia
Halifax, Nova Scotia, Canada

Gang Feng
University of New South Wales
Kensington, Australia

Peter M. Fenwick
University of Auckland
Auckland, New Zealand

Paul Fieguth
University of Waterloo
Waterloo, Ontario, Canada

Igor Filanovsky
University of Alberta
Edmonton, Alberta, Canada

Wladyslau Findeisen
Warsaw University of Technology
Warsaw, Poland

Dion Fralick
NASA Langley Research Center
Hampton, VA

Lawrence Fryda
Central Michigan University
Mt. Pleasant, MI

Mumtaz B. Gawargy
Concordia University
Montreal, Quebec, Canada

Frank Gerlitz
Washtenaw College
Ann Arbor, MI

Antonio Augusto Gorni
COSIPA
Cubatao, Brazil

Lee Goudelock
Laurel, MS

Alex Grant
Institut für Signal- und
Informationsverarbeitung
Zurich, Switzerland

Thomas G. Habetler
Georgia Tech
Atlanta, GA

Haldun Hadimioglu
Polytechnic University
Brooklyn, NY

Dave Halchin
RF MicroDevices
Greensboro, NC

Thomas L. Harman
University of Houston
Houston, TX

P. R. Hemmer
RL/EROP
Hanscom Air Force Base, MA

Vincent Heuring
University of Colorado
Boulder, CO

Andreas Hirstein
Swiss Electrotechnical Association
Fehraltorf, Switzerland

Robert J. Hofinger
Purdue University School of
Technology at Columbus
Columbus, IN

Michael Honig
Northwestern University
Evanston, IL

Yan Hui
Northern Telecom
Nepean, Ontario, Canada

Suresh Hungenahally
Griffith University
Nathan, Queensland, Australia

Iqbal Husain
University of Akron
Akron, OH

Eoin Hyden
Madison, NJ

Marija Ilic
MIT
Cambridge, MA

Mark Janos
Uniphase Fiber Components
Sydney, Australia

Albert Jelalian
Jelalian Science & Engineering
Bedford, MA

Anthony Johnson
New Jersey Institute of Technology
Newark, NJ

C. Bruce Johnson
Phoenix, AZ

Brendan Jones
Optus Communications
Sydney, Australia

Suganda Jutamulia
In-Harmony Technology Corp.
Petaluma, CA

Richard Y. Kain
University of Minnesota
Minneapolis, MN

Dikshitulu K. Kalluri
University of Massachusetts
Lowell, MA

Alex Kalu
Savannah State University
Savannah, GA

Gary Kamerman
FastMetrix
Huntsville, AL

Avishay Katz
EPRI
Palo Alto, CA

Wilson E. Kazibwe
Telegyr Systems
San Jose, CA

David Kelley
Penn State University
University Park, PA

D. Kennedy
Ryerson Polytechnic Institute
Toronto, Ontario, Canada

Mohan Ketkar
University of Houston
Houston, TX

Jerzy Klamka
Silesian Technical University
Gliwice, Poland

Krzysztof Kozłowski
Technical University of Poznan
Poznan, Poland

Ron Land
Penn State University
New Kensington, PA

Robert D. Laramore
Cedarville College
Cedarville, OH

Joy Laskar
Georgia Institute of Technology
Atlanta, GA

Matti Latva-aho
University of Oulu
Linannmaa, Oulu, Finland

Thomas S. Laverghetta
Indiana University-Purdue University
at Fort Wayne
Fort Wayne, IN

