L

L-band frequency band of approximately 1–2 GHz.

L-L *See* line to line fault.

label a tag in a programming language (usually assembly language, also legal in C) that marks an instruction or statement as a possible target for a jump or branch.

labeling (1) the computational problem of assigning labels consistently to objects or object components (segments) appearing in an image.

(2) a technique by which each pixel within a distinct segment is marked as belonging to that segment. One way to label an image involves appending to each pixel of an image the label number or index of its segment. Another way is to specify the closed contour of each segment and to use a contour filling technique to label each pixel within a contour.

ladder diagram (1) the connection of the coils and contacts used in a control circuit shown one line after the other that looks like a ladder.

(2) a visual language for specifying the Boolean expressions, which are the core of the control law of PLC.

laddertron a microwave vacuum tube oscillator with a slow-wave structure coupled to a single-cavity resonator.

lag the inability of an imaging tube to respond to instantaneous changes in light. For measurement purposes, lag has two components: rise lag is the response time from dark to light, whereas decay lag is the response time from light to dark. Lag is a very short-term effect, and should not be confused with image retention, image burn, or sticking.

lag circuit a simple passive electronic circuit designed to add a dominant pole to compensate the performance of a given system. A lag circuit is generally used to make a system more stable by reducing its high-frequency gain and/or to improve its position, velocity, or acceleration error by increasing the low frequency gain. A nondominant zero is included in the lag circuit to prevent undue destabilization of the compensated system by the additional pole.

lag network a network where the phase angle associated with the input–output transfer function is always negative, or lagging.

lag-lead network the phase shift versus frequency curve in a phase lag-lead network is negative, or lagging, for low frequencies and positive, or leading, for high frequencies. The phase angle associated with the input–output transfer function is always positive or leading.

Lagrange formulation a formulation where the equations of motion are derived in a systematic way by choosing a set of generalized coordinates, forming the Lagrangian of the mechanical system (as a difference of total kinetic energy and potential energy of the system) and by solving the Lagrange equations

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_i} - \frac{\partial \mathcal{L}}{\partial q_i} = \tau_i \qquad i = 1, \ldots, n$$

where $\mathcal{L}$ stands for Lagrangian, q_i is the generalized coordinate, $\dot{q}_i$ is its derivative, and τ_i is a generalized force, and n denotes number of degrees of freedom of the mechanical system. Last equations establish the relations existing between the generalized forces applied to the manipulator and the joint positions, velocities, and accelerations in so called closed form. *See also* Newton–Euler recursive algorithm.

Lagrange stable state *See* bounded state.

Lagrangian interpolation a classic interpolation procedure used in numerical analysis. The sampling theorem is a special case.

Laguerre polynomial a solution to the differential equation $xy'' + (1 - x)y' + ny = 0$. Laguerre polynomials $L_0(x) = 1$, $L_1(x) = 1 - x$, $L_2(x) = 1 - 2x + x^2/2$, and $L_3 = 1 - 3x + 3x^2/2 - x^3/6$. Additional Laguerre polynomials may be obtained from the recursion formula $(n+1)L_{n+1}(x) - (2n+1-x)L_n(x) + L_{n-1}(x) = 0$.

Laguerre–Gaussian beam electromagnetic beam solution of the paraxial wave equation in which the field is a product of a Laguerre polynomial and a Gaussian function of distance from the beam axis.

Lamb dip decrease in output power of a Doppler-broadened standing-wave laser oscillator as a function of length tuning when the resonant frequency is within approximately one homogeneous linewidth of gain center; results from the interaction of both the right and left travelling waves with the same atoms for line-center tuning.

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

Lambert's cosine law a law stating that, for a ideal matte (Lambertian) surface, the apparent brightness of the surface is proportional to the cosine of the angle of incidence and independent of both the angle of reflection and the phase angle between the incident and reflected beams.

Lambertian source a source whose directional emission pattern follows Lambert's law; a cosine variation.

Lambertian surface a surface with perfect diffusion properties, i.e., for which the reflectance function depends only on the angle of incidence of illumination.

laminate multi-chip module (MCM-L) a multi-chip module built using advanced PCB manufacturing techniques.

lamination a thin sheet of metal used to build up the core of an electromagnetic device. Laminations are insulated from each other to reduce the losses associated with eddy currents.

land pattern a combination of lands intended for the mounting, interconnection, and testing of a particular component.

Landauer formula describes the conductance as a fundamental property of wave (electron) transmission through a structure.

Lange coupler four coupled lines used with interconnections to provide tight coupling. A practical implementation to increase the coupling between edge-coupled lines by using several lines parallel to each other, so that the fringing fields at edges of the line contribute to coupling.

Langevin, Paul (1872–1946) Born: Paris, France

Langevin is best known as the developer of echolocation, which is the precursor to modern sonar. Langevin was the first to describe paramagnetism and diamagnetism.

LAOS *See* light-amplifying optical switch.

lap winding an armature winding on a DC machine in which the two ends of each coil are connected to adjacent bars on the commutator ring. The lap winding provides "P" parallel paths through the armature winding, where P is the number of poles in the machine.

Laplace's equation a partial differential equation mathematically described by $\nabla^2\phi = 0$, where ∇^2 is the Laplacian and ϕ is the equation's solution.

Laplace, Pierre-Simon, Marquis de (1749–1827) Born: Beaumont-en-Auge, Normandy, France

Laplace is best known for his development of basic tools of mathematical analysis including the Laplace transform, the Laplace theorem, and the Laplace coefficients. Laplace studied in Paris with the great mathematician Jean d'Alembert. Laplace was heavily involved in politics throughout his career and held many government posts. Laplace's theoretical work was heavily in the field of celestial mechanics. He helped to establish the mathematical basis for the field and in doing so confirmed significant parts of Newton's work.

Laplace transform the transform of a function $f(t)$ given by

$$F(s) = \int_{-\infty}^{\infty} f(t)e^{-st}dt$$

where $s = a + j\omega$ is a complex variable. The one sided or unilateral Laplace transform is given by the same equation except that the lower limit is 0 and not $-\infty$. The region of convergence of the Laplace integral is a vertical strip R in the s-plane. The inverse Laplace transform is given by

$$f(t) = 1/(2\pi j)\int_L F(s)e^{st}ds$$

where L is a vertical line in R. The Fourier Transform of $f(t)$ is given by $F(j\omega)$.

Laplacian operator the second-order operator, defined in $\mathcal{R}^n$ as $\nabla^2 = \partial^2/\partial x_1^2 + \cdots + \partial^2/\partial_n^2$. The zero crossings of an image to which the Laplacian operator has been applied usually correspond to edges, as in such points a peak (trough) of the first derivative components can be found. Also simply called the Laplacian.

Laplacian pyramid a set of Laplacian images at multiple scales used in pyramid coding. An input image G_1 is Gaussian lowpass filtered and downsampled to form G_2. Typically G_2 is one quarter the size of G_1, i.e., it is downsampled by a factor of 2 in each direction. G_2 is upsampled and Gaussian lowpass filtered to form R_1 which is then subtracted from G_1 to give L_1. The process then repeats using G_2 as input. The sets of multiresolution images so generated are called "pyramids": $G_1 \ldots G_n$ form a Gaussian pyramid; $L_1 \ldots L_n$ form a Laplacian pyramid.

lapped orthogonal transform (LOT) a critically sampled block transform, where the blocks overlap, typically by half a block. Equivalently the LOT is a critically sampled filter bank, where typically the filter lengths are equal to twice the number of channels or filters. The LOT was motivated by reducing the blocking effect in transform coding by using overlapping blocks. A cosine modulated filter bank is a type of LOT.

large cell cell with the radius of 5–35 km (such as those found in Groupe Special Mobile systems). *See also* cell.

large disturbance a disturbance for which the equation for dynamic operation cannot be linearized for analysis.

large-scale integration (LSI) (1) term usually used to describe the level of integration at which entire integrated circuits can be placed on a single chip.

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

large-scale process (system) partitioned complex process (system) composed of several sub-processes (subsystems) that are either physically interconnected or must be considered jointly due to the nature of the control objectives.

LASCR *See* light-activated silicon controlled rectifier

laser acronym that stands for light amplification by stimulated emission of radiation. Usually refers to an oscillator rather than an amplifier; commonly also refers to similar systems that operate at non-optical frequencies or with nonelectromagnetic wave fields.

laser amplifier usually refers to a medium that amplifies light by the process of stimulated emission; sometimes refers to amplification of some other field (nonoptical electromagnetic, phonon, exciton, neutrino, etc.) or some other process (nonlinear optics, Brillouin scattering, Raman scattering, etc.).

laser array systematic distribution of lasers intended to provide more power than a single laser.

laser beam localized electromagnetic field distribution produced by a laser.

laser efficiency output power from a laser divided by the input power (sometimes the pump power into the laser medium and sometimes the wall-plug power).

laser medium the material in a laser that emits light; it may be a gas, solid, or liquid.

laser oscillator oscillator usually producing an optical frequency output and usually based on amplification by stimulated emission in a resonant cavity.

laser pumping mechanism for obtaining a population inversion in a laser medium; the use of a laser beam to pump another laser.

laser threshold the condition under which the round-trip gain in a laser is equal to the round-trip loss.

laser transient a time-dependent laser behavior such as mode-locking, loss switching, spontaneous pulsations, relaxation oscillations.

laser transition transition in a medium that has the capability of exhibiting more stimulated emission than absorption or spontaneous emission.

last-in-first-out (LIFO) *See* first-in-last-out.

latch a small temporary holding cell for a value, the value on the input wires is buffered upon occurrence of some event, such as a clock pulse or rising edge of a separate latch signal.

latency (1) total time taken for a bit to pass through the network from origin to destination.

(2) the time between positioning a read/write head over a track of data and when the beginning of the track of data passes under the head.

lateral (1) a lateral on a primary distribution line is a short tap from the main distribution line which serves a local set of loads. Single phase laterals are common in residential districts.

(2) a three-phase or single-phase power line which supplies the distribution transformers along a street. *See* feeder.

lateral inhibition in the human visual system, the inhibitory effect between nearby cells which acts to enhance changes (temporal or spatial) in the stimulus.

lateral superlattice refers to a lithographically defined structure in which a periodic (superlattice) potential is induced onto the surface of a normal semiconductor (or metallic) system. Since the periodic potential is induced in the lateral variations of the surface, it is called a lateral superlattice.

lateral wave wave generated by a beam of bounded extent incident at an angle close to the critical angle. It manifests by producing a lateral shift of the bounded reflected wave.

lattice constant the length of the sides of the three dimensional unit cell in a crystal.

lattice structure a filter used in linear prediction that has two outputs, the forward prediction error $f_m[n]$ and the backward prediction error $g_m[n]$. These two error signals are defined recursively:

$$f_m[n] = f_{m-1}[n] + K_m g_{m-1}[n-1]$$
$$g_m[n] = K_m^* f_{m-1}[n] + g_{m-1}[n-1]$$

where the K_m are the called the lattice coefficients of the predictor.

lattice vector quantization (1) a structured vector quantizer where the reproduction vectors are chosen from a highly regular geometrical structure known as a "lattice." The method is employed mainly because of the reduction in storage capacity obtained (compared to optimal vector quantization).

(2) vector quantization, where codewords represent prototype vectors arranged in a regular lattice in n-dimensional space.

lattice VQ *See* lattice vector quantization.

law of excluded middle a logical law stating that for Boolean variable X, X must be either Z or not Z.

law of the first wavefront *See* Haas effect.

layout specifies the position and dimension of the different layers of materials as they would be laid on the silicon wafer.

LC-oscillator a type of oscillator that is practical at the frequencies above 50 kHz and up to 500 MHz, where it is rational to use high-Q tuned circuits for frequency selection (as a result, sometimes they are called tuned-circuit oscillators). It is impossible to classify all circuits of LC-oscillators, yet a wide group of LC-oscillators are reduced to the circuit that includes one active device (a FET characterized by transconductance g_m and drain-source impedance r_o is shown as an example; it can be substituted by a bipolar transistor; this essentially does not change the results), a load resistor, and three reactances (if X_1 and X_2 are coils, the mutual reactance X_m should be considered as well).

The frequency of oscillation is given by the condition

$$X_1 + X_2 + X_3 + 2X_m = 0$$

and the threshold condition for self-starting is

$$g_m \frac{r_o R_L}{r_o + R_L} \geq \frac{X_2 + X_m}{X_1 + X_m}$$

If X_1 is a tuned coil in the gate, X_2 is the drain coil, $2X_m$ is the mutual inductance between the two coils, the circuit is called tuned-gate oscillator, if the single tuned circuit is moved into the drain, the circuit is called tuned-drain oscillator. Other frequently used configurations are Colpitts oscillator and Hartley oscillator.

LCD *See* liquid crystal display.

LCI *See* load-commutated inverter.

LCLV *See* liquid crystal light valve.

LDD *See* lightly doped drain.

lead a conductive path, usually self-supporting; the portion of an electrical component that connects it to outside circuitry.

lead circuit a simple passive electronic circuit designed to add a dominant zero to compensate the performance of a given system. It is generally used to make an oscillatory system more damped. A nondominant pole must be included to make the circuit causal. This pole also limits the high frequency gain of the lead circuit, thereby avoiding excessive amplification and transmission of undesirable noise.

lead frame the metallic portion of the device package that makes electrical connections from the die to other circuitry.

lead lanthanum zirconium titanate (PLZT) a quadratic electro-optic material where the refractive index changes quadratically with applied electric field. Commonly available as a hot-pressed polycrystalline ceramic, although single-crystal film is being developed.

leader an elongated region of ionized gas that extends from one electrode to another just before a high-voltage breakdown.

leader-follower game *See* Stackelberg equilibrium.

leading-edge triggered pertaining to a device that is activated by the leading edge of a signal.

leakage the flux in a magnetic circuit that does not do any useful work.

leakage flux the flux that does not link all the turns of a winding or in coupled circuits, flux that links one winding but not another. For example, the magnetic flux produced by the primary winding of a transformer that is not coupled to the secondary winding.

leakage reactance the amount of inductive reactance associated with leakage flux. The leakage flux is the flux which traverses in paths farther from the designated paths such as the magnetic core in transformers and the air gap in electric machines and constitutes the non-useful flux. The electric circuit symbol of leakage reactance is X_l. It is a function of the leakage inductance and the frequency of operation. Higher values of leakage reactance affect the regulation and efficiency of the system. X_l is expressed in ohms.

leaky feeder an antenna consisting of a cable that continuously radiates a signal from all points along the entire length of the cable. Such a cable is typically used as the radiating antenna in places such as tunnels and mines where the range of radio propagation is limited. *Compare with* distributed antenna.

leaky modes *See* tunneling modes.

leaky wave a wave that radiates signal power out of an imperfectly closed and shielded system. Open waveguides are able, under certain circumstances, to produce leaky waves, which can be used for radiation purposes. In this case, a leaky antenna couples power in small increments per unit length, either continuously or discretely, from a bound mode of the open waveguide.

learning in neural networks, the collection of learning rules or laws associated with each processing element. Each learning law is responsible for adapting the input–output behavior of the processing element transfer function over a period of time in response to the input signals that influence the processing element. This adaptation is usually obtained by modification of the values of variables (weights) stored in the processing element's local memory.

Sometimes neural network adaptation and learning can take place by creating or destroying the connections between processing elements. Learning may be also achieved by replacing the transfer function of a processing element by a new one.

learning law *See* learning rule.

learning rate a parameter in a learning rule which determines the amount of change for a parameter during the current iteration. While a large value may increase the rate of learning, it may also prevent a learning algorithm from converging.

learning rule in neural networks, an equation that modifies the connection weights in response to input, current state of the processing element, and possible desired output of the processing element.

learning vector quantization (LVQ) a supervised learning algorithm first proposed by Kohonen that uses class information to move the Voronoi vectors slightly, so as to improve the quality of the classifier decision regions.

The training algorithm for LVQ is similar to its unsupervised counterpart with supervised error correction. After the winner is found, the weights of the winner and its neighbors will be updated according to the following rules:

If the class is correct,

$$w_i(t+1) = w_i(t) + \alpha \cdot (x_i(t) - w_i(t)) \ ,$$

otherwise

$$w_i(t+1) = w_i(t) - \alpha \cdot (x_i(t) - w_i(t)) \ ,$$

See also self-organizing system, self-organizing algorithm.

least mean square (LMS) algorithm in some cases of parameter estimation for stochastic dynamic systems, it is not feasible to use the least squares based algorithms due to the computational effort involved in updating and storing the $P(t)$ (probability) matrix. This is especially so when the number of parameters is large. In this case, it is possible to use a variant of the stochastic gradient algorithm — the least mean square (LMS) algorithm, which has the form

$$\hat{\theta}(t+1) = \hat{\theta}(t) + \phi(t)(y(t+1) - \phi^T(t+1)\hat{\theta}(t))$$

where $\hat{\theta}$ is a parameter's estimates vector, ϕ is a regressor vector.

least recently used (LRU) algorithm a replacement algorithm based on program locality by which the choice of an object (usually a page) to be removed is based on the longest time since last use. The policy requires bookkeeping of essential information regarding the sequence of accesses, which may be kept as LRU bits or as an LRU stack.

least squares an approach to determining the optimal set of free parameters $\vec{w}$ of an input-output mapping $\vec{y} = \vec{F}(\vec{x}, \vec{w})$, whereby the square of the difference between the output of the function $\vec{y}$ and the desired output $\vec{d}$ is minimized.

least squares algorithm an adaptive algorithm that adjusts the weights of a digital filter to minimize a least squares (LS) cost criterion. For equalization, this cost criterion is

$$\sum_{k=1}^{i} w^{i-k} |b_k - y_k|^2$$

where b_k is the transmitted symbol, y_k is the filter output, both at time i, and where w is an exponential weighting factor which discounts past data.

least squares filter the optimal filter, in the least squares sense, for restoring a corrupted signal. Specifically, given observations of a signal $x[n]$, the least squares filter produces the $\hat{x}[n]$, which minimizes $E[\sum |x[n] - \hat{x}[n]|^2]$. *See also* Wiener filter.

least squares solution the set of free parameters that satisfies the least squares criterion.

least-significant bit (LSB) in a binary word, a bit with the lowest wight associated with it.

least-square-error fit an algorithm or set of equations resulting from fitting a polynomial or other type curve, such as logarithmic, to data pairs such that the sum of the squared errors between data points and the curve is minimized.

LED *See* light emitting diode.

LEF *See* lighting effectiveness factor.

left-hand circular polarization the state of an electromagnetic wave in which the electric field vector rotates anticlockwise when

viewed in the direction of propagation of the wave.

left–right models typical hidden Markov models adopted in automatic speech recognition. The state diagram for these models is a directed acyclic graph, that is, there are no cycles apart from self-loops.

legacy system applications that are in a maintenance phase but are not ready for retirement.

Legendre functions a collection of functions, typically denoted as $P_\nu(x)$ and $Q_\nu(x)$, that satisfy Legendre's equation:

$$(1-x^2)\frac{d^2f}{dx^2} - 2x\frac{df}{dx} + \nu(\nu+1)f = 0\ ,$$

where f is equal to either P_ν or Q_ν; ν is the order of the function and x is its argument. Typically, Legendre functions arise in boundary value problems that are based upon a spherical coordinate system.

Leibniz's formula a formula that is satisfied by the three types of *Lie derivatives*,

$$L_{[\mathbf{f},\mathbf{g}]}h = \langle \nabla h, [\mathbf{f},\mathbf{g}]\rangle = L_\mathbf{g}L_\mathbf{f}h - L_\mathbf{f}L_\mathbf{g}h\ .$$

Leibniz, Gottfried Wilhelm (1646–1716) Born: Leipzig, Germany

Leibniz is best known for his work in mathematics. Leibniz's work was an important contribution to the development of differential calculus and logic. Leibniz also improved Pascal's early calculating machine, extending its capacity to include multiplication and division. Leibniz' later years were embittered by the charge that he had plagiarized some of Isaac Newton's work on the development of the calculus. Subsequent investigations have proved this charge to be baseless.

Lempel–Ziv coding *See* Ziv–Lempel coding.

Lempel–Ziv compression *See* Ziv–Lempel coding.

Lempel-Ziv-Welch (LZW) coding a variant of the dictionary-based coding scheme invented by Ziv and Lempel in 1978 (LZ78), where strings of symbols are coded as indices into a table. The table is built up progressively from the input data, such that strings already in the table are extended by one symbol each time they appear in the data.

lengthened code a code constructed from another code by adding message symbols to the codewords. Thus an (n, k) original code becomes, after the adding of one message symbol, an $(n+1, k+1)$ code.

lens optical element for focusing or defocusing electromagnetic waves.

lens aberrations any deviation of the real performance of an optical system (lens) from its ideal performance. Examples of lens aberrations include coma, spherical aberration, field curvature, astigmatism, distortion, and chromatic aberration.

lens array a two-dimensional array of (often small) lenses fabricated on a single substrate.

lens design the mathematical determination of the parameters of the optical elements in an optical instrument or system required to satisfy its performance goals. Rays are traced through the system to predict its performance and then changes of one or more parameters are made to improve its performance. Now performed using computer software packages.

lenslet array interconnect free-space interconnect that uses lenslet arrays to control optical paths from sources to detectors. Each lenslet images the source array onto the detector array. It has no property of dynamic reconfiguration.

lenslike medium beam propagation medium in which the gain and index of refraction

may have linear or quadratic variations with distance away from the optical axis.

level crossing rate *See* fading rate.

level-1 cache in systems with two separate sets of cache memory between the CPU and standard memory, the set nearest the CPU. Level-1 cache is often provided within the same integrated circuit that contains the CPU. In operation, the CPU accesses level-1 cache memory; if level-1 cache memory does not contain the required reference, it accesses level-2 cache memory, which in turn accesses standard memory, if necessary.

level-2 cache in systems with two separate sets of cache memory between the CPU and standard memory, the set between level-1 cache and standard memory.

level-sensitive pertaining to a bistable device that uses the level of a positive or negative pulse to be applied to the control input, to latch, capture, or store the value indicated by the data inputs.

level-triggered *See* level-sensitive.

Levenshtein distance *See* edit distance.

LFSR *See* linear-feedback shift register.

Liapunoff *See* Lyapunov, Alexandr M.

Liapunov *See* Lyapunov, Alexandr M.

Lichtenburg figure a pattern produced on a powder-coated flat electrode or upon photographic film held between a pair of flat electrodes subjected to a high voltage impulse as from a lightning stroke. Impulse polarity, magnitude and waveform can be estimated by examination of its characteristic pattern.

lid the fuse-holder portion of a cut-out.

Lie derivative one of three types of special derivatives.

1. The derivative of a vector field with respect to a vector field that is also known as the Lie bracket. If $\mathbf{f}, \mathbf{g} : \mathbb{R}^n \to \mathbb{R}^n$ are two differentiable vector fields, then their Lie bracket is

$$[\mathbf{f}, \mathbf{g}] = \frac{\partial \mathbf{f}}{\partial \mathbf{x}}\mathbf{g} - \frac{\partial \mathbf{g}}{\partial \mathbf{x}}\mathbf{f} ,$$

where $\frac{\partial \mathbf{f}}{\partial \mathbf{x}}$ and $\frac{\partial \mathbf{g}}{\partial \mathbf{x}}$ are the Jacobian matrices of the vector fields $\mathbf{f}$ and $\mathbf{g}$, respectively. Often the negative of the above is used.

2. The derivative of a function h with respect to a vector field $\mathbf{f}$ defined as

$$L_{\mathbf{f}} h = \langle \nabla h, \mathbf{f} \rangle = (\nabla h)^T \mathbf{f} ,$$

where $\nabla h : \mathbb{R}^n \to \mathbb{R}^n$ is the gradient of h.

3. The derivative of $dh = (\nabla h)^T$ with respect to the vector field,

$$L_{\mathbf{f}}(dh) = \left(\frac{\partial \nabla h}{\partial \mathbf{x}} \mathbf{f} \right)^T + (\nabla h)^T \frac{\partial \mathbf{f}}{\partial \mathbf{x}} .$$

See also Leibniz's formula.

lifetime broadening a spectral line broadening mechanism that is a consequence of the finite lifetime of the excited state. Numerically, the lifetime broadened linewidth is equal to the inverse lifetime of the excited state.

LIFO *See* first-in-last-out.

lift-off process a lithographic process by which the pattern transfer takes place by coating a material over a patterned resist layer, then dissolving the resist to "lift off" the material that is on top of the resist.

light emitting diode (LED) a forward-biased p-n junction that emits light through spontaneous emission by a phenomenon termed electroluminescence.

light guide system of lenses, mirrors, graded index, or graded gain media that has the capability of overcoming diffraction and guiding an electromagnetic wave at optical frequencies.

light loss factor (LLF) the ratio of the illumination when it reaches its lowest level at the task just before corrective action is taken, to the initial level if none of the contributing loss factors were considered.

light pen an input device that allows the user to point directly to a position on the screen. This is an alternative to a mouse. Unlike a mouse, a light pen does not require any hand/eye coordination skills, because the users point to where they look with the pen.

light scattering (1) spreading of the light as it passes or is reflected by an optically inhomogeneous medium.

(2) the process in which a beam of light interacts with a material system and becomes modified in its frequency, polarization, direction of propagation, or other physical property. *See also* spontaneous light scattering, stimulated light scattering, Brillouin scattering, Raman scattering.

light valve *See* spatial light modulator.

light-activated silicon controlled rectifier a silicon controlled rectifier in which the gate terminal is activated by an optical signal rather than an electrical signal.

light-amplifying optical switch (LAOS) vertically integrated heterojunction phototransistor and light emitting diode that has latching thyristor-type current-voltage characteristics.

lighting effectiveness factor (LEF) the ratio of equivalent sphere illumination to ordinary measured or calculated illumination.

lighting system any scheme used for illuminating a scene, usually for acquisition by a digital system. Illumination is crucial to digital images, since even illumination gradients that cannot be perceived by the eye can have an influence on the results of digital processing. For inspection tasks and document digitization, a uniform, reproducable, high level of lighting is usually required. Other applications have other requirements for uniformity, frequency, and intensity.

Structured lighting schemes are used to collect multiple images of a scene each having different illumination .
Strobe lights can be used to effectively freeze motion, and are useful for many visual inspection tasks. *See also* structured light.

lightly doped drain (LDD) in an MOS transistor, an extension to the source/drain diffusion that is separated slightly from the gate region which contains lower doping than that used for the source/drain diffusions. Since the source and drain diffusions are heavily doped, the lightly doped extension tends to increase the width of the depletion region around the drain which lowers the electric field intensity, to increase the breakdown voltage of the drain region of deep submicron devices.

lightning arrestor a voltage-dependent resistor which is connected in parallel with lightning-susceptible electrical equipment. It provides a low-resistance electrical path to ground during overvoltage conditions, thus diverting destructive lightning energy around the protected equipment.

lightning choke one of several arrangements of conductors, usually a single or multi-turn coil, used to reduce lightning currents by increasing a power line's impedance at lightning frequencies.

lightwave communications optical communications techniques that used guided wave optical devices and fiber optics.

lightwave technology technology based on the use of optical signals and optical fiber for the transmission of information.

likelihood ratio the optimum processor for reducing a set of signal-detection mea-

surements to a single number for subsequent threshold comparison.

likelihood ratio test a test using the likelihood ratio that can be used along with threshold information to test different information-content hypotheses. An example of a signal detection problem is the demodulation of a digital communication signal, for which the likelihood ratio test may be used to decide which of several possible transmitted symbols has resulted in a given received signal.

limit cycle undamped but bounded oscillations in a power system caused by a disturbance.

limited-look-ahead control predictive control policy whereby — unlike in the case of open-loop-feedback control — the decision mechanism used at each intervention instant takes into account one or more, but not all, remaining future interventions; this in particular means that such decision mechanism requires the usage of at least two scenarios of the future free input values over the considered prediction interval.

limiter an equipment or circuit that has a function to keep output power constant. It can also be used to protect other circuits not to be overdriven.

limiting spatial resolution for an imaging photodetector, the maximum number of black and white bar pairs of equal width and spacing that can be resolved per unit length, usually given in units of line-pairs per millimeter.

Linde–Buzo–Gray (LBG) algorithm (1) an algorithm for vector quantizer design, due to Y. Linde, A. Buzo and R. M. Gray (1980). The procedure is based on the principles of the generalized Lloyd algorithm and the K-means clustering algorithm.

(2) an iterative method for designing a codebook for a vector quantizer using a set of training data that is representative of the source to be coded. Otherwise known as the generalized Lloyd algorithm or K-means algorithm.

line (1) on a bus structure, one wire of the bus, which may be used for transmitting a datum, a bit of an address, or a control signal.

(2) in a cache, a group of words from successive locations in memory stored in cache memory together with an associated tag, which contains the starting memory reference address for the group.

(3) a power-carrying conductor or group of conductors.

line broadening nonzero spectral width of an absorbing or emitting transition; caused by many physical effects.

line code modification of the source symbol stream in a digital communication system to control the statistics of the encoded symbol stream for purposes of avoiding the occurrence of symbol errors that may arise due to limitations of practical modulation and demodulation circuitry. Also called recording codes or modulation codes.

line conditioner *See* power conditioner.

line detection the location of lines or line segments in an image by computer. Often accomplished with the Hough transform.

line drop compensator a multiply-tapped autotransformer equipped with a load-sensing relay which will adjust the line voltage to compensate for the impedance drop in the circuit between the device and the load center.

line hose split rubber tubing which is applied over energized electric conductors as temporary insulation to protect nearby workers.

line impedance stabilization network (LISN) a network designed to present a defined impedance at high frequency to a de-

vice under test, to filter any existing noise on the power mains, and to provide a 50-Ω impedance to the noise receiver.

line of sight (LOS) the shortest possible straight line that can be envisioned, regardless of possible obstacles in the way, between a transmitter and a receiver. If a line of sight between transmitter and receiver is not blocked, the strongest signal will be received from the line-of-sight direction.

line outage distribution factor a ratio used in contingency analysis. Given two parallel lines in a power system called x and y, assume that line y is removed from service. The line outage distribution factor of line x for the outage of line y is the ratio of the change in power flow on line x to the flow on line y before the outage.

line rate *See* horizontal rate.

line shape function shape of the spectrum of an emission or absorption line.

line spread function the response of a system to a 2-D input consisting of a single line. If the system is linear and space invariant, its output to any image with a 1-D pattern is a sum of weighted line spread functions. Such patterns are often used in vision experiments. *See also* linear shift invariant system, point spread function, space invariance.

line to line fault a fault on a three phase power line in which two conductors have become connected.

line width width of the spectrum of an emission or absorption line; often full width at half maximum, but other definitions also used.

line-connected reactor *See* shunt reactor.

line-current harmonic *See* electromagnetic interference filter.

line-impact printer a printer that prints a whole line at a time (rather than a single character). An impact printer has physical contact between the printer head and the paper through a ribbon. A dot-matrix printer is an impact printer, whereas an ink-jet printer is not. A line-impact printer is both a line and impact printer.

line-reflect-match (LRM) calibration an error correction scheme (calibration) where the calibration standards used are a transmission line, a reflect load, and a matched load. Line-reflect-match (LRM) two-port calibration requires a line standard (1 picosecond line), reflect standard (open circuit is preferred, short circuit is optional), and match standard (50 ohm load). The LRM technique is similar to the TRL technique, except the reference impedance is determined by a load instead of a transmission line. It has the advantages of self-consistency, requires only two standards to contact, and has no bandwidth limitations.

line-reflect-reflect-match (LRRM) calibration an extension of line-reflect-match (LRM) calibration. The second reflect standard in LRRM is used for correcting the inductance caused by the match standard.

line-to-line run-length difference coding a coding scheme for graphics. In this approach, correlation between run-lengths in successive lines is taken into account. Differences between corresponding run-lengths of successive scan lines are transmitted.

line-to-line voltage a voltage measurement of a three phase line made between any two conductors.

linear a circuit or element in which the output spectrum is proportional through gain(s), attenuation(s) and delay(s) to the input spectrum, and in which no spectral shift, conversion or generation takes place. True linearity is seldom encountered in the real world, but often used in approximate descrip-

tions, thereby promoting understanding and simplifying computation.

linear approximation any technique used for the purpose of analysis and design of nonlinear systems. For example, one way of analyzing the stability of a system described by nonlinear differential equations is to linearize the equations around the equilibrium point of interest and check the location of the eigenvalues of the linear system approximation.

linear block code a block coding scheme for which the mapping can be described by a linear transformation of the message block. The transformation matrix is referred to as the generator matrix.

linear code a forward error control code or line code whose code words form a vector space. Equivalently, a code where the element-wise finite field addition of any two code words forms another code word.

linear constant-coefficient equation a general Nth-order linear constant-coefficient differential equation is of the form

$$\sum_{0}^{N} a_k \frac{d^k y(t)}{dt^k} = \sum_{0}^{M} b_k \frac{d^k x(t)}{dt^k}$$

while an Nth-order linear constant-coefficient difference equation is of the form

$$\sum_{0}^{N} a_k y[n-k] = \sum_{0}^{M} b_k x[n-k]$$

Linear constant-coefficient equations at initial rest are linear time invariant and causal, and can be conveniently analyzed using transform techniques.

linear dynamic range of Bragg cell regime of cell operation where the amplitude of the principal diffracted beam is approximately proportional to the acoustic signal amplitude modulating the acousto-optic interaction medium.

linear filter a filter whose output signal is a linear function of the input (that is, input and output are related via a convolution). *See also* convolution, linear system.

linear generator *See* linear machine.

linear interpolation linear interpolation is a procedure for approximately reconstructing a function from its samples, whereby adjacent sample points are connected by a straight line.

linear least squares estimator (LLSE) the linear estimator $\hat{\boldsymbol{x}} = K\boldsymbol{y} + c$, where matrix K and vector c are chosen to minimize the expected squared error $E\left[(\hat{\boldsymbol{x}} - \boldsymbol{x})^T(\hat{\boldsymbol{x}} - \boldsymbol{x})\right]$. The general LLSE solution to estimate a random vector $\boldsymbol{x}$ based on measurements $\boldsymbol{y}$ is given by

$$\hat{\boldsymbol{x}}(\boldsymbol{y}) = E[\boldsymbol{x}] + \text{cov}(\boldsymbol{x}, \boldsymbol{y}) \cdot \text{cov}(\boldsymbol{y}, \boldsymbol{y})^{-1} \cdot (\boldsymbol{y} - E[\boldsymbol{y}])$$

where "cov" represents the covariance operation. *See also* least squares, covariance, expectation, minimum mean square estimator.

linear load an electrical load with a current that is linearly proportional to the voltage supplied.

linear machine a machine in which the moving member constitutes linear motion instead of the more conventional rotary motion. Each of the rotary machine types can be produced in linear versions. The most widely known use of linear motors are in the field of transportation, where the stator is usually the moving vehicle and the conducting rotors are the rails. In these machines, the induced currents provide levitation in addition to providing the main propulsion.

linear medium (1) medium in which the constitutive parameters are not functions of the electric or magnetic field amplitudes.

