

SECOND EDITION

COMPREHENSIVE

DICTIONARY

OF

ELECTRICAL

ENGINEERING

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EDITOR-IN-CHIEF
Phillip A. Laplante



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Preface to the Second Edition

Since the publication of the first edition of this dictionary more than 5 years ago, many changes in technology have occurred, particularly in the rapidly changing fields of image processing, computer electronics, fuel cells, and nanotechnology. I must say, however, that preparing the second edition of this dictionary was significantly easier than the first edition (see [preface to first edition](#)). It was easier to prepare because, fortunately, I had a set of handy resources that included terms related to these technological changes. That is, I was able to incorporate new terms from the many new CRC handbooks published within the last 2 years including, the *Fuel Cell Technology Handbook*, *Electric and Hybrid Vehicles: Design Fundamentals*, *The Computer Engineering Handbook*, *Digital Color Imaging Handbook*, *Handbook of Nanoscience Engineering and Technology*, *The RF and Microwave Handbook*, *The Power Electronics Handbook*, *Biomedical Photonics Handbook*, and *The Mechatronics Handbook*. I was also able to incorporate new terms and corrections suggested by readers of the first edition (for which I heartily thank those readers), as well as additions and corrections that are invariably needed after even the fifth read-through.

In total, more than 1500 terms were added, updated, expanded, improved, or corrected, resulting in a dictionary with over 11,000 terms and abbreviations related to electrical engineering. However, if readers discover any errors or think that any important terms have been omitted, please inform me at plaplante@psu.edu with your proposed changes. I will be happy to consider those changes for future printings and editions.

In keeping within the scope established with the first edition, most terms pertaining to computer science, information technology, and software engineering that are not directly linked to the underlying hardware were omitted. For these, please refer to *Comprehensive Dictionary of Computer Science, Engineering and Technology* (CRC Press).

Once again I want to thank Nora Konopka and the fine editorial and production staff at Taylor & Francis, especially Helena Redshaw and Amy Rodriguez, for helping to bring this second edition into being. These folks have always been a pleasure to work with.

Finally, I want to thank my family for their patience and support as I worked countless hours on this project, which most certainly would never have been completed without their blessing. Therefore, this dictionary is dedicated to Nancy, Christopher, and Charlotte.

Phillip A. Laplante, P.E., Ph.D.

Preface to the First Edition

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 $2\frac{1}{2}$ 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 more than 100 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, P.E., Ph.D.
Editor-in-Chief

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
- 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 *Comprehensive Dictionary of Computer Science, Engineering, and Technology* includes 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 over 100 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 tasks of arbitrating conflicting definitions, rewording those that did not seem descriptive enough, and identifying missing ones were 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 (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.
- Frank MacCrory, Norma Trueblood, Nora Konopka, Carole Sweatman, and my wife Nancy for converting, typing, and/or entering many of the terms.

- Jill Welch, Nora Konopka, Ron Powers, Amy Rodriguez, Susan Fox, Karen Feinstein, Joe Ganzi, Gerry Axelrod, and others from CRC for editorial support.
- *CRC Comprehensive Dictionary of Mathematics* and *CRC Comprehensive Dictionary of Physics* editor Stan Gibilisco for sharing many ideas with me.
- My friend Peter Gordon for many of the biographical entries.
- 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@psu.edu. If your submission is incorporated, you will be recognized as a contributor in future editions of the dictionary.

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Dr. Laplante earned 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. He is a senior member of IEEE and a member of numerous other professional societies, program committees, and boards, and is a licensed professional engineer in Pennsylvania.

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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.

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.

$n_s h$ 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

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

are equivalent.

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

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

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

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

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 to ground fault](#).

3-dB bandwidth for a causal low-pass or band-pass 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 subcarrier phase. A leak factor is chosen before computing prediction error to main the quality of the image. For example, with 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 Basic Impulse Insulation Level (BIL) of the equipment.

A

A-mode display returned ultrasound echoes displayed as amplitude versus depth into the body.

