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ELECTRICAL ENGINEERING DICTIONARY

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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.

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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

Electric motors and machines
- Power Engineering
- Power Electronics

Digital electronics, VLSI, hardware description language
- Consumer Electronics
- Electronic Devices
- Industrial Electronics
- Instruments and Measurements

Microelectronics and solid state devices
- Industrial Electronics
- Instruments and Measurements

RF, radio, and television
- Broadcast Technology

Communications and information processing
- Communications
- Information Theory
- Systems, Man, and Cybernetics
- Reliability

Signal and image processing
- Signal Processing
- Systems, Man, and Cybernetics

Circuits and systems
- Circuits and Systems
- Instruments and Measurements

Control systems
- Control Systems
- Robotics and Automation

Electromagnetics
- Electromagnetic Compatibility
- Magnetics

Computer engineering (processors)
- Computer

Computer engineering (I/O and storage)
- Computer

Microwave systems
- Antennas and Propagation
- Microwave Theory and Techniques

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

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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.

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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 take 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.

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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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- Lisa Levine for providing excellent copy editing of the final manuscript.

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.laplante@ieee.org` or `plaplante@pit.edu`. If your submission is incorporated, you will be recognized as a contributor in future editions of the dictionary.

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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.

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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.

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

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

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

ϵ_r common symbol for relative dielectric constant.

$\eta_{\mathbf{DC}}$ 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.

$\Gamma_{\mathbf{opt}}$ 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. $\omega = 2 \cdot \pi \cdot$ frequency.

θ_+ common symbol for positive transition angle in degrees.

θ_- common symbol for negative transition angle in degrees.

$\theta_{\mathbf{cond}}$ common symbol for conduction angle in degrees.

$\theta_{\mathbf{sat}}$ common symbol for saturation angle in degrees.

θ_{CC} common symbol for FET channel-to-case thermal resistance in °C/watt.

θ_{JC} common symbol for bipolar junction-to-case thermal resistance in °C/watt.

A^* common symbol for Richardson's constant. $A^* = 8.7$ amperes $\cdot$ cm/°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.

$n_s h$ common symbol for shot noise in watts.

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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

$$\begin{aligned} x_{i+1,j+1} &= -A_1A_2x_{i,j} + A_1x_{i+1,j} \\ &\quad + A_2x_{i,j+1} + Bu_{ij} \\ y_{ij} &= Cx_{ij} + Du_{ij} \end{aligned}$$

$i, j \in Z_+$ (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

$$\begin{aligned} x_{i+1,j+1} &= A_0x_{i,j} + A_1x_{i+1,j} \\ &\quad + A_2x_{i,j+1} + Bu_{ij} \quad (1a) \\ y_{ij} &= Cx_{ij} + Du_{ij} \quad (1b) \end{aligned}$$

$i, j \in Z_+$ (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

$$\begin{aligned} x_{i+1,j+1} &= A_1x_{i+1,j} + A_2x_{i,j+1} \\ &\quad + B_1u_{i+1,j} + B_2u_{i,j+1} \quad (2) \end{aligned}$$

$i, j \in Z_+$ 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

$$\begin{aligned} x_{i+1,j+1} &= A_0x_{i,j} + A_1x_{i+1,j} \\ &\quad + A_2x_{i,j+1} + B_0u_{ij} \\ &\quad + B_1u_{i+1,j} + B_2u_{i,j+1} \\ y_{ij} &= Cx_{ij} + Du_{ij} \end{aligned}$$

$i, j \in Z_+$ (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

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

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

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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

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

$A \in R^{k\times p}[s]$, $B \in R^{q\times m}[s]$, $C \in R^{k\times m}[s]$ 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

$$\begin{bmatrix} x^h_{i+1,j} \\ x^v_{i,j+1} \end{bmatrix} = \begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix} \begin{bmatrix} x^h_{ij} \\ x^v_{ij} \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} u_{ij}$$

$i, j \in Z_+$ (the set of nonnegative integers),

$$y_{ij} = C \begin{bmatrix} x^h_{ij} \\ x^v_{ij} \end{bmatrix} + Du_{ij}$$

Here $x^h_{ij} \in R^{n_1}$ and $x^v_{ij} \in R^{n_2}$ 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

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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 subcarrier phase. A leak factor is chosen before computing prediction error to main the quality of the image. For example a leak factor of $\frac{31}{32}$ the prediction decay is maintained at the center of the dynamic range.

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

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.

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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

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