(2) medium in which any response is directly proportional in magnitude to the magnitude of the applied field.

linear motor *See* linear machine.

linear multistep method this is a class of techniques for solving ordinary differential equations which is widely used in circuit simulators.

linear network a network in which the parameters of resistance, inductance and capacitance are constant with respect to voltage or current or the rate of change of voltage or current and in which the voltage or current of sources is either independent of or proportional to other voltages or currents, or their derivatives.

linear phase system where the phase shift produced by the filter at frequency w is a linear function of w ($\angle H(w) = dw$). If a signal $x(t)$ is passed through a unit magnitude, linear phase filter with slope d, the output signal will be $x(t+d)$, the input signal time-shifted by d seconds.

linear polarization a polarization state of a radiated electromagnetic field in which the tip of the electric field vector remains on a line and does not rotate as a function of time for a fixed position.

linear prediction for a stochastic process, the prediction of its samples based upon determining a linear model capable of estimating the samples with minimal quadratic error.

linear prediction based speech coding *See* linear predictive coding.

linear predictive coding speech coding methods where short-term redundancy of the speech signal is removed by linear prediction analysis prior to encoding. *See also* adaptive differential pulse code modulation.

linear predictor a predictor that uses a weighted sum of K previous samples of the original signal with $\alpha_i, i = 1, \ldots, K$ as weights.

linear quadratic control for a linear deterministic plant, the problem of determining the control structure that minimizes the performance index.

Given a plant in the form of the state-space equation

$$\dot{x}(t) = Ax(t) + Bu(t)$$

The associated performance index is the quadratic form

$$J = \frac{1}{2}x(T)S(T)x(T) + \frac{1}{2}\int_{t_0}^{T}(x^T(t)Qx(t) + u^T(t)Ru(t)dt$$

with symmetric weighting matrices $S(T) \geq 0$, $Q \geq 0$, $R > 0$. Both plant and weighting matrices can be functions of time. Linear quadratic control is the problem of determining the control $u^o(t)$ on (t_0, T) that minimizes the performance index J with $x(T)$ free and T fixed. Also called LQ control.

linear quadratic Gaussian control for a plant, the problem of finding the control structure that minimizes the expected cost.

The linear stochastic plant is given in the following state-space form:

$$\dot{x}(t) = Ax(t) + Bu(t) + Gw(t)$$

with white noise $w(t)$ and $x(t_0)$ a random variable. The associated performance index is the quadratic form

$$J = \frac{1}{2}x^T(T)S(T)x(T) + \frac{1}{2}\int_{t_0}^{T}(x^T(t)Qx(t) + u^T(t)Ru(t)dt$$

with symmetric weighting matrices $S(T) \geq 0$, $Q \geq 0$, $R > 0$. The plant and weighting

matrices can be functions of time. It is desired to determine the control u^o on (t_0, T) which minimizes the expected cost

$$j = E(J)$$

with $x(T)$ free and T fixed. This problem is called the linear quadratic Gaussian control.

linear response the characteristic of many physical systems that some output property changes linearly in response to some applied input. Such systems obey the principle of linear superposition.

linear scalar quantization *See* uniform scalar quantization. Also known as linear SQ.

linear scrambler a linear one-to-one mapping of a codeword, $\mathbf{c}$, of length n onto a new codeword, $\mathbf{c}_c$, also of length n. $\mathbf{c}_c$ is determined as $\mathbf{c}_c = \mathbf{S}\,\mathbf{c}$, where $\mathbf{S}$ is the linear scrambler matrix. This matrix is full rank and, for the binary case, has all binary entries. In the binary case, modulo-2 arithmetic is performed.

linear separation the process of determining the hyper plane that separates a given set of patterns according to their membership. Of course, such separation can only be obtained once the patterns are linearly separable.

linear shift invariant (LSI) system a linear discrete-time system $T[]$, with $y[n] = T[x[n]]$ and $y[n - n_0] = T[x[n - n_0]]$. *See also* linear system, linear time invariant system, shift invariance.

linear SQ *See* uniform scalar quantization.

linear susceptibility the coefficient χ relating the polarization P of a material system (assumed to exhibit linear response) to the applied electric strength E according to $P = \chi E$.

linear system the systems in which the components exhibit linear characteristics, i.e., the principle of superposition applies. Strictly speaking, linear systems do not exist in practice; they are idealized models purely for the simplicity of theoretic analysis and design. However, the system is essentially linear when the magnitude of the signals in a control system are limited to a range in which the linear characteristics exist.

More formally, consider a system with zero initial conditions such that any two input/output signal pairs $\{f_1, y_1\}$ and $\{f_2, y_2\}$ satisfy the system equation. The system is additive if the input/output pair $\{f_1 + f_2, y_1 + y_2\}$ also satisfies the system equation. The system is homogeneous if for any real constant C, the input/output pair $\{Cf_1, Cy_1\}$ satisfies the system equation. The system is linear if it is additive and homogeneous. In other words, for any real constants C_1 and C_2, the input/output pair $\{C_1 f_1 + C_2 f_2, C_1, y_1 + C_2 y_1\}$ satisfies the system equation. If a system is not linear, then it is nonlinear. The theory of linear systems is well-developed, hence many tools exist for the analysis of system behavior. In practice, nonlinear systems are often approximated by a linear model so that the tools may be exploited.

linear systems with Markov jumps a class of piecewise deterministic processes that follows linear dynamics between random jumps of parameters that in turn can be described by finite-state Markov processes. In the continuous-time case, linear systems with Markov jumps could be modeled by linear state equations of the form:

$$\dot{x}(t) = A(\xi(t))x(t) + B(\xi(t))u(t)$$

where $t \in [0, T]$, T being finite or infinite control horizon, $x(t) \in \mathbf{R}^n$ is the process state, $u(t) \in \mathbf{R}^m$ is the process control, A, B are real valued matrices of respective dimensions depending on the random process $\{\xi(t)\}$. This process is a continuous-time discrete-state Markov process taking values in a finite set $\mathbf{S} = \{1, 2, \ldots, s\}$ called mode

with transition probability matrix $P = \{p_{ij}\}$ given by

$$p_{ij} = Pr(\xi(t+\delta t) = j | \xi(t) = i) = q_{ij}\delta t + O(\delta t)$$

if $i \neq j$ and

$$p_{ii} = 1 + q_{ii}\delta t + O(\delta t)$$

where $\delta t > 0$, q_{ij} is the intensitivity or transition rate from i to j if $i \neq j$ and

$$q_{ii} = -q_i = -\sum_{j=1, j\neq i}^{s} q_{ij}$$

Linear systems with Markov jumps may serve as models for continuous-time processes subject to abrupt changes in parameter values because of component failures, sudden shifts in environment or subsystems connections. Generally, linear systems with jumps are hybrid in the sense that their state combines a part taking values from continuous space (process state) and a part that takes values from discrete space (mode).

linear threshold unit a neural element that computes the weighted sum of its inputs and compares that sum to a threshold value. If the sum is greater than (or equal to) the threshold, the output of the element takes on the value $+1$. Otherwise, the output takes on the value 0 (in a binary system) or -1 (in a bipolar system).

linear time invariant (LTI) system a linear system $T[]$, with $y(t) = T[x(t)]$ and $y(t - t_0) = T[x(t - t_0)]$. *See also* linear system, linear shift invariant system (LSI), shift invariance.

linear time-invariant lumped-parameter (LTIL) system a continuous system that can be described by an ordinary differential equation with real constant coefficients. A single loop RLC circuit is an example of a linear time-invariant lumped-parameter system (LTIL), with the following differential equation relating the input voltage $f(t)$ to the output loop current $y(t)$:

$$L\frac{d^2y}{dt^2} + R\frac{dy}{dt} + \frac{1}{C}y = \frac{df}{dt}$$

A discrete time system is a LTIL system if it can be modeled by a difference equation with real constant coefficients. For example, the following LTIL difference equation represents a discrete time approximation of a differentiator:

$$y[k] = \frac{1}{T}(f[k] - f[k-1])$$

A large number of physical systems are LTIL systems. Since the theory for modeling and analysis of such systems is well developed, LTIL systems are often used to approximately model physical processes in order to simplify the mathematical analysis.

linear transformation a transformation operator A which satisfies superposition,

$$A(x_1 + x_2) = Ax_1 + Ax_2$$

and homogeneity

$$A(\lambda x_1) = \lambda A x_1.$$

For a discrete linear transform A is a matrix and x_1 and x_2 are vectors. Any matrix transform is linear. *See* linear system, superposition.

linear-feedback shift register (LFSR) a shift register formed by D flip-flops and exclusive OR gates, chained together, with a synchronous clock.

linear-quadratic game one of a class of noncooperative infinite dynamic games with state equations linear with respect to state variables x and players actions u_i; $i = 1, 2, \ldots, N$ and cost functions quadratic with respect to those variables with weighting matrices semipositive definite for the state and positive definite for the players actions. The existence and uniqueness of the open-loop

Nash equilibrium in such games is guaranteed under assumptions on the existence of a unique solution for respectively defined coupled Riccati equations. The equilibrium strategies appear to be linear functions of the associated state trajectories. The existence and linear form for the feedback Nash strategies could be guaranteed by the existence of positive semidefinite solution to the relevant coupled Riccati equations but it does not attribute an uniqueness features to the solution set. For the zero-sum linear-quadratic games, the situation becomes simpler both in discrete-time and continuous-time cases. The saddle point strategies could be found by solving standard Riccati equations, and whenever both open-loop and closed-loop solutions do exist they generate the same state trajectories. For example, in the continuous-time zero-sum linear-quadratic game defined by the state equation

$$\dot{x} = Ax + B_1u_1 + B_2u_2$$

and the quadratic cost functional

$$J = \frac{1}{2}\int_0^T (x'Qx + u_1'u_1 + u_2'u_2)dt$$

the saddle point strategies are given by

$$u_i = (-1)^i B_i'K(t)x;\ i = 1, 2$$

where $K(t)$ is a unique symmetric bounded solution to the matrix differential Riccati equation

$$\dot{K} + A'K + KA + Q - K(B_1B_1' - B_2B_2') = 0$$

with $K(T) = 0$.

linearity a property of a system if that system obeys the principle of superposition. In other words, if the output $y(t)$ is a function of the input $x(t)$, i.e., $y(t) = f(x(t))$, and if $x(t) = \alpha x_1(t) + \beta x_2(t)$, then for a linear system, $y(t)$ will be $= \alpha y_1(t) + \beta y_2(t)$ where $y_1(t) = f(x_1(t))$ and $y_2(t) = f(x_2(t))$.

linearization approximation of a nonlinear evolution equation in a small neighborhood of a point by a linear equation. This is obtained by keeping only the first order terms in the Taylor series expansion of the nonlinearities about this point.

linearized machine equations state equations obtained by linearizing the nonlinear voltage and electromagnetic torque equations of induction or synchronous machines. The state variables can be either currents, or flux linkages. The linearization can be accomplished using a Taylor series expansion of the machine variables about an operating point, i.e.,

$$g(f) = g(f_0) + g'(f_0)\Delta f + \text{higher order terms}$$

where $f = f_0 + \Delta f$ (and f_0 is the value of f at a given operating point).

The small displacement characteristics are then approximated as

$$g(f) - g(f_0) = \Delta g = g'(f_0)\Delta f$$

The linearized equations are typically manipulated into a standard state model form

$$\frac{dx}{dt} = Ax + Bu$$
$$y = Cx + Du$$

and are used for Eigensystem, stability, and control analysis and design.

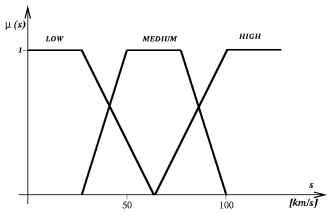
linearizer an equipment or circuit that is used to reduce distorted components generated in nonlinear amplifiers such as traveling-wave tube amplifier (TWTA) or solid state power amplifier (SSPA). There are various kinds of linearizers, such as predistortion, feedback, and feedforward types.

lineman utility employee working on primary facilities, distribution class equipment, as opposed to customer service level facilities.

linguistic hedge *See* modifier.

linguistic variable variable for which values are not numbers, but words or sentences

in a natural or artificial language. In fuzzy set theory, the linguistic values (or terms) of a linguistic variable are represented by fuzzy sets in an universe of discourse. In the example shown in the figure, the linguistic variable is *speed*, the universe of discourse is associated to the base variable s, and the fuzzy sets (through the plot of their membership functions) associated to the linguistic values *low*, *medium*, and *high*.



Definition of the linguistic variable speed.

See also membership function, fuzzy set.

link (1) the portion of the compilation process in which separate modules are placed together and cross-module references resolved.

(2) a linkage (joint) in a manipulator arm.

link inertial parameters for a manipulator arm, consists of six parameters of the inertia tensor, three parameters of its center of mass multiplied by mass of the link (more precisely, three components of the first order moment) and mass of the link. Dynamic properties of each link are characterized by 10 inertial parameters. They appear in the dynamic equations of motion of the manipulator.

linkage flux also called magnetizing or mutual flux. In a magnetically coupled circuit such as a transformer, the linkage flux is the flux that links all the windings. For example, in a transformer the magnetic flux produced by the primary winding which is coupled to the secondary winding.

linker a computer program that takes one or more object files, assembles them into blocks that are to fit into particular regions in memory, and resolves all external (and possibly internal) references to other segments of a program and to libraries of precompiled program units.

Linville stability factor the inverse of the Rollett stability factor (K), C is a measure of potential stability in a 2-port circuit operating under small signal conditions, but standalone is insufficient to guarantee stability. A 2-port circuit that is matched to a positive real source and load impedance is unconditionally stable if $0 < C < 1$, $B_1 > 0$ (port 1 stability measure) and $B_2 > 0$ (port 2 stability measure). The design must provide sufficient isolation from the RF input and output ports to the bias ports to allow a reasonable interpretation of the "2-port" device criteria.

$$C = \frac{1}{K} = \frac{2 \cdot | s_{12} \cdot s_{21} |}{1 - | s_{11} |^2 - | s_{22} |^2 + | \Delta |^2}$$

where $\Delta = s_{11} \cdot s_{22} - s_{12} \cdot s_{21}$.

Lipschitz condition for a vector function $f : \Re^n \longrightarrow \Re^n$, where $\Re^n$ is the n-dimensional real Euclidean space, the condition

$$\| f(x) - f(y) \| \leq b \| x - y \|$$

where $\|.\|$ is any vector norm in n and b, which is called the Lipschitz constant, is a positive real number.

Lipschitz continuous system *See* incremental gain.

liquid crystal class of organic polymeric materials made up of elongated molecules that show various degrees of order in one, two, and three dimensions.

liquid crystal display (LCD) the screen technology commonly used in notebook and smaller computers.

liquid crystal light valve (LCLV) a type of optically addressed spatial light modulator

that uses twisted nematic liquid crystal material and a photosensitive layer for optical inputs.

liquid crystal on silicon (SLM) a type of electrically addressed spatial light modulator using liquid crystal material on top of a VLSI silicon circuit used for electrical signal input and signal preprocessing.

liquid laser laser in which the active medium is a liquid, dye lasers being the most common example.

LISN *See* line impedance stabilization network.

list decoding decoding procedure in which the decoder, instead of producing a single estimate of the transmitted codeword, yields a list of candidate codewords, for example the L most likely.

list of capabilities usually associated with a process, defining a set printed circuit board that can be plugged into a main board to enhance the functionality or memory of a computer.

literal a data type consisting of alphanumeric data.

lithium niobate ($LiNbO_3$) a strong linear electro-optic material, also strongly piezoelectric and possessing high acousto-optic figure of merit with low acoustic attenuation.

lithography (1) for a semiconductor manufacturing process, the process of printing images of the various circuit layers on the wafer via a photographic technique. The technique uses a radiation source, such as light, electrons, or X-rays, to generate a pattern in a radiation-sensitive material. The radiation-sensitive material is illuminated through a mask, that prevents certain portions of the material from being exposed. Exposed material is changed chemically such that it is either removed by or resistant to a solution used to develop the image.

(2) a method of producing three-dimensional relief patterns on a substrate (from the Greek *lithos*, meaning stone, and *graphia*, meaning to write).

little endian a memory organization whereby the byte within a word with the lowest address is the least significant, and bytes with increasing address are successively more significant. Opposite of big endian. Sometimes believed (with no merit) to be either the "right" or the "wrong" memory organization, hence the name (cf. Swift's Gulliver's Travels).

For example, in a 32-bit, or four-byte word in memory, the most significant byte would be assigned address i, and the subsequent bytes would be assigned the addresses $i-1$, $i-2$, and $i-3$. Thus, the least significant byte would have the lowest address of $i-3$ in a computer implementing the little endian address assignment. *See also* big endian.

live insertion the process of removing and/or replacing hardware components (usually at the board level) without removal of system power and without shutting down the machine.

live tank breaker a power circuit breaker where the tank holding the interrupting chamber is not at ground potential. SF6 circuit breakers, for example, are typically live tank breakers.

livelock a condition where attempts by two or more processes to acquire a resource run indefinitely without any process succeeding.

LLF *See* light loss factor.

Lloyd–Max scalar quantization a scalar quantizer designed for optimum performance (in the minimum mean squared error sense). The method, and the corresponding design algorithm, are due to S. P. Lloyd (1957) and

J. Max (1960). Also referred to as PDF-optimized quantization, since the structure of the scalar quantizer is optimized to "fit" the probability density function (PDF) of the source.

Lloyd–Max SQ *See* Lloyd–Max scalar quantization.

LLSE *See* linear least squares estimator.

LMS *See* least mean square algorithm.

LMS algorithm *See* least mean square algorithm.

LNA *See* low noise amplifier.

load balancing the process of trying to distribute work evenly among multiple computational resources.

load break device any switch, such as a circuit breaker or sectionalize capable of disconnecting a power line under load.

load buffer a buffer that temporarily holds memory-load (i.e., memory-write) requests.

load bypass a read (or load) request that bypasses a previously issued write (store) request. Read requests stall a processor, whereas writes do not. Therefore high-performance architectures permit load bypass. Typically implemented using write-buffers.

load center the geographic point within a load area, used in system calculations, at which the entire load could be concentrated without affecting the performance of the power system.

load flow study *See* power flow study.

load frequency control the purpose of load frequency control is to maintain the power system frequency at its nominal value while maintaining the correct outputs on individual generators to satisfy the loading on the system. As the load varies, the inputs to the generator prime movers must be controlled to keep the generation in balance with the loads.

load instruction an instruction that requests a datum from a virtual memory address, to be placed in a specified register.

load line with a slope, also known as the permeance coefficient, determined solely by the geometry of the magnetic circuit, this line intersects with the normal demagnetization curve to indicate a magnet's operating point.

load mismatch the load impedance does not match the device output impedance, resulting in power reflection. A perfect match occurs when the real parts of the load and device output impedance are equal and the reactive parts cancel or resonate, resulting in maximum power transfer. The magnitude of the load mismatch is usually expressed in terms VSWR, reflection coefficient or return loss.

load tap changer (LTC) a tapped transformer winding combined with mechanically or electronically switched taps that can be changed under load conditions. The load tap changer is used to automatically regulate the output of a transformer secondary as load and source conditions vary.

load torque the resisting torque applied at the motor shaft by the mechanical load that counterbalances the shaft torque generated by the motor and available at the shaft.

load-break device any switch which can be opened while the circuit is loaded

load-commutated inverter (LCI) an inverter in which the commutating voltages are supplied by the load circuit.

load-pull the systematic variance of the magnitude and phase of the load termination of a device under test.

load-pull measurement *See* active load-pull measurement, harmonic load-pull measurement.

load/store architecture a system design in which the only processor operations that access memory are simple register loads and stores.

load/store unit a computer based on the load/store architecture.

loaded Q dimensionless ratio of the average over any period of time (T = 1/frequency) of the ratio of the maximum energy stored (U_{max}) to the power absorbed or dissipated ($p_{absorbed} = p_{in} - p_{out}$) in a passive component or circuit, including external loading effects, expressed as a dimensionless ratio. For most applications, the higher the Q, the better the part.

local area network a network of computers and connection devices (such as switches and routers) that are located on a single site. The connections are direct cables (such as UTP or optical fiber) rather than telecommunication lines. The computer network in a university campus is typically a local area network.

local bus the set of wires that connects a processor to its local memory module.

local controllability of generalized 2-D model the generalized 2-D model

$$Ex_{i+1,j+1} = A_0x_{ij} + A_1x_{i+1,j} + A_2x_{i,j+1} + B_0u_{ij} + B_1u_{i+1,j} + B_2u_{i,j+1}$$

$i, j \in Z_+$ (the set of nonnegative integers) is called locally controllable in the rectangle $[0, N_1] \times [0, N_2]$ if for admissible boundary conditions x_{i0} for $i \in Z_+$ and x_{0j} for $j \in Z_+$, there exists a sequence of inputs u_{ij} for $0 \le i \le N_1 + n_1$ and $0 \le j \le N_2 + n_2$ such that $x_{N_1N_2} = 0$ where $x_{ij} \in R^n$ is the local semistate vector, $u_{ij} \in R^m$ is the input vector, E, A_k, B_k ($k = 0, 1, 2$) are real matrices with E possibly singular, and (n_1, n_2) is the index of model. *See also* local reachability of generalized 2-D model.

local decision unit control agent or a part of the controller associated with a given subsystem of a partitioned system; local decision unit is usually in charge of the local decision variables and is a component of a decentralized or a hierarchical control system.

local decision variable control inputs associated with a given subprocess (subsystem) of the considered partitioned process (system); local decision variables can be either set locally by local decision unit, or globally by a centralized controller.

local field effect effect associated with the distinction that occurs in condensed matter between the spatially averaged electric field and the field that acts on a representative molecule of the material system. A consideration of local field effects leads to the Lorentz–Lorenz and Clausius–Mossotti relations.

local memory memory that can be accessed by only one processor in a multiprocessor or distributed system. In many multiprocessors, each processor has its own local memory. *See also* global memory.

local minimum a minimum of a function that is not the global minimum.

local mode oscillation this mode of oscillation is associated with the swinging of units at a generating station with respect to the rest of the power system. The oscillations are thus localized to within a small part of the system.

local observability of 2-D Fornasini–Marchesini model the 2-D Fornasini–Marchesini model

$$x_{i+1,j+1} = A_1x_{i+1,j} + A_2x_{i,j+1} + B_1u_{i+1,j} + B_2u_{i,j+1}$$
$$y_{ij} = Cx_{ij}$$

$i, j \in Z_+$ (the set of nonnegative integers) is called locally observable in the rectangle $[0, N_1] \times [0, N_2]$ if there is no local states $x_{10} \neq 0$ and $x_{01} \neq 0$ such that for zero inputs u_{ij} for $0 \leq i \leq N_1$ and $0 \leq j \leq N_2$ and zero boundary conditions $x_{i0} = 0$ for $i \geq 2$ and x_{0j} for $j \geq 2$ the output is also zero $y_{ij} = 0$ for $0 \leq i \leq N_1$ and $0 \leq j \leq N_2$. The model is locally observable in $[0, N_1] \times [0, N_2]$ if and only if

$$\text{rank} \begin{bmatrix} CT_{10} \\ \vdots \\ CT_{N_1-1,0} \\ CT_{01} \\ \vdots \\ CT_{0,N_2-1} \\ CT_{11} \\ \vdots \\ CT_{N_1-1,N_1-1} \end{bmatrix} [A_1, A_2] = 2n$$

where the transition matrix T_{ij} of the model is defined by

$$T_{ij} = \begin{cases} I_n \text{ for } i = j = 0 \\ T_{ij} = A_1 T_{i-1,j} + A_2 T_{i,j-1} \\ \text{for } i, j \geq 0 \ (i + j \neq 0) \\ T_{ij} = 0 \text{ for } i < 0 \text{ or/and } j < 0 \end{cases}$$

local observability of 2-D Roesser model the 2-D Roesser model

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

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

$i, j \in Z_+$ (the set of nonnegative integers) is called locally observable in the rectangle $[0, N_1] \times [0, N_2]$ if there is no local initial state $x_{00} \neq 0$ such that for zero inputs $u_{ij} = 0$ for $0 \leq i \leq N_1$ and $0 \leq j \leq N_2$ and zero boundary conditions $x^h_{0j} = 0$ for $j \geq 1$ and $x^v_{i0} = 0$ for $i \geq 1$, the output is also zero $y_{ij} = 0$ for $0 \leq i \leq N_1$ and $0 \leq j \leq N_2$ where $x^h_{ij} \in R^{n_1}$ 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 are real matrices. The model is locally observable in $[0, N_1] \times [0, N_2]$ and only if

$$\text{rank} \begin{bmatrix} C \\ CT_{10} \\ CT_{01} \\ \vdots \\ CT_{ij} \\ \vdots \\ CT_{N_1N_2} \end{bmatrix} = n$$

where the transition matrix is defined by

$$T_{ij} = \begin{cases} I \text{ for } i = j = 0 \\ \begin{bmatrix} A_1 & A_2 \\ 0 & 0 \end{bmatrix} \text{ for } i = 1, \ j = 0 \ ; \\ \begin{bmatrix} 0 & 0 \\ A_3 & A_4 \end{bmatrix} \text{ for } i = 0, \ j = 1 \text{ and} \\ T_{10} T_{i-1,j} + T_{01} T_{i,j-1} \text{ for} \\ \quad i, j \in Z_+ \ (i + j \neq 0) \\ T_{ij} = 0 \text{ for } i < 0 \text{ or/and } j < 0 \end{cases}$$

local oscillator (1) an oscillator or circuit that produces a periodic signal whose function is to be utilized in the demodulation of a received radio signal. This periodic signal is typically a sinusoid and the oscillator is typically located in a radio receiver. The tuning of the radio to a given channel, or station, typically involves the tuning of the local oscillator. The local oscillator is part of the radio frequency (RF) front end of a radio receiver and is an important component in a heterodyne receiver.

(2) the signal applied to a mixer circuit that is of a sufficient level to bias the diodes within the mixer into a nonlinear region so that the mixing process may occur.

local oxidation of silicon (LOCOS) masked oxidation of silicon to provide electronic isolation between devices. Made possible by relatively slow oxidation of silicon nitride, which is used as a mask.

local reachability of generalized 2-D model the generalized 2-D model

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

$i, j \in Z_+$ (the set of nonnegative integers) is called locally reachable in the rectangle $[0, N_1] \times [0, N_2]$ if for admissible boundary conditions $x_{i0}, i \in Z_+$ and $x_{0j}, j \in Z_+$ and every vector $x_f \in R^n$ there exists a sequence of inputs u_{ij} for $0 \le i \le N_1 + n_1$ and $0 \le j \le N_2 + n_2$ such that $x_{N_1 N_2} = x_f$, where $x_{ij} \in R^n$ is the local semistate vector, $u_{ij} \in R^m$ is the input vector, E, A_k, B_k $(k = 0, 1, 2)$ are real matrices with E possibly singular. The model is locally reachable in $[0, N_1] \times [0, N_2]$ if and only if

$$\begin{aligned} & \text{rank} \left[M_0, M1^1, \ldots, M^1_{\bar{N}_1}, M^2_1, \ldots, M^2_{\bar{N}_2}, \right. \\ & \left. M_{11}, \ldots, M_{1\bar{N}_2}, M_{21}, \ldots, M_{\bar{N}_1,\bar{N}_2} \right] = n \\ & M_0 = T_{N_1-1,N_2-1} B_0, \\ & M^1_p := T_{N_1-p,N_2-1} B_1 + T_{N_1-p-1,N_2-1} B_0 \\ & \text{for } p = 1, \ldots, \bar{N}_1 = N_1 + n_1 \\ & M^2_q := T_{N_1-1,N_2-q} B_2 + T_{N_1-1,N_2-q-1} B_0 \\ & \text{for } q = 1, \ldots, \bar{N}_2 = N_2 + n_2 \\ & M_{pq} := T_{N_1-p-1,N_2-q-1} B_0 \\ & \quad + T_{N_1-p,N_2-q-1} B_1 + T_{N_1-p-1,N_2-q} B_2 \\ & \text{for } \begin{cases} p = 1, \ldots, \bar{N}_1 \\ q = 1, \ldots, \bar{N}_2 \end{cases} \end{aligned}$$

and the transition matrix T_{pq} is defined by

$$ET_{pq} = \begin{cases} A_0 T_{-1,-1} + A_1 T_{0,-1} \\ \quad + A_2 T_{-1,0} + I \text{ for } p = q = 0 \\ A_0 T_{p-1,q-1} + A_1 T_{p,q,-1} \\ \quad + A_2 T_{p-1,q} \\ \quad \text{for } p \ne 0 \textit{ and/or } q \ne 0 \end{cases}$$

and

$$\begin{aligned} & [Ez_1 z_2 - A_0 - A_1 z_1 - A_2 z_2]^{-1} \\ & \quad = \sum_{p=-n_1}^{\infty} \sum_{q=-n_2}^{\infty} T_{pq} z_1^{-(p+1)} z_2^{-(q+1)} \end{aligned}$$

pair (n_1, n_2) of positive integers n_1, n_2 such that $T_{pq} = 0$ for $p < -n_1$ and/or $q < -n_2$ is called the index of the model.

local stability *See* stable state.

local wavelength distance between the phase fronts of a non-planewave signal inferred from measurements that are local in space; 2 pi over the magnitude of the local propagation constant, which is the gradient of the total phase. *See also* wavelength, instantaneous frequency.

locality one of two forms of program memory relationships.

1. Temporal locality: if an object is being used, then there is a good chance that the object will be reused soon.

2. Spatial locality: when an object is being used, there is a good chance that objects in its neighborhood (with respect to the memory where these objects are stored) will be used.

These two forms of locality facilitate the effective use of hierarchical memory. Registers exploit temporal locality. Caches exploit both temporal and spatial locality. Interleaved memories exploit spatial locality. *See also* sequential locality.

localization refers to the "trapping" of an electron into a potential well minimum, so that the wave function ceases to be describable by a propagating wave. This localization can be "strong" localization such as when an electron is trapped by an ionized donor or other ionized potential, or "weak" localization in which it is induced by a "self" interference effect. *See also* weak localization.

lock a synchronization variable, used in shared-memory multiprocessors, that allows only one processor to hold it at any one time, thus enabling processors to guarantee that only one has access to key data structures or critical sections of code at any one time.

lock range the range of frequencies in the vicinity of the voltage controlled oscillator

(VCO) free-running frequency over which the VCO will, once locked, remain synchronized with the signal frequency. Lock range is sometimes called tracking bandwidth.

lock-in amplifier a system for detecting weak, noisy periodic signals based on Synchronous detection, and incorporating all the other components necessary for recording the amplitude profile of the weak incoming signal, including input AC amplifier, diode or other detectors, low-pass filter, DC amplifier, and any special filters. Such instruments are nowadays constructed with increasing amounts of digital and computerized circuitry, depending on the frequency of operation.

lock-out phenomenon exhibited during channel switching that results from a fast automatic gain control (AGC) system interacting with the horizontal automatic frequency control (AFC), thereby reducing the pull-in range of the AFC system.

lock-up-free cache *See* nonblocking cache.

locked-rotor current the current drawn by an induction motor when the shaft is not moving and rated voltage is applied. The starting current is essentially equal to the locked rotor current and may be as much as eight times the rated current of the machine.

locked-rotor torque the torque produced in an induction motor when the rotor is locked and rated AC voltage is applied to the stator.

locking *See* bus locking.

lockout the condition following fault clearing when the circuit will not attempt a reclose. Transformers, generators, and buses typically trip once and lockout immediately. Transmission lines and distribution lines will generally attempt one or more recloses, and will lockout if the fault remains following the last reclose in the sequence.

lockout relay an auxiliary relay which is operated by protective relay(s) that in turn opens the appropriate circuit breakers or other fault clearing devices. The lockout relay will remain in the trip position until manually reset, and is used in protective zones where temporary faults are unusual and the potential for equipment damage is high.