J. N. Lee
Naval Research Laboratory
Washington, D. C.

Fred Leonberger
UT Photonics
Bloomfield, CT

Ging Li-Wang
Dexter Magnetic Materials
Fremont, CA

Yilu Liu
Virginia Tech
Blacksburg, VA

Jean Jacques Loiseau
Institute Recherche en Cybernetique
Nantes, France

Harry MacDonald
San Diego, CA

Chris Mack
FINLE Technologies
Austin, TX

Krzysztof Malinowski
Warsaw University of Technology
Warsaw, Poland

S. Manoharan
University of Auckland
Auckland, New Zealand

Horacio J. Marquez
University of Alberta
Edmonton, Alberta, Canada

Francesco Masulli
University of Genoa
Genoa, Italy

Vincent P. McGinn
Northern Illinois University
DeKalb, IL

John A. McNeill
Worcester Polytechnic Institute
Worcester, MA

David P. Millard
Georgia Institute of Technology
Atlanta, GA

Monte Miller
Rockwell Semiconductor Systems
Newbury Park, CA

Linn F. Mollenauer
AT&T Bell Labs
Holmdel, NJ

Mauro Mongiardo
University of Perugia
Perugia, Italy

Michael A. Morgan
Naval Postgraduate School
Monterey, CA

Amir Mortazawi
University of Central Florida
Orlando, FL

Michael S. Munoz
TRW Corporation

Paolo Nesi
University of Florence
Florence, Italy

M. Nieto-Vesperinas
Instituto de Ciencia de Materiales
Madrid, Spain

Kenneth V. Noren
University of Idaho
Moscow, ID

Behrooz Nowrouzian
University of Alberta
Edmonton, Alberta, Canada

Terrence P. O'Connor
Purdue University School of
Technology at New Albany
New Albany, IN

Ben O. Oni
Tuskegee University
Tuskegee, AL

Thomas H. Ortmeyer
Clarkson University
Potsdam, NY

Ron P. O'Toole
Cedar Rapids, IA

Tony Ottosson
Chalmers University of Technology
Göteborg, Sweden

J. R. Parker
University of Calgary
Calgary, Alberta, Canada

Stefan Parkval
Royal Institute of Technology
Stockholm, Sweden

Joseph E. Pascente
Downers Grove, IL

Russell W. Patterson
Tennessee Valley Authority
Chattanooga, TN

Steven Pekarek
University of Missouri
Rolla, MO

Marek Perkowski
Portland State University
Portland, OR

Roman Pichna
University of Oulu
Oulu, Finland

A. H. Pierson
Pierson Scientific Associates, Inc.
Andover, MA

Pragasen Pillay
Clarkson University
Potsdam, NY

Agostina Poggi
Università di Parma
Parma, Italy

Aun Neow Poo
Postgraduate School of Engineering
National University of Singapore
Singapore

Ramas Ramaswami
MultiDisciplinary Research
Ypsilanti, MI

Satiskuman J. Ranade
New Mexico State University
Las Cruces, NM

Lars K. Rasmussen
Centre for Wireless Communications
Singapore

Walter Rawle
Ericsson, Inc.
Lynchburg, VA

C. J. Reddy
NASA Langley Research Center
Hampton, VA

Greg Reese
Dayton, OH

Joseph M. Reinhardt
University of Iowa
Iowa City, IA

Nabeel Riza
University of Central Florida
Orlando, FL

John A. Robinson
Memorial University of Newfoundland
St. John's, Newfoundland, Canada

Eric Rogers
University of Southampton
Highfield, Southampton, England

Christian Ronse
Université Louis Pasteur
Strasbourg, France

Pieter van Rooyen
University of Pretoria
Pretoria, South Africa

Ahmed Saifuddin
Communication Research Lab
Tokyo, Japan

Robert Sarfi
ABB Power T & D Co., Inc.
Cary, NC

Simon Saunders
University of Surrey
Guildford, England

Helmut Schillinger
IOQ
Jena, Germany

Manfred Schindler
ATN Microwave
North Billerica, MA

Warren Seely
Motorola
Scottsdale, AZ

Yun Shi
New Jersey Institute of Technology
Newark, NJ

Mikael Skoglund
Chalmers University of Technology
Göteborg, Sweden

Rodney Daryl Slone
University of Kentucky
Lexington, KY

Keyue M. Smedley
University of California
Irvine, CA

William Smith
University of Kentucky
Lexington, KY

Babs Soller
University of Massachusetts Medical Center
Worcester, MA

Y. H. Song
Brunel University
Uxbridge, England

Janusz Sosnowski
Institute of Computer Science
Warsaw, Poland

Elvino Sousa
University of Toronto
Toronto, Ontario, Canada

Philip M. Spray
Amarillo, TX

Joe Staudinger
Motorola
Tempe, AZ

Roman Stemprow
Denton, TX

Diana Stewart
Purdue University School of Technology
at New Albany
New Albany, IN