A-site in a ferroelectric material with the chemical formula ABO_3 , the crystalline location of the A atom.

a posteriori probability posterior statistics.

a priori probability prior statistics.

A/D See [analog-to-digital converter](#).

AAL See [ATM adaptation layer](#).

ABC See [absorbing boundary condition](#).

ABCD propagation of an optical ray through a system can be described by a simple 2×2 matrix. In ray optics, the characteristic of a system is given by the corresponding ray matrix relating the ray's position from the axis and slope at the input to those at the output.

ABCD formalism analytic method using two-by-two ABCD matrices for propagating Gaussian beams and light rays in a wide variety of optical systems.

ABCD law analytic formula for transforming a Gaussian beam parameter from one reference plane to another in paraxial optics, sometimes called the Kogelnik transformation. ABCD refers to the ABCD matrix.

ABCD matrix the matrix containing ABCD parameters. See [ABCD parameters](#).

ABCD parameters a convenient mathematical form that can be used to characterize two-port networks. Sometimes referred to as chain parameters. ABCD parameters are widely used to model cascaded connections of two-port microwave networks, in which case the ABCD matrix is defined for each two-port network. ABCD parameters can also be used in analytic formalisms for propagating Gaussian beams and light rays. Ray matrices and beam matrices are similar but are often regarded as distinct.

ABC parameters have a particularly useful property in circuit analysis where the composite ABCD parameters of two cascaded networks are the matrix products of the ABCD parameters of the two individual circuits. ABCD parameters are defined as

$$\begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} v_2 \\ i_2 \end{bmatrix}$$

where v_1 and v_2 are the voltages on ports one and two, and i_1 and i_2 are the branch currents into ports one and two.

aberration an imperfection of an optical system that leads to a blurred or a distorted image.

abnormal event any external or program-generated event that makes further normal program execution impossible or undesirable, resulting in a system interrupt. Examples of abnormal events include system detection of power failure; attempt to divide by 0; attempt to execute privileged instruction without privileged status; memory parity error.

abort (1) to terminate the attempt to complete the transaction, usually because there is a deadlock or because completing the transaction would result in a system state that is not compatible with "correct" behavior, as defined by a consistency model, such as sequential consistency.

(2) in an accelerator, terminating the acceleration process prematurely, either by inhibiting the injection mechanism or by removing circulating

V

V parameter describes the number of modes M in an optical fiber.

$$V = 2 \pi i \frac{a}{\lambda_o} NA$$

where a is the fiber core radius, λ is the wavelength, and NA is the fiber's numerical aperture. $V < 2.405$ for single-mode operation. Often referred to as normalized frequency.

V system See [vee system](#).

$V_{IN_{p-p}}$ common notation for peak-to-peak input voltage in volts.

$V_{OUT_{p-p}}$ common notation for the peak-to-peak output voltage in volts.

V_{DS} common notation for the FET drain-to-source voltage.

V_{GD} common notation for the FET gate-to-drain voltage.

V_{GS} common notation for the FET gate-to-source voltage.

V-curves the characteristic curves that show the variation of the armature current versus the field current in synchronous motors.

V-V transformer See [open-delta transformer](#).

vacuum capacitor a capacitor with a vacuum between its plates.

vacuum circuit breaker a power circuit breaker where a vacuum chamber is used as an insulating and arc clearing medium.

vacuum insulation any insulation scheme which depends upon the dielectric capabilities of a high vacuum.

vagueness a property indicating the lack of specifics and clarity and which is allied to imprecision and fuzziness.

valence band the lower of the two partially filled bands in a semiconductor. See also [conduction band](#).

valid bit a bit used in caches and virtual memories that records whether the cached item or page contains valid data.

validation (1) in electronic active and passive device modeling, the pass/fail process in which a completed, ready to use model is used in a simulation, then compared to an intended application, and is determined to suitably predict reality.