LOCOS *See* local oxidation of silicon.

log periodic antenna broadband antenna designed using physical dimensions (lengths, spacings, diameters, etc.) that vary logarithmically. The result of such designs is an antenna whose performance parameters (e.g., input impedance) is periodic with respect to the logarithm of the frequency.

log-likelihood function the likelihood function of y given x is the conditional PDF, $p(y|x)$. The log-likelihood function is the logarithm of the likelihood function, $\log(p(y|x))$.

log-normal distribution probability distribution with density

$$f(x) = 1/(\sqrt{(2\pi)}\sigma x)e^{-((\log x-\mu)^2/(2\sigma^2))}$$

where μ and σ are the mean and standard deviation of the logarithm.

logarithmic quantization a method for non-linear scalar quantization where the input signal is transformed logarithmically and then coded using uniform quantization. The transformation is utilized to enhance performance for sources having nonuniform probability distribution, and to give robustness towards varying input signal dynamics.

logic analyser a machine that can be used to send signals to, and read output signals from, individual chips or circuit boards.

logic circuit a circuit that implements a logical function, such as AND, OR, NAND, NOR, NOT, or XOR. (DB)

logic gate a basic building block for logic systems that controls the flow of pulses.

logic level the high or low value of voltage variable that is assigned to be a 1 or 0 state.

logical operation the machine-level instruction that performs Boolean operations such as AND, OR, and COMPLEMENT.

logical register *See* virtual register.

logical shift a shift in which all bits of the register are shifted. *See also* arithmetic shift.

long code in a spread-spectrum system, a (periodic) spreading code (spreading sequence) with a period (substantially) longer than a bit duration. *See also* short code.

long duration *See* voltage variation.

long integer an integer that has double the number of bits as a standard integer on a given machine. Some modern machines define long integers and regular integers to be the same size.

long-term stability a measure of a power system's long-term response to a disturbance after all post-disturbance transient oscillations have been damped out, often associated with boiler controls, power plant and transmission system protection, and other long-period factors.

longitudinal excitation laser pumping process in which the pump power is introduced into the amplifying medium in a direction parallel to the direction of propagation of the resulting laser radiation.

longitudinal mode term (somewhat misleading) used in referring to the longitudinal structure or index of the mode of a laser oscillator.

longitudinal modelocking forcing the longitudinal modes of a laser oscillator to be equally spaced in frequency and have a fixed phase relationship; useful for obtaining very short and intense pulsations.

longitudinal phase velocity phase velocity of microwave propagation in the axial direction of a slow-wave structure of traveling wave tube.

longitudinal redundancy check an error checking character written at the end of each block of information on a track of magnetic tape. The character is calculated by counting the number of one on a track and adding either an additional one or zero in the character so that the total number of ones in the block is even.

longitudinal section electric and magnetic modes (LSE, LSM) are alternative choices for the electromagnetic potentials. For a waveguiding structure, the most common choices are potentials directed in the propagation direction (i.e., TE and TM modes). Sometimes, especially when layered dielectric are present, it is more convenient to consider the LSE, LSM potential, perpendicular to the longitudinal section.

look-ahead carry the concept (frequently used for adders) of breaking up a serial computation in which a carry may be propagated along the entire computation into several parts, and trying to anticipate what the carry will be, to be able to do the computation in parallel and not completely in series.

look-up table model a model in which measured data is stored in a data base, allowing the user to access the data and interpolate or extrapolate performance based on that data. S-parameter data is an example that is encountered frequently in RF and microwave design. Sophisticated look-up tables may reduce the data by polynomial curve fitting and retaining only the coefficients. Look-up table

models generally have a very low modeling valuation coefficient.

lookahead for conditional branches, a strategy for choosing a probable outcome of the decision that must be made at a conditional branch, even though the conditions are not known yet, and initiates "speculative" execution of the instructions along the corresponding control path through the program. If the chosen outcome turns out to be incorrect, all effects of the speculative instructions must be erased (or, alternately, the effects are not stored until it has been determined that the choice was correct). Some lookahead mechanisms attempt execution of both possibilities from a conditional branch, and others will cascade lookahead choices from several conditional branches that occur in close proximity in the program flow.

lookbehind for an instruction buffer, a means of holding recently executed instructions in a buffer within the control unit of a processor to permit fast access to instructions in a loop.

loop (1) a set of branches forming a closed current path, provided that the omission of any branch eliminates the closed path.

(2) a programming construct in which the same code is repeated multiple times until a programmed condition is met.

loop analysis *See* mesh analysis.

loop antenna a two-terminal, thin wire antenna for which the terminals are close to one another and for which the wire forms a closed path.

loop feeder a closed loop formed by a number of feeders. The resulting configuration allows a load area to be served without interruption if one feeder should fail.

loop filter the filter function that follows the phase detector and determines the system dynamic performance.

loop gain the combination of all DC gains in the PLL.

loop network *See* ring network.

loop primary feeder a feeder in a distribution system which forms a loop around the load area.

loop system a secondary system of equations using loop currents as variables.

loop-set *See* circuit-set.

loosely coupled multiprocessor a system with multiple processing units in which each processor has its own memory and communication between the processors is over some type of bus.

Lorentz force the mutually perpendicular force acting on a current-carrying element placed perpendicular to a magnetic field.

Lorentz medium a frequency-dependent dielectric whose complex permittivity is described by an equation with a second-order Lorentz pole involving a resonant frequency and a damping constant. Some optical materials and artificial dielectrics may require several Lorentz poles to describe their behavior over the frequency band of interest.

Lorentz theorem for isotropic and reciprocal media, the Lorentz reciprocity theorem states that, in a source-free region bounded by a surface S, the electromagnetic fields produced by two sources, denoted by subscripts a, b, satisfy the equation

$$\oint_S (\mathbf{E}_a \times \mathbf{H}_b - \mathbf{E}_b \times \mathbf{H}_a)\, d\mathbf{S} = 0$$

Lorentz, Hendrik Antoon (1853–1928) Born: Arnhem, Holland

Lorentz is best known for his work in electromagnetic theory. Along with Pieter Zeeman, he shared the 1902 Nobel Prize for Physics. His theoretical work was in the extension and refinement of Maxwell's theory.

Lorentz's work was an essential cornerstone in Einstein's, Special Theory of Relativity.

Lorentzian line shape the shape of a spectral line that results from certain physical mechanisms, such as the finite lifetime of the upper level of an atomic transition. It is characterized by broad wings, that decrease as the inverse square of the frequency separation from line center.

Lorentzian lineshape function spectrum of an emission or absorption line that is a Lorentzian function of frequency; characteristic spectrum of homogeneously broadened media.

Lorenz, Ludwig Valentin (1829–1891) Born: Elsinore, Denmark

Lorenz was not well known. He did, however, do significant work on electromagnetic theory, on the continuous loading method for cables, and for the acceptance of the ohm as the resistance standard.

LOS *See* line of sight.

loss (1) decrease of intensity of an electromagnetic wave due to any of several physical mechanisms. *See also* attenuation.

(2) a term for electric power which does not register on the consumer's electric meter, e.g., through ohmic losses in transmission lines, iron losses in transformers, or theft.

loss coefficient a factor used in economic dispatch calculations that relates power line losses to the power output of generating plants.

loss factor the product of the dielectric constant and the power factor.

loss of service the complete loss of electric power exclusive of sags, swells, and impulses.

loss tangent *See* dissipation factor.

loss-of-field relay a protection relay used to trip a synchronous generator when the excitation system is lost. Loss of excitation causes the generator to run as an induction generator drawing reactive power from the system. This can cause severe system voltage reductions and damage to stator due to excessive heating.

lossless coding *See* lossless source coding.

lossless compression compression process wherein the original data can be recovered from the coded representation perfectly, i.e., without loss. Lossless compressors either convert fixed length input symbols into variable length codewords (Huffman and arithmetic coding) or parse the input into variable length strings and output fixed-length codewords (Ziv-Lempel coding). Lossless coders may have a static or adaptive probability model of the input data. *See also* entropy coding.

lossless predictive coding a lossless coding scheme that can encode an image at a bit rate close to the entropy of the mth-order Markov source. This is done by exploiting the correlation of the neighboring pixel values.

lossless source coding source coding methods (for digital data) where no information is "lost" in the coding, in the sense that the original can be exactly reproduced from its coded version. Such methods are used, for example, in computers to maximize storage capacity. *Compare with* lossy coding.

lossless source encoding *See* lossless source coding.

lossy coding *See* lossy source coding.

lossy compression compression wherein perfect reconstruction of the original data is not possible. Aims to minimize signal degradation while achieving maximum compres-

sion. Degradation may be defined according to signal error or subjective impairment.

lossy encoding *See* lossy source coding.

lossy source coding refers to noninvertible coding, or quantization. In lossy source coding information is always lost, and the source data cannot be perfectly reconstructed from its coded representation. *Compare with* lossless source coding.

lossy source encoding *See* lossy source coding.

LOT *See* lapped orthogonal transform.

low byte the least-significant 8 bits in a larger data word.

low level waste nuclear waste such as gloves and towels which have comparatively low radioactivity.

low noise amplifier (LNA) (1) an amplifier that boosts low-level radio/microwave signal received without adding substantial distortions to the signal.

(2) an amplifier in which the primary cause of noise is due to thermally excited electrons and is designed to introduce minimum internally generated noise.

low order interleaving in memory interleaving, using the least significant address bits to select the memory module and most significant address bits to select the location within the memory module.

low output capacitance Plumbicon tube a picture tube designed to reduce the capacitance of the target to ground, resulting in an improved signal-to-noise ratio.

low-pass filter (1) filter exhibiting frequency selective characteristic that allows low-frequency components of an input signal to pass from filter input to output unattenuated; all high-frequency components are attenuated.

(2) a filter that passes signal components whose frequencies are small and blocks (or greatly attenuates) signal components whose frequencies are large. For the ideal case, if $H(\omega)$ is the frequency response of the filter, then $H(\omega) = 0$ for $|\omega| > B$, and $H(\omega) = 1$ for $|\omega| < B$. The parameter B is the bandwidth of the filter. A filter whose impulse response is a low-pass signal.

low resistance grounded system an electrical distribution system in which the neutral is intentionally grounded through a low resistance. Low resistance grounding will limit ground fault current to a value that significantly reduces arcing damage but still permits automatic detection and interruption of the fault current.

low side pertains to the portion of a circuit which is connected to the lower-voltage winding of a power transformer.

low state a logic signal level that has a lower electrical potential (voltage) than the other logic state. For example, the low state of TTL is defined as being less than or equal to 0.4 V.

low voltage holding coil a holding coil that keeps the main-line contactor closed on low voltage conditions. Controllers that contain this feature are used in places where the motor is vital to the operation of a process, and it is necessary to maintain control of the motor under low voltage conditions.

low-level transmitter a transmitter in which the modulation process takes place at a point where the power level is low compared to the output power.

low-level vision the set of visual processes related to the detection of simple primitives, describing raw intensity changes and/or their relationships in an image.

low-pass equivalent (LPE) model a method of representing bandpass signals and systems by low-pass signals and systems. This technique is extremely useful when developing discrete time models of bandpass continuous-time systems. It can substantially reduce the sampling rate required to prevent aliasing and does not result in any loss of information. This, in turn, reduces the execution time required for the simulation. This modeling technique is closely related to the quadrature representation of bandpass signals.

low-pass signal a signal whose Fourier transform has frequency components that are small for frequencies greater than some intermediate frequency value. To define mathematically, let $X(\omega)$ be the Fourier transform of the signal then $X(\omega) = 0$ for $|\omega| > B$, for some $B > 0$. In the strict sense, if B is the smallest value for which the above holds, then B is the bandwidth of the signal.

low-power TV (LPTV) a television service authorized by the FCC to serve specific confined areas. An LPTV station may typically radiate between 100 and 1000 W of power, covering a geographic radius of 10 to 15 miles.

low-pressure discharge a discharge in which the pressure is less than a torr or a few torrs; low-pressure gases can be easily excited, giving spectra characteristic of their energy structure.

lower frequency band edge the lower cutoff frequency where the amplitude is equal to the maximum attenuation loss across the band.

lower side frequency the difference frequency that is generated during the heterodyning process or during the amplitude-modulating process. For example, if a 500 kHz carrier signal is amplitude-modulated with a 1 kHz frequency, the lower side frequency is 499 kHz.

LPE model *See* low-pass equivalent model.

LPTV *See* low-power TV.

LQ control *See* linear quadratic control.

LRM calibration *See* line-reflect-match calibration.

LRRM calibration *See* line-reflect-reflect-match calibration.

LRU *See* least recently used algorithm.

LRU bits a set of bits that record the relative recency of access among pairs of elements that are managed using an LRU replacement policy. If n objects are being managed, the number of bits required is $n(n-1)/2$. Upon each access, n bits are forced into certain states; to check one of the objects to determine whether it was the least recently accessed, n bits need to be examined.

LRU replacement *See* least recently used algorithm.

LRU stack a stack-based data structure to perform the bookkeeping for a least recently used (LRU) management policy. An object is promoted to the top of the stack when it is referenced; the object that has fallen to the bottom of the stack is the least recently used object.

LS algorithm *See* least squares algorithm.

LSB *See* least-significant bit.

LSI *See* large-scale integration.

LTC *See* load tap changer and tap changing under load.

LTI *See* linear time invariant system.

LTIL system *See* linear time-invariant lumped-parameter system.

lumen the SI unit of illumination measurement. Also, the hollow interior of a blood vessel or airway.

luminance (1) formally, the amount of light being emitted or reflected by a surface of unit area in the direction of the observer and taking into account the spectral sensitivity of the human eye.

(2) the amount of light coming from a scene. *See also* candela.

(3) part of the video signal that provides the brightness information; often designated as the "Y" component in RGB systems where $Y = .3R + .59G + .11B$.

luminance ratio the ratio between the luminance of two areas in the visual field.

luminescence emission of light caused by relaxation of an electron excited to a higher energy level. Excitation of the electron may have occurred as a result of light absorption (fluorescence or phosphorescence), a chemical reaction (chemiluminescence), or from some living organisms (bioluminescence).

luminosity the ratio of luminous flux (total visible energy emitted) to the corresponding radiant flux (total energy emitted) usually in lumens per watt.

luminous efficiency the measure of the display output light luminance for a given input power, usually measured in lumens per watt, which is equivalent to the nit.

lumped element a circuit element of inductors, capacitors, and resistors; its dimension is negligible relative to the wavelength.

LVQ *See* learning vector quantization.

Lyapunov, Alexandr M. (1857–1918) also transliterated as Liapunov or Liapunoff. Russian mathematician noted for his contributions to the stability of dynamical systems. His most influential work is titled *The General Problem of the Stability of Motion,* and it was published in 1892 by the Kharkov Mathematical Society. Lyapunov was a student of Chebyshev at St. Petersburg, and taught at the University of Kharkov from 1885 to 1901. He became academician in applied mathematics at the St. Petersburg Academy of Sciences. *See also* direct method.

Lyapunov equation in statistics and linear systems theory a set of equation-classes that describe system evolution. In each case, P, Q are symmetric positive definite; A, B are arbitrary. The continuous-time algebraic Lyapunov equation:

$$0 = AP + PA^T + BQB^T.$$

The discrete-time, time-dependent Lyaponov equation:

$$P(t+1) = A(t)P(t)A^T(t) + B(t)Q(t)B^T(t).$$

The discrete-time algebraic Lyanpunov equation:

$$P = APA^T + BQB^T.$$

See also Riccati equation.

Lyapunov function corresponding to an equilibrium state $\mathbf{x}_{eq} \in \mathbb{R}^n$ of the system $\dot{\mathbf{x}} = \mathbf{f}(t, \mathbf{x})$ is a continuously differentiable function $V = V(t, \mathbf{x})$ such that $V(t, \mathbf{x}_{eq}) = 0$, it is positive in a neighborhood of $\mathbf{x}_{eq}$, that is, V is positive definite with respect to $\mathbf{x}_{eq}$, and the time derivative of V evaluated on the trajectories of the system $\dot{\mathbf{x}} = \mathbf{f}(t, \mathbf{x})$ is negative semidefinite with respect to $\mathbf{x}_{eq}$. For the discrete-time model, $\mathbf{x}(k+1) = \mathbf{f}(k, \mathbf{x})$, continuous differentiablity is replaced with continuity, and the time derivative $\dot{V}$ is replaced with the first forward difference ΔV. The existence of a Lyapunov function for a given equilibrium state implies that this equilibrium is stable in the sense of Lyapunov. If the time derivative, respectively the forward difference, of V is negative definite with respect to the equilibrium, then this equilibrium

is asymptotically stable in the sense of Lyapunov.

Lyapunov function candidate for an equilibrium state of $\dot{\mathbf{x}} = \mathbf{f}(t, \mathbf{x})$, its Lyapunov function candidate is any continuously differentiable function $V = V(t, \mathbf{x})$ that is positive definite with respect to the equilibrium $\mathbf{x}_{eq}$. For an equilibrium state of the discrete-time system $\mathbf{x}(k+1) = \mathbf{f}(k, \mathbf{x})$, a Lyapunov function candidate is any continuous function $V = V(k, \mathbf{x})$ that is positive definite with respect to the equilibrium state.

Lyapunov stability also known as stability in the sense of Lyapunov; concerned with the behavior of solutions of a system of differential, or difference, equations in the vicinity of its equilibrium states. The concept of stability in the sense of Lyapunov can be related to that of continuous dependence of solutions upon their initial conditions. An equilibrium state is stable in the sense of Lyapunov if the system trajectory starting sufficiently close to the equilibrium state stays near the equilibrium state for all subsequent time. Formally, the equilibrium state $\mathbf{x}_{eq} \in \mathbb{R}^n$ of the system $\dot{\mathbf{x}} = \mathbf{f}(t, \mathbf{x})$, or the system $\mathbf{x}(k+1) = \mathbf{f}(k, \mathbf{x})$, is stable, in the sense of Lyapunov, if for any $\varepsilon > 0$ there exists a $\delta = \delta(t_0, \varepsilon)$ such that if the initial condition $\mathbf{x}(t_0)$ is within δ-neighborhood of $\mathbf{x}_{eq}$, that is,

$$\|\mathbf{x}(t_0) - \mathbf{x}_{eq}\| < \delta \ ,$$

then the system trajectory $\mathbf{x}(t)$ satisfies

$$\|\mathbf{x}(t) - \mathbf{x}_{eq}\| < \varepsilon$$

for all $t \geq t_0$, where $\| \cdot \|$ is any Hölder norm on $\mathbb{R}^n$.

Lyapunov surface the set of all points $x \in \Re^n$ (n-dimensional real Euclidean space) that satisfy $V(x) =$ positive real number, where $V(x)$ is a Lyapunov function.

Lyapunov's direct method *See* Lyapunov's second method.

Lyapunov's first method the method that allows one to assess the stability status of an equilibrium point of a nonlinear system based on stability investigation of the equilibrium point of the linearized version of that system. This method is also called Lyapunov's indirect method.

Lyapunov's indirect method *See* Lyapunov's first method.

Lyapunov's second method the method of stability assessment that relies on the use of energy-like functions without resorting to direct solution of the associated evolution equations. This is also called Lyapunov's direct method.

LZ77 refers to string-based compression schemes based on Lempel and Ziv's 1977 method. An input string of symbols that matches an identical string previously (and recently) transmitted is coded as an offset pointer to the previous occurrence and a copy length.

LZ78 refers to string-based compression schemes based on Lempel and Ziv's 1978 method. A dictionary of prefix strings is built at the encoder and decoder progressively, based on the message. The encoder searches the dictionary for the longest string matching the current input, then encodes that input as a dictionary index plus the literal symbol which follows that string. The dictionary entry concatenated with the literal is then added to the dictionary as a new string.

M

M common notation for the number of modes in a step index fiber, given by

$$M = \frac{V^2}{2}$$

where V is the fiber parameter.

M (mega) abbreviation for 1,048,576 (not for 1 million).

M-algorithm reduced-complexity breadth-first tree search algorithm, in which at most M tree nodes are extended at each stage of the tree.

m-ary hypothesis testing the assessment of the relative likelihoods of M hypotheses $H_1, H_2, \ldots, H_M$. Normally we are given prior statistics $P(H_1), \ldots, P(H_M)$ and observations $\boldsymbol{y}$ whose dependence $p(\boldsymbol{y}|H_1)$, $\ldots$, $p(\boldsymbol{y}|H_M)$ on the hypotheses are known. The solution to the hypothesis testing problem depends upon the stipulated criterion; possible criteria include maximizing the posterior probability (MAP) or minimizing the expected "cost" of the decision (a cost C_{ij} is assigned to the selection of hypothesis j when i is true). *See also* binary hypothesis testing. *See also* conditional statistic, a priori statistics,a posteriori statistics, maximum a posteriori estimator.

m-phase oscillator *See* multi-phase oscillator.

m-sequence maximal length sequence. A binary sequence generated by a shift register with a given number of stages (storage elements) and a set of feedback connections, such that the length of the sequence period is the maximum possible for shift registers with that number of stages over all possible sets of feedback connections. For a shift register with n stages, the maximum sequence period is equal to $2^n - 1$.

Mach band a perceived overshoot (lighter portion) on the light side of an edge and an undershoot (darker portion) on the dark side of the edge. The Mach band is an artifact of the human visual system and not actually present in the edge. *See also* brightness, simultaneous contrast.

machine code the machine format of a compiled executable, in which individual instructions are represented in binary notation.

machine interference the idle time experienced by any one machine in a multiple-machine system that is being serviced by an operator (or robot) and is typically measured as a percentage of the total idle time of all the machines in the systems to the operator (or robot) cycle time.

machine language the set of legal instructions to a machine's processor, expressed in binary notation.

machine vision *See* robot vision.

macro *See* macroprogram.

macro cell a cell in a cellular communication system that has a size that is significantly larger than the cell size of a typical cellular system. Macro cells are sometimes designed with the base station being located in a satellite. Macro cells typically cover large areas such as rural areas in cases where the user density is low.

macro diversity a diversity technique, used in a cellular communication system, that is based on the transmission of multiple copies of the same signal from transmitters that have a separation that is a significant fraction of the coverage area of a cell. Macro diversity also refers to the concept in a cellular system where coverage at a par-

ticular location may be obtained from multile transmitters, typically utilizing different frequency channels. Macro diversity is typically utilized to overcome the type of signal fading typically known as shadow fading.

macro shadowing shadowing due to the obstacles in the propagation path of the radio wave. *See also* micro shadowing.

macroinstruction a short code-like text, defined by the programmer, that the assembler or compiler will recognize and that will result in an inline insertion of a predefined block of code into the source code.

macroprogram a sequence of macroinstructions.

macrotiming diagram a graphical display showing how the waveforms vary with time but with a time scale that does not have sufficient resolution to display the delays introduced by the individual basic elements of the digital circuit.

MAD *See* maximal area density.

made electrode a ground electrode for a lightning rod which has been especially constructed for the purpose, as opposed to using a building frame or water pipe for the purpose.

magic T *See* magic tee.

magic T junction *See* magic tee junction.

magic tee a combination of E-plane (series) and H-plane (shunt) tees forming a hybrid waveguide junction. Typically used to split or couple two microwave signals that are in or out of phase in the same wave guide. Also called a hybrid tee.

magic tee junction a four-port microwave device, that couples the input signal at port 1 equally into ports 2 and 3, but not into port 4. Input signal at port 3 is coupled equally into ports 1 and 4, but not into port 2, etc. At microwave frequency, the waveguide junction that makes up this device involves three magnetic plane arms and one electric field plane arm resembling T and hence is called magic tee junction.

maglev *See* magnetic levitation.

magnet any object that can sustain an external magnetic field.

magnetic actuator any device using a magnetic field to apply a force.

magnetic bearing a component of a machine that uses magnetic force to provide non-contact support for another component moving relative to it.

magnetic bias a constant magnetic field on which is superimposed a variable, often sinusoidal, perturbation magnetic field in devices like magnetic bearings.

magnetic brake any device using a magnetic field to retard motion.

magnetic charge density a fictitious source of the electromagnetic field that quantifies the average number of discrete magnetic charges (also fictitious) per unit volume. The magnetic charge density is often introduced in problems where duality and equivalence concepts are employed.

magnetic circuit the possible flux paths within a system consisting of a source of flux (electromagnets, permanent magnets), permeable flux carrying materials (steel, nickel) and non-flux carrying materials (aluminum, air).

magnetic clamp a device employing a magnetic field to deliver a clamping action.

magnetic core memory a persistent, directly addressable memory consisting of an

array of ferrite toruses (cores) each of which stores a single bit. Now obsolete.

magnetic current density a fictitious source vector in electromagnetics that quantifies the amount of magnetic charge (also fictitious) crossing some cross-sectional area per unit time. The magnetic current density is often introduced in problems where duality and equivalence concepts are employed. The direction of the magnetic current density is in the direction of magnetic charge motion. SI units are volts per square meter.

magnetic damper any device using a magnetic field to damp motion.

magnetic dipole an arrangement of one or more magnets to form a magnet system that produces a magnetic field with one pair of opposite poles.

magnetic disk a persistent, random-access storage device in which data is stored on a magnetic layer on one or both surfaces of a flat disk. *See also* hard disk, floppy disk, diskette.

magnetic drive *See* magnetic torque coupling.

magnetic drum a persistent storage device in which data is stored on a magnetic layer on the surface of a cylinder. Now obsolete.

magnetic field magnetic force field where lines of magnetism exist.

magnetic field integral equation (MFIE) used in the method of moments to solve for the surface current on an object in terms of the incident magnetic field. The MFIE is valid only for closed surfaces.

magnetic field intensity a force field that is a measure of the magnitude and direction of the force imparted upon an elemental current normalized to the elemental current's value. Depends on material characteristics. The units are amperes per meter.

magnetic flux the integral of the component of magnetic flux density perpendicular to a surface, over the given surface.

magnetic flux density a vector quantifying a magnetic field, so that a particle carrying unit charge experiences unit force when traveling with unit velocity in a direction perpendicular to the magnetic field characterized by unit magnetic flux density. It has the units of volt-seconds per square meter in the SI system of units.

magnetic head *See* read/write head.

magnetic induction the flux density within a magnetic material when driven by an external applied field or by its self demagnetizing field, which is the vector sum of the applied field and the intrinsic induction.

magnetic leakage *See* leakage.

magnetic length the effective distance between the north and south poles within a magnet, which varies from 0.7 (alnico) to 1.0 (NdFeB, SmCo, hard ferrite) times the physical length of the magnet.

magnetic levitation (1) noncontact support of an object using magnetic forces. Abbreviated as maglev.

(2) a method of melting metals without contacting a surface. A cone-shaped high-frequency coil produces eddy currents in the metal which are strong enough to both suspend and melt it, generally in a neutral atmosphere.

(3) one of several techniques of suspending a driveshaft within a bearing so that no contact is made between the shaft and other surfaces. *See* magnetic bearing.

(4) one of several techniques for suspending a railroad train above its tracks so that wheels are not needed. Typically, superconducting magnets are needed, and propulsion

is by a linear induction motor *cf* whose armature lies along the rails.

magnetic loss losses in magnetic flux in a magnetic circuit, primarily due to magnetic leakage and fringing. *See also* core loss.

magnetic moment for a current-carrying coil in an external magnetic field, the ratio of the torque sensed by the coil to the flux density of the external field. In permanent magnets, the product of the polar flux and the magnetic length; the product of the intrinsic flux density and the magnet volume.

magnetic monopole a magnet system that produces a magnetic field of a single polarity. Although nonexistent, may be approximated by one pole of a very long magnet.

magnetic motor starter motor starter that uses electromechanical devices such as contactors and relays.

magnetic orientation the preferred direction of magnetization for an anisotropic magnetic material.

magnetic overload an overload sensor in a motor controller used to shut off the motor in event of an over current condition. With a magnetic overload, the sensor uses a magnetic coil to sense the overload condition, then trips the overload contact(s). *See also* overload heater, overload relay.

magnetic permeability tensor relationship between the magnetic field vector and the magnetic flux density vector in a medium with no hysteresis; flux density divided by the magnetic field in scalar media.

magnetic polarization vector an auxiliary vector in electromagnetics that accounts for the presence of atomic circulating currents in a material. Macroscopically, the magnetic polarization vector is equal to the average number of magnetic dipole moments per unit volume.

magnetic quardrupole *See* quadrupole.

magnetic recording air gap term referring to two aspects of a magnetic recording system.

1. The gap between the poles of a read/write head is often referred to as the "air gap." Even though filled with a solid, it is magnetically equivalent to an air gap. With a recorded wavelength of λ, and a head gap of d, the read signal varies as $\sin(\pi x)/x$ where $x = \lambda/d$. The gap must then have $d < \lambda/2$ for reliable reading.

2. The space between the head and the recording surface is also referred to as an "air gap." The signal loss for a head at height h from the surface is approximately $55h/\lambda$ dB; if $d = \lambda/5$ the loss is 11 dB.

High recording densities therefore require heads "flying" very close to the recording surface and at a constant height – 0.1 μm or less in modern disks. Such separations are achieved by shaping the disk head so that its aerodynamics force it to fly at the correct separation.

magnetic recording code method used to record data on a magnetic surface such as disk or tape. Codes that have been used include return-to-zero (RZ), in which two signal pulses are used for every bit — a change from negative to positive pulse (i.e., magnetization in the "negative" direction) is used for a stored 0, a change from a positive to a negative pulse (i.e., magnetization in the "positive" direction) is used for a stored 1, and a return to the demagnetized state is made between bits; non-return-to-zero (NRZ), in which a signal pulse occurs only for a change from 1 to 0 or from 0 to 1; non-return-to-zero-inverted (NRZI), in which a positive or negative pulse is used for — a sign change occurs for two consecutive 1s — and no pulse is used for a 0; double frequency (DF) (also known as frequency modulation (FM)), which is similar to NRZI but which includes an interleaved clock signal on each bit cell; phase encoding (PE), in which a positive pulse is used for a 1 and a negative pulse is used for a 0; return-to-

bias (RB), in which magnetic transitions are made for 1s but not for 0s, as in NRZI, but with two transitions for each 1; and modified-return-to-bias (MRB), which is similar to RB, except that a return to the demagnetized state is made for each zero and between two consecutive 1s.

RZ is self-clocking (i.e., a clock signal is not required during readout to determine where the bits lie), but the two-signals-per-bit results in low recording density; also, a 0 cannot be distinguished from a "dropout" (i.e., absence of recorded data). NRZ is not self-clocking and there requires a clocking system for readout; it also requires some means to detect the beginning of a record, does not distinguish between a dropout and a stored bit with no signal, and if one bit is in error, then all succeeding bits will also be in error up to the next signal pulse. NRZI has similar properties to NRZ, except that an error in one bit does not affect succeeding bits. PE is self-clocking.

magnetic resonance imaging (MRI) (1) a form of medical imaging with tomographic display that represents the density and bonding of protons (primarily in water) in the tissues of the body, based upon the ability of certain atomic nuclei in a magnetic field to absorb and reemit electromagnetic radiation at specific frequencies. Also called nuclear magnetic resonance.

(2) an imaging modality that uses a pulsed radio frequency magnetic field to selectively change the orientation of the magnetization vectors of protons within the object under study. The change in net magnetic moment as the protons relax back to their original orientation is detected and used to form an image.

magnetic saturation the condition in a magnetic material when an increase in the magnetizing force does not result in a useful increase in the magnetic induction of the material.

magnetic separator a device employing magnetic fields to separate magnetic materials from nonmagnetic ones.

magnetic stabilization the act of purposely demagnetizing a magnet with reverse fields or a change in temperature so that no irreversible losses are experienced when the magnet operates under similar conditions in the field.

magnetic susceptibility the ratio of the magnetization to the applied external field.