Francis Swarts
University of the Witwatersrand
Johannesburg, South Africa

Andrzej Swierniak
Silesian Technical University
Gliwice, Poland

Daniel Tabak
George Mason University
Fairfax, VA

Tadashi Takagi
Mitsubishi Electric Corporation
Ofuna, Kamakura, Japan

Jaakko Talvitie
University of Oulu
Oulu, Finland

Hamid A. Toliyat
Texas A&M University
College Station, TX

Austin Truitt
Texas Instruments
Dallas, TX

Pieter van Rooyen
University of Pretoria
South Africa

Jonas Vasell
Chalmers University of Technology
Göteborg, Sweden

John L. Volakis
University of Michigan
Ann Arbor, MI

Annette von Jouanne
Oregon State University
Corvallis, OR

Liancheng Wang
ABB Power T & D Co., Inc.
Cary, NC

Ronald W. Waynant
FDA/CDRH
Rockville, MD

Larry Wear
Sacramento, CA

Wilson X. Wen
AI Systems
Talstra Labs
Clayton, Australia

Barry Wilkinson
University of North Carolina
Charlotte, NC

Robert E. Wilson
Western Area Power Administration
Montrose, CA

Stacy S. Wilson
Western Kentucky University
Bowling Green, KY

Denise M. Wolf
Lawrence Berkeley National Laboratory
Berkeley, CA

E. Yaz
University of Arkansas
Fayetteville, Arkansas

Pochi Yeh
University of California
Santa Barbara, CA

Jeffrey Young
University of Idaho
Moscow, ID

Stanislaw H. Zak
Purdue University
West Lafayette, IN

Qing Zhao
University of Western Ontario
London, Ontario, Canada

Jizhong Zhu
National University of Singapore
Singapore

Omar Zia
Marietta, GA

Special Symbols

α -level set a crisp set of elements belonging to a fuzzy set A at least to a degree α

$$A_\alpha = \{x \in X \mid \mu_A(x) \geq \alpha\}$$

See also [crisp set](#), [fuzzy set](#).

Δf common symbol for bandwidth, in hertz.

ϵ_{rGaAs} common symbol for gallium arsenide relative dielectric constant. $\epsilon_{\text{rGaAs}} = 12.8$.

ϵ_{rSi} common symbol for silicon relative dielectric constant. $\epsilon_{\text{rSi}} = 11.8$.

ϵ_0 symbol for permittivity of free space. $\epsilon_0 = 8.849 \times 10^{-12}$ farad/meter.

ϵ_r common symbol for relative dielectric constant.

η_{DC} common symbol for DC to RF conversion efficiency. Expressed as a percentage.

η_a common symbol for power added efficiency. Expressed as a percentage.

η_t common symbol for total or true efficiency. Expressed as a percentage.

Γ_{opt} common symbol for source reflection coefficient for optimum noise performance.

μ_0 common symbol for permeability of free space constant. $\mu_0 = 1.257 \times 10^{-16}$ henrys/meter.

μ_r common symbol for relative permeability.

ω common symbol for radian frequency in radians/second. $\omega = 2 \cdot \pi \cdot \text{frequency}$.

θ_+ common symbol for positive transition angle in degrees.

θ_- common symbol for negative transition angle in degrees.

θ_{cond} common symbol for conduction angle in degrees.

θ_{sat} common symbol for saturation angle in degrees.

θ_{CC} common symbol for FET channel-to-case thermal resistance in $^{\circ}\text{C}/\text{watt}$.

θ_{JC} common symbol for bipolar junction-to-case thermal resistance in $^{\circ}\text{C}/\text{watt}$.

A^* common symbol for Richardson's constant. $A^* = 8.7$ amperes $\cdot \text{cm}/^{\circ}\text{K}$

BV_{GD} See [gate-to-drain breakdown voltage](#).