(2) a review to establish the quality of a software product for its operational purpose.

validation set the set of data to evaluate the performance of a system which was trained on a separate set of data.

valuation in electronic active and passive device modeling, valuation is a measure of the intrinsic value of a model in predicting a new application, condition or change in the device. The most valuable model (assigned a valuation coefficient of 1.0) would be a complete omnipotent physical based model that could be utilized to predict exact circuit response. The least valuable model (assigned a valuation coefficient of 0.0) such as a lookup table, would only be able to predict a circuit response to a specific set of conditions for a very specific device excited in a specific way.

van de Graf generator a high-voltage device that generates high static voltages on a sphere. It is driven by a mechanical belt, which delivers the charges.

van der Pol oscillator an oscillator or oscillating system described by the equation

$$\frac{d^2x}{dt^2} - \mu(1 - \epsilon x^2)\frac{dx}{dt} + x = 0$$

This equation is mentioned in almost any book on oscillators or on nonlinear mechanics. The reason is that this equation is relatively simple, yet it successfully lumps together two rather complex processes associated with oscillators, namely, the process of generation of periodic waveform and the process of automatically stabilizing the amplitude of this wave. The attempts to improve the solutions of the van der Pol equation and to apply to design of low-distortion oscillators can be traced to recent publications.

Vander Lugt filter encoded optical mask for representing, in the Fourier-transform domain, the reference or library functions needed in an image correlator; encoding is performed holographically.

vanishing point the point in the perspective projection plane in which a system of 3-D parallel lines converge.

Vapnik–Chervonenk (VC) dimension a measure of the expressive power of a learning system with binary or bipolar outputs. For neural networks it is closely related to the number of weights in the network. For single-layer networks it is simply equal to the number of weights (including biases) but for multilayer and other networks, analytic expressions for VC dimension are not available.

vapor cooling a cooling technique for power vacuum tubes utilizing the conversion of hot water to steam as a means of safely conducting heat from the device and to a heat sink.

VAR See [volt-ampere reactive](#).

varactor a reverse biased PN or Schottky diode that uses the voltage variable depletion region

as a tuning element or as a nonlinear frequency multiplier.

varactor diode a diode designed to have a repeatable and high capacitance vs. reverse voltage characteristic. A two terminal semiconductor device in which the electrical characteristic of primary interest is the voltage dependent capacitance.

varactor tuner a tuning circuit at the input of a television receiver that uses a varactor diode. The tuning capability comes from the characteristic of a varactor, or varicap, to function as a voltage-sensitive capacitance.

variable bit rate (VBR) describes a traffic pattern in which the rate at which bits are transmitted varies over time; such patterns are also referred to as bursty. VBR sources often result from compressing CBR sources, for example, a 64 kbps voice source in its raw form has a constant bit rate; after compression by removing the silence intervals, the source becomes VBR.

variable frequency drive electric drive system in which the speed of the motor can be varied by varying the frequency of the input power.

variable length code to exploit redundancy in statistical data, and to reduce average number of bits per word luminance levels having high probability are assigned short code words and those having low probability are assigned longer code words. This is called variable length coding or entropy coding. See also [entropy coding](#).

variable loss machine loss that changes with a change in the mode of machine operation such as loading, temperature and current. For example, in a transformer, the winding losses are a function of the load current, while the core losses are almost independent of the load current.

variable polarity plasma arc welding (VP-PAW) a welding process that produces

coalescence of metals by heating them with a constricted variable polarity arc between an electrode and the parts to be joined (transferred arc) or between the electrode and the constricting nozzle (transferred arc). Shielding is obtained from the hot, ionized gas issuing from the torch as well as from a normally employed auxiliary shielding gas source. Pressure is not applied and filler metal may or may not be added.

variable reflectivity mirror mirror in which the reflection profile varies across the mirror surface; useful for discriminating against high-order transverse modes in a resonator. *See also* [tapered reflectivity mirror](#).