Tensor relationship between the magnetic field vector and the magnetization vector in a medium with no hysteresis; magnetization divided by the permeability of free space and the magnetic field in scalar media. It is an indicator of how easily a material is magnetized and has no units in the SI system of units (pure number).

magnetic suspension *See* magnetic levitation.

magnetic tape a polyester film sheet coated with a *ferromagnetic* powder, which is used extensively in auxiliary memory. It is produced on a reel, in a cassette, or in a cartridge transportation medium. Often used for backups.

magnetic torque coupling any device utilizing a magnetic field to transmit torque.

magnetic vector potential an auxiliary field used to simplify electromagnetic computations. This field satisfies a wave equation, the curl of this field is related to the magnetic field intensity vector field, and the divergence of this field is specified by some gage which is to be specified in each problem.

magnetic-tape track each bit position across the width of a magnetic tape read/write head, running the entire length of the tape.

magnetization curve *See* hysteresis curve.

magnetizing current the current required to magnetize the different parts of a magnetic circuit. It is calculated as the ratio of the total magnetomotive force (F) and the number of turns (N). More or less in transformers, and AC synchronous and induction machines, the magnetizing current is the current through the magnetizing inductance. Denoted by I_m, it is calculated as the ratio of the induced EMF across the magnetizing inductance to its magnetizing reactance X_m.

magneto plasma a plasma medium that in the presence of a static magnetic field behaves like an anisotropic dielectric medium whose dielectric function is a tensor.

magnetohydrodynamic MHD machine a form of electric machine in which a stream of electrically conductive gas or liquid is passed through pairs of orthogonally positioned magnetic poles and electrodes. In an MHD generator, the fluid is forced by the prime mover to produce a DC across the electrodes. In the MHD motor, a current across the electrodes through the fluid forces the stream to flow.

magneto-hydrodynamic (MHD) generator a heat-to-electricity conversion device with an intermediate kinetic energy stage. In the MHD generator, a partially conducting gas is heated by a fuel-fired source or a nuclear reactor to convert the heat energy to kinetic energy, and then passed between the poles of an electromagnet, which converts some of the kinetic energy to electrical energy. The electrical energy is collected through a pair of electrodes situated in the gas channel.

magneto-optic Bragg cell a magnetically tunable microwave signal processing device that uses optical Bragg diffraction of light from a moving magneto-optic grating generated by the propagation of magnetostatic waves within the magnetic medium.

magneto-optic modulator any of a class of light modulators that use magneto-optic effects, such as Faraday rotation for light modulation.

magneto-optical Kerr effect the rotation of the plane of polarization of a linearly polarized beam of light upon reflection from the surface of a perpendicularly magnetized medium.

magneto-resistive head *See* read/write head.

magnetoimpedance the change in impedance of a ferromagnetic conductor experiencing a change in applied magnetic field.

magnetomotive force (MMF) a magnetic circuit term referring to that phenomenon that pushes magnetic flux through the reluctance of the circuit path. MMF is analogous to the concept of electromotive force (voltage) in an electric circuit. For a magnetic core with a single coil of N turns, carrying current I, the MMF is NI, with units of amperes (sometimes expressed as ampere-turns).

magnetoresistance the change in electrical resistance in a conducting element experiencing a change in applied magnetic field. This is most pronounced when the magnetic field is perpendicular to current flow.

magnetostriction a change in the length of a ferromagnetic material as the flux changes under the influence of an applied magnetic field, or resulting from domain formation after cooling from above Curie temperature. In an AC device, the steel in the core expands and contracts twice each cycle, creating audible noise (e.g., transformer hum).

magnetostrictive smart material one of a class of materials with self-adaptively modifiable elastic properties in response to a magnetic field applied in proportion to sensed stress–strain information.

magnetotransport motion of electrons or holes in a conducting material in the presence of an applied magnetic field.

magnetron any arrangement of magnets in a sputter deposition or etch system that provides the magnetic field required to trap electrons in closed loops near the cathode, thus enhancing deposition/etch rates.

magnitude (1) the absolute value of a scalar.

(2) the norm of a vector, i.e., the square root of the sum of the squares of the vector components.

magnitude response the magnitude of the frequency response of a system. *See* frequency response.

magnitude scaling a procedure for changing the values of network elements in a filter section without affecting the voltage ratio or current ratio transfer function of the section. Resistors and inductors are multiplied by the parameter a, while capacitors are divided by a. If $1 < a < \infty$, then the magnitudes of the impedances are increased.

magnitude squared coherence (MSC) a measure of the degree of synchrony between two electrical signals at specific frequencies.

magnon a polariton in a magnetic medium.

Mahalanobis distance a distance measure used in certain decision rules.

Let $p(\mathbf{x}, c_i)$ be the probability distribution that pattern $\mathbf{x}$ belong to class c_i. A commonly used decision rule is that of looking for $\arg\max_i p(\mathbf{x}, c_i)$. Furthermore, let us assume that $p(\mathbf{x}|c_i)$ is Gaussian, that is

$$p(\mathbf{x}|c_i) = \frac{1}{\sqrt{(2\pi)^n \det R_i}} \exp\left(-\frac{1}{2}(\mathbf{x}-\mu_i)' R_i^{-1}(\mathbf{x}-\mu_i)\right)$$

and that $\forall i = 1, \ldots, n\ R_i = R$ (the same covariance matrices). Hence, the previously defined decision rule reduces straightforwardly to a distance evaluation where one looks for $\arg\max_i (\mathbf{x}-\mu_i)' R_i^{-1} (\mathbf{x}-\mu_i)$. This distance is commonly referred to as the Mahalanobis distance. *See also* weighted Euclidean distance.

MAI *See* multiple access interference.

mailbox an operating system abstraction containing buffers to hold messages. Messages are sent to and received from the mailbox by processes.

main beam in antenna theory, the direction in which the global maximum of the radiation pattern occurs.

main memory the highest level of memory hierarchy.

main switch a switch which controls all power to a building's wiring or other electric installation.

mains voltage European term for the voltage at the secondary of the distribution transformer.

mainframe a large centralized machine that supports hundreds of users simultaneously.

maintainability the probability that an inoperable system will be restored to an operational state within the time t.

maintenance the changes made on a system to fix errors, to support new requirements, or to make it more efficient.

major hysteresis loop for a magnetic material, the loop generated as intrinsic or magnetic induction (B_i or B) is plotted with respect to applied field (H) when the material is driven from positive saturation to negative

saturation and back, showing the lag of induction with respect to applied field.

major orbit a larger helical orbit of an electron beam in a gyrotron.

majority carrier an electron in an n-type or a hole in a p-type semiconductor.

majority-logic decoding a simple, and in general suboptimal, decoding method for block and convolutional codes based on the orthogonality of the parity-check sums.

male connector a connector presenting pins to be inserted into a corresponding female connector that presents receptacles.

MAN *See* metropolitan-area network.

management by exception *See* coordination by exception.

Manhattan distance *See* city-block distance.

manipulability measure is a kind of distance of the manipulator from singular configuration. Mathematically it is defined as follows: $W(q) = \sqrt{\det(J(q)J^T(q))}$, which vanishes at a singular configuration. It is clear that by maximizing this measure, redundancy is exploited to move away from singularities. Partial derivative of the manipulability measure with respect to a vector of generalized positions allows to define an arbitrary vector of joint velocities in the inverse kinematics problem for redundant manipulators.

manipulated input a quantity influencing the controlled process from outside, available to the controller and used to meet the control objectives; attributes of the inflowing streams of material, energy, or information may serve as manipulated inputs. A manipulated input is defined by a continuous trajectory over given time interval or by a sequence of values at given time instants. Also known as control input.

manipulator workspace a manipulator workspace defines all existing manipulator positions and orientations that can be obtained from the inverse kinematics problem. The lack of a solution means that the manipulator cannot attain the desired position and orientation because it lies outside of the manipulator's workspace.

Manley–Rowe criteria *See* Manley–Rowe relations.

Manley–Rowe relations relations among the intensities of optical fields interacting in a nonlinear material. These can be understood in terms of the discrete nature of the transfer of energy in terms of the emission and absorption of photons.

mantissa the portion of a floating-point number that represents the digits. *See also* floating-point representation.

manually-controlled shunt capacitors a bank of shunt capacitors that are controlled via SCADA signals from an operating center as opposed to local automatic control by voltage sensing.

MAP *See* maximum a posteriori estimator.

MAP estimator *See* maximum a posteriori estimator.

mapping the assignment of one location to a value from a set of possible locations. Often used in the context of memory hierarchies, when distinct addresses in a level of the hierarchy map a subset of the addresses from the level below.

MAR *See* memory address register.

Marconi, Guglielmo (1874–1937) Born: Bologna, Italy

Marconi is best known for work that led to the development of the commercial radio industry. Marconi's many experiments with radio waves (long wavelength electromagnetic radiation) led to many communications innovations. Marconi traveled to England to find support for his ideas, and there formed the Marconi Wireless Telegraph Company, Ltd. In 1909, Marconi shared the Nobel Prize for physics with K. F. Braun. Marconi's most famous demonstration came in 1901 when he was able to send the first Morse-coded message from the Pondhu, Cornwall, England to St. Johns, Newfoundland, Canada.

Markov chain a particular case of a Markov process, where the samples take on values from a discrete and countable set. Markov chains are useful signal generation models for digital communication systems with intersymbol interference or convolutional coding, and Markov chain theory is useful in the analysis of error propagation in equalizers, in the calculation of power spectra of line codes, and in the analysis of framing circuits.

Markov model a modeling technique where the states of the model correspond to states of the system and transitions between the states in the model correspond to system processes.

Markov process a discrete-time random process, $\{\Psi_k\}$, that satisfies $p(\psi_{k+1}|\psi_k, \psi_{k-1}, \ldots) = p(\psi_{k+1}|\psi_k)$. In other words, the future sample ψ_{k+1} is independent of past samples $\psi_{k-1}, \psi_{k-2}, \ldots$ if the present sample $\Psi_k = \psi_k$ is known.

Markov random field an extension of the definition of Markov processes to two dimensions. Consider any closed contour Γ, and denote by Γ_i and Γ_o the points interior and exterior to Γ, respectively. Then a process ψ is a Markov random field (MRF) if, conditioned on $\psi(\Gamma)$, the sets $\psi(\Gamma_i)$ and $\psi(\Gamma_o)$ are independent. That is,

$$p(\psi(\Gamma_i), \psi(\Gamma_o)|\psi(\Gamma)) = p(\psi(\Gamma_i)|\psi(\Gamma)) \cdot p(\psi(\Gamma_o)|\psi(\Gamma)).$$

See also Markov process, conditional statistic.

Marr-Hildreth operator (1) edge-detection operator, also called Laplacian-of-Gaussian or Gaussian-smoothed-Laplacian, defined by

$$\nabla^2 G = -\frac{1}{\sqrt{2\pi}\sigma^3}(1 - \frac{x^2+y^2}{\sigma^2})e^{\frac{-(x^2+y^2)}{2\sigma^2}}.$$

It generates a smoothed isotropic second derivative. Zero crossings of the output correspond to extrema of first derivative and thus include edge points. (2) The complete edge detection scheme proposed by Marr and Hildreth, including use of the $\nabla^2 G$ operator at several scales (i.e., gaussian variances), and aggregation of their outputs.

Marx generator a high-voltage pulse generator capable of charging capacitors in parallel and discharging them in series.

maser acronym for microwave amplification by stimulated emission of radiation.

maser amplifier usually refers to a medium that amplifies microwaves by the process of stimulated emission; sometimes refers to amplification of some other field (nonoptical electromagnetic, phonon, exciton, neutrino, etc.) or some other process (nonlinear optics, Brillouin scattering, Raman scattering, etc.).

maser oscillator oscillator usually producing a microwave frequency output and usually based on amplification by stimulated emission in a resonant cavity.

mask (1) in digital computing, to specify a number of values that allow some entities in a set, and disallow the others in the set, from being active or valid. For example, masking an interrupt.

(2) for semiconductor manufacturing, a device used to selectively block photolithographic exposure of sensitized coating used for preventing a subsequent etching process from removing material. A mask is analogous to a negative in conventional photography.

(3) a glass or quartz plate containing information (encoded as a variation in transmittance and/or phase) about the features to be printed. Also called a photomask or a reticle.

(4) in image processing, a small set of pixels, such as a 3×3 square, that is used to transform an image. Conceptually, the mask is centered above every input pixel, each pixel in the mask is multiplied by the corresponding input pixel under it and the output (transformed) pixel is the sum of these products. If the mask is rotated 180° before the arithmetic is performed, the result is a 2-D convolution and the mask represents the impulse response function of a linear, space-invariant system. Also called a kernel. *See also* convolution, impulse response, kernel.

mask aligner a tool that aligns a photomask to a resist-coated wafer and then exposes the pattern of the photomask into the resist.

mask biasing the process of changing the size or shape of the mask feature in order for the printed feature size to more closely match the nominal or desired feature size.

mask blank a blank mask substrate (e.g., quartz) coated with an absorber (e.g., chrome), and sometimes with resist, and used to make a mask.

mask linearity the relationship of printed resist feature width to mask feature width for a given process.

mask programming programming a semiconductor read-only-memory (ROM) by modifying one or more of the masks used in the semiconductor manufacturing process.

mask set consists of the dozen or so (varies with process and company) individual masks that are required to complete a MMIC wafer fabrication from start to finish. Examples of masks or mask levels are "first level metal" (defines all the primary metal structure on the circuit), "capacitor top plate" (defines the pattern for the metal used to form the top plate of MIM capacitors), and "dielectric etch" (defines areas where dielectric (insulator) material will be removed after coating the entire wafer with it).

maskable interrupt interrupt that can be postponed to permit a higher-priority interrupt by setting mask bits in a control register. *See also* nonmaskable interrupt.

masking a phenomenon in human vision in which two patterns P_1 and $P_1 + P_2$ cannot be discriminated even though P_2 is visible when seen alone. P_1 is said to mask P_2.

mass storage a storage for large amounts of data.

massively parallel architecture a computer system architecture characterized by the presence of large numbers of CPUs that can execute instructions in parallel. The largest examples can process thousands of instructions in parallel, and provide efficient pathways to pass data from one CPU to another.

massively parallel processor a system that employs a large number, typically 1000 or more, of processors operating in parallel.

master the system component responsible for controlling a number of others (called slaves).

master boot record a record of the disk containing the first code and table that are loaded at the bootstrap of the computer. It is read even before the partition table sector.

master control relay (MCR) used in programmable logic controllers to secure entire programs, or just certain rungs of a program. An MCR will override any timer condition, whether it be time-on or time-off, and place all contacts in the program to a safe position whenever conditions warrant.

master copy in coherence protocols, the copy of the object that is guaranteed to hold the "correct" contents for the object. Coherence protocols can be designed around the tagging of master copies. The master copy can be read (rather then the copy in slower memory) to speed program execution, and it can be written, provided that all other copies are invalidated. *See also* MESI protocol.

master-oscillator-power-amplifier (MOPA) laser system in which the output from a highly stabilized low-power laser oscillator is amplified by one or more high-power laser amplifiers.

master–slave flip-flop a two-stage flip-flop in which the first stage buffers an input signal, and on a specific clock transition the second stage captures and outputs the state of the input.

matched filter a filter matched to a certain known signal waveform. The matched filter is the complex conjugate of the known signal waveform. If the known signal waveform falls in the matched filter, the output sample at the optimum sampling instant gives the received signal energy.

matched load load that does not reflect any energy back into the transmission line. It could be a load equal to the characteristic impedance of the transmission line or a structure with electromagnetic absorbing properties.

matched uncertainty *See* matching condition.

matching when referring to circuits, the process by which a network is placed between a load and a transmission line in order to transform the load impedance to the characteristic impedance of said line and thus eliminate the presence of standing waves on the line.

matching condition the condition that requires that the uncertainties affect the plant dynamics the same way as the control input does. For example, in the following model of a dynamical system, the matching condition is satisfied,

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}(\mathbf{u} + \mathbf{d}),$$

where the vector function $\mathbf{d}$ models matched uncertainties.

matching conditions conditions imposed on the structure of the uncertainty, which may be viewed as the assumption that uncertainty drives the state equations not stronger than a control variable. For linear systems, the matching conditions are given as the assumptions imposed on the perturbations of system matrices ΔA, ΔB and disturbances $Cv(t)$ in the following way:

$$\Delta A = BD;\ \Delta B = BG;\ C = BF$$

where D, G, F are unknown but bounded matrices and B is an input matrix. It enables to describe the uncertain linear system by the following state equation:

$$\dot{x} = Ax + B(u + e)$$

where e is the entire system uncertainty moved into the input of the system.

matching elements elements such as posts, screws, etc., often used in order to achieve the desired reflection coefficient of a given microwave component.

matching network an electric circuit designed to maximize the transfer of electric power from an electrical source to an electrical load. Maximum power is transferred

from a source with an output impedance that is the complex conjugate of the input impedance of the load it is driving. A matching network is connected between a source and its load. Its input impedance is the complex conjugate of the source output impedance, while its output impedance is the complex conjugate of the load impedance, thereby matching the source to the load and ensuring maximum transfer of power.

matching stub matching technique that employs short-circuited (or open-circuited) sections of transmission lines as reactive elements.

material dispersion wavelength dependence of the pulse velocity. It is caused by the refractive index variation with wavelength of glass.

math coprocessor a separate chip, additional to the CPU, that offloads many of the computation-intensive tasks from the CPU.

mathematical modeling a mathematical description of the interrelations between different quantities of a given process. In particular, a mathematical description of a relation between the input and output variables of the process. *See also* truth model and design model.

mathematical morphology an algebraic theory of non-linear image transformations based on set-theoretical (or lattice-theoretical) operations, which is generally considered as a counterpart to the classical linear filtering approach of signal processing. This methodology in image processing arose in 1964 through the works of Matheron and Serra at Fontainebleau (France), was developed in the seventies by Sternberg at Ann Arbor (Mich.), and became internationally known in the eighties. It has been successfully applied in various fields requiring an analysis of the structure of materials from their images, for example biomedical microscopy, stereology, mineralogy, petrography. *See* closing, dilation, erosion, morphological operator, opening.

matrix an n by m matrix is an array of $n \times m$ numbers of height n and width m representing a linear map from an m-dimensional space into an n-dimensional space. An example of a 2×2 real matrix is $A = \begin{bmatrix} 2 & 3 \\ 5 & 6 \end{bmatrix}$. *See also* circulant matrix, Hermitian matrix, orthogonal matrix, positive definite matrix, positive semi-definite matrix, singular matrix, Toeplitz matrix.

matrix addressing the control of a display panel consisting of individual light-producing elements by arranging the control system to address each element in a row/column configuration.

matrix element in quantum mechanics, the expectation value of a quantum mechanical operator that is associated with a particular pair of basis states. The term matrix element derives from the fact that the expectation values associated with all possible pairs of states can be written as a matrix.

matrix of configuration of information system in Pawlak's information system $S = (U, A)$ whose universe U has n members x_i and the set A consists of attributes $\mathbf{a}_j$, the elements of the universe are linked with each other. Connections between the elements of the universe U may be given, for example, by a function

$$\varphi : U \times U \to \{-1, 0, 1\}.$$

The pair (U, φ) is called the configuration of the information system S. The matrix of the information system S is an $n \times n$ matrix whose elements are

$$c_{ij} = \varphi\left(x_i, x_j\right).$$

matrix optics formalism for the analysis and synthesis of optical systems in which each system element is represented by a ma-

trix, the overall system being representable as a product of the elemental matrices.

matrixing in a color television transmitter, the process of converting the three color signals (red, green, blue) into the color-difference signals that modulate the chrominance subcarrier. In a color TV receiver, the process of converting the color-difference signals into the red, green, and blue signals.

Mauchley, John Graham (1907–1980) Born: Cincinnati, Ohio, U.S.A.

Mauchley is best known as one of the designers of ENIAC, an early electronic computer. It was Mauchley, in 1942, who wrote a proposal to the Army for the design of a calculating machine to calculate trajectory tables for their new artillery. Mauchley was a lecturer at the Moore School of Electrical Engineering at the time. The school was awarded the contract and he and J. Presper Eckert were the principal designers of ENIAC. They later went on to form their own company. Mauchley was the software engineer behind the development of one of the first successful commercial computers, UNIVAC I.

max operation an operation on two or more variables where the resultant value is formed by taking the largest value, or maximum, among these variables.

Max–Lloyd scalar quantization *See* Lloyd–Max scalar quantization.

Max–Lloyd SQ *See* Lloyd–Max scalar quantization.

max-min composition a frequently used method of composition of two fuzzy relations which, as the name implies, makes use of the min operation followed by the max operation.

maximal area density (MAD) for a magnetic disk, the maximum number of bits that can be stored per square inch. Computed by multiplying the bits per inch in a disk track times the number of tracks per inch of media.

maximally flat a circuit response in which the low-pass prototype attenuation loss (expressed in decibels) has a smooth response.

maximally flat delay (MHD) filter a filter having a time delay that is as flat (constant) as possible versus frequency while maintaining a monotonic characteristic.

maximum a posteriori probability the probability of a certain outcome of a random variable given certain observations related to the random variable, i.e., x was transmitted and y was received, then $P(x|y)$ is the *a posteriori* probability. The maximum *a posteriori* probability is found by considering all valid realizations of x.

For example, between two strings A and B it is defined as

$$D_{MPP} = Pr\{B|A\}$$

where $Pr(B|A)$ is the probability that A is changed into B. Sometimes called maximum posterior probability (MPP) even though, strictly speaking, it is a similarity rather than distance measure.

maximum a posteriori (MAP) estimator to estimate a random $\boldsymbol{x}$ by maximizing its posterior probability; that is,

$$\hat{x}_{MAP} = \arg_x \max p(\boldsymbol{x}|\boldsymbol{y}),$$

where $\boldsymbol{y}$ represents an observation. $\boldsymbol{x}$ is explicitly modeled as a random quantity with known prior statistics. *See also* maximum likelihood estimation, Bayesian estimation. *See also* Bayes' rule , prior statistics, posterior statistics.

maximum accumulated matching a defuzzification scheme for a classification problem in which a pattern is assigned to the class outputed by the rules that accumulates the maximum firing degree.

maximum distance separable (MDS) code an (n, k) linear binary or nonbinary block code, with minimum distance $d_{min} = n - k + 1$. Except for the trivial repetition codes, there are no binary MDS codes. Nonbinary MDS codes such as Reed–Solomon codes do exist.

maximum effective aperture in antenna theory, the ratio of the time-average power available at the terminals of an antenna due to power incident in the direction of the main beam that is polarized for maximum reception to the time-average power density of the incident field.

maximum entropy a procedure that maximizes the entropy of a signal process.

maximum entropy inequality an information theoretic inequality, upper bounding the possible value of entropy for probability distributions subject to certain moment constraints. A common example states that for any probability density function $f(x)$, subject to a power (second moment) constraint, $\int x^2 f(x) \leq \sigma^2$,

$$h(f) \leq \frac{1}{2} h(2\pi e \sigma^2) \ .$$

See also differential entropy.

maximum entropy restoration an iterative method of image restoration. At each iteration, an image is chosen whose Fourier transform agrees with that of the principal solution, i.e., the model of degradation, while maximizing the entropy.

maximum excitation limiter a controller that is used to limit the maximum amount of field current, or over-excitation, at a synchronous generator. This excitation limit is set by rotor winding heating limit.

maximum input power the maximum incident RF power that will be applied to a component or circuit without either damage or performance degradation, expressed in watts. The user normally will specify whether it is damage or degradation that is important. If performance degradation is, then how the degradation is manifested should be specified.

maximum likelihood estimation to estimate an unknown $\boldsymbol{x}$ by maximizing the conditional probability of the observations; that is,

$$\hat{x}_{ML} = \arg_x \max p(\boldsymbol{y}|\boldsymbol{x})$$

where $\boldsymbol{y}$ represents an observation. $\boldsymbol{x}$ is considered unknown; it is not a statistical quantity. *See also* maximum a posteriori estimator, Bayesian estimation, Bayes' rule, prior statistics.

maximum matching a defuzzification scheme for a classification problem in which a pattern is signed to the class outputed by the rule that achieve the maximum firing degree.

maximum permissible exposure (MPE) the limit adopted by a standards-setting body for exposures of unlimited duration. Generally, some allowance is made in the standard for time and/or space averaging of higher exposure conditions.

maximum posterior probability distance *See* maximum a posteriori probability.

maximum rated FET gate-to-source voltage the maximum gate-to-source voltage that the device is designed to function without damage due to breakdown, as determined by the device manufacturer. The actual breakdown voltage may be much larger than this voltage, dependent process variation and manufacturer derating criteria and margins. This voltage rating is usually in the -2.0 volt (low noise devices) to -10 volt (power devices) range.

maximum stable gain (MSG) the maximum gain derived from a transistor, which is obtained after making a stable condition by adding some excess loss elements for the case when a simultaneous matching for input

and output of the transistor causes an unstable condition.

maximum stable power gain figure of merit specified as the maximum value of transducer gain for which stability factor K is equal to one. Equivalently, this represents the maximum value of transducer gain of a circuit or device when the device is terminated with impedance values, or by using other methods such as feedback, and so on, such that K is equal to one.

maximum transducer power gain maximum value of transducer power gain a circuit or device exhibits; occurs when the input and output ports of the circuit are terminated with simultaneous conjugate match conditions. The transducer power gain is defined as the ratio of power delivered to a load to the power available from the source.

maximum-likelihood the maximum of the likelihood function, $p(y|x)$ or equivalently, the log-likelihood function. Maximum-likelihood is an optimality criterion that is used for both detection and estimation.

maximum-likelihood decoding a scheme that computes the conditional probability for all the code words given the received sequence and identifies the code word with maximum conditional probability as the transmitted word. Viterbi algorithm is the simplest way to realize maximum-likelihood decoding.

maxterm a Boolean sum term in which each variable is represented in either true or complement form only once. For example, $x+y'+w+z'$ is a maxterm for a four variable function.

Maxwell's equations a set of four vector equations published in 1873 that govern the generation and time evolution of electromagnetic fields of arbitrary electric source distributions. Sometimes called the Maxwell–Heaviside equations because Heaviside first wrote them in their familiar vector form.

For fictitious magnetic current density $\overline{J}$ and charge density ρ, electric field E, magnetic field H, μ is the permeability and ϵ is the dielectric constant or permittivity.

Maxwell's equations take on the following form:

$$\nabla \times \overline{E} = \frac{\partial \overline{B}}{\partial t} \text{ (Faraday's law of induction)}$$

$$\nabla \times \overline{H} = \frac{\partial \overline{D}}{\partial t} + \overline{J} \text{ (Ampere's law)}$$

$$\nabla \cdot \overline{B} = 0$$

$$\nabla \cdot \overline{D} = q$$

where $\overline{E}$ is electric field strength, $\overline{D}$ is electric flux density, $\overline{H}$ is magnetic field strength, $\overline{B}$ is magnetic flux density, $\overline{J}$ is current density and q is volume charge density.

Maxwell, James Clerk (1831–1879)
Born: Edinburgh, Scotland

Maxwell is best known as the greatest theoretical physicist of the 19th century. It was Maxwell who discovered, among other things, that light consisted of waves. He developed the fundamental equations describing electromagnetic fields in his work, *A Dynamical Theory of the Electromagnetic Field*, published in 1864. Maxwell also gave us the mathematical foundation for the kinetic theory of gases. Maxwell's life was cut short by cancer, and thus he was unable to see his greatest theoretical propositions proven by experiment.

MBE *See* molecular beam epitaxy.

MBP *See* morphotropic phase boundary.

McCulloch–Pitts neuron originally a linear threshold unit that responded with a binary output at time $t+1$ to an input applied at time t. In current usage, usually a linear threshold unit.

MCM a unit of area used to specify the cross-sectional area of a wire, equal to 1000 circular mils .

MCM-D *See* deposited multi-chip module.

MCM-L *See* laminate multi-chip module.

MCP *See* motor circuit protector.

MCR *See* master control relay.

MCT *See* metal-oxide semiconductor controlled thyristor.

MDA *See* monochrome display adapter.

MDR *See* memory data register.

MDS code *See* maximum distance separable code.

MDT *See* mobile data terminal.

Meachem bridge a bridge circuit where one of the arms (the reactance arm) is a series connection of an inductance, a capacitor, and a resistor, all three other arms are resistors. The Meachem bridge has a very steep phase frequency characteristics in the vicinity of the reactance arm resonance frequency. The steepness increases with higher Q-factor of the reactance arm and better tuning of the bridge balance at the resonance frequency. This combination of the bridge and reactance selectivity properties has secured the main application of the Meachem bridge as the feedback circuit of high precision crystal oscillators.

Meachem-bridge oscillator an oscillator where the Meachem bridge is used in the amplifier feedback. This circuit is usually used in design of high-frequency stability crystal oscillators where the bridge reactance branch is substituted by a crystal. Tuning of the bridge allows to obtain an extremely steep phase frequency response of the bridge near the oscillation frequency which coincides with the crystal series-mode frequency.

mean *See* mean value.

mean delay the time interval between transmission of a pulse through a wideband communication channel and the instant corresponding to the centroid of its power-delay profile.

mean ergodic theorem a mathematical theorem that gives the necessary and/or sufficient conditions for a random process to be ergodic in mean. Let $x(n)$ be a wide-sense stationary random process with autocorrelation sequence $c_x(k)$. A necessary and sufficient condition for $x(n)$ to be ergodic in the mean is

$$\lim_{N->\infty} \sum_{k=0}^{N-1} c_x(k) = 0.$$

The sufficient conditions for $x(n)$ to be ergodic in the mean are that

$$c_x(0) < \infty \quad \text{and} \quad \lim_{k->\infty} c_x(k) = 0.$$

mean filter a filter that takes the mean of the various input signal components, or in the case of an image, the mean of all the pixel intensity values within the neighborhood of the current pixel.

mean free path the length of the straight line segment travelled by a photon between two successive hits at scattering centers of an inhomogeneous medium.

mean of a random variable *See* expected value of a random variable.

mean of a stochastic process the expected value of a stochastic process at some point in time.

mean of max method a method of defuzzification in which the resultant defuzzi-

fied quantity is obtained from the mean of the maximum grades of membership.

mean opinion score (MOS) (1) a subjective measure of the human-perceived quality of a particular telecommunication parameter, e.g., transmitted voice quality. Assessed by methodical exposure of human test subjects to stimuli corrupted with a known level of technical imperfection, and then requesting the test subjects to rate the stimuli on a subjective quality scale.

(2) a subjective method of quantitatively assessing the quality of signals. Subjects rate the quality of presented signals (e.g., images) on a quality or impairment scale. The mean of these ratings is calculated as the mean opinion score.

mean pyramids the approach of forming hierarchies by averaging over blocks of pixels (typically 2×2), thus eliminating the difficulties associated with subsampling approaches.

mean squared error (MSE) measure of the difference between a discrete time signal x_i, defined over $[1 \ldots n]$, and a degraded, restored or otherwise processed version of the signal $\hat{x_i}$, defined as $MSE = \frac{1}{n}\sum_{i=1}^{n}(x_i - \hat{x_i})^2$. MSE is sometimes normalized by dividing by $\sum_{i=1}^{n}(x_i)^2$.

mean time to failure (MTTF) given as the expected working lifetime for a given part, in a given environment, as

$$\text{MTTF} = \int_0^\infty r(t)dt$$

where $r(t)$ is a reliability function for the part. If the failure rate $\frac{1}{\lambda}$ is constant, then

$$\text{MTTF} = \frac{1}{\lambda}.$$

mean time to repair (MTTR) a prediction for the amount of time taken to repair a given part or system.

mean value the expected value of a random variable or function. The mean value of a function f is defined as

$$m_f = E(f) = \int_{-\infty}^{\infty} fp(f)df$$

where $p(f)$ is the probability density function of f. *See also* expectation.

mean-*q* convergence for a stochastic process, the property that the mean of the absolute difference between that process and some random variable, raised to the qth power ($q > 0$) approaches zero in time.

mean-square estimation an estimation scheme in which the cost function is the mean-square error.

mean/residual vector quantization (MRVQ) an image coding technique where a prediction is made of the original image based on a limited set of data, and then a residual image is formed by taking the difference between the prediction and the original image. Prediction data are encoded using a scalar quantizer and the residual image is encoded using a vector quantizer.

mean/residual VQ *See* mean/residual vector quantization.

measurement system the sum of all stimulus and response instrumentation, device under test, interconnect, environmental variables, and the interaction among all the elements.

mechanical degree the spatial angle of the stator of a machine, expressed in radians or degrees. Mechanical degree also represents one revolution of the rotor (360°).

mechanical loss *See* rotational loss.

mechanical power energy per unit time associated with mechanical motion. For linear motion, it is force $\times$ speed; for rotational motion, it is torque x rotational speed. In SI

units, $P = \omega T$, where P is in watts, T is in newton-meters, and ω is in rads per second.

media-access control a sublayer of the link layer protocol whose implementation is specific to the type of physical medium over which communication takes place and which controls access to that medium.

medial axis a subset of blob pixels that are centers of maximal lines, squares, or disks contained in the blob.

let X be a non-empty bounded set in a Euclidean space; assume that X is topologically closed, in other words it contains its border ∂X. For every point x in X, the Euclidean distance $d(x, X^c)$ of x to the complement X^c of X is equal to the distance $d(x, \partial X)$ of x to the border ∂X; let $B(x)$ be the closed ball of radius $d(x, \partial X)$ centered about x; it is the greatest closed ball centered about x and included in X. The medial axis transfor is the operation transforming X into its medial axis or distance skeleton $S(X)$ which can be defined in several ways:

1. $S(X)$ is the set of points x such that $B(x)$ is not included in $B(y)$ for any other y in X; in other words $B(x)$ is, among all balls included in X, maximal for the inclusion.