BV_{GS} See [gate-to-source breakdown voltage](#).

dv/dt rate of change of voltage withstand capability without spurious turn-on of the device.

H_{ci} See [intrinsic coercive force](#).

n_e common symbol for excess noise in watts.

n_sh common symbol for shot noise in watts.

n_t common symbol for thermal noise in watts.

10base2 a type of coaxial cable used to connect nodes on an Ethernet network. The 10 refers to the transfer rate used on standard Ethernet, 10 megabits per second. The base means that the network uses baseband communication rather than broadband communications, and the 2 stands for the maximum length of cable segment, 185 meters (almost 200). This type of cable is also called “thin” Ethernet, because it is a smaller diameter cable than the 10base5 cables.

10base5 a type of coaxial cable used to connect nodes on an Ethernet network. The 10 refers to the transfer rate used on standard Ethernet, 10 megabits per second. The base means that the network uses baseband communication rather than broadband communications, and the 5 stands for the maximum length of cable segment of approximately 500 meters. This type of cable is also called “thick” Ethernet, because it is a larger diameter cable than the 10base2 cables.

10baseT a type of coaxial cable used to connect nodes on an Ethernet network. The 10 refers to the transfer rate used on standard Ethernet, 10 megabits per second. The base means that the network uses baseband communication rather than broadband communications, and the T stands for twisted (wire) cable.

2-D Attasi model a 2-D model described by the equations

$$\begin{aligned} x_{i+1,j+1} &= -A_1 A_2 x_{i,j} + A_1 x_{i+1,j} \\ &\quad + A_2 x_{i,j+1} + B u_{ij} \\ y_{ij} &= C x_{ij} + D u_{ij} \end{aligned}$$

$i, j \in Z_+$ (the set of nonnegative integers). Here $x_{ij} \in R^n$ is the local state vector, $u_{ij} \in R^m$ is the input vector, $y_{ij} \in R^p$ is the output vector, and A_1, A_2, B, C, D are real matrices. The model was introduced by Attasi in “Systemes lineaires homogenes a

deux indices,” *IRIA Rapport Laboria*, No. 31, Sept. 1973.

2-D Fornasini–Marchesini model a 2-D model described by the equations

$$\begin{aligned} x_{i+1,j+1} &= A_0 x_{i,j} + A_1 x_{i+1,j} \\ &\quad + A_2 x_{i,j+1} + B u_{ij} \quad (1a) \\ y_{ij} &= C x_{ij} + D u_{ij} \quad (1b) \end{aligned}$$

$i, j \in Z_+$ (the set of nonnegative integers) here $x_{ij} \in R^n$ is the local state vector, $u_{ij} \in R^m$ is the input vector, $y_{ij} \in R^p$ is the output vector A_k ($k = 0, 1, 2$), B, C, D are real matrices. A 2-D model described by the equations

$$\begin{aligned} x_{i+1,j+1} &= A_1 x_{i+1,j} + A_2 x_{i,j+1} \\ &\quad + B_1 u_{i+1,j} + B_2 u_{i,j+1} \quad (2) \end{aligned}$$

$i, j \in Z_+$ and (1b) is called the second 2-D Fornasini–Marchesini model, where x_{ij}, u_{ij} , and y_{ij} are defined in the same way as for (1), A_k, B_k ($k = 0, 1, 2$) are real matrices. The model (1) is a particular case of (2).

2-D general model a 2-D model described by the equations

$$\begin{aligned} x_{i+1,j+1} &= A_0 x_{i,j} + A_1 x_{i+1,j} \\ &\quad + A_2 x_{i,j+1} + B_0 u_{ij} \\ &\quad + B_1 u_{i+1,j} + B_2 u_{i,j+1} \\ y_{ij} &= C x_{ij} + D u_{ij} \end{aligned}$$

$i, j \in Z_+$ (the set of nonnegative integers) here $x_{ij} \in R^n$ is the local state vector, $u_{ij} \in R^m$ is the input vector, $y_{ij} \in R^p$ is the output vector and A_k, B_k ($k = 0, 1, 2$), C, D are real matrices. In particular case for $B_1 = B_2 = 0$ we obtain the first 2-D Fornasini–Marchesini model and for $A_0 = 0$ and $B_0 = 0$ we obtain the second 2-D Fornasini–Marchesini model.