variable reluctance machine salient pole machine consisting of stators having concentrated excitation windings and a magnetic rotor devoid of any windings, commutators, or brushes. The machine operates on the principle of varying reluctance along the length of the air gap. Torque is produced by the tendency of the rotor to align itself with the stator produced flux waves in such a way that the stator produced flux-linkages are maximized. The motor operates continuously in either direction of rotation with closed loop position feedback.

variable resolution hierarchy an approach where images corresponding to the levels of the hierarchy vary in spatial resolution. This results in a pyramid structure where the base of the pyramid represents the full resolution and the upper levels have lower resolution.

variable speed AC drive an AC motor drive that is capable of delivering variable frequency AC power to a motor to cause it to operate at variable speeds. Induction motors and synchronous motors are limited to operation at or near synchronous speed when a particular frequency is applied. Variable speed drives rectify the incoming AC source voltage to create a DC voltage that is then inverted to the desired frequency and number of phases.

variable speed DC drive a DC motor controller that allows the DC motor to operate over a wide speed range. A common type of variable speed DC drive uses a separately excited DC motor. Armature voltage control is used to provide operation below base speed, and field weakening is used to provide operation above base speed.

variable speed drive *See* variable speed AC drive or variable speed DC drive.

variable structure system a dynamical system whose structure changes in accordance with the current value of its state. A variable structure system can be viewed as a system composed of independent structures together with a switching logic to switch between each of the structures. With appropriate switching logic, a variable structure system can exploit the desirable properties of each of the structures the system is composed of. A variable structure system may even have a property, such as asymptotic stability, that is not a property of any of its structures.

variable-length instruction the fact that the machine language instructions for a computer have different numbers of bits with the length dependent on the type of instruction.

variance the mean-squared variability of a random variable about its mean: $\sigma^2 = \int_{-\infty}^{\infty} (x - \mu)^2 p(x) dx$ where σ^2 is the variance, μ is the mean and $p(x)$ is the probability density function. *See* [covariance](#), [correlation](#).

variational formula a formula that provides the sought unknown quantity a in terms of another unknown quantity b . The advantage is in the fact that, for variational formulas, an error in b provides only a modest error in a . Hence, by approximating b we can get a fairly good estimate of a .

variational problem a problem in which solving a differential equation is equivalent to seeking a function that minimizes an integral expression.

variational similarity between two vectors $x = (x_1, \dots, x_n)$ and $y = (y_1, \dots, y_m)$ is the match score in the following dynamic matching procedure:

Suppose the current point is (x_i, y_j) . The next point to match should be selected from (x_{i+1}, y_j) , (x_{i+1}, y_{j+1}) , and (x_{i+1}, y_{j+2}) . If there is one match only among them, take it as the current match point and go on in the same manner. If there is no match, select (x_{i+1}, y_{j+1}) . If there is more than one match including (x_{i+1}, y_{j+1}) , select (x_{i+1}, y_{j+1}) , otherwise, select (x_{i+1}, y_{j+2}) . This process continues until at least one of the vectors is exhausted.

During the above procedure, if there is at least one match in one step increase the match score by 1.

Varsharmov–Gilbert bound the lower bound on the minimum distance of linear (n, k) code asymptotically satisfies

$$\frac{d_{\min}}{n} \geq \alpha$$

where α is given by

$$\frac{k}{n} = 1 + \alpha \log_2 \alpha + (1 - \alpha) \log_2 \alpha \quad 0 \leq \alpha \leq \frac{1}{2}$$

vault See [transformer vault](#).

VBR See [variable bit rate](#).

VC dimension See [Vapnik–Chervonenk dimension](#).

VCO See [voltage-controlled oscillator](#).

VCO gain the ratio of the VCO output frequency to the DC control input level. This is usually expressed in units of radians per second per volt.

VCP See [visual comfort probability](#).

VDS See [drain-to-source voltage](#).