2. $S(X)$ is the set of points x such that $B(x)$ intersects ∂X in at least two points.

3. $S(X)$ is the set of points x at which the distance function $f(x) = d(x, \partial X)$ is not differentiable.

These three definitions coincide up to closure, in the sense that the three skeletons that they define may be different, but have the same topological closure. When X is connected and has a connected interior, its skeleton $S(X)$ is also connected and has the same number of holes as X.

For digital figures and a digital distance d, one uses only the first definition: the skeleton $S(X)$ is the set of centers of maximal "balls" (in the sense of distance d) included in X; but then the skeleton of a connected set is no longer guaranteed to be connected. *See* distance, morphological skeleton.

medial axis transform (MAT) *See* medial axis.

median filter a filter that takes the median of the various input signal components or, in the case of an image, the median of all the pixel intensity values within the neighborhood of the current pixel, the median being defined as the center value of the ordered signal components.

medical imaging a multi-disciplinary field that uses imaging scanners to reveal the internal anatomic structure and physiologic processes of the body to facilitate clinical diagnoses. *See also* X-ray, CT, magnetic resonance imaging, ultrasound, positron emission tomography, and radiography.

medium-scale integration (MSI) (1) an early level of integration circuit fabrication that allowed approximately between 12 and 100 gates on one chip.

(2) a single packaged IC device with 12 to 99 gate-equivalent circuits.

megacell a cell with the radius of 20–100 km. *See also* cell.

megaflop (MFLOP) one million floating point operations per second. Usually applied as a measurement of the speed of a computer when executing scientific problems and describes how many floating point operations were executed in the program.

meggar a power system device for measuring high-voltage insulation or ground connections.

mel scale the mel is the unit of pitch.

Mellin transform a transform often arises in the study of wideband signals. The Mellin transform $F_M(s)$ of a function $f(t)$ defined on the positive real axis $0 < t < \infty$ is

$$F_M(s) = \int_0^\infty f(t)t^{s-1}\,dt.$$

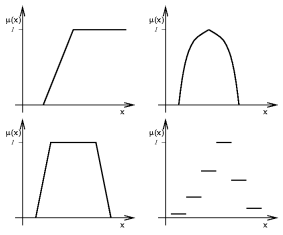
The integral in general only exists for complex values of $s = a + jb$ for $a_1 < a < a_2$, where a_1 and a_2 depend on the function $f(t)$.

melting time the time required for current to melt the fusible element of a fuse.

membership function a possibility function, with values ranging from 0 to 1, that describes the degree of compatibility, or degree of truth, that an element or object belongs to a fuzzy set. A membership function value of 0 implies that the corresponding element is definitely not an element of the fuzzy set while a value of 1 implies definite membership. Values between 0 and 1 implies a fuzzy (non-crisp) degree of membership.

Rigorously, let $\mu(.)$ be a membership function defining the membership value of an element x of an element of discourse X to a fuzzy set. If A is a fuzzy set, and x is an element of A, then the membership function takes values in the interval $[a, b]$ of the real line $(\mu_A(x) : X \Rightarrow [a, b]\ ,\ a, b \in \Re)$.

Usually, fuzzy sets are modeled with a normalized membership function $(\mu_A(x) : X \Rightarrow [0, 1])$. Some examples of membership functions are shown in the figure. If A is



Membership function: some examples of normalized fuzzy sets.

a crisp (nonfuzzy) set, $\mu_A(x)$ is 1 if x belongs to A and 0, otherwise $(\mu_A(x) : U \Rightarrow \{0, 1\})$. *See also* crisp set, fuzzy set.

membership grade the degree to which an element or object belongs to a fuzzy set. It is also referred to as degree of membership.

membrane the functional boundary of a cell. Nerve cells possess membranes that are excitable by virtue of their nonlinear electrical conductance properties.

membrane probe used for performing high power on wafer test for large periphery MMIC power amplifiers and discrete devices with non-50-W interfaces.

memory (1) area for storing computer instructions and data for either short-term or long-term purposes.

(2) the property of a display pixel that allows it to remain stable in an initially established state of luminance. Memory gives a display high luminance and absence of flicker.

memory access time the time from when a read (i.e., load) request is submitted to memory to the time when the corresponding data becomes available. Usually smaller than the memory cycle time.

memory address computation the computation required to produce an effective memory address; may include indexing and translation from a virtual to a physical address.

memory address register (MAR) a register inside the CPU that holds the address of the memory location being accessed while the access is taking place.

memory alignment matching data to the physical characteristics of the computer memory. Computer memory is generally addressed in bytes, while memories handle data in units of 4, 8, or 16 bytes. If the "memory width" is 64 bits, then reading or writing an 8 byte (64 bit) quantity is more efficient if data words are aligned to the 64 bit words of the physical memory. Data that is not aligned may require more memory accesses and more-or-less complex masking and shifting, all of which slow the operations.

Some computers insist that operands be properly aligned, often raising an exception or interrupt on unaligned addresses. Others allow unaligned data, but at the cost of lower performance.

memory allocation the act of reserving memory for a particular process.

memory bandwidth the maximum amount of data per unit time that can be transferred between a processor and memory.

memory bank a subdivision of memory that can be accessed independently of (and often in parallel with) other memory banks.

memory bank conflict conflict when multiple memory accesses are issued to the same memory bank, leading to additional buffer delay for such accesses that reach the memory bank while it is busy serving a previous access. *See also* interleaved memory.

memory block contiguous unit of data that is transferred between two adjacent levels of a memory hierarchy. The size of a block will vary according to the distance from the CPU, increasing as levels get farther from the CPU, in order to make transfers efficient.

memory bounds register register used to ensure that references to memory fall within the space assigned to the process issuing the references; typically, one register holds a lower bound, another holds the corresponding upper bound, and accesses are restricted to the addresses delimited by the two.

memory cell a part in a semiconductor memory holding one bit (a zero or a one) of information. A memory is typically organized as a two-dimensional matrix of cells, with "word lines" running horizontally through the rows, and "bit lines" running vertically connecting all cells in that column together. *See also* bit line.

memory compaction the shuffling of data in fragmented memory in order to obtain sufficiently large holes. *See also* memory fragmentation.

memory cycle the sequence of states of a memory bus or a memory (sub-)system during a read or write. A memory cycle is usually uninterruptible.

memory cycle time the time that must elapse between two successive memory operations. Usually larger than the memory access time.

memory data register (MDR) a register inside the CPU that holds data being transferred to or from memory while the access is taking place.

memory density the amount of storage per unit; specifically, the amount of storage per unit surface or per chip.

memory element a bistable device or element that provides data storage for a logic 1 or a logic 0.

memory fragmentation *See* internal fragmentation, external fragmentation.

memory hierarchy *See* hierarchical memory.

memory interleaving *See* interleaved memory.

memory latency the time between the issue of a memory operation and the completion of the operation. May be less than the time for a memory cycle.

memory management unit (MMU) a hardware device that interfaces between the central processing unit (CPU) and memory, and may perform memory protection, translation of virtual to physical addresses, and other functions. An MMU will translate vir-

tual addresses from the processor into real addresses for the memory.

memory mapped I/O I/O scheme in which I/O control and data "registers" and buffers are locations in main memory and are manipulated through the use of ordinary instructions. Computers with this architecture do not have specific I/O commands. Instead, devices are treated as memory locations. This simplifies the structure of the computer's instruction set.

memory mapping (1) the extension of a processor-generated address into a longer address, in order to create a large virtual address or to extend a virtual address that is too short to address all of real memory when translated.

(2) the mapping between the logical memory space and the physical memory space, i.e., the mapping of virtual addresses to real addresses.

memory module a physical component used in the implementation of a memory. *See also* memory bank, interleaved memory.

memory partitioning when multiple processes shares the physical main memory, the memory is partitioned between the processes. If the partitioning is static, and the amount of main memory for each process is not changed during the execution, the memory partitioning is fixed, otherwise it is said to be dynamic.

memory port an access path to a memory unit.

memory protection a method for controlling access to memory; e.g., a process may have no access, or read-only access, or read/write access to a given part of memory. The control is typically provided by a combination of hardware and software.

memory reference a read of one item of data (usually a word) from memory or a write of one item of data to memory (same as memory reference).

memory reference instruction an instruction that communicates with virtual memory, writing to it (store) or reading from it (load).

memory refresh the process of recharging the capacitive storage cells used in dynamic RAMs. DRAMs must have every row accessed within a certain time window or the contents will be lost. This is done as a process more or less transparent to the normal functionality of the memory, and affects the timing of the DRAM.

memory select line a control line used to determine whether a unit of memory will participate in a given memory access.

memory stride the difference between two successive addresses presented to memory. An interleaved memory with a simple assignment of addresses performs best when reference strides are 1, as the addresses then fall in distinct banks.

memory swapping the transfer of memory blocks from one level of the memory hierarchy to the next lower level and their replacement with blocks from the latter level. Usually used to refer to pages being moved between main memory and disk.

memory width the number of bits stored in a word of memory. The same as the width.

memory word the total number of bits that may be stored in each addressable memory location.

memoryless system a system whose output at any instant in time depends only on the input at that instant of time. The impulse response of a linear, time-invariant, memoryless system is the impulse itself, multiplied by a constant. *See also* impulse,impulse re-

sponse , linear time invariant (LTI) system, system, system with memory.

MEMS *See* microelectromechanical system.

MEMS for microwave *See* microelectromechanical system for microwave.

mercurous chloride an acousto-optic material with very slow acoustic velocity and thus very high theoretical acousto-optic figure-of-merit. The slow acoustic velocity also gives potential for high time-bandwidth deflectors.

mercury delay-line memory *See* ultrasonic memory.

meridional ray a ray that is contained in a plane passing through the fiber axis.

MESFET *See* metal-electrode semiconductor field-effect transistor.

mesh analysis a circuit analysis technique in which KVL is used to determine the mesh currents in a network. A mesh is a loop that does not contain any loops within it.

mesh networks an interconnection network in which processors are placed in a two-dimensional grid of wires, with processors at the intersections of the wires in the x and y dimensions. “Mesh” is occasionally used to refer to similar networks of higher than two dimensionality.

meshed network a complete interconnection of all nodes in a network by means of point-to-point links. They are usually a combination of ring and star networks.

MESI protocol a cache coherence protocol for a single bus multiprocessor. Each cache line exists in one of four states, modified (M), exclusive (E), shared (S), or invalid (I). (BW)

mesopic formally, a description of luminances under which both human rod and cone cells are active. The mesopic luminance range lies between the photopic and scotopic ranges. Informally, describing twilight luminances. *See also* photopic, scotopic.

message passing in object orientation, the exchange of messages between objects.

message switching a service-oriented class of communication in which messages are exchanged among terminating equipment by traversing a set of switching nodes in a store-and-forward manner. This is analogous to an ordinary postal system. The destination terminal need not be active at the same time as the originator in order that the message exchange take place.

message-passing system a multiprocessor system that uses messages passed among the processors to coordinate and synchronize the activities in the processors.

messenger cable a fully-insulated three-phase aerial cable in which three individual insulated conductors are carried on insulated looms hung upon a bare messenger wire. Such cable is used frequently in distribution work.

messenger wire a grounded wire which is used to structurally support an aerial cable.

metabolic process the method by which cells use oxygen and produce carbon dioxide and heat.

metadyne a DC machine with more than two brush sets per pair of poles. The additional brushes are located in the direct axis for the armature MMF to provide most of the excitation for higher gains.

metal halide molecule formed by the reaction of metals and halogen atoms.

metal-electrode semiconductor field-effect transistor (MESFET) a specific type of FET that is the dominant active (amplifying) device in GaAs MMICs. An FET is composed of three terminals called the gate, drain, and source, and a conducting "channel." In an amplifier application, the source is connected to ground, and DC bias is applied between the drain and source causing a current to flow in the channel. The current flow is controlled and "modulated" by the AC or DC voltage applied to the gate.

metal–insulator–metal (MIM) capacitor a capacitor, which has a thin insulator layer between two metal electrodes. Generally, this capacitor is fabricated in semiconductor process, and this insulator layer provides high capacitance. Two extreme behaviors of a capacitor are that it will act as an open circuit to low frequencies or DC (zero frequency), and as a short frequency at a sufficiently high frequency (how high is determined by the capacitor value). Also called a thin film capacitor.

metal-organic chemical vapor deposition (MOCVD or OMCVD) a material growth technique that uses metal organic molecules in an atmospheric or low pressure growth chamber and a controlled chemical reaction on a heated substrate to grow a variety of II-VI, III-V, and group IV materials with atomic layer control. Used to create material structures for a variety of electronic and optical devices using quantum wells, heterostructures and superlattices (for example, TEG, TMG, and TEA).

metal-oxide semiconductor (MOS) the basic structure in an insulated-gate field-effect transistor. In this technology, a layered capacitor, with the added property of applying a voltage of a proper polarity, causes the underlying semiconductor to be switched from n-type to p-type or vice versa. MOS technology has been responsible for the mainstream of integrated circuit technology for many years.

metal-oxide semiconductor controlled thyristor (MCT) a voltage-controlled four-layer (pnpn) device for medium power (700 A) and medium speed (20 kHz) applications, with projections to 2000 A and 100 kHz. Unlike transistors, MCTs can only be on or off, with no intermediate operating states. The MCT has high current handling capabilities, a low forward voltage drop, and low gate drive requirements (no large negative gate current required for turn off).

metal-oxide semiconductor field-effect transistor (MOSFET) a transistor that uses a control electrode, the gate, to capacitively modulate the conductance of a surface channel joining two end contacts, the source and the drain. The gate is separated from the semiconductor body underlying the gate by a thin gate insulator, usually silicon dioxide. The surface channel is formed at the interface between the semiconductor body and the gate insulator. Used for low power (200 A) and high speed (1 MHz) applications.

In power electronics applications, MOSFETs are typically operated as switches, in either their fully on or off states, to minimize losses. The gate is insulated from the semiconductor portion to enable faster switching. A gate-source voltage permits a current to flow between the drain and the source, where continuous gate voltage is required to be in the on-state. The primary disadvantage is the high forward voltage drop. The "metal" in MOSFET refers to the gate electrode, which was fabricated from a metal in early MOSFETs, but is now typically fabricated from a material such as polysilicon.

metal-oxide semiconductor memory memory in which a storage cell is constructed from metal-oxide semiconductor. Usually called MOS memory.

metal-oxide varistor a voltage-dependent resistor frequently used to protect electronic devices from overvoltages due to lightning or switching surges. The resistance of the

device drops to a few ohms if the voltage applied across it exceeds a calibrated value.

metallization the deposited thin metallic coating layer on a microcircuit or semiconductor.

meteor burst communication VHF radio communication using the reflective properties of the ionized trails that burning meteorite bursts leave in the atmosphere.

method of moments (MOM) a common procedure used in order to solve integral and differential equations. The unknown function is expanded on a complete (but not necessarily orthogonal) set of functions, often called basis functions or expansion set. This expansion is truncated after a finite number of terms, N. The original functional equation is then tested, i.e., multiplied and integrated, by another set of functions, often called weighting or testing functions, hence reducing the original functional equation to a matrix equation suitable for numerical computation. The common choice of taking the same set of functions for the expansion and test is often referred to as Galerkin version of the moment method. *See also* integral equation.

method of successive projections an iterative procedure for modifying a signal so that the modified signal has properties which match an ideal objective.

metric (1) a measure of goodness against which items are judged.

(2) methodologies for the measurement of software features including matters as performance and cost estimation.

metrology the process of measuring structures on the wafer, such as the width of a printed resist feature.

metropolitan-area network (MAN) a computer communication network spanning a limited geographic area, such as city; sometimes features interconnection of LANs.

Mexican-hat function a function that resembles the profile of a Mexican hat. According to anatomy and physiology, the lateral interaction between cells in mammalian brains has a Mexican-hat form, that is, excitatory between nearby cells and inhibitory at longer range with strength falling off with distance. According to this phenomenon, Kohonen proposes a training algorithm for self-organizing system to update not only the weights of the winner but also the weights of its neighbors in competitive learning. *See also* self-organizing algorithm.

MFD filter *See* maximally flat delay filter.

MFIE *See* magnetic field integral equation.

MFLOP *See* megaflop.

MHD *See* magneto-hydrodynamic generator .

MHz megahertz, or millions of operations per second.

micro cell a cell in a cellular communications system having a size (or cell radius) that is significantly smaller than the cell size of a typical cellular system. Such systems have cells with radii that are at most a few hundred meters and utilize base stations placed at heights that are of the order of the height of the mobile terminal.

micro diversity a diversity technique, used in a cellular where multiple antennas are separated by distances equal to a few wavelengths and the diversity transmission/reception is utilized to overcome the effect of multipath fading. *Compare with* macro diversity

micro shadowing shadowing due to both the orientation with respect to transmitter and receiver. *See also* macro shadowing.

micro-stepping a control technique — also called mini-stepping — that results in a finer positioning resolution than can be obtained with simple on/off control of the phase currents of a stepper motor. The practical implementation of micro-stepping requires the accurate and continuous control of all the phase currents of the step motor.

microbending sharp curvatures involving local fiber axis displacements of a few micrometers and spatial wavelengths of a few millimeters. Microbending causes significant losses.

microcell a low-power radio network that transmits its signal over a confined distance.

microchannel diode a high-frequency planar monolithic Schottky barrier diode structure fabricated with micromachining that has very small parasitics and is used as a millimeter or submillimeter wave mixer or harmonic multiplier.

microchannel-plate spatial light modulator (MSLM) an optically addressed spatial light modulator. When input light is incident onto a photocathode on the write-in side of the MSLM, a photoelectron image is formed, which is multiplied to about hundred thousand times by the microchannel plate. The resulting charge pattern will in turn affect the second layer, which is the $LiNbO_3$ crystal plate having electro-optic effect. The refractive index of the crystal plate is now modulated by the electric charge pattern. When output light passes through the crystal plate, the phase of output light is modulated by the varying refractive index of the crystal plate. Since the $LiNbO_3$ is birefringence, phase modulation becomes polarization modulation. Polarization modulation is visualized as intensity variation using a polarizer. The generation of electric charge and its effect to the crystal layer are nonlinear. Their combined effect has thresholding capability that can be utilized for constructing optical logic gates.

microchannel-plate spatial light modulator logic gate an optical logic gate utilizing thresholding capability of a microchannel-plate spatial light modulator (MSLM).

microcode a collection of low-level operations that are executed as a result of a single instruction being issued.

microcommand an n-bit field specifying some action within the control structure of a CPU, such as a gate open or closed, function enabled or not, control path active or not, etc.

microcomputer a computer whose CPU is a microprocessor chip, and its memory and I/O interface are LSI or VLSI chips.

microcontroller an integrated circuit chip that is designed primarily for control systems and products. In addition to a CPU, a microcontroller typically includes memory, timing circuits, and I/O circuitry. The reason for this is to permit the realization of a controller with a minimal quantity of chips, thus achieving maximal possible minituarization. This in turn, will reduce the volume and the cost of the controller. The microcontroller is normally not used for general-purpose computation as is a microprocessor.

microelectromechanical system (MEMS) micrometer-scale devices fabricated as discrete devices or in large arrays using integrated circuit fabrication techniques. Movable compact micromechanical or optomechanical structures and microactivators made using batch processing techniques.

microelectromechanical system (MEMS) for microwave a new multidisciplinary technology field with enormous potential for various applications, including microwave. MEMS are fabricated by integrated circuit processing methods and commonly include sensors and actuators with physical dimensions of less than 1 mm on a side.

microinstruction the set of microcommands to be executed or not, enabled or not. Each field of a microinstruction is a microcommand.

microlithography lithography involving the printing of very small features, typically on the order of micrometers or below in size.

micromachine a fabrication process that uses integrated circuit fabrication techniques such as diffusion, oxidation, wet and dry etching to realize mechanical and electrical structures such as resonators, membranes, cavities, waveguide structures and a variety of thermal, medical, and chemical transducers.

micromemory *See* control memory.

microphone a device that converts acoustical signals into electrical signals.

microprocessor a CPU realized on an LSI or VLSI chip.

microprogram a set of microcode associated with the execution of a program.

microprogramming the practice of writing microcode for a set of microinstructions.

microscopy an imaging modality that uses optical light, laser light, electrons, or another radiation source to illuminate a sample. The image is formed by gathering reflected and scattered energy.

microsensor a sensor that is fabricated using integrated circuit and micromachining technologies.

microstrip a transmission line formed by a printed conductor on top of a conductive-backed dielectric. It is often used in high-frequency, printed circuit board applications.

microstrip antenna a radiating element consisting of a conducting patch formed on the surface of a dielectric slab, which in turn lies on a ground plane. Microstrip antennas are usually printed on circuit boards and fed by microstriplines etched on the same board. Also called microstrip patch antenna.

microstrip patch antenna *See* microstrip antenna.

microtiming diagram a graphical display showing how the waveforms vary with time but with a time scale that has sufficient resolution to display clearly the delays introduced by the individual basic elements of the digital circuit.

microwave term used to refer to a radio signal at a very high frequency. One broad definition gives the microwave frequency range as that from 300 MHz to 300 GHz.

microwave coplanar probe a specially designed test probe for measuring devices from DC to microwave frequencies using a wafer probe station. The probe tip is constructed using coplanar waveguide to present a highly controlled impedance (usually 50 ohms) to a device under test.

microwave engineering the engineering of devices in the frequency range from 1 GHz to 1000 GHz corresponding to the wavelengths from 30 cm down to 0.3 mm.

microwave transition analyzer a device that can combine the functionality of several dedicated measurement instruments. It is a pulsed RF measurement system that operates in the time domain like a high frequency sampling oscilloscope. Using the fast Fourier transform, the information can be converted into frequency domain. It can operate as a sampling oscilloscope, pulsed network analyzer, and a spectrum analyzer.

mid-term stability refers to system responses which are shorter than long-term *cf* but shorter than transient *cf* response, generally associated with maximum excitation

limiters, load tap changers and other slow-acting devices.

Mie scattering electromagnetic theory that describes the scattering of light by spheres.

mildly nonlinear a circuit or element in which the output spectrum is made up of two parts, the first of which is proportional through gain(s), attenuation(s) and delay(s) to the input spectrum, and the second in which spectral shift(s), conversion(s) or generation(s) takes place in an orderly and predictable way. Most real-world circuits and elements are mildly nonlinear at some level of excitation within hyperspace, and all active devices are mildly nonlinear.

Miller capacitance an excess amount of capacitance that appears in parallel with the input of an inverting amplifier stage.

Miller effect the increase in the effective grid-cathode capacitance of a vacuum tube or a transistor due to the charge induced electrostatically on the grid by the anode through the grid–anode capacitance.

Miller oscillator the name is usually applied to crystal oscillators with one active device (usually a FET with the source AC grounded) where the crystal is connected between the gate and ground. The crystal is used like an inductor, another tunable parallel LC-circuit in the drain is used as an inductor as well, and the capacitance between the drain and gate (Miller capacitance hence the name) is used as a third reactance of LC-oscillator. The circuit becomes similar to Hartley oscillator.

Miller's rule a semi-empirical rule, of good but not exact validity, which states that the value of the nonlinear susceptibility of order n for a given material is proportional to $n + 1$ products of the linear susceptibility of that material.

millimeter wave an electromagnetic wave in the part of the electromagnetic spectrum that has a wavelength on the order of a millimeter. This band is centered at about 300 GHz.

MIM capacitor *See* metal–insulator–metal capacitor.

MIMD *See* multiple instruction multiple data architecture.

MIMO system *See* multi-input–multi-output system. *See also* single-input–single-output system.

min operation an operation on two or more variables where the resultant value is formed by taking the smallest value, or minimum, among these variables.

min-max control a class of control algorithms based on worst-case design methodology in which control law is chosen in such a way that it optimizes the performance under the most unfavorable possible effect of parameter variations and/or disturbances. The design procedure can be viewed as a zero-sum game with control action and uncertainty as the antagonistic players. In the case of linear models and quadratic indices, the min-max control could be found by solving zero-sum linear-quadratic games. Minimax operations may be performed on cost functionals, sensitivity functions, reachability sets, stability regions or chosen norms of model variables.

mini-stepping *See* micro-stepping.

minicell a cell with a radius of 300 m to 2 km, typically for pedestrian mobile users. *See also* cell.

minimal orientation representation minimal orientation representation describes the rotation of the end-effector frame with respect to the base frame, e.g., Euler angles (there exists a set of 12 Euler angles). Mini-

mal orientation representation usually has to be calculated through the computation of the elements of the rotation matrix i.e., n, o, and a vectors. *See* external space.

minimal realization for linear stationary finite-dimensional continuous-time dynamical system, is a set of four matrices A, B, C, D that form state and output equations in the state space R^n with minimal dimension n. A minimal realization of linear stationary dynamical system is always controllable and observable. The similar statements hold true for linear stationary finite-dimensional discrete-time dynamical systems.

minimax estimate the optimum estimate for the least favorable prior distribution.

minimum discernible signal a signal power level equal to the noise power, usually expressed in watts or decibels. Thus measuring the system output power with no signal applied, and then increasing the input signal power until a 3 dB increase is observed results in the signal power being equal to the noise power (i.e., $S/N = 1$). Also called the minimum detectable signal.

minimum distance in a forward error control block code, the smallest Hamming distance between any two code words. In a convolutional code, the column distance at the number of encoding intervals equal to the constraint length.

minimum energy control of generalized 2-D model given the generalized 2-D model

$$Ex_{i+1,j+1} = A_0 x_{ij} + A_1 x_{i+1,j} + A_2 x_{i,j+1} + B_0 u_{ij} + B_1 u_{i+1,j} + B_2 u_{i,j+1}$$

$i, j \in Z_+$ (the set of nonnegative integers) with admissible boundary conditions $x_{i0}, i \in Z_+$, x_{0j}, $j \in Z_+$ and the performance index

$$I(u) := \sum_{i=0}^{\bar{N}_1} \sum_{j=0}^{\bar{N}_2} u_{ij}^T Q_{ij}$$

$$\left(\bar{N}_1 := N_1 + n_1;\ \bar{N}_2 := N_2 + n_2\right)$$

find a sequence of inputs u_{ij} for $0 \le i \le \bar{N}_1$ and $0 \le j \le \bar{N}_2$ that transfers the model to the desired final state $x_f \in R^n$, $x_{N_1 N_2} = x_f$ and minimizes the performance index $I(u)$ where $x_{ij} \in R^n$ is the local semistate vector $u_{ij} \in R^m$ is the input vector, E, A_k, B_k $(k = 0, 1, 2)$ are given real matrices, $Q \in R^{m \times m}$ symmetric and positive definite weighting matrix and (n_1, n_2) is the index of the model. *See also* local reachability of generalized 2-D model.

minimum energy control of linear systems a design problem such that for a given initial and final condition, find a control that steers dynamical system on a given time interval from initial conditions to final conditions and has minimum energy. Minimum energy control problem has a solution for every controllable linear (continuous or discrete) dynamical system. This solution strongly depends on system parameters and the given initial and final states.

minimum excitation limiter a controller that is used to limit the minimum amount of field current, or under-excitation, at a synchronous generator. This excitation limit is set by stability limit.

minimum free distance for any convolutional code, it is the minimum Hamming distance between the all-zero path and all the paths that diverge from and merge with the all-zero path at a given node of the trellis diagram.

minimum mean square error (MMSE) a common estimation criterion which seeks to minimize the mean (or expected) squared error,

$$\mathcal{E} = E\left[\boldsymbol{e}^T \boldsymbol{e}\right]$$

where $\boldsymbol{e}$ represents the error.

minimum mean square estimator (MMSE) a broad class of estimators based on minimizing the expected squared error criterion. Both

the Linear least squares estimator and the Bayesian least squares estimator are special cases. *See also* minimum variance unbiased estimator, linear least squares estimator, Bayesian least squares estimator, maximum a posteriori estimator, maximum likelihood estimation.

minimum noise factor for an active circuit or device, occurs when the input terminal is terminated with an impedance which produces the minimum noise factor.

minimum phase system a system that has all poles and zeroes inside the unit circle. It is called minimum phase because the poles and zeroes inside the unit circle cause the group delay, which is the derivative of the phase of the signal to be minimized.

minimum polynomial for a given element α of a field, and for a subfield F, the polynomial of smallest degree, with coefficients in F having α as a root. The set of roots of a minimum polynomial form a conjugacy class that is defined by the polynomial.

minimum time-to-clear *See* clearing time.

minimum time-to-melt *See* melting time.

minimum variance unbiased estimator an estimator $\hat{\theta}$ of a parameter θ is said to have minimum variance and to be unbiased if

$$E\hat{\theta} = \theta$$

and

$$E(\hat{\theta} - \theta)^2 \leq E(\tilde{\theta} - \theta)^2,$$

where $\tilde{\theta}$ is any other estimator of θ.

minimum-shift keying (MSK) a variant of FSK in which the separation between transmitted frequencies is $1/(2T)$, where T is the symbol duration. In addition, the initial phase associated with each bit is adjusted so that phase transitions between successive bits are continuous.

minimum-shift keying Gaussian (GMSK) a variant of MSK in which the transmitted frequency makes smooth transitions between the frequencies associated with the input bits. A GMSK signal can be generated when the input to the voltage-controlled oscillator (VCO) is a PAM signal with a Gaussian baseband pulse shape.

minisub in European usage, a miniature substation.

Minkowski distance between two real valued vectors $(x_1, x_2, \ldots, x_n)$ and $(y_1, y_2, \ldots, y_n)$ a difference measure given by

$$D_{Minkowski} = \left(\sum_{i=1}^{n} |x_i - y_i|^{\lambda} \right)^{\frac{1}{\lambda}}$$

minor hysteresis loop a hysteresis loop generated within the major hysteresis loop when a magnetic material is not driven to full positive or negative saturation.

minority carrier a hole in an n-type or an electron in a p-type semiconductor.

minterm a Boolean product term in which each variable is represented in either true or complement form. For example, $u \cdot v' \cdot w \cdot z'$ is a minterm for a four-variable function.

MIPS millions of instructions per second, a measure of the speed of a computer.

mirror optical element that reflects and may also transmit incident light rays and beams; used to provide feedback in laser oscillators.

mirroring fault tolerance architecture for managing two or more hard disks as a unique disk by replicating the same data on all the disks in the mirroring system. The system also includes mechanism for verifying that all disks contain the same information.

MISD *See* multiple instruction single data architecture.

MISO *See* multi-input–single-output system.

miss the event when a reference is made to an address in a level of the memory hierarchy that is not mapped in that level, and the address must be accessed from a lower level of the memory hierarchy.

miss probability the probability of falsely announcing the absence of a signal.

miss rate the percentage of references to a cache that do not find the data word requested in the cache, given by $1 - h$ where h is the hit rate. Also miss ratio.

miss ratio *See* miss rate.

missile terminal guidance seeker located in the nose of a missile, a small radar with short-range capability that scans the area ahead of the missile and guides it during the terminal phase toward a target such as a tank.

mix-and-match lithography a lithographic strategy whereby different types of lithographic imaging tools are used to print different layers of a given device.

mixed A/D simulator a simulator that is capable of simulating combined analog and digital circuitry.

mixed method coordination in case of any mixed method both direct coordination instruments — as in the direct method — and the dual coordination instruments — as in the price method — are used by the coordinator to modify local decisions until the coordination objectives are met; different combinations of direct and dual coordination instruments may be used, and so a variety of mixed methods can be conceived.

mixed mounting technology a component mounting technology that uses both through-hole and surface-mounting technologies on the same packaging and interconnecting structure.

mixer a nonlinear device containing either diodes or transistors, the function of which is to combine signals of two different frequencies in such a way as to produce energy at other frequencies. In a typical down converter application, a mixer has two inputs and one output. One of the inputs is the modulated carrier RF or microwave signal at a frequency f_{rf}, the other is a well controlled signal from a local oscillator or VCO at a frequency f_{lo}. The result of down conversion is a signal at the difference frequency $f_{rf} - f_{lo}$, which is also called the intermediate frequency f_{if}. A filter is usually connected to the output of the mixer to allow only the desired IF frequency signal to be passed on for further processing. For example, for an RF frequency of 10.95 GHz (=10,950 MHz) and an LO frequency of 10 GHz (=10,000 MHz), the IF frequency would be 950 MHz.

mixing amplifier *See* harmonic amplifier.

ML *See* maximum likelihood estimation.

MLR *See* multilayer resist.

MMF *See* magnetomotive force.

MMIC *See* monolithic microwave integrated circuit.

MMSE *See* minimum mean square estimator or minimum mean square error.

MMU *See* memory management unit.

MMX register a register designed to hold as many as eight separate pieces of integer data for parallel processing by a special set of MMX instructions. An MMX register can hold a single 64-bit value, two 32-bit values, four 16-bit values, or eight-byte integer values, either signed or unsigned. In implementation, each MMX register is aliased to a

corresponding floating-point register. MMX technology is a recent addition to the Intel Pentium architecture.

MNOS acronym for metal-nitride-oxide-si. A structure used in a type of nonvolatile memory device in which the oxide is sufficiently thin to permit electron/hole tunneling while the nitride and the nitrode/oxide interface are used to store charge.

mobile data terminal (MDT) a computer terminal installed in a service vehicle which, through some wireless link, communicates work order information between the crews and their dispatch center.

mobile station that part of a radio communications system, which is not permanently located in a given geographical location.

mobile charge the charge due to the free electrons and holes.

mobile ion a charged ionic species that is mobile in a dielectric. In metal-oxide-si (MOS) devices, Na^+ is most often the source of the mobile ions.

mobile robot a wheeled mobile robot is a wheeled vehicle which is capable of an autonomous motion because it is equipped for its motion, with actuators that are driven by an on-board computer. Therefore mobile robot does not have an external human driver and is completely autonomous.

mobility electron mobility $\mu_n = (2LK)/(C_{ox}W)$ where

C_{ox} = capacitance per unit area of the gate-to-channel capacitor for which the oxide layer serves as a dielectric.

L = length of the channel

W = width of the channel

μ_n = the mobility of the electrons in the induced n channel

K = constant.

proton mobility $\mu_p \cong \mu_n/2$.

MOCVD *See* metal-organic chemical vapor deposition.

modal analysis the decomposition of a solution to an electromagnetic analysis problem into a linear combination (weighted sum) of elementary functions called modes. The elementary functions are usually orthogonal; typical functions used include sine and cosine functions for problems cast in rectangular coordinates, Bessel functions for cylindrical coordinates, and spherical Bessel functions for spherical coordinates.

This technique can be used in order to find the field produced by an arbitrary source inside a waveguide, be it open or closed, or to find the scattering matrix relative to the discontinuity between different waveguides. *See also* eigenfunction expansion.

modal expansion *See* modal analysis.

modal solution *See* modal analysis.

modality (1) a part of a computer's instruction that specifies how another part of the instruction is interpreted.

(2) a specific medical imaging technique, such as *X-ray CT*, magnetic resonance imaging, or ultrasound, that is used to acquire an image data set.

modality-specific a task that is specific to a single sense or movement pattern.

mode (1) one possible wave solution of an infinite number of time–harmonic wave solutions that exist in a waveguide or transmission line. Each mode is identified by a collection of numbers and is usually designated in electromagnetics as either transverse electric, transverse magnetic, or transverse electromagnetic.

(2) electromagnetic field distributions that match the boundary conditions imposed by a laser or other cavity.

See also propagating mode, cladding, tunneling modes, leaky modes, multi-mode optical fiber, single-mode fiber.

mode chart a graphical illustration of the variation of effective refractive index (or equivalently, propagation angle θ) with normalized thickness d/λ for a slab waveguide or normalized frequency V for an optical fiber.

mode field radius the radius at which the electric field in a single mode fiber falls to $1/e$ of its value at the center of the core.

mode filter a filter that takes the mode of the distribution containing the various input signal components or, in the case of an image, the mode of the distribution of all the pixel intensity values within the neighborhood of the current pixel. Complications can arise from the sparsity of the local pixel intensity distribution, and the mode should be that of the underlying rather than the actual intensity distribution.

mode matching a particular type of modal analysis referred to the analysis of a junction between different waveguides, where the modal expansion on one side of the junction is matched to the modal expansion on the other side of the junction.

mode-locking forcing the modes of a laser oscillator to be equally spaced in frequency and have a fixed phase relationship; sometimes also occurs spontaneously. *See also* longitudinal modelocking, transverse mode-locking.

model based image coding (1) image compression using stored models of known objects at both encoder and decoder, the encoder using computer vision techniques to analyze incoming images in terms of the models, and the decoder using computer graphics techniques to re-synthesize images from the models. The transmitted data are model parameters that describe at a relatively high level, the motion of the model parts. For example, if the stored model is of a human head, the transmitted data may be muscle flexions.

(2) the appreciation that all image coding relies on some model of the source, and the categorization of methods according to the type of model. In this scheme, definition 1 is termed "known-object coding" or "semantic coding."

model reference control the control scheme in which the controlled system is made to mimic the behavior of a reference model system that possesses ideal behavioral characteristics.

model-based predictive control *See* predictive control.

modeling the process of creating a suitable description that emulates the performance or characteristics of the actual item being modeled, over some portion of the device hyperspace. Modeling involves all or parts of model creation, device characterization, de-embedding, parameter extraction, verification, validation, valuation and documentation. *See also* mathematical modeling, fuzzy modeling.

modem abbreviation for modulator-demodulator. A device containing a modulator and a demodulator. The modulator converts a binary stream into a form suitable for transmission over an analog medium such as telephone wires or (in the case of a wireless modem) air. The demodulator performs the reverse operation, so two modems connected via an analog channel can be used to transfer binary data over the (analog) channel.

modem-FEC coding error control coding (ECC), applied to a digital signal such that feedforward error correction (FEC), can be used in the modem, thus detecting and often correcting transmission errors.

moderator a material contained in a nuclear reactor core which slows down neutrons to thermal energies, primarily by neutron scattering.

MODFET acronym for modulation doped FET. *See* high electron mobility transistor.

modified nodal formulation a modification of the classical nodal formulation which allows any network to be described. The modification consists of adding extra equations and unknowns when an element not normally modeled in classical nodal analysis is encountered.

modified signed-digit computing a computing scheme in which a number is represented by modified signed-digit. This number system offers carry free addition and subtraction. Instead of 0 and 1, numbers are represented by -1, 0, and 1 for the same radix 2. If a number is represented by 0 and 1, we may need carry in the addition. However, since the number can be represented by three possibilities -1, 0, and 1, the addition and subtraction can be directly performed without carry following a specific trinary logic truth table for this number system.

modified z-transform a z-transform of signals and systems that contain nonzero deadtime τ in the range

$$0 \leq \tau < T$$

where T is the sampling interval. Modified z-transforms are usually derived from fundamental principles and given as separate columns in z-transform tables for standard functions.

modified-return-to-bias recording *See* magnetic recording code.

modifier an operation that modifies the membership of a fuzzy set. Examples of modifiers are

1. *very* $A = \mu_{con(A)}(u) = (\mu_A(u))^2$ (concentration);

2. *more or less* $A = \mu_{dil(A)}(u) = (\mu_A(u))^{.5}$ (dilatation).

See also fuzzy set, linguistic variable.

modular network a network whose overall computation is carried out by subnetworks whose outputs are combined in some appropriate way. The term is most commonly applied to networks that partition the input space so that the subnetworks operate on "local" data, but is also applied to the case where a problem can be decomposed into successive tasks, each being implemented by a suitable subnetwork.

modularity design principle that calls for design of small, self-contained unit that should lead to maintainability.

modulated filter bank a filter bank obtained by shifting the spectrum of a prototype low pass filter in the frequency domain to cover the entire frequency band. Different properties can be obtained by using different modulation schemes and imposing other conditions. Cosine-modulated filter banks are the most commonly used modulated filter banks.

modulating signal the baseband source signal used to encode information onto a carrier wave by varying one or more of its characteristics (e.g., the amplitude, frequency, or phase of a sinusoid; or the amplitude, width, repetition rate, or position of each pulse in a periodic pulse train).

modulation (1) variation of the amplitude or phase of an electromagnetic wave.

(2) the process of encoding an information-carrying waveform onto a carrier waveform, typically in preparation for transmission. *See* amplitude modulation, frequency modulation, phase modulation.

modulation efficiency ratio of the baseband bit rate to the transmission bandwidth after modulation.

modulation index for an angle-modulated signal, the modulation index is the ratio of the maximum modulation deviation to the modulating frequency, and represents the maxi-

mum phase deviation in the modulating signal.

modulation property a property of the Fourier transform in which the Fourier transform of a modulated signal $c(t)e^{jw_o t}$ is equal to $C(w - w_o)$, where $C(w)$ is the Fourier transform of $c(t)$.

modulation transfer function (MTF) for an imaging system the Fourier transform of the system line spread function. The MTF describes the spatial frequency resolution of the system.

modulator device that varies the amplitude or phase of an electromagnetic wave.

modus ponens a rule of reasoning which states that given that two propositions, A and $A \Rightarrow B$ (implication), are true, then it can be inferred that B is also true.

modus tollens a rule of reasoning which states that if a proposition B is not true and given that $A \Rightarrow B$, then it can be inferred that A is also not true.

Moire pattern image caused by a combination of two effects, sampling rate and reconstruction filter shape; they occur in image signals when two conditions are met. First, when the sampling frequency is close to the Nyquist Frequency for the signal (i.e., two times the highest frequency in the image signal). Second, the cutoff frequency of the reconstruction filter is located beyond one half the sampling frequency (e.g., a first order filter). These two problems result in mirror images of frequency components around the sampling frequency causing banding in the image signal. The Moire effect is seen in practical applications due to real world problems of finite filter lengths and errors in sampling rates.

molded case circuit breaker a low-voltage air circuit breaker that includes thermal and/or magnetic overcurrent sensing which directly trips the breaker. The molded case circuit breaker is nearly always manually closed, opened, and reset.

molecular beam a source of molecules traveling primarily in one direction. In practice, molecular beams are usually realized by expansion of an atomic or molecular vapor into a vacuum through a small aperture. The resulting expanding cloud of molecules is usually made nearly unidirectional by a collimator that blocks or otherwise removes all molecules not propagating within a narrow range of angles.

molecular beam epitaxy (MBE) a material growth technique that uses atomic or molecular beams in an ultra high vacuum chamber to grow a variety of II-VI, III-V, and group IV materials with atomic layer control. Individual molecules or atoms are excited from heated sources (effusion cells) and attach to the substrate in an ordered manner. High quality growth is achieved when the surface diffusion coefficient is sufficiently high that the atoms can arrange themselves coherently on the surface.

Used to create material structures for a variety of electronic and optical devices using quantum wells, heterostructures, and superlattices.

molecular transition coupling of energy levels in an atom by means of absorption or emission processes.

molecular vapor a material composed of molecules in the vapor phase.

Mollow gain gain that originates when a 2-level system is driven by a strong, near resonant, electromagnetic field.

MOM *See* method of moments.

moment a statistic of a random variable. For example, the first moment is called the mean. In general, the nth moment is given

by

$$m_n = E(X^T n) = \int_{-\infty}^{\infty} x^n X(x) dx,$$

where $f_X(x)$ is the probability density function of X. Moments are often used to aid the recognition of shapes. *See also* probability density function.

moment method *See* method of moments.

momentary interruption a loss of voltage of less than 0.1 pu for a time period of 0.5 cycles to 3 seconds.

momentary monitoring the duration at supply frequency from 30 cycles to 3 seconds.

momentary overvoltage an increase in voltage above the system's specified upper limit for more than a few seconds. Generally a rather loosely-defined term.

momentum relaxation time the characteristic time for loss of momentum or velocity due to scattering processes.

monaural attribute attribute of ear input signals (e.g., timbre, loudness) that require only one ear to be detected.

monitor (1) the main display device of a personal computer. Usually uses cathode ray tube (CRT) or liquid-crystal display (LCD) technology.

(2) a computer program providing basic access to the register contents and memory locations, usually for debugging purposes.

monitor display *See* monitor.

monochromatic light light that has only one frequency component.

monochrome the representation of an image, analog or digital, using only one color and black.

monochrome display adapter (MDA) a monocrome video adapter with 25 lines and supporting 80 columns, proposed by IBM in 1981.

monocular vision a vision model in which points in a scene are projected onto a single image plane.

monolayer one atomic or, in the case of materials such as GaAs, diatomic layer of atoms.

monolithic microwave integrated circuit (MMIC) integrated circuits made of gallium arsenide (GaAs), silicon, or other semiconducting materials where all of the components needed to make a circuit (resistors, inductors, capacitors, transistors, diodes, transmission lines) are formed onto a single wafer of material using a series of process steps.

Attractive features of MMICs over competing hybrid (combination of two or more technologies) circuits are that a multitude of nearly identical circuits can be processed simultaneously with no assembly (soldering) using batch processing manufacturing techniques. A disadvantage is that circuit adjustment after manufacture is difficult or impossible. As a consequence, significantly more effort is required to use accurate computer-aided-design (CAD) techniques to design MMICs that will perform as desired without adjustment. Of course, eventually assembly and packaging of MMICs is performed in order to connect them into a system such as a DBS receiver. MMICs are only cost-effective for very high volume costs, because the cost of the initial design is very high, as is the cost of wafer manufacture. These costs can only be recovered through high volume manufacture. (The word "monolith" refers to a single block of stone that does not (in general) permit individual variations).

monopole *See* magnetic monopole.

monopole antenna an antenna consisting of a straight conducting rod, wire, or

other structure oriented perpendicularly to a ground plane and fed at the junction of the structure and the ground plane.

monostatic scattering the reflection of a portion of an electromagnetic wave back in the direction of the wave source. Monostatic scattering is measured by having the transmitter and receiver collocated.

Monte Carlo method a numerical technique that replaces a deterministic description of a problem with a set of random descriptions that have been chosen based on distributions that match the underlying physical description of the problem. This technique is widely used to investigate transport and terminal characteristics in small semiconductor structures.

Moore's law the observation that the number of transistors on a typical chip doubles about every 18 months. Named for Gordon Moore, one of the founders of Fairchild Semiconductor and Intel.

MOPA *See* master-oscillator-power-amplifier.

MOPS acronym for millions of operations per second.

morphological duality a morphological property. There are three standard meanings of duality for morphological operators:
1. Order-theoretic duality: To any property or concept corresponds the dual property or concept, where the relations $\subseteq$, $\leq$ and operations $\cup$, $\cap$, sup, inf, etc., are replaced by their duals $\supseteq$, $\geq$ and $\cap$, $\cup$, inf, sup, etc.
2. Duality under complementation (or gray-level inversion): Let ψ be a morphological operator, and let N be the operation transforming an image I into its negative $N(I)$ (when I is a set, $N(I)$ is its complement, while when I is a gray-level numerical function, $N(I)$ has the gray-level inverted at each point). Then the dual of ψ is the operator ψ^* arising from applying ψ to the negative of an image; in other words ψ^* transforms I into $N(\psi(N(I)))$.
3. Adjunction duality: The dilation and erosion by B, namely $\delta_B : X \mapsto X \oplus B$ and $\varepsilon_B : X \mapsto X \ominus B$, form an adjunction, which means that for every X, Y we have

$$\delta_B(X) \leq Y \iff X \leq \varepsilon_B(Y),$$

"the dilation of X is below Y if and only if X is below the erosion of Y." This relation constitutes a bijection between the family of dilations and that of erosions, and it can thus be considered as a duality between them.

In the latter two cases, duality inverts the ordering relation $\leq$ between operators. *See* dilation, erosion, morphological operator.

morphological filter a morphological operator ψ that is both:
1. idempotent: applying it twice gives the same result as applying it only once; mathematically speaking, given an object X, we have $\psi(\psi(X)) = \psi(X)$;
2. increasing: it preserves the ordering relation $\leq$ between objects; given two objects X and Y, $X \leq Y$ implies $\psi(X) \leq \psi(Y)$. Openings and closings are morphological filters. *See* closing, morphological operator, opening.

morphological operator an operation for transforming images, which does not arise from the traditional signal processing methodology using linear filters and Fourier analysis but which is rather based on set-theoretical operations. Such an operator for sets (binary images) combines union, intersection, translation, and sometimes complementation. For numerical functions (gray-level images), union and intersection are replaced by supremum and infimum (upper and lower envelope), while gray-level inversion takes partially the role of set complementation. However morphological operators for gray-level images can be visualized by applying the corresponding morphological operator for binary images to the umbra of a gray-level image. *See* closing, dilation, erosion, mathematical morphology, opening, umbra.

morphological processing low-level processing technique for binarized images involving the shrinking or growing of local image regions to remove noise and reduce clutter.

morphological skeleton an archetypal stick figure that internally locates the central axis of an image.

Let B be the closed ball of unit radius centered about the origin; for any radius $r \geq 0$, let rB be the homothetic of B by factor r (thus rB is the closed ball of radius r centered about the origin). Given a non-empty bounded set X in a Euclidean space and a point p in X, p is the center of a closed ball of radius r, which is included in X, but not contained in a larger ball included in X, if and only if

$$p \in X \ominus rB \text{ and } \forall \varepsilon > 0,\ p \notin (X \ominus rB) \circ \varepsilon B.$$

Here $\ominus$ and $\circ$ denote the erosion and opening operations respectively. The medial axis of X is the set of all points p such that there is some $r \geq 0$ for which this equation holds. The morphological skeleton is defined in the same way, except that it does not restrict itself to the isotropic Euclidean ball: take the same formula above, but consider in it the set B to be any convex, bounded, and topologically closed structuring element instead of the unit ball.

For sets in digital space, the above approach is simplified as follows: For $r = 0, 1, 2, \ldots$, one takes a bounded digital structuring element B_r, with B_0 being restricted to the origin, and B_r increasing with r; the morphological skeleton is made of all pixels p such that there is some integer $r \geq 0$ for which

$$p \in X \ominus B_r \qquad \text{and} \qquad p \notin (X \ominus B_r) \circ B_1.$$

See erosion, medial axis transform, opening, structuring element.

morphological system a non-linear counterpart of linear shift invariant systems, based on morphological operators which are invariant under both spatial and gray-level shifts. *See* linear shift invariant system, morphological operator.

morphology *See* mathematical morphology.

morphotropic phase boundary (MPB) materials that have a MPB assume a different crystalline phase depending on the composition of the material. The MPB is sharp (a few percent in composition) and separates the phases of a material. It is approximately independent of temperature in PZT.

MOS *See* mean opinion score or metal-oxide semiconductor.

MOS memory *See* metal-oxide semiconductor memory.

MOSFET *See* metal-oxide semiconductor field effect transistor.

MOSIS acronym for metal-oxide semiconductor implementation service. *See* metal-oxide semiconductor.

mother wavelet the wavelet from which wavelets in different scales are obtained by the translation and dilation operations. *See also* father wavelet.

motherboard in a computer, the main printed circuit board which contains the basic circuits and to which the other components of the system are attached. *See also* daughter board.

motion analysis determination of the motion of objects from sequences of images. It plays important roles in both computer vision and image sequence processing. Examples for the latter include image sequence data compression, image segmentation, interpolation, image matching, and tracking.

motion blur blur that is due to the motion of an object: it frequently arises when images

containing moving objects are grabbed by an insufficiently rapid digitizer.

motion compensation generation of a prediction image, an interpolated or extrapolated frame, from pixels, blocks, or regions from known frames, displaced according to estimates of the motion between the known frames and the target frame.

motion estimation (1) process of estimating the displacement of moving objects in a scene.

(2) strictly, the estimation of movement within a video sequence, including camera movement and the independent motion of objects in the scene. In practice, refers to the determination of optical flow (the spatiotemporal variation of intensity) which may not correspond to real movement (when, for example, an object moves against a background of the same color). Gradient-based methods are based on the expansion of a Taylor series for displaced frame difference yielding an "optical flow constraint equation". This must be combined with other constraints to yield a variational problem whose solution requires the iterative use of spatial and temporal derivatives. Block-matching methods rely on finding minimum error matches between blocks of samples centered on the point of interest. Frequency-based techniques measure phase differences to estimate motion.

motion measurement the measurement of velocities. Usual motion measurement techniques such as optical flow give incomplete and unstable results which must be regularized by comparing velocities over a whole moving object (the latter must first be segmented).

motion segmentation the decomposition of a scene into different objects according to the variation of their velocities. Motion segmentation requires the measurement of velocities across the scene.

motion stereo a specific case in motion estimation in which the 3-D scene is stationary and the only camera is in rigid motion.

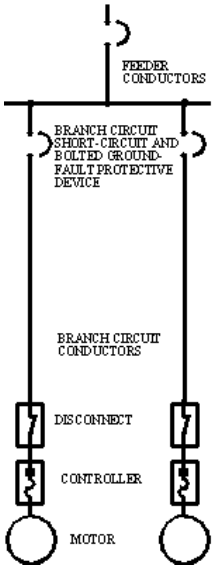
motion vector a vector displacement representing the translation of a pixel, block, or region between two frames of video, usually determined by optical flow calculation or block matching (see motion estimation). For instance, in the case of dense motion field, say, an optical flow field, a motion vector is assigned to each pixel on the image plane. In the case of block matching for image coding, a motion vector is assigned to each block. In the case of computer vision, a motion vector sometimes refers to the velocity of a point or an object in the 3-D space. Sometimes motion vectors are referred to as displacement vectors.

motional time constant a material parameter that is inversely proportional to the product of the frequency and Q-factor for a particular mode.

motor an electromechanical device that converts electrical energy from a DC or an AC source into mechanical energy, usually in the form of rotary motion.

motor circuit the three components of an electrical circuit are source, load, and interconnecting circuit conductors. A motor circuit is an electrical circuit designed to deliver power to a motor. It includes the overcurrent protective devices, controller, disconnect switch, circuit conductors, and the motor itself, as shown in the figure.

motor circuit protector (MCP) a listed combination motor controller containing an adjustable instantaneous-trip circuit breaker and coordinated motor overload protection. MCPs can provide short-circuit and bolted ground-fault protection via the circuit breaker magnetic element, overload protec-



A typical electric motor circuit.

tion via the overload device, motor control, and disconnecting means all in one assembly.

motor control center an enclosure with one or more sections containing motor control units that have a common power bus.

motor control circuit a circuit containing devices such as the start/stop switches, main-line coil, main-line sealing contacts, overload contacts, timers and timer contacts, limit switches, antiplugging devices, and anything else used to control devices in the motor circuit.

motor current signature analysis the use of the currents of an electric machine to provide diagnostic or other information on the health of the machine, coupling, or load.

motor operated switch a switch operated by a motor that is capable of being controlled from a remote location.

motor starter an electric controller, either manual or automatic, for accelerating a motor from rest to normal speed and for stopping the motor.

motor-generator set a set consisting of a motor mechanically coupled to and driving one or more generators. The set used to be employed for AC-to-DC or DC-to-AC power conversion or voltage level or frequency conversion. Solid-state conversion units are replacing motor-generator sets in most applications.

mouse an I/O device with a trackball used to produce signals which are interpreted as x/y coordinates. It is used as locator device, as are the joystick, trackball and tablet. The mouse is the most commonly used locator for working with windowing systems for its similarity with the movements of the hand, metaphor or the moving hand.

A mouse may present 1, 2, or 3 buttons. The actions associated to the pressing of buttons can lead to draw objects, select objects, activate menu, delete objects, etc. The action of pressing is called “click.” Rapidly double-clicking the mouse produces a different, program-dependent effect.

MOV *See* metal-oxide varistor.

move instruction a computer instruction that transfers data from one location to another within a computing system. The transfer may be between CPU registers, between CPU registers and memory or I/O interface in either direction. Some systems (such as Motorola M68000) permit transfer by a move instruction between memory locations (memory-to-memory transfer).

moving average an Nth order moving average relationship between an input x and output y takes the form

$$y[n] = \sum_{i=0}^{N-1} \alpha_i x[n-i].$$

A moving average process is any process y which can be expressed as the mov-

ing average of white noise x. *See also* autoregressive.

Moving Picture Experts Group (MPEG) group that standardizes methods for moving picture compression. MPEG-1 and MPEG-2 are very flexible generic standards for video coding, incorporating audio and system-level multiplex information. They use block-based motion-compensated prediction on 16×16 "macroblocks," and residue coding with the 8×8 discrete cosine transform. Frames types are intraframes (coded without reference to other frames), P frames (where the prediction is generated from preceding I and P frames), and B frames (where the prediction is generated bidirectionally from surrounding I and P frames).

MOVPE *See* metal-organic chemical vapor deposition.

MOX mixed oxide fuel, containing a mixture of U235 and PU239 oxides as the fissile material.

MPE *See* maximum permissible exposure.

MPEG *See* Moving Picture Experts Group.

MPP distance
See maximum a posteriori probability.

MPPC *See* mutually pumped phase conjugator.

MQW *See* multiple quantum well.

MRI *See* magnetic resonance imaging.

MRVQ *See* mean/residual vector quantization.

MSB in a binary word, a bit with the highest weight associated with it.

MSC *See* magnitude squared coherence.

MSE *See* mean squared error.

MSG *See* maximum stable gain.

MSI *See* medium-scale integration.

MSK *See* minimum-shift keying.

MSLM *See* microchannel-plate spatial light modulator.

MSLM logic gate *See* microchannel-plate spatial light modulator logic gate.

MTF *See* modulation transfer function.

MTTF *See* mean time to failure.

MTTR *See* mean time to repair.

MUI multi-user interference. *See* multiple access interference.

multi-carrier communications a communications method where the bandwidth is subdivided into several smaller frequency bands. Either the same information is transmitted over all subbands or different information is transmitted either simultaneously of successively over these bands. By doing so, the detrimental effects of frequency selective fading can be minimized.

multi-carrier modulation a modulation technique in which the channel is divided into narrow frequency bins (subchannels), and input bits are multiplexed into substreams, each of which is transmitted over a particular subchannel. The bit rates and transmitted powers associated with the substreams can be selected to maximize the total transmitted bit rate, subject to a total average power constraint, and also to achieve a desired transmitted spectrum.

multi-input–multi-output system (MIMO) also known as multivariable (MV) systems. A system that can transform two or more input signals to two or more output signals.

multi-input–single-output system (MISO) a system which can transform two or more input signals to one output signal. *See also* single-input–single-output system and multiple-input–multiple-output system.

multi-mode code a line code where each source word is represented by a code word selected from a set of alternatives. Code words are selected according to a predefined criterion, which may depend in part on the statistics of the encoded sequence, thereby causing the same source word to be represented by a number of different code words throughout the encoded sequence.

multi-mode fiber an optical fiber with a relatively large core diameter in which more than one and usually from several hundred to several thousand modes may propagate. The optical fiber may be either a step index or a graded index fiber.

multi-mode optical fiber *See* multi-mode fiber.

multi-mode oscillation oscillation in more than a single cavity mode.

multi-phase oscillator an oscillator that provides m sinusoidal voltages shifted with respect to each other by $2\pi/m$ phase angle. It is obtained by connection of m similar isolated phase-shifting circuits in a loop. The outputs of isolating stages provide the required output voltages. These oscillators are usually used in instrumentation where lightweight auxilliary three-phase power supplies are required. Also called m-phase oscillator.

multi-resolution analysis *See* multi-scale analysis.

multi-scale analysis the analysis or transformation of a signal using analysis basis Functions or analysis filters with differing time resolutions or spatial resolutions. Equivalently the basis functions have differing frequency resolutions. This is in contrast to the continuous or discrete Fourier transform whose analysis basis functions all have (roughly) the same frequency and time resolution. For discrete multi-resolution analysis a multi-level filter bank is often used: the discrete wavelet transform being a classic example. *See also* multiscale.

multi-user CDMA a term that has been used to denote a CDMA system where the multiple access interference is used constructively in the receiver to enhance performance and not treated merely as interfering noise as for the conventional single-user receiver. In principle, any CDMA system is multi-user CDMA, since it supports multiple users.

multi-user detection joint detection of the data symbols for all the users in a multiple access system, as opposed to single-user detection where the data symbol for each user is detected individually.

multi-user detector a detector in a spread spectrum multiple access system or CDMA system where the data bits from all the users are detected using a joint detection algorithm. Such a detector typically has significantly better performance (results in lower bit error probabilities) in comparison to a detector that detects the various signals individually and, in detecting a bit from a given user, treats all the other signals (from other users) as a composite source of interference.

multi-user interference (MUI) *See* multiple access interference.

multi-user receiver a spread spectrum or CDMA receiver that utilizes a multi-user detector.

multi-variable system (MV) *See* multi-input–multi-output system.

multibus a standard system bus originally developed for use in Intel's Microcomputer Development System (MDS). This standard gives a full functional, electrical, and me-

chanical specification for a backplane bus through which a number of circuit boards may be interconnected. A full range of devices may be involved, including computers, memory boards, I/O devices, and other peripherals.

multichannel acousto-optic device acousto-optic device with multiple independent transducers bonded to the acousto-optic medium to introduce multiple independent acoustic signals in the device.

multigrid an efficient numerical algorithm for solving large sets of linear equations $A\boldsymbol{x} = \boldsymbol{b}$, particularly for "stiff" (nearly singular) A. The algorithm defines a hierarchy of grids, with interpolation and decimation operations defined between successive grids in the hierarchy. A system of equations $A_g\boldsymbol{x}_g = \boldsymbol{b}_g$ is defined on each grid g: the systems on finer grids yield higher resolution solutions, however coarser grids yield much faster convergence times. Various empirical strategies have been devised which dictate the order in which different grids are used to contribute to the final solution. *See also* interpolation, decimation, multiscale.

multigrid block matching a block matching technique that is carried out with a hierarchical structure, known as a multigrid structure. In the highest hierarchical level an image may be decomposed into large blocks each with equal size. Each block in a higher level is further equally decomposed into subblocks, forming the next level. The block matching is first applied to the highest level. The matching results obtained are then propagated to the next hierarchical level. That is, the matching results obtained in the highest level are utilized as initial estimates and refined in the second highest level. This process continues until the last hierarchical level. It is noted that the term multigrid block matching is sometimes intermixed with multiresolution block matching in the literature. In the strict sense they are different. In the former, different levels in the hierarchical structure have the same resolution, while in the latter, different levels have different resolutions.

multilayer control operation or structure of the control system with the (multilayer) controller decomposed into two or more control layers; usually in case of the controller with two control layers one uses the terms two-layer control and two-layer controller. Typically within the multilayer control hierarchy the frequency of interventions made by control layers decreases as one moves up the hierarchy.

multilayer perceptron an artificial neural network consisting of an input layer, possibly one or more hidden layers of neurons (perceptrons), and an output layer of neurons. Each layer receives input from the previous layer and the outputs of the neurons feed into the next layer.

multilayer resist (MLR) a resist scheme by which the resist is made up of more than one layer, typically a thick conformal bottom layer under a thin imaging layer, possibly with a barrier layer in between.

multilayered medium a medium composed by several different layers of dielectric materials. Such media find wide application for both microwave and optical integrated circuits.

multilevel cache a cache consisting of two or more levels, (typically) of different speeds and capacities. *See also* hierarchical memory.

multilevel code in this scheme each bit (level) of a signal is encoded with different error correction codes of same block length. It has inherent unequal error protection capability.

multilevel control operation or structure of the control system, where the controller, or the given control layer, is composed of sev-

eral local decision units coordinated (see coordination) by a supremal unit (coordinator unit); the number of levels can be greater than two — in this case decision units situated at an intermediate level are supremal (coordinating) units for the subordinated lower level units and at the same time are local units as perceived by the level above; the term multilevel control is equivalent to the hierarchical control, when the latter term is used in the narrow sense.

multilevel memory *See* hierarchical memory.

multilevel optimization decision mechanism (or operation of such mechanism) whereby the decisions are made by solving a large-scale optimization problem, partitioned (decomposed) into several smaller problems; in a two-level optimization case local decisions are influenced by the coordinator — in the process of iterative coordination until overall satisfactory decisions are worked out; in a three-level or in a multilevel case the coordinating unit of the higher level coordinates the decisions of several subordinate units, which themselves can be coordinating units for the lower levels.

multimedia a generic category of computer-controlled media that combines text, sound, video, animation, and graphics into a single presentation. An example of multimedia would be an electronic encyclopedia in CD-ROM format.

multiparameter sensitivity appears as an effort to introduce generalized functions that represent the influence of all circuit elements. If the circuit function depends on more than one component, then $F(s, x_1, x_2, \ldots, x_n) = F(s, \mathbf{x})$ and one may write that

$$\frac{dF(s,\mathbf{x})}{F(s,\mathbf{x})} = d\ln F(s,\mathbf{x}) = \sum_{i=1}^{n} \mathbf{S}_{x_i}^{F(s,\mathbf{x})} \frac{dx_i}{x_i}$$

One can introduce a multiparameter sensitivity row vector

$$\mathbf{S}_{\mathbf{x}}^{F(s,\mathbf{x})} = \left[\mathbf{S}_{x_1}^{F(s,\mathbf{x})} \mathbf{S}_{x_2}^{F(s,\mathbf{x})} \ldots \mathbf{S}_{x_n}^{F(s,\mathbf{x})}\right]$$

To characterize and compare the vectors of this type one introduces different vector measures that are called sensitivity indices. Sometimes these sensitivity indices are considered as multiparameter sensitivities.

multipath (1) propagation of electromagnetic waves along various paths from the transmitter to the receiver.

(2) interference of electromagnetic waves due to multiple propagation paths (e.g., direct wave plus ground reflection).

multipath propagation the process by which a radio signal propagates from the transmitter to the receiver by way of multiple propagation paths. Depending on the frequency range employed in transmission, the physical propagation phenomena contributing to multipath propagation include reflections from terrain and man-made obstacles, diffraction and refraction. Multipath propagation leads, similar to acoustic echoes, into multiple replicas of the transmitted signal to be received, each having experienced potentially different delays, attenuations, and phase shifts.

multiple access channel a multiple transmitter, single receiver communication system, in which the received signal is a (possibly non-deterministic) function of all transmitted signals. *See also* broadcast channel, interference channel, two-way channel.

multiple access interference (MAI) also multi-user interference (MUI). Interference between users in a multiple access system stemming from nonorthogonality between users, e.g., nonorthogonal code sequences in CDMA or (partially) overlapping frequency bands (FDMA) or time-slots (TDMA).

multiple dwell detector a detector typically used in spread spectrum PN sequence acquisition (i.e., PN sequence synchronization) where the detection process is carried out in stages. In the PN code acquisition process, in a spread spectrum receiver, the receiver makes a hypothesis about the correct PN code phase and then tests the hypothesis by correlating the received signal with a locally generated version with a phase equal to the hypothesized phase. If the value of the resulting correlation is less than a given threshold value, then the receiver examines a new phase. If the correlation is greater than the threshold value, then the receiver continues the examination of the same PN code phase by performing a further correlation with the same phase in a detection stage commonly referred to as the confirmation stage.

multiple instruction multiple data (MIMD) architecture a parallel processing system architecture where there are more than one processors and where each processor performs different instructions on different data values.

In an optical computer implementation, this can be done with a lenslet array, a hologram array, or a set of beamsplitters.

multiple instruction single data (MISD) architecture a parallel processing architecture where more than one processor performs different operations on a single stream of data, passing from one processor to another.

multiple quantum well (MQW) collection of alternating thin layers of semiconductors (e.g, GaAs and AlGaAs) that results in strong peaks in the absorption spectrum which can be shifted with an applied voltage.

multiple reflection algorithm a technique for the solution of nonlinear device-circuit interactions that uses a time domain representation of the nonlinear device waveforms and a frequency domain representation of the linear circuit waveforms coupled together with an ideal zero length transmission line.

multiple scattering strong interaction, with multiple hits, of the light wave with a highly inhomogenous medium. This produces large changes both in the amplitude, phase, and state of polarization of the wave.

multiple signal classification (MUSIC) a method in array processing for estimating parameters such as direction of arrival (DOA), based on estimating the noise subspace and exploiting the fact that the true signal (with the true parameters) belongs to the signal subspace (the orthogonal complement to the noise subspace).

multiple sub-Nyquist encoding (MUSE) a technique used in Japanese HDTV systems.

multiple-access time-division a method for allowing many users to communicate simultaneously with a single receiver by assigning transmissions to different time slots. The channel, which is shared among the users, is divided into successive frames, which are subdivided into time slots. Each user (or packet) is assigned a specific time slot within the current frame.

multiple-input–multiple-output system a system that transforms two or more input signals to two or more output signals. Also known as SISO system and single-variable (SV) system. *See also* system, single-input–single-output system.

multiple-operand instruction a computer instruction that contains two or more data elements that are used while executing the instruction, i.e., ADD Z, X, Y is a multiple operand instruction that specifies the values of X and Y are added together and stored into Z.

multiple-stage decision making decision making involving future operation of the system, as in the case of closed-loop feedback

control or limited-lookahead control, where possible future measurements and decision interventions are taken into account when considering the decision taken at a given time.

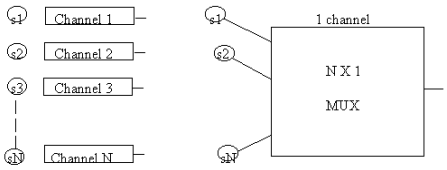
multiplex (1) to use a single unit for multiple purposes, usually by time sharing or frequency sharing. *See also* multiplexer, multiplexing.

(2) the armature winding of a commutated electrical machine in which multiple, identical coil windings are placed on the rotor. In general, the number of the "plex" describes the total number of parallel windings between brush positions and, thus, also the multiplier on the number of parallel paths between brushes that would be provided by a simplex winding. For example, a duplex winding will have twice as many parallel electrical paths between brushes as a simplex winding, a triplex winding will have three times the number of paths, etc. *See also* simplex, duplex, reentrancy.

multiplexer a combinational logic device with many input channels and usually one output, connecting one and only one input channel at a time to the output.

multiplexer channel a computer I/O subsystem that allows multiple slow to medium speed devices to transfer data to or from the computer concurrently. *See also* byte multiplexer channel, block multiplexer channel, selector channel.

multiplexing (1) the process of transmitting a large number of information units over a smaller number of channels or lines. For example, if we have *N* independent signals that we want to transmit, then without using a multiplexer we need *N* independent channels to do so. Using a multiplexer to control the flow of these signals in only one channel reduces the number of wires, thus decreasing cost and increasing efficiency. Multiplexing is the superimposition of multiple signals to make up one signal. This is done to make



Multiplexing.

the transmission of the signals efficient. Signals are multiplexed at the sending end of communication systems, and demultiplexed at the receiving end, in order to obtain the original signals.

(2) of or being a communication system that can simultaneously transmit two or more messages on the same circuit or radio channel.

multiplication pattern for arrays of similar elements, it is the product of the pattern of a single element and the array factor of the array.

multiplicative acousto-optic processing acousto-optic signal processing where the light is repeatedly modulated by a sequence of acousto-optic devices to result in a multiplication operation of the individual light amplitude or intensity modulations.

multiplier an electronic system or computer software which performs the multiplication calculation.

multiplying D/A a D/A conversion process where the output signal is the product of a digital code multiplied times an analog input reference signal. This allows the analog reference signal to be scaled by a digital code.

multipoint bus a bus to which multiple components may be attached. The PCI bus is an example of a multipoint bus. See also point-to-point bus.

multiport a circuit presenting multiple access ports.

multiport memory one memory module can be accessed by two devices simultaneously. One example is a video memory, which is interfaced to a graphics co-processor as well as the video interface of the monitor.

multiprocessor a computer system that has more than one internal processor capable of operating collectively on a computation. Normally associated with those systems where the processors can access a common main memory.

There are some additional stipulations for a "genuine multiprocessor:"

1. It must contain two or more processors of approximately comparable capabilities.

2. All processors share access to a common, shared memory.

3. All processors share access to common I/O facilities.

4. The entire system is controlled by a single operating system (OS).

See also multiple instruction multiple data architecture, operating system, shared memory architecture.

multiprogramming a system that allows the processor to execute two or more programs concurrently.

multipulse converter a three-phase converter that generates more than six pulses of DC per cycle. Multiple converters are connected so that the harmonics generated by one converter are canceled by harmonics produced by other converters, in order to reduce the line harmonics and improve the system power quality.

multirate finite impulse response filter a finite impulse response (FIR) filter in which the sampling rate is not constant.

multirate signal processing a system in which there is at least one change of sampling rate. Typically an input signal is split into two or more sub-signals each with a sampling rate lower than the input signal.

multiresolution analysis analysis method that decompose a signal into components at different resolution level; the fine to coarse features are revealed in the fine to coarse resolution components.

multiresolution coding coding schemes that involve a multiresolution structure.

multiscale characterized by a parameterization or decomposition in scale, as opposed to (for example) time or frequency, in particular, an algorithm that computes or analyzes a function or an image at multiple resolutions. *See also* wavelet, multigrid, Laplacian pyramid, quadtree, resolution.

multispectral image an image that contains information from more than one range of frequencies. In this sense, an RGB color image is multispectral in that it contains red, green, and blue information. More usually, multispectral refers to frequencies of such number and type that it presents difficulties in interpretation and display. Adding infrared, ultraviolet, and radar information to an RGB image creates a problem, since the data cannot be simply drawn on a display. The use of many frequencies also provides a wealth of information sometimes needed to make fine distinctions between regions in an image, especially in satellite imagery. *See also* data fusion, sensor fusion.

multispeed motor a motor that can be operated at any one of two or more definite speeds. For DC and induction motors, the speed settings are practically independent of the load, although the speed may vary with load for certain types of motors. Multispeed induction motors typically have two or more sets of windings on the stator with a different number of poles, one of which is excited at any given time.

multistage depressed collector klystron a specially designed klystron in which decreasing voltage zones cause the electron beam to be reduced in velocity before striking

the collector element. The effect is to reduce the amount of heat that must be dissipated by the device, improving operating efficiency.

multistage detection an iterative detection strategy where increasingly more reliable tentative decisions are made for each iteration (stage) of the detection algorithm.

multistage interconnection network an interconnection network built from small switches (often with fan-in and fan-out of 2); if 2^n modules are connected on each side of the network, $2n$ stages are required.

multistage subset decoding in this scheme decoding is done, first on the lowest partition level of the signal set and then gradually on the higher level with decoded information flow from the lower to the higher level.

multistage vector quantization a method for constrained vector quantization where several quantizers are cascaded in order to produce a successively finer approximation of the input vector. Gives loss in performance, but lower complexity than optimal (single-stage) vector quantization.

multistage VQ *See* multistage vector quantization.

multithreaded several instruction streams or threads execute simultaneously.

multitone testing a measurement technique whereby an audio system is characterized by the simultaneous application of a combination of sine waves to a device under test.

MUSE *See* multiple sub-Nyquist encoding.

MUSIC *See* multiple signal classification.

mutual coupling electromagnetic interaction between the elements in a phased array antenna in which the radiation from one element causes distortion of the current distributions or aperture field distributions of the other elements. Feed network mutual coupling occurs when the amplitude and phase of the excitation at a feed point are altered by the presence of reflected waves in the network.

mutual exclusion a synchronization problem requiring that two or more concurrent activities do not simultaneously access a shared resource.

mutual inductance the property that exists between two current-carrying conductors when the magnetic lines of force from one link with those from another.

mutual information information theoretic quantity representing the amount of information given by one random variable about another. For two discrete random variables X and Y, with joint probability mass function $p(x, y)$ and marginal probability mass functions $p(x)$ and $p(y)$, respectively, the mutual information $I(X; Y)$ is given by

$$I(X; Y) = \sum_{x \in \mathcal{X}} \sum_{y \in \mathcal{Y}} p(x, y) \log \frac{p(x, y)}{p(x)p(y)}$$

where $\mathcal{X}$ and $\mathcal{Y}$ are the support sets of X and Y respectively. *See also* differential entropy, relative entropy.

mutually pumped phase conjugator (MPPC) a phase conjugator in which two phase conjugate waves are generated simultaneously when two beams are incident into the phase conjugator. With a mutually pumped phase conjugator, two incident laser beams mutually pump the photorefractive medium and produce two phase conjugate waves. There are many physical mechanisms that can yield mutually pumped phase conjugation, for example, MPPC via self-oscillation in four-wave mixing, MPPC with

stimulated scattering, MPPC with ring resonator, etc.

MV multi-variable system. *See* multi-input–multi-output system.

MVA interrupting rating the interrupting rating of a device expressed in terms of megavolt-amperes. The conversion between fault volt-amps and fault current in three-phase systems is $VA = 1.73$ — operating RMS line-line voltage — largest phase fault current expressed in RMS symmetrical amperes. Power circuit breakers can have separate MVA and maximum current interrupting ratings, with adjustments when the circuit breaker is operated below rated voltage.

MWIR laser a laser producing light in the midwavelength (2 – 5 micron) range, useful in chemical species identification and other applications.

N

n-channel MOSFET a MOSFET where the source and drain are composed of heavily doped n-type semiconductor regions on a p-type surface. Electrons form drain-source current when the applied gate and substrate potentials invert the p-type surface between them.

n-well a region of n-type semiconductor located at the surface of a p-type substrate (or larger P-well) usually created in order to contain p-channel MOSFETs.

NA *See* numerical aperture.

Nakagami fading a general model of fading used in the modeling of radio communication channels, introduced by Nakagami in 1960, which includes as a special case the Rayleigh model of fading.

NaN acronym for not a number. Used in IEEE floating-point representations to designate values that are not infinity or zero or within the bounds of the representation.

NAND gate a logic circuit that performs the operation equivalent to the AND gate followed by the inverter. The output of a NAND gate is low only if all inputs are high.

nano prefix for metric unit that indicates division by one billion.

nanocell cell of radius up to 10 m. *See also* cell.

nanoelectronics a future integrated circuit technology characterized by minimum lateral feature sizes in the range 1 – 100 nanometers. Also pertains to ICs utilizing quantum devices.

nanolithography Lithography involving the printing of ultra-small features, typically on the order of nanometers in size.

nanometer a metric measure of distance equivalent to one billionth of a meter.

narrow band referring to a bandwidth of 300 hertz or less.

narrow-band fading fading in which the communication channel amplitude can be assumed independent of fading. Occurs when the transmitted signal bandwidth is considerably less than the coherence bandwidth of the channel.

narrow-band filter narrow-band filters are those which pass signals undistorted in one or a set of narrow frequency bands and attenuate or totally eliminate signals in the remaining frequency bands.

narrow band FM frequency modulation scheme where the ratio of peak frequency deviation to the frequency of the modulating signal is smaller than 0.2.

narrow-band interference (NBI) interference from a source that occupies a smaller bandwidth that the desired signal. One example is a single sinusoid (or a narrow-band communication system) interfering with a wide-band system, possibly a spread-spectrum system.

nasal a sonorant phone that is produced with the vocal tract closed and the velum open. Nasals have a formant-like spectrum, but much information is carried out during the transition for the opening of the velum. Hence, the design of very effective automatic systems for the recognition of particular nasals (e.g., $/m/$, $/n/$) must take into account these brief transitions.

Nash equilibrium a noncooperative equilibrium in nonzero-sum games defined by an outcome for each player that cannot be im-

proved by altering his decision unilaterally. The roles of all players are symmetric in the sense that they make their decisions independently and none of them dominates any other. If $J_i, i = 1, 2, \ldots, N$ is a cost function of ith player in N-person game and d_i his strategy then N-tuple $d_1^*, d_2^*, \ldots, d_N^*$ constitutes a Nash equilibrium solution if

$$\begin{aligned} J_1\left(d_1^*, d_2^*, \ldots, d_N^*\right) &\leq J_1\left(d_1, d_2^*, \ldots, d_N^*\right) \\ J_2\left(d_1^*, d_2^*, \ldots, d_N^*\right) &\leq J_2\left(d_1^*, d_2, \ldots, d_N^*\right) \\ &\vdots \\ J_N\left(d_1^*, d_2^*, \ldots, d_N^*\right) &\leq J_N\left(d_1^*, d_2^*, \ldots, d_N\right) \end{aligned}$$

for any admissible $d_i; i = 1, 2, \ldots, N$. The nonzero-sum game may admit more than one Nash equilibrium solution with outcomes different in each case. Since the total ordering among N-tuples of numbers does not exist, it is usually not possible to declare one of them as the most favorable. Nevertheless, some of strategies may be viewed as better than other ones if the respective outcomes are in partial order. With this notion of betterness, a Nash equilibrium strategy N-tuple is admissible if there exists no better one. In the case when the game is played, many times in the same conditions, the Nash equilibrium may be defined for average values of the cost functional and mixed strategies.

NASTRAN a widely used computer code for mechanical and structural analysis, such as for opto-mechanical and thermal analyses.

National Electrical Code (NEC) a standard for electrical construction, published by the National Fire Protection Association (NFPA 70-1). The National Electrical Code is often adopted by local jurisdictions and used by their electrical inspectors.

National Electrical Manufacturers Association (NEMA) an electrical trade association that establishes standards for electrical equipment. In the case of electric motors, NEMA establishes standard frame sizes, starting torque, starting current, and other quantities for a given horsepower machine.

National Fire Protection Association (NFPA) sponsor and publisher of the National Electrical Code and other safety standards.

National Television System Committee (NTSC) a body that recommended the standard for colored television broadcasts in the U.S. in 1953. NTSC video contains 525 lines, a field rate of 59.94 fields/second, a horizontal frequency of 15,734.264 Hz, and an interlaced color subcarrier frequency of 3.579545 MHz. The NTSC format is also in use by many countries other than the U.S.

natural broadening spectral broadening of a transition in a laser medium due to spontaneous decay; sometimes called lifetime broadening.

natural commutation commutation of current from one switching device to another in a power electronics converter at the instant the incoming voltage has a higher potential than that of the outgoing wave, without the aid of any commutation circuitry. *See also* commutation.

natural constraint constraint that results from the particular mechanical and geometric characteristics of the task configuration. Used to define a particular situation occurring between the manipulator end-effector and the work environment. These constraints are defined in terms of linear and angular velocities and forces and/or torques that are specified to execute the task. Natural constraints are intrinsically associated with the particular task. For example, consider a task that an end-effector moves along a rigid surface and is not free to move through that surface. In this particular situation, a natural position constraint exists. In addition, if the surface is frictionless, the end-effector is not free to apply arbitrary force tangent to the surface, and hence a natural force constraint exists.

natural frequency the frequency of any oscillating term in the response of the linear

system which is due to the initial value of that system. For linear time invariant systems the total response of the system can be represented as the sum of the zero-input response plus the zero state response. The characteristic polynomial of a system (representing the zero input response), $Q(\lambda) = (l - l_1)(l - l_2) \ldots (l - l_n) = 0$ has n roots; these roots are called the Natural frequencies. Natural frequencies are also known as the characteristic values, eigenvalues, and characteristic roots of the system.

natural laser a laser occurring in nature.

nautical mile (nm) 1,852 meters, exactly. Approximately 1 minute of arc on the earth's surface.

NBI *See* narrow-band interference.

NDR *See* negative differential resistance.

near field (1) in antennas, the electromagnetic field that is in the vicinity of an antenna where the angular field distribution is dependent on the distance from the antenna.

(2) in optics, region close to a diffracting aperture where neither the form nor the size of a transmitted beam have changed significantly from their values at the aperture.

near infrared light in the wavelength region of the infrared electromagnetic spectrum which is adjacent to the visible spectrum. The spectral range of the near infrared region is typically considered to be 700 – 2500 nm.

near–far effect large dissimilarities in received power from different users, thereby causing trouble in detecting the weaker users. Commonly found in DS-CDMA systems.

near–far resistant a device, e.g., a detector or parameter estimator, that is insensitive to the near–far effect.

nearest neighbor algorithm a method of classifying samples in which a sample is assigned to the class of the nearest training set pattern in feature space, a special case of the K-nearest neighbor algorithm.

NEC *See* National Electrical Code.

Necker cube a classical example of ambiguous wireframe geometrical figures. The Necker cube can take either of two perspectives, as it were seen from above or from below.

NEESLA *See* nonuniformly excited equally spaced linear array.

negation operator *See* complement operator.

negative definite function a scalar function $V(x, t)$ where $-V(x, t)$ is positive definite.

negative differential resistance (NDR) a condition where the slope of the current vs. voltage characteristic is negative. Negative differential devices include quantum devices such as tunnel diodes and resonant tunneling structures. Negative differential resistance can also be obtained in a variety of circuit topologies.

negative photoresist a photoresist whose chemical structure allows for the areas that are exposed to light to develop at a slower rate than those areas not exposed to light.

negative resistance oscillator oscillator circuit that functions based on an active device where the device is biased under certain conditions and terminated with impedance levels such that it exhibits a negative resistance at a particular frequency or frequency range.

negative semidefinite function a scalar function $V(x, t)$, where $-V(x, t)$ is positive semi-definite.

negative sequence the set of balanced but reverse sequence (acb) components used in symmetrical component analysis. Normal load currents contain no negative sequence current.

negative sequence overcurrent relay a protective relay that senses and operates on negative sequence overcurrent. Typical applications include the sensing of unbalanced faults and the protection of synchronous and induction machines from rotor overheating.

negative transition angle the angular portion of the time based output signal that has a negative slope, expressed in degrees. This quantity could be loosely interpreted as the "trailing edge" angle.

negative-positive-zero (NPO) an ultrastable temperature coefficient ($\pm$ 30 ppm/°C from $-55°$ to 125°C) temperature-compensating capacitor.

negative-sequence impedance the impedance offered by a circuit when negative-sequence currents alone flow through it, expressed in ohms. The impedance is complex, with its real part being the circuit resistance and imaginary part, which is a function of frequency and inductance referenced as negative-sequence reactance, also expressed in ohms.

negative-sequence reactance inductive reactance offered by a circuit for the flow of negative-sequence currents alone. Expressed in ohms, the inductive reactance is a function of frequency and the inductance of the circuit to negative-sequence current flow. *See also* negative-sequence impedance.

neighborhood in self-organizing system an area surrounding the winner in self-organizing competitive learning. According to so-called Mexican-hat interaction between the brain cells, Kohonen proposes that weight updating should be conducted not only for the winner but also for its neighbors. *See also* Mexican-hat function, self-organizing algorithm.

neighborhood operation an operation, such as averaging or median filtering, that is dependent upon the locality of samples in a signal, not the signal as a whole. Also called a window operation. *See* windowing.

NEMA *See* National Electrical Manufacturers Association.

NEMA code letter the nameplate letter designation used to indicate the input kilowatt-amp rating of a motor under locked-rotor, or starting conditions.

NEMA size a standard-size device, such as a motor controller. The NEMA size establishes the rating of the device. *See also* National Electrical Manufacturers Association.

NEMA type for induction motors NEMA establishes five types of induction motors (A, B, C, D, and E) that have different torque-speed characteristics to account for various types of loads.

nematic the type of liquid crystal in which the molecular chains align; such alignment can be controlled across the liquid crystal if it can be constrained at the boundaries.

nematic liquid crystal one of the state of liquid crystal materials, where the elongated liquid crystal molecules are all oriented in the same direction within a layer. The molecules can be reoriented with an external electric field, allowing use in displays and spatial light modulators. *See also* liquid crystal on silicon, twisted nematic.

neocognitron a biologically inspired hierarchical network developed primarily for the recognition of spatial images. The network has up to nine layers. The lower layers respond to simple features and the higher layers

respond to more complex features. Learning can be unsupervised or supervised.

neodymium-iron-boron a high energy magnetic material composed of the three nominal elements and other additives, characterized by a high residual induction and high coercivity. NdFeB has a high magnetic temperature coefficient, which is undesirable for high-temperature use.

neper a natural logarithm of a ratio.

nested structure an information structure in which each player has an access to the information acquired by all his precedents, i.e., players situated closer to the beginning of the decision process. If the difference between the information available to a player and his closer precedent involves only his actions, then the structure is ladder-nested. This structure enables decomposition of the decision process onto static games that in turn results in recursive procedure for its solution. For dynamic infinite discrete-time decision processes, the ladder-nested structure results in the classical information pattern.

nested subroutine a subroutine called by another subroutine. The programming technique of a subroutine calling another subroutine is called nesting.

network analyzer a test system that measures RF or microwave devices in terms of their small signal characteristics. The results are typically presented as two-port parameter matrices such as s-parameters, y-parameters, or z-parameters.

network distribution system a distribution system in which each load is supplied by more than one path.

network function the ratio $H(s)$ of the Laplace transform of the output function to the Laplace transform of the input function. *See also* transfer function.

network interface card (NIC) the physical device or circuit used to interface the network with a local workstation or device.

network measurement division (NMD) connector a special coaxial connector type developed by Hewlett Packard for test cables used in conjunction with an s-parameter test set.

network pruning (1) the removal from a network of interconnections and/or neural units that are identified (after training) as being either unnecessary or unimportant. After pruning, the network must be retrained.

(2) the process of cutting out nodes or unwanted connections in a neural network, to save computation or computational hardware. *See also* artificial neural network.

network time constant minimum of the allowable transfer delay and the time required to fill up the buffer in the node. The NTC is indicative of how long transients last inside a network node. The NTC is the interval over which network traffic must be averaged.

network weight a scalar value representing the strength of the connection between the output of one neuron and the input of another.

neural network a parallel distributed information processing structure consisting of processing elements, called neurons, interconnected via unidirectional signal channels called connections. Neurons can possess a local memory and can carry out localized information processing operations. Each neuron has a single output connection. The neuron output signal can be of any mathematical type desired. The information processing that goes on within each processing element can be defined arbitrarily, with the restriction that it must be completely local (it depends only on the current values of the input signals arriving at the processing element and on values stored in the processing element's local memory, e.g., weights).

neural tree a tree-structured neural network. Such networks arise in the application of certain kinds of constructive algorithm.

neuro-fuzzy control system control system involving neural networks and fuzzy systems, or fuzzy neural networks. *See also* adaptive fuzzy system.

neuron a nerve cell. Sensory neurons carry information from sensory receptors in the peripheral nervous system to the brain; motor neurons carry information from the brain to the muscles.

neutral axis the axis near which the direction of the velocity of armature conductors is exactly parallel to the magnetic flux lines so that the EMF induced in the conductors is zero. This axis, also referenced as the magnetic neutral axis, shifts in the direction of rotation of the machine as a generator or motor. The amount of shift depends on the armature current and hence on the load of the machine.

neutral a conductor which completes the electric circuit from the load to the source in three-phase Y-connected and single phase AC electric power systems, typically at or near the potential of the earth.

neutral plane *See* neutral axis.

neutral zone in permanent magnets, a plane through which all lines of flux are parallel to the direction of magnetization, i.e., the plane between north and south poles.

neutrino laser laser in which the amplified field consists of neutrinos rather than electromagnetic waves; suggested importance in the early universe.

New York City blackout a particularly disastrous failure of the power system in New York City in 1977.

Newton's method a class of numerical root-finding methods; that is, to solve $f(x) = 0$. The methods are based on iteratively approximating f using a low order polynomial and finding the roots of the polynomial. The most commonly used first-order method iterates the following equation:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

where f' represents the derivative of f.

Newton–Euler recursive algorithm used in robotics, to calculate joint generalized forces as a result of two recursions along the kinematical structure of the robot. First one, a forward recursion, calculates spatial velocities and accelerations from the base of the manipulator towards its tip. Second one, a backward recursion calculates the spatial forces and torques along the structure in the opposite direction. Projection of the spatial force and torques at the joint axis results in the generalized force at the joint. The resulting Newton–Euler equations of motion are not in closed form as opposite to the result of using Lagrange formalism to the dynamical system of the robot itself. *See also* Lagrange formulation.

Newton–Raphson method a numerical method for finding the solution to a set of simultaneous nonlinear equations. Variations of this method are commonly used in circuit simulation programs.

Neyman–Pearson detector a detector that minimizes the miss probability within an upperbound constraint on the false-alarm probability.

NFPA *See* National Fire Protection Association.

nibble four bits of information.

nibble-mode DRAM an arrangement where a dynamic RAM can return an extra

three bits, for a total of four bits (i.e., a nibble), with every row access.

The typical organization of a DRAM includes a buffer to store a row of bits inside the DRAM for column access. Additional timing signals allow repeated accesses to the buffer without a row-access time. *See also* two-dimensional memory organization.

NIC *See* network interface card.

Nichols chart in control systems, a plot showing magnitude contours and phase contours of the return transfer function referred to ordinates of logarithmic loop gain and abscissae of loop phase angle.

night vision *See* scotopic vision.

NMD connector *See* network measurement division connector.

NMI *See* nonmaskable interrupt.

NMR nuclear magnetic resonance. *See* magnetic resonance imaging.

NMOS *See* n-channel MOSFET.

no fetch on write strategy in the write-through cache policy where a line is not fetched from the main memory into the cache on a cache miss if the reference is a write reference. Also called non-allocate on write, as space is not allocated in the cache on write misses.

no load tap changer device that provides for changing the tap position on a tapped transformer when the transformer is de-energized. Different taps provide a different turns ratio for the transformer.

no voltage holding coil a holding coil that keeps the main-line contactor closed on zero voltage conditions. DC motor controllers that contain this feature are used in places where the motor is vital to the operation of a process. These controllers can maintain control to the motor under momentary line power loses, by using the CEMF of the coasting armature to keep power to the main-line coil/contactor. If power to the motor controller is not restored within a short period of time, the motor coasts to a speed where it can no longer keep the main-line contactor closed. At this point, the m-coil drops out to insure starting resistors are placed back in the circuit.

no-load test measurement of input parameters of an induction motor while running at nearly synchronous speed, with zero output on the shaft. This test is used to determine the magnetizing reactance of the motor equivalent circuit. *See also* open-circuit test.

no-op a computer instruction that performs no operation. It can be used to reserve a location in memory or to put a delay between other instruction execution.

no-write allocate part of a write policy that stipulates that if a copy of data being updated are not found in one level of the memory hierarchy, space for a copy of the updated data will not be allocated in that level. Most frequently used in conjunction with a write-through policy.

nodal cell cell with a radius of up to 300 m. Typically an isolated cell acting as a high capacity network node. *See also* cell.

nodal system a secondary system of equations using nodal voltages as variables.

node a symbol representing a physical connection between two electrical components in a circuit. *See also* graph.

node analysis a circuit analysis technique in which KCL is used to determine the node voltages in a network.

noise (1) any undesired disturbance, whether originating from the transmission medium or the electronics of the receiver it-

self, that gets superimposed onto the original transmitted signal by the time it reaches the receiver. These disturbances tend to interfere with the information content of the original signal and will usually define the minimum detectable signal level of the receiver.

(2) any undesired disturbance superimposed onto the original input signal of an electronic device; noise is generally categorized as being either external (disturbances superimposed onto the signal before it reaches the device) or internal (disturbances added to the signal by the receiving device itself). *See also* noise figure, noise power ratio. Some common examples of external noise are crosstalk and impulse noise as a result of atmospheric disturbances or manmade electrical devices. Some examples of internal noise include thermal noise, shot noise, 1/f noise, and intermodulation distortion.

noise bandwidth an equivalent bandwidth, W_N, of a system expressed as

$$W_N = \frac{\int_0^{\text{inf}} |H(\omega)|^2}{|H(\omega_0|^2} ,$$

where $H(\omega)$ is the transfer function of the system and ω_0 is the central frequency.

noise circles circles of constant noise figure plotted on the Smith chart. These circles can be used to graphically impedance match a device to achieve a desired noise figure.

noise clipping a process by which high noise peaks are clipped or limited to eliminate most of their energy, thereby removing the worst effects of impulse noise.

noise factor *See* noise figure.

noise figure an indication of the contribution of that component or system to the level of noise observed at the output. The noise figure therefore gives an idea of the amount of noise generated within the component or system itself. It is usually expressed in decibels (dB) and is given by the ratio of the input signal-to-noise ratio to the output signal-to-noise ratio of the component or system. This is defined as

$$\text{Noise Figure (NF)} \triangleq \frac{(S/N)_{\textbf{input}}}{(S/N)_{\textbf{output}}} .$$

In decibels this is given by:

$$[\text{NF}]_{\textbf{dB}} \triangleq 10 \log_{10} \left[\frac{(S/N)_{\textbf{input}}}{(S/N)_{\textbf{output}}} \right]$$

noise figure meter a system that makes accurate noise figure readings possible. It measures the amount of the noise added by a device. Noise figure is the ratio of the signal-to-noise ratio at the input of a device to the signal-to-noise ratio at the output of that device.

noise floor the lowest input signal power level which will produce a detectable output signal in an electrical system. Noise floor is determined by the thermal noise generated in the electrical system.

noise immunity a logic device's ability to tolerate input voltage fluctuation caused by noise without changing its output state.

noise power the amount of power contained within a noise signal. The noise power can be found by integrating the power spectral density (PSD) of the noise signal over all possible frequencies. If the power spectral density is given by $S(\omega)$, the power, p, contained in the noise signal, is then given by

$$p \triangleq \frac{1}{2\pi} \int_{-\infty}^{\infty} S(\omega) d\omega .$$

In most cases, noise signals are bandwidth limited to between say ω_1 and ω_2 and in these cases the noise power will be given by

$$p \triangleq \frac{1}{2\pi} \int_{\omega_1}^{\omega_2} S(\omega) d\omega .$$

Generally, the power spectral density is expressed in watts per hertz (W/Hz) and the noise power is expressed in watts. *See also* noise, noise spectrum.

noise power ratio (NPR) intermodulation distortion product generated in nonlinear transfer components such as high power amplifiers (HPAs) amplifying multiple carriers. It is defined as a ratio of an averaged power of white noise having a narrow notch, which represents multiple carriers, to an averaged power falling into a narrow bandwidth of notch.

noise rejection the ability of a feedback control system to attenuate (reduce) the amplitude of any unwanted signal generated by the measurement of its output variable.

noise smoothing any process by which noise is suppressed, following a comparison of potential noise points with neighboring intensity values, as for mean filtering or median filtering.

noise spectrum indicates the frequency components in a noise signal. For ideal thermal noise (AWGN), the spectrum is flat across all frequencies and is referred to as the noise power spectral density expressed in watts per hertz (W/Hz). *See also* noise, noise power.

noise subspace in an orthogonal decomposition of a space, the orthogonal complement to the signal subspace.

noise suppression any process by which noise is eliminated or suppressed: a more general term than noise smoothing, since it includes such processes as noise clipping and band-pass filtering.

noise temperature an alternate representation of noise power. It is generally accepted that noise is the result of the random motion of electrons within components in electronic systems. The greater the temperature of a component, the greater the random motion of electrons within the component, and this causes an increased instantaneous noise current to be present within the component. With an increase in noise current, the noise power also increases. The noise power generated within a component at T Kelvin, over a bandwidth of B hertz is given by

$$p = kTB$$

with $k = 1.38 \times 10^{-23}$ J/K, which is Boltzmann's constant.

From this equation, it is clear that a component at absolute zero temperature (0 K), generates no noise power. Therefore, given a particular bandwidth, B noise power can also be expressed as a temperature in Kelvin (K).

noise whitening a process by which noise whose power spectrum is not white (i.e., not identical at all frequencies) is brought to this condition, e.g., by means of a frequency dependent filter.

noiseless source coding *See* lossless source coding.

noiseless source coding theorem states that any source can be losslessly encoded with a code whose average number of bits per source symbol is arbitrarily close to, but not less than, the source entropy in bits.

noisy channel vector quantization a general term for methods in vector quantizer transmission for noisy channels. *See also* channel robust vector quantization, channel optimized vector quantization, channel matched VQ, redundancy-free channel coding.

noisy channel VQ *See* noisy channel vector quantization.

noisy source coding *See* lossy source coding.

nominal voltage a number given to a system to name its classification of voltage, such as rated values.

non-binary codes codes in which the fundamental information units or symbols as-

sume more than two values. This is in contrast to binary codes, for which the fundamental information symbols are two-valued or binary, only. *See also* binary code, block code, convolutional code.

non-customer-call call placed by passerby to utility, either emergency personnel or otherwise, to indicate that a scenario exists which is potentially disrupting electrical service.

non-return-to-zero inverted recording *See* magnetic recording code.

non-return-to-zero recording *See* magnetic recording code.

non-time delay fuse *See* single-element fuse.

non-transposition refers to a three-phase electric power transmission line whose conductors are not transposed *See* transposition.

nonallocate on write *See* no fetch on write.

nonblocking cache a cache that can handle access by the processor even though a previous cache miss is still unfinished.

noncausal system *See* causal system.

noncentrosymmetric medium *See* centrosymmetric medium.

noncoherent integration where only the magnitude of received signals is summed.

noncollinear geometry acousto-optical tunable filter an acousto-optical tunable filter (AOTF) device that operates similar to a Bragg cell where the incident light and acoustic wave are not collinear and the diffracted light can be spatially separate from the incident light.

noncollinear geometry AOTF *See* noncollinear geometry acousto-optical tunable filter.

noncooperative game one of a class of decision processes in which decision makers (players) pursue their own interests, which are at least partly conflicting with others'. A conflicting situation or collision of interests results the situation in which a player has to make a decision and each possible one leads to a different outcome valued differently by all players. Depending on the number of decision makers involved in the process, the game may be two-person or multi-person; depending on how the outcome is viewed by the players, the process may be a zero-sum game (only two-person) or a nonzero-sum game (two- or multi-person). If the order in which the decisions are made is important, a game is dynamic, if not it is static. Dynamics of the game is usually related to the access of the decision makers to different information. Regarding the number of possible decisions available to the decision makers, a game is finite or infinite (in this case, the number of possible actions is usually a continuum). Dynamic games are usually formulated in extensive form, which for finite games leads to a finite tree structure, while for infinite ones, involves difference (in discrete-time) or differential (in continuous-time) equations describing an evolution of the underlying decision process.

nondegenerate network a network that contains neither a circuit composed only of capacitors and/or independent or dependent voltage sources nor a cutset composed only of inductors and/or independent or dependent current sources.

nondegenerate two-wave mixing a general case of two wave mixing in which the two beams are of different frequencies. In two-wave mixing, if the frequencies of the two laser beams are different, the interference fringe pattern is no longer stationary. A moving volume refractive index grating can

still be induced provided that the intensity fringe pattern does not move too fast. The amplitude of the refractive index modulation decreases as the speed of the fringe pattern increases. This is related to the finite time needed for the formation of the refractive index grating in the photorefractive medium. Such a kind of two-wave mixing is referred to as nondegenerate two-wave mixing.

nondestructive readout when data are read from a particular address in a memory device, the contents of the memory at that address remain unaltered after the read operation.

nondispersive medium medium in which the index of refraction does not vary significantly with frequency.

nonfuzzy output a function of the firing degrees and the fuzzy outputs of fired fuzzy rules regardless of what defuzzification method is used.

nonhomogeneous linear estimator an estimator which is a nonhomogeneous linear function of the data.

noninteraction of photons the nature of photons that they do not interact to each other. Unlike electrons governed by Coulomb's law, a photon cannot affect another photon. A light beam passes through another light beam without any change. If photons interacted as electrons do, the image we see from one direction would be distorted by other streams of photons, and we would never understand what we see. The noninteraction of photons provides parallelism and enables us viewing in free space. On the other hand, it makes controlling or switching light using light impossible.

noninvasive sensor the interface device of an instrumentation system that measures a physiologic variable from an organism without interrupting the integrity of that organism. This device can be in direct contact with the surface of the organism or it can measure the physiologic quantity while remaining remote from the organism.

noninvertible system *See* invertible system.

nonlinear dielectric property the distinct dependence of the electric permittivity of certain dielectric materials on the intensity of an applied electric field.

nonlinear distortion a change in signal properties due to circuit transmission characteristics not being completely linear. This may result in changes in the relative amplitude or phase of the various frequency components of the signal or may result in intermodulation.

nonlinear effect effect that cannot be written as linear functions of the driving fields

nonlinear electro-acoustic property nonlinear interaction between the atomic displacement and the electric field experienced in certain materials that would cause modulation effects resulting in the generation of new sideband frequencies (called Raman frequencies).

nonlinear electro-optic property nonlinear changes in the refractive index of certain optically transparent materials with change(s) in the externally applied electric field.

nonlinear filter *See* linear filter.

nonlinear load an electrical load operating in the steady state that has a current that is not continuous or in which the impedance changes during each cycle of the supply voltage.

nonlinear magnetic property nonlinear dependence of the magnetic susceptibility of

certain materials on the intensity of an applied magnetic field.

nonlinear mean-square estimate the optimum estimate under the mean-square performance criterion.

nonlinear medium medium in which the constitutive parameters are not functions of the electric or magnetic field amplitudes.

nonlinear model a small signal model that includes internal components, essentially voltage controlled current sources and capacitors, which depend on the applied voltages to the transistors. Nonlinear models are quite useful for understanding the behavior of transistors.

nonlinear optics (1) the study of optical phenomena that occur through the use of light fields (e.g., laser beams) sufficiently intense to modify the optical properties of a material system. From a formal perspective, these phenomena are nonlinear in the sense that the material polarization depends on the applied electric field strength in a nonlinear manner.

(2) optical processes in materials capable of producing output light with wavelengths different from that of the input light.

nonlinear response the characteristic of certain physical systems that some output property changes in a manner more complex than linearly in response to some applied input.

nonlinear Schrödinger equation the fundamental equation describing the propagation of short optical pulses through a nonlinear medium, so-called because of a formal resemblance to the Schrödinger equation of quantum mechanics.

nonlinear susceptibility a quantity describing the nonlinear optical response of a material system. More precisely, the nonlinear susceptibility of order n, often designated χ^n, is defined through the relation $P^n = c\chi^n E^n$, where E is the applied electric field strength and P^n is the nth order contribution to the polarization. The coefficient c is of order unity and differs depending on the conventions used in defining the electric field strength. The nonlinear susceptibility of order n is a tensor of rank $n + 1$.

nonlinear system a system that does not obey the principle of superposition.

The superposition principle states that if

$$y(t) = f(x(t)), \quad y_1(t) = f(x_1(t))$$

and

$$y_2(t) = f\,(x_2(t))$$

and if

$$x(t) = \alpha x_1(t) + \beta x_2(t)$$

then

$$y(t) = \alpha y_1(t) + \beta y_2(t)$$

See also linear system.

nonlinear-optic logic gate an optical logic gate utilizing thresholding capability of nonlinear-optic materials.

nonlinear-optic material a material from the following group: GaAs, ZnS, ZnSe, CuCl, InSb, InAs, and CdS. When these transparent materials are illuminated with input light, their refractive indices depend nonlinearly on the illuminating light intensity. The relation of refractive index and illuminating intensity resembles a threshold function. The phase of output light transmitting through the nonlinear material will be modulated by the refractive index of material. The phase modulation is translated into intensity variation using an interferometer.

nonlinearity response of a medium that is not directly proportional in magnitude to the magnitude of applied fields.

nonlocal optics due to spatial dispersion, the dielectric function of a material may depend on the wave vector. In such a case, the

relation between the electric field and the current density will be nonlocal. The nonlocal effect will play an important role in modeling the interaction of electromagnetic waves with metals when the frequency of the electromagnetic wave is around the plasma frequency of the metal.

nonmaskable interrupt (NMI) an external interrupt to a CPU that cannot be masked (disabled) by an instruction. *See also* maskable interrupt.

nonorthogonal projection a nonorthogonal projection is a projection of a vector **c** onto a vector **b** in a direction orthogonal to $\mathbf{g} = \mathbf{Q_g b}$, where $\mathbf{Q_g}$ is an arbitrary rotation matrix in the plane spanned by **b** and **c**. It is defined as

$$\mathbf{c_b} = \left(\frac{\mathbf{b}^T \mathbf{Q_g c}}{\mathbf{b}^T \mathbf{Q_g b}} \right) \mathbf{b}$$

nonorthogonal wavelets *See* orthogonal wavelet.

nonparabolic band refers to an energy band in which the energy dependence upon the momentum deviates from the classical quadratic behavior.

nonparametric estimation an estimation scheme in which no parametric description of the statistical model is available.

nonradiating dielectric (NRD) waveguide a rectangular dielectric waveguide bound by two infinite parallel metallic plates. The dielectric constant and the separation between the plates is chosen such that the electromagnetic wave is above cut-off and propagating in the dielectric, and is below cut-off outside the dielectric, and does not radiate out of the parallel plates.

nonrecurring engineering (NRE) costs the foundry charges the ASIC customer. These costs include engineering time, making the masks, fabricating one lot of wafers, and packaging and testing the prototype parts.

nonrecursive equation *See* recursive equation.

nonredundant number system the system where for each bit string there is one and only one corresponding numerical value.

nonremovable disk *See* removable disk.

nonrigid body motion *See* rigid body motion.

nonsaturated region *See* ohmic region.

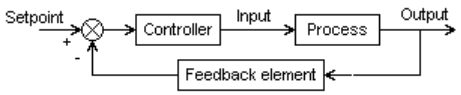
nonseparable data *See* separable data.

nonstate variable network variable that is not a state variable.

nonuniform sampling *See* uniform sampling.

nonuniformly excited equally spaced linear array (NEESLA) an antenna array in which all the centers of the antennas are collinear and equally spaced, but each antenna can have a unique harmonic amplitude and can have a unique phasing.

nonunity feedback the automatic control loop configuration shown in the figure.



Nonunity feedback configuration.

nonvolatile *See* nonvolatile memory.

nonvolatile memory (1) memory that retains its contents even when the power supply is removed. Examples are secondary memory and read-only memory.

(2) the class of computer memory that retains its stored information when the power supply is cut off. It includes magnetic tape, magnetic disks, flash memory, and most types of ROM.

nonvolatile random-access memory (NVRAM) SRAM or DRAM with nonvolatile storage cells. Essentially each storage cell acts as a normal RAM cell when power is supplied, but when power is removed, an EEPROM cell is used to capture the last state of the RAM cell and this state is restored when power is returned.

nonzero-sum game one of a class of games in which the sum of the cost functions of the players is not constant. A number of players is not limited to two as in zero-sum games, and in this sense one may distinguish between two-person and multiperson nonzero-sum games. Since the objectives of the players are not fully antagonistic, cooperation between two or more decision makers may lead to their mutual advantage. However, if the cooperation between the players is not admissible because of information constraints, lack of faith, or impossibility of negotiation, the game is noncooperative and an equilibrium may be defined in a variety of ways. The problem of solving the nonzero-sum game differs from that of the zero-sum game. The most natural solution is Nash equilibrium, which is relevant to the saddle point equilibrium in zero-sum games. Its main feature is that there is no incentive for any unilateral deviation by any one of the players and their roles are symmetric. If one of the players has the ability to enforce his strategy on the other ones, then a hierarchical equilibrium called von Stackelberg equilibrium is rational. Yet another solution for the player is to protect himself against any irrational behavior of the other players and adopt min-max strategy by solving a zero-sum game, although the original is nonzero-sum.

NOR gate a logic circuit that performs the operation equivalent to the OR gate followed by the inverter. The output of a NOR gate is low when any or all inputs are high.

norator an idealized two-terminal network element for which the voltage across it and the current through it are determined by the network to which it is connected.

norm a vector space V, a *norm* is a real-valued function N defined on V, satisfying the following requirements for every $v, w \in V$ and scalar λ:
1. $N(0) = 0$ and for $v \neq 0$, $N(v) > 0$.
2. $N(\lambda v) = |\lambda| N(v)$.
3. $N(v + w) \leq N(v) + N(w)$. The most usual norms are the L^1, L^2, and L^∞ norms; for a vector x with n coordinates $x_1, \ldots, x_n$ we have

$$\|x\|_1 = \sum_{k=1}^{n} |x_k|,$$

$$\|x\|_2 = \left(\sum_{k=1}^{n} |x_k|^2\right)^{1/2},$$

$$\text{and } \|x\|_\infty = \max_{k=1}^{n} |x_k|;$$

for a function f defined on a set E, these norms become

$$\|f\|_1 = \int_E |f(x)|\, dx,$$

$$\|f\|_2 = \left(\int_E |f(x)|^2\, dx\right)^{1/2},$$

and

$$\|f\|_\infty = \min\{r \geq 0 \mid |f(x)| \leq r \text{ almost everywhere}\}.$$

Given a norm N, the function d defined by $d(x, y) = N(x - y)$ is a distance function on V. *See* chessboard distance, Euclidean distance, Manhattan distance.

normal demagnetization curve the second quadrant portion of the hysteresis loop generated when magnetic induction (B) is

plotted against applied field (H), which is mathematically related to the intrinsic curve; used to determine the performance of a magnet in a magnetic circuit.

normal dispersion increase of index of refraction with increasing frequency; tends to occur near the center of amplifying transitions or in the wings of absorbing transitions.

normal distribution *See* Gaussian distribution.

normal tree a tree that contains all the independent voltage sources, the maximum number of capacitors, the minimum number of inductors, and none of the independent current sources.

normal vector a vector perpendicular to the tangent plane of a surface. Also, a vector which is geometrically perpendicular to another vector.

normalization (1) the process of reformatting a floating point number into a standard form at the completion of a floating point arithmetic operation.

(2) the process of equalizing signal energies, amplitudes, or other features prior to comparison.

normalized number a floating-point number in which the most significant digit of the significand (mantissa) is non-zero. In the IEEE 754 floating-point standard, the normalized significands are larger than or equal to 1, and smaller than 2.

normally closed contact contact of a contactor that is closed when the coil of the contactor is deenergized and opened when the coil is energized.

normally closed, time to close a relay that is closed when the power to its actuator is off, but has a time delay to close when power is removed from the actuator. When power is applied, the relay immediately opens.

normally open contact a contact that is open under normal operating conditions and closes when an action is initiated in its controller. For a contact that is part of a relay, the contact remains open when the relay is deenergized and closes when the relay is energized.

normally open, time to close a time delay relay that is open when the power to its actuator is off. When power is applied to the actuator, the relay remains open for an adjustable time delay, after which it closes. When power is removed from the actuator, the relay opens immediately.

Northeast blackout a 1965 failure of much of the power grid in the northeastern states of the USA.

Norton theorem states that the voltage across an element that is connected to two terminals of a linear, bilateral network is equal to the short-circuit current between these terminals in the absence of the element, divided by the admittance of the network looking back from the terminals into the network, with all generators replaced by their internal admittances.

NOT a Boolean operation that returns the 1's complement of the data to which it is applied.

notch a disturbance of the normal voltage waveform of duration less than 0.5 cycles, is of a polarity that is opposite to the waveform and is hence subtracted from the normal waveform with respect to the peak value of the disturbance voltage.

Noyce, Robert N. (1927–1990) Born: Denmark, Iowa, U.S.A.

Noyce is best known as one of the founders and co-chair of Intel Corporation, and a developer of the first commercially successful microchip, along with Gordon Moore. Noyce began his career with William Shockley's short-lived company. He

and other engineers split with Shockley and formed Fairchild Semiconductor. Fairchild was the first of the very successful "Silicon Valley" high-tech firms. Noyce's patent on the microchip was challenged by Jack Kilby and Texas Instruments. A court ruled in favor of Noyce, although it is commonly accepted that the original ideas were Kilby's.

NPO *See* negative-positive-zero.

NPR *See* noise power ratio.

NRC the Nuclear Regulatory Commission, a US regulatory body which oversees civilian power reactors.

NRD waveguide *See* nonradiating dielectric waveguide.

NRE *See* nonrecurring engineering.

NTSC *See* National Television System Committee.

NuBus an open bus specification developed at MIT and used by several companies. It is a general-purpose backplane bus, designed for interconnecting processors, memory, and I/O devices.

nuclear fuel fissile material, including natural uranium, enriched uranium, and some plutonium prepared for use in a nuclear reactor.

nuclear fuel management the process of managing the degree of enrichment, the timing of insertion into the core, and the placement and possible relocation of fuel within the core during the lifetime of the fuel.

nuclear magnetic resonance the phenomenon in which the resonant frequency of nuclear spin is proportional to the frequency of an applied magnetic field. *See* magnetic resonance imaging.

nuclear power plant a thermal electric power plant in which the heat for steam turbines is produced by nuclear fission.

nuclear reaction a reaction which causes changes in the nucleus of an atom, thus changing elements to another element or isotope, usually with the release of energy.

nuclear reactor (1) an apparatus designed to facilitate, contain, and control a nuclear chain reaction.

(2) any heat-producing array of fissile radioactive materials constructed so as to produce a controlled chain-reaction.

null a point on the radiation pattern that corresponds to zero or minimum values.

null controllability a dynamical system that is controllable to zero end state. In many cases, null controllability is equivalent to controllability. This is always true for linear finite-dimensional continuous-time dynamical system. However, in discrete case, controllability may be the stronger notion than null controllability. In this case, the two concepts are equivalent if and only if $\text{rank}(A) = n$. For dynamical systems with delays, these two notions are essentially different. For infinite-dimensional systems the relations between null controllability and controllability depend on the properties of the semigroup $S(t)$ generated by the operator A.

null space the set of vectors that are orthogonal to every vector of a set forming vector space. For an (n, k) code, the dimension of the null space is $n - k$.

null space of the Jacobian the subspace $N(J)$ in R^n of joint generalized velocities that do not produce any end-effector velocity, in the given manipulator posture. Nonzero subspace for a redundant manipulator allows to handle redundant degrees of freedom. The existence of nonzero subspace allows for redundant manipulator to generate internal motions of the manipulator structure that do not

change the end-effector position and orientation. As a consequence allows manipulator reconfiguration into more dexterous postures for execution of a given task.

null steering a technique used to form an antenna's radiation pattern in such a way that there is no radiation in the direction of an interfering signal. This technique has been used with great success, for example, where CDMA systems have been overlaid with fixed microwave communication systems.

null-to-null bandwidth the width of the main lobe of a signal or system transfer function in the frequency domain.

nullator an idealized two-terminal network element that conducts no current and yet maintains zero volts across itself. This element is often used to represent a virtual connection.

number system the representation of numbers as a sequence of digits with an interpretation rule which assigns a value to each sequence. The conventional number systems are fixed-radix and positional systems, where the digit in position i has a weight of r^i, where r is the radix.

numerical aperture (NA) a parameter describing the light-gathering capacity of an optical fiber. It is defined as the sine of half the maximum angle of light acceptance into the fiber

$$NA = \sqrt{n_{co} - n_{cl}}$$

where n_{co} is the refractive index of the core, and n_{cl} is the refractive index of the cladding.

Also used as a measure of the maximum angle of the cone of light entering or emerging from an optical fiber.

numerical methods methods useful for obtaining quantitative solutions of electromagnetic and microwave problems that have been expressed mathematically, including the study of the errors and bounds on errors in obtaining such solutions.

NUREG a contraction for Nuclear Regulations, which are published by the NRC.

NVRAM *See* nonvolatile random-access memory.

nybble *See* nibble.

Nyquist A/D converter A/D converter that samples analog signals that have a maximum frequency that is less than the Nyquist frequency. The Nyquist frequency is defined as one-half of the sampling frequency. If a signal has frequencies above the Nyquist frequency, a distortion called aliasing occurs. To prevent aliasing, an antialiasing filter with a flat passband and very sharp roll-off is required.

Nyquist band for pulse (or quadrature) amplitude modulation, the frequency band which is the support of the Nyquist pulse shape. For a symbol rate of $1/T$, the Nyquist band is the interval $-1/(2T)$ to $1/(2T)$.

Nyquist criterion in analog-to-digital conversion, the stipulation that the bandwidth of the sampling frequency must be greater than twice the bandwidth of the frequency of the signal being sampled.

Nyquist frequency *See* Nyquist rate.

Nyquist I criterion the Nyquist I criterion for zero inter-symbol interference states that if $h(t)$ is the signaling pulse and the symbol period is T, then we must have $h(kT) = 1$ for $k = 0$ and 0 for $k \neq 0$, where k is an integer.

Nyquist noise *See* thermal noise.

Nyquist plot a parametric frequency response plot with the real part of the transfer function on the abscissa and the imaginary part of the transfer function on the ordinate.

Nyquist pulse for pulse (or quadrature) amplitude modulation, the minimum bandwidth pulse which satisfies the Nyquist I criterion. Given a symbol rate $1/T$, the Nyquist pulse is $T^{-1}\sin(\pi t/T)/(\pi t/T)$, which has two-sided bandwidth $1/T$.

Nyquist rate the lowest rate at which recovery of an original signal from its sampled signal is possible. If the highest frequency of the analog signal is f_H, the Nyquist frequency is the frequency of the samples f_S for proper recovery of the signal at the receiving end.

$$f_{\textbf{Nyquist}} = f_S \text{ should be } > 2f_H$$

In digital transmission systems, the analog signal is transformed to a digital signal using an A/D converter.

Nyquist sampling theorem fundamental signal processing theorem that states that in order to unambiguously preserve the information in a continuous-time signal when sampled, the sampling frequency, $f_s = 1/T$, must be at least twice the highest frequency present in the signal. *See also* aliasing.

O

object in object-orientation, an instance of a class definition.

object based coding video compression based on the extraction, recognition, and parameterization of objects in the scene. Unknown-object coding finds geometrical structures representing 2D or 3D surfaces and codes these areas and their movement efficiently. Known-object coding relies on the detection of objects for which the system has a high-level structural model. *See* model based image coding.

object code a file comprising an intermediate description of a program segment.

object detection the detection of objects within an image. This type of process is cognate to pattern recognition. Typically, it is used to locate products ready for inspection or to locate faults during inspection. An object usually denotes a larger characteristic in an image, such as an alignment of points, a square, a disk, or a convex portion of a region, etc.; its detection involves nonlocal image transforms, such as the *Hough transform* or the medial axis transform. *See* edge detection, Hough transform, key point detection, medial axis transform. *See also* feature detection.

object measurement the measurement of objects, with the aim of recognition or inspection to determine whether products are within acceptable tolerances.

object orientation measurement of the orientation of objects, either as part of the recognition process or as part of an inspection or image measurement process.

object recognition the process of locating objects and determining what types of objects they are, either directly or indirectly through the location of sub-features followed by suitable inference procedures. Typically, inference is carried out by application of Hough transforms or association graphs.

object type the type of an object determines the set of allowable operations that can be performed on the object. This information can be encoded in a "tag" associated with the object, can be found along an access path reaching to the object, or can be determined by the compiler that inserts "correct" instructions to manipulate the object in a manner consistent with its type.

object-oriented analysis a method of analysis that examines requirements from the perspective of the classes and objects found in the problem domain.

object-oriented design a design methodology viewing a system as a collection of objects with messages passed from object to object.

object-oriented methodology an application development methodology that uses a top-down approach based on a decomposition of a system in a collection of objects communicating via messages.

object-oriented programming object-oriented programming or task-level programming allows the user to command desired subgoals of the task directly, rather that to specify the details of every action the robot is to take. In another words, task-level programming describes the assembly task as a sequence of positional goals of the objects rather than the motion of the robot needed to achieve these goals, and hence no explicit robot motion is specified. Task-oriented programming is the most advanced programming system for robots. Not many industrial robots are equipped with such a system.

objective function when optimizing a structure toward certain result, i.e., during optimization routines, the objective function is a measure of the performance which should be maximized or minimized (to be extremized). *See also* optimization of microwave networks.

objective lens a well-corrected lens of high numerical aperture, similar to a microscope objective, used to focus the beam of light onto the surface of the storage medium. The objective also collects and recollimates the light reflected from the medium.

observability (1) the property of a system that ensures the ability to determine the initial state vector by observing system outputs for a finite time interval. For linear systems, an algebraic criterion that involves system and output matrices can be used to test this property. *See also* observability conditions.

(2) the ability to determine the signal value at any node in a circuit by applying appropriate input states to the circuit and observing its outputs.

observability conditions a linear finite-dimensional continuous and stationary dynamical system is observable if and only if

$$\text{rank}\left[C^T \left| A^T C^T \right| \left(A^T\right)^2 C^T \right. \\ \left. |\ldots| \left(A^T\right)^{n-1} C^T\right] = n$$

It should be pointed out that observability of stationary dynamical systems does not depend on the length of time interval.

observer an algorithm to estimate the state variables from the input and output variables of the system.

OCC *See* one-cycle control.

occlusion (1) the hiding or partial hiding of an object by another object or objects in a scene. The pattern of occlusion depends on the viewpoint, as well as on the relative positions of the objects.

(2) is the hiding of one object by another. In images of scenes, occluded objects are invisible and irrelevant unless their presence can be inferred, e.g., by motion analysis: partially visible objects are often said to be occluded, though strictly speaking they are partially occluded. Occlusion and disocclusion of objects in the 3-D space add difficulties to motion analysis and structure estimation related problems. For instance, when occlusion takes place, some motion information will be lost, while as disocclusion takes place, some areas that are originally occluded will become newly visible. Often no previous information will be available regarding these areas, thus making analysis more difficult.

occupancy of energy levels number of atoms (or molecules, holes, electrons, etc.) per unit volume occupying an energy state.

OCR *See* optical character recognition.

octal number system a number system consists of eight digits from 0 to 7; it is also referred to as base 8 system.

octave a frequency ratio of two.

octave filter bank a filter bank with octave spaced subbands. That is any given subband has twice the bandwidth of the adjacent lower frequency subband, except for the subband adjacent to the lowpass subband. The discrete wavelet transform is an octave-band filter bank.

octtree the 3-dimensional generalization of the *quadtree*, it gives a representation of a volumetric image as a tree, where each parent node has 8 children nodes and each leaf node has a label corresponding to the color of the corresponding region. It is built recursively as follows. The root node corresponds to the whole image; if all voxels are of the same color, then this node receives that color's label, and is a leaf; otherwise, we subdivide the

image into 8 sub-images whose dimensions are half of those of the whole image, and each smaller image corresponds to a node which is child of the root. Each of the 8 children nodes is the root of a sub-tree which is the octtree of the corresponding sub-image; thus: if the sub-image has all its voxels of the same color, this node is a leaf to which the color's label is attached, otherwise we subdivide this sub-image into 8 smaller sub-images, to each of which corresponds a child node of the actual node. This recursive subdivision ends when one reaches a sub-image of a single color, giving a leaf node with the corresponding label. *See* quadtree.

odd function a real-valued function $x(t)$ in which $x(-t) = -x(-t)$ for all values of t. *Compare with* even function.

odd order response a circuit gain or insertion loss versus frequency response in which there are an odd number of peaks in the ripple pattern, due to an odd number of paired elements in the circuit. Odd order circuits exhibit a peak for each element pair and a peak equal to L_{Amin} (minimum attenuation loss across the band) at DC (low pass) or at w_o (band pass).

odd signal *See* odd function. *See also* even function.

odd-mode characteristic impedance characteristic impedance of a circuit due to an odd-mode current or voltage excitation. Often applied in the context of a transmission line coupler where the odd-mode excitation consists of applying equal amplitude but opposite polarity voltages or currents on two conductors. The resulting impedance under this excitation is defined as the odd-mode characteristic impedance.

ODP *See* open drip-proof.

ODP code *See* optimum distance profile code.

OEIC *See* optoelectronic integrated circuit.

Oersted, Hans Christian (1777–1851)
Born: Rudkobing, Langeland, Denmark

Oersted is best known as the discoverer of electromagnetism. Oersted was a strong teacher and did much to bring Danish science up to world-class standards. Oersted predicted the magnetic effect of electric current in 1813, but was unable to prove it until 1820. The publication of his results spurred the work of Faraday and Ampere. Oerstad went on to make other contributions in other sciences. He did not, however, return to his study of electricity.

OFD code *See* optimum free distance code.

OFDM *See* orthogonal frequency division multiplex.

off-axis illumination illumination that has no on-axis component, i.e., that has no light which is normally incident on the mask. Examples of off-axis illumination include annular and quadrupole illumination.

off-line error detection techniques of detecting faults by device testing (e.g., with the use of BIST) such that the device is allowed to perform useful work while under test.

off-line testing testing process carried out while the tested circuit is not in use.

offset a sustained derivation or error due to an inherent characteristic of positioning controller action. The difference exists at any time between the set point and the value of the controlled variable.

offset short a short circuit impedance standard with a phase offset from the reference plane used in the process of calibrating vector network analyzers.

offset voltage for an ideal differential pair or op-amp, zero output corresponds to zero differential input. In reality, some nonzero input called the "offset voltage" is required for the output to be zero. This means that in the presence of an offset voltage error, a zero input will produce a nonzero output. Offset voltage is caused primarily by mismatch in the two transistors of a differential pair. *See also* common centroid.

Ohm's Law a fundamental law which states that the voltage across a resistance is directly proportional to the current flowing through it. The constant of proportionality is known as the resistance.

This concept can be generalized to include the relationship between the voltage and current in all situations, including alternating voltages and currents. In this case, all the quantities are measured as complex numbers, known as phasors, that are functions of frequency. This broadens the basic definition of resistance, which is a real number measured in ohms, to that of impedance, which is a complex number with magnitude measured in ohms and phase angle in degrees. The real part of the complex number representing impedance is the resistance while the imaginary part is the reactance. Ohm's Law is a central concept to most electrical engineering theories.

Ohm, Georg Simon (1789–1854) Born: Erlangen, Germany

Ohm is best known for his discovery of what we now call Ohm's Law. Ohm held a variety of teaching posts at secondary schools as well as universities. In 1827 he published his greatest work, *Die Galvanische Kette.* Along with Andre Ampere, Ohm was the first to publish rigorously mathematical and theoretical work on electricity. Ohm's famous law states that current in a resistor is proportional to the applied voltage and inversely proportional to the resistance. Ohm's work was initially scorned because it lacked the experimental evidence. Worldwide acclaim changed Ohm's fortunes several years later. He is honored by having his name used as the unit of resistance, the ohm, and the unit of conductivity, the mho.

ohmic contact a heavily doped and/or low barrier height metal to semiconductor interface or contact that has a very low resistance relative to the remainder of the device, such that the device performance is not significantly degraded. At lower doping levels, the ohmic contact is described by Ohm's Law, while at higher doping levels, tunneling dominates.

ohmic loss a term used to describe the power dissipated due to the finite conductivity of the metallic structure of an antenna, waveguide, transmission line, etc.

ohmic medium a medium in which conductivity is independent of the applied field.

ohmic region the voltage-controlled resistance region of operation of a transistor. Also referred to as the triode region, nonsaturated region, and pinch-off region. This region is in effect up to the point that the channel of the transistor is completely depleted of charge carriers.

oil circuit breaker a power circuit breaker that uses oil as an insulating and arc-clearing medium.

oil-filled transformer a transformer in which the magnetic core and the windings are submerged in an insulating oil. In addition to serving as an insulator, the oil provides a heat exchange medium to cool the transformer.

oil-paper insulation an insulation scheme used in transformers and cables in which conductors are insulated with heavy paper impregnated with a dielectric oil.

OLAP *See* optical linear algebraic processor.

OLE *See* optical logical etalon.

OMCVD *See* metal-organic chemical vapor deposition.

omnidirectional