2-D polynomial matrix equation a 2-D equation of the form

$$AX + BY = C \quad (1)$$

where $A \in R^{k \times p}[s]$, $B \in R^{k \times q}[s]$, $C \in R^{k \times m}[s]$ are given, by a solution to (1) we

mean any pair $X \in R^{p \times m}[s]$, $Y \in R^{q \times m}[s]$ satisfying the equation. The equation (1) has a solution if and only if the matrices $[A, B, C]$ and $[A, B, 0]$ are column equivalent or the greatest common left divisor of A and B is a left divisor of C . The 2-D equation

$$AX + YB = C \quad (2)$$

$A \in R^{k \times p}[s]$, $B \in R^{q \times m}[s]$, $C \in R^{k \times m}[s]$ are given, is called the bilateral 2-D polynomial matrix equation. By a solution to (2) we mean any pair $X \in R^{p \times m}[s]$, $Y \in R^{k \times q}[s]$ satisfying the equation. The equation has a solution if and only if the matrices

$$\begin{bmatrix} A & 0 \\ 0 & B \end{bmatrix} \text{ and } \begin{bmatrix} A & C \\ 0 & B \end{bmatrix}$$

are equivalent.

2-D Roesser model a 2-D model described by the equations

$$\begin{bmatrix} x_{i+1,j}^h \\ x_{i,j+1}^v \end{bmatrix} = \begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix} \begin{bmatrix} x_{ij}^h \\ x_{ij}^v \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} u_{ij}$$

$i, j \in \mathbb{Z}_+$ (the set of nonnegative integers),

$$y_{ij} = C \begin{bmatrix} x_{ij}^h \\ x_{ij}^v \end{bmatrix} + Du_{ij}$$

Here $x_{ij}^h \in R^{n_1}$ and $x_{ij}^v \in R^{n_2}$ are the horizontal and vertical local state vectors, respectively, $u_{ij} \in R^m$ is the input vector, $y_{ij} \in R^p$ is the output vector and $A_1, A_2, A_3, A_4, B_1, B_2, C, D$ are real matrices. The model was introduced by R.P. Roesser in "A discrete state-space model for linear image processing," *IEEE Trans. Autom. Contr.*, AC-20, No. 1, 1975, pp. 1-10.

2-D shuffle algorithm an extension of the Luenberger shuffle algorithm for 1-D case. The 2-D shuffle algorithm can be used for checking the regularity condition

$$\det[Ez_1z_2 - A_0 - A_1z_1 - A_2z_2] \neq 0$$

for some $(z_1, z_2) \in C \times C$ of the singular general model (See [singular 2-D general model](#)).

The algorithm is based on the row compression of suitable matrices.

2-D Z-transform $F(z_1, z_2)$ of a discrete 2-D function f_{ij} satisfying the condition $f_{ij} = 0$ for $i < 0$ or/and $j < 0$ is defined by

$$F(z_1, z_2) = \sum_{i=0}^{\infty} \sum_{j=0}^{\infty} f_{ij} z_1^{-i} z_2^{-j}$$

An 2-D discrete f_{ij} has the 2-D Z-transform if the sum

$$\sum_{i=0}^{\infty} \sum_{j=0}^{\infty} f_{ij} z_1^{-i} z_2^{-j}$$

exists.

2DEGFET See [high electron mobility transistor](#)(HEMT).

2LG See [double phase ground fault](#).

3-dB bandwidth for a causal low-pass or bandpass filter with a frequency function $H(j\omega)$ the frequency at which $|H(j\omega)|_{dB}$ is less than 3 dB down from the peak value $|H(\omega_p)|$.

3-level laser a laser in which the most important transitions involve only three energy states; usually refers to a laser in which the lower level of the laser transition is separated from the ground state by much less than the thermal energy kT . *Contrast with 4-level laser*.