VDSL See [very high-speed digital subscriber line](#).

vector a quantity having both magnitude and direction.

vector controlled induction motor a variable speed controller and motor in which the magnetizing and torque producing components of current are controlled separately. Some vector drives require rotor position sensors. Vector controlled induction motors can operate over a wider speed range, and may produce rated torque even at zero speed, much like a DC motor. Thus, vector controlled induction motors are often used for applications that might otherwise require a DC motor drive.

vector field when the field needed to describe some physical phenomenon has several components, it is customary to represent such a field by a vector function $\mathbf{V}(x, y, z)$ which depends on the space coordinates x, y, z .

vector image an image consisting of mathematical descriptions of the objects in the scene, e.g., equations for lines and curves. The image is independent of resolution so it can be stretched, rotated and skewed with no degradation. Vector images are often used in CAD applications. See [bitmapped image](#), [CAD](#), [image](#).

vector network analyzer a microwave receiver designed to measure and process the magnitude and phase of transmitted and reflected waves from the linear network under test.

vector operation a hardware instruction that performs multiple similar operations on data arranged in one or more arrays.

vector processor a computer architecture with specialized function units designed to operate very

efficiently on vectors represented as streams of data.

vector quantization (VQ) quantization applied to vectors or blocks of outputs of a continuous source.

Each possible source block is represented by a reproduction vector chosen from a finite set (the “codebook”). According to rate-distortion theory, vector quantization (VQ) is able to perform arbitrarily close to the theoretical optimum if the lengths of the input blocks are permitted to grow without limit. The method was suggested by Claude Shannon in his theoretical work on source coding (during the late 1940s and the 1950s), but has found practical importance first in recent years (during the 1980s and 1990s) because of the relatively high complexity of implementation and design compared to scalar methods. Also referred to as “block source coding with a fidelity criterion.”

vector quantization encoding an encoding scheme whereby an image is decomposed into n dimensional image vectors. Each image vector is compared with a collection of representative templates or codevectors from a previously generated codebook. The best match codevector is chosen using a minimum distortion rule. Then the index of the codevector is transmitted. At the receiver this is used with a duplicate codebook to reconstruct the image. Usually called VQ encoding.

vector quantizer (VQ) a device that performs vector quantization.

vector space an algebraic structure comprised of a set of elements over which operations of vector addition and scalar multiplication are defined. In a linear forward error control code, code words form a vector space when addition and multiplication are defined in terms of element-wise operations from the finite field of code symbol values.

vector stride the number of consecutive memory addresses from the beginning of one element

to the next of a vector stored in memory. Also used to refer to the difference in vector index between two consecutively accessed vector elements.

vector wave wave that cannot be adequately described in terms of a single field variable.

vector wave equation an equation (or more specifically, a set of scalar equations) governing the various components of a vector wave, the Maxwell–Heaviside equations, for example.

vectored interrupt an interrupt request whereby the processor is directed to a predetermined memory location, depending on the source of the interrupt, by the built-in internal hardware. In the X86 processors, the addresses are stored in an array in memory (a mathematical vector) and indexed by the interrupt number. In the 8080 and Z80, the interrupt number becomes part of a CALL instruction with an implied address that is executed on an interrupt cycle.

vectorscope an oscilloscope-type device used to display the color parameters of a video signal. A vectorscope decodes color information into R-Y and B-Y components, which are then used to drive the X and Y axis of the scope. The total lack of color in a video signal is displayed as a dot in the center of the vectorscope. The angle, distance around the circle, magnitude, and distance away from the center indicate the phase and amplitude of the color signal.

vee system a 3-level system in which the highest two energy states are coupled by electromagnetic fields to a common, intermediate, lower state. This system is so named because schematic representations of it often look like a capital letter V.

velocity error the final steady difference between a ramp setpoint and the process output in a unity feedback control system. Thus, it is the asymptotic error in position that arises in a closed loop system that is commanded to move with

constant velocity. *See also* [acceleration error](#) and [position error](#).

velocity error constant a gain K_v from which the velocity error e_v is readily determined. It is a concept that is useful in the design of unity feedback control systems since it transforms a constraint on the final error to a constraint on the gain of the open loop system. The relevant equations are

$$e_v = \frac{1}{K_v} \text{ and } K_v = s \lim_{s \rightarrow \infty} sq(s)$$

where $q(s)$ is the transfer function model of the open loop system, including the controller and the process in cascade. *See also* [acceleration error constant](#) and [position error constant](#).

velocity filtering means for discriminating signals from noise or other undesired signals because of their different apparent velocities.

velocity flow field the velocity field calculated in optical flow computation.

velocity manipulability ellipsoid an ellipsoid that characterizes the end-effector velocities that can be generated with the given set of joint velocities, with the manipulator in a given posture.

Consider a set of generalized joint velocities $\dot{q}$ of constant, unit norm $\dot{q}^T \dot{q} = 1$. Taking into account the differential kinematics J and properties of the pseudo-inverse of the geometrical Jacobian, the unit norm can be rewritten as follows: $v^T (J J^T)^{-1} v = 1$, which is the equation of the points on the surface of an ellipsoid in the end-effector velocity space.

velocity of light in vacuum, a constant equal to 2.997928×10^8 meters/second. In other media, equal to the vacuum value divided by the refractive index of the medium.

velocity saturation a physical process in a semiconductor where the carrier velocity becomes

constant independent of the electric field due to high energy scattering and energy loss, compared to low electric field transport where the velocity is linearly related to the field by the mobility.

verification the process of proving that the implementation of hardware or software meets the published system requirements.

verification kit known impedance standards traced to NIST, other than calibration standards, used to verify the calibrated performance of a vector network analyzer system.

Verilog a hardware description language for electronic design and gate-level simulation. *See* [VHDL](#), [VHSIC](#).

Versa Module Europe bus (VME bus) a standardized processor backplane bus system originally developed by Motorola. The bus allows multiple processors to share memory and I/O devices.

vertical cavity laser semiconductor laser in which the electromagnetic fields propagate in a direction perpendicular to the amplifying plane (the vertical direction).

vertical deflection the direction of an entity is caused to move by some physical action; commonly describes the vertical movement of an electron beam caused by electrostatic or magnetic forces applied to produce a required scan. Magnetic deflection is frequently used with a CRT video display and requires a large deflection angle.

vertical microinstruction a field that specifies one microcommand via its op code. In practice, microinstructions that typically contain three or four fields are called vertical.

vertical polarization a term used to identify the position of the electric field vector of a linearly polarized antenna or propagating EM wave relative to a local reference, usually the ground or

horizon. A vertically polarized EM wave is one with its electric field vector aligned perpendicular to the local horizontal.

vertical roll in television, the apparent continuous upward or downward movement of the picture, resulting from the lack of synchronization between the transmitter and receiver.

vertical sync pulse a signal interval of the NTSC composite video signal provided for the synchronization of the vertical deflection system; the vertical sync interval has a duration of three horizontal lines and is serrated with six pulses. The vertical sync interval starts after six equalizing pulses (3 horizontal line periods) that identify the beginning of the vertical blanking interval. The vertical serration preserves the horizontal line synchronization information during the vertical sync pulse interval with the one-half horizontal line time-signal transition from the composite video blanking signal level to the sync signal level. The serrated vertical pulse duration is at the blanking level for $7 \pm 1\%$ of the horizontal line time.

vertically integrated utility a utility in which generation, transmission, and distribution divisions are all owned by a single entity.

very high-speed digital subscriber line (VDSL) a digital subscriber line (DSL) that provides very high rates (13 Mbps, 26 Mbps, and 52 Mbps) through short subscriber loops (1 to 3 kft). A VDSL may support asymmetric rates between the customer premise and the central office.

very-large-scale-integration (VLSI) (1) a technology that allows the construction and interconnection of large numbers (millions) of transistors on a single integrated circuit.