3-level system a quantum mechanical system whose interaction with one or more electromagnetic fields can be described by considering primarily three energy levels. For example, the cascade, vee, and lambda systems are 3-level systems.

4-level laser a laser in which the most important transitions involve only four energy states; usually refers to a laser in which the lower level of the laser transition is separated from the ground state by much more

than the thermal energy kT . Contrast with [3-level laser](#).

45 Mbs DPCM for NTSC color video

a codec wherein a subjectively pleasing picture is required at the receiver. This does not require transparent coding quality typical of TV signals. The output bit-rate for video matches the DS3 44.736 Megabits per second rate. The coding is done by PCM coding the NTSC composite video signal at three times the color subcarrier frequency using 8 bit per pixel. Prediction of current pixel is obtained by averaging the pixel three after current and 681 pixels before next to maintain the sub-carrier phase. A leak factor is chosen before computing prediction error to main the quali-

ty of the image. For example a leak factor of $\frac{31}{32}$ the prediction decay is maintained at the center of the dynamic range.

$$X_L^- = 128 + \frac{31}{32} (X^- - 128) .$$

Finally, a clipper at the coder and decoder is employed to prevent quantization errors.

90% withstand voltage a measure of the practical lightning or switching-surge impulse withstand capability of a piece of power equipment. This voltage withstand level is two standard deviations above the BIL of the equipment.

product codes, M/RVQ, I/RVQ, G/SVQ, CVQ, FSVQ) for codebook design are employed to reduce computational costs low. *See also* [vector quantization](#), [tree structured VQ](#).

codebook generation a fundamental problem in vector quantization. Codebooks are typically generated by using a training set of images that are representative of the images to be encoded. The best training image to encode a single image is the image itself. This is called a local codebook. The main question addressed here is what codevectors should be included in the codebook. *See also* [vector quantization](#).

codebook training the act of designing a codebook for a source coding system. The LBG algorithm is often used to design the codebook for vector quantizers.

codec word formed from encoder and decoder. A device that performs encoding and decoding of communications protocols.

coded modulation an integrated modulation and coding approach for bandwidth-constrained channel where the redundancy introduced by the code is compensated by increasing the number of signals, for performance improvement without additional bandwidth or transmission power.

codeword the channel symbol assigned by an encoder to a source symbol. Typically the codeword is a quantized scalar or vector.

coding the process of programming, generating code in a specific language. The process of translating data from a representation form into a different one by using a set of rules or tables. *See also* [ASCII](#), [EBCDIC](#), [binary](#).

coding at primary rates for videoconferencing *See* [image coding for videoconferencing](#).

coding gain (1) the reduction in signal-to-noise ratio required for a specified error performance in a block or convolutional forward error control system as compared to an uncoded system with the same information rate, channel impairments, and modulation and demodulation techniques. In a trellis coded modulation system, it is the ratio of the squared free distance in the coded system to that of the uncoded system.

(2) the difference between the SNR/bit (dB) required for an uncoded and a coded system to attain the same arbitrary error probability. Depends on the code parameters and also on the SNR per bit.

coding of graphics use of a representation scheme for graphics. Graphics coding is typically a two-level coding scheme. Both exact and approximate methods are applicable to this type of coding. Run-length coding, predictive coding, line-to-line predictive differential coding, and block coding are typical for graphic coding.

coding of line drawings use of a representation scheme for line drawings. Line drawings are typically coded using chain codes where the vector joining two successive pixels are assigned a codeword. Higher efficiency is obtained by differential chain coding in which each pixel is represented by the difference between two successive absolute codes.

coding redundancy *See* [redundancy](#).

coefficient of thermal expansion (CTE) mismatch the difference between the coefficients of thermal expansion of two components, i.e., the difference in linear thermal expansion per unit change in temperature. (This term is not to be confused with thermal expansion mismatch).

coefficient of utilization (CU) the ratio of the lumens reaching the working plane to the total lumens generated by the lamp. This factor takes into account the efficiency