(2) an integrated circuit made of tens of thousands to hundreds of thousands of transistors.

very long instruction word (VLIW) a computer architecture that performs no dynamic anal-

ysis on the instruction stream and executes operations precisely as ordered in the instruction stream.

very small aperture terminal (VSAT) a small earth station suitable for installation at a customer's premises. A VSAT typically consists of an antenna less than 2.4 m, an outdoor unit to receive and transmit signals, and an indoor unit containing the satellite and terrestrial interface units.

vestigial sideband (1) a portion of one sideband in an amplitude modulated signal, remaining after passage through a selective filter.

(2) Amplitude modulated signal in which one sideband has been partially or largely suppressed.

(3) The small amount of energy emitted in the unused sideband in a single-sided transmitter.

VGA See [video graphics adapter](#).

VHDL acronym for very high speed integrated circuit (VHSIC) hardware description language. See VHSIC, [Verilog](#).

VHF very high frequency. See VHF power.

VHF power in television, the band of frequencies ranging from 30MHz to 300MHz.

VHSIC (1) acronym for very high speed integrated circuit.

(2) acronym for very high speed integrated circuit, a type of digital logic circuit. See VHDL.

via a hole in the insulator between two metal layers on a multilayer integrated circuit that is etched and filled with a conducting material so that the two metal layers are electrically connected. Via resistance is typically less than 10 ohms.

via hole hole chemically etched from the back of a MMIC wafer and filled with metal in such a way as to allow an electrical connection between the backside of a wafer and the topside of the wafer.

vibration damper any of a number of devices mounted on a power line to reduce vibrations caused by wind.

vibrational transition transition between vibrational states of a molecule.

video (1) representation of moving images for storage and processing. Often used interchangeably with television. In particular, “video signal” and “television signal” are synonyms.

(2) a particular stored sequence of moving images, e.g., on a tape or within a database.

video amplifier (1) in television, the wideband stage (or stages) that amplifies the picture signal and presents it to the picture tube.

(2) A similar wideband amplifier, such as an instrument amplifier or preamplifier having at least a 4-MHz bandwidth.

video coding compression of moving images. Coding can be done purely on an Intraframe (within-frame) basis, using a still image-coding algorithm, or by exploiting temporal correlations between frames (interframe coding). In the latter case, the encoder estimates motion between the current frame and a previously-coded reference frame, encodes a field of motion vectors that describe the motion compactly, generates a motion-compensated prediction image and codes the difference between this and the actual frame with an intraframe residue coder—typically the 8×8 discrete cosine transform. The decoder receives the motion vectors and encoded residue, constructs the prediction picture from its stored reference frame and adds back the difference information to recover the frame. *See* [MPEG](#).

video compression *See* video coding.

video graphics adapter (VGA) a video adapter proposed by IBM in 1987 as an evolution of EGA. It is capable of emulating EGA, CGA, and MDA. In graphic mode, it allows to reach 640×480 pixels (wide per high) with 16 colors selected from

a pallet of 262144, or 320×240 with 256 colors selected from a pallet of 262144.

video RFI undesired radio-frequency signals that compete with the desired video signal.

video signal the video signal in the U.S. is defined by the NTSC standard. *See* [National Television System Committee](#).

video signal processing The area of specialization concerned with the processing of time sequences of image data, i.e., video.

video transmission the combined amplitude-modulated carrier, sync, and blanking pulses that make up a video signal.

virtual address (1) an address that refers to a location of virtual memory.

(2) the address generated by the processor in a paging (virtual memory) system. *Compare with* real address.

virtual channel a concept used to describe unidirectional transport of ATM cells associated by a common unique identifier value.

virtual circuit an abstraction that enables a fraction of a physical circuit to be allocated to a user. To a user, a virtual circuit appears as a physical circuit; multiple virtual circuits can be multiplexed onto a single physical circuit.

virtual connection a representation of the circuit between the input leads of an ideal op-amp. The voltage across and the current through a virtual connection are both zero. If one input lead of an ideal op-amp is connected to ground, the virtual connection is often termed a virtual ground.

virtual DMA DMA in which virtual addresses are translated into real addresses during the I/O operation.

virtual instrument an instrument created through computer control of a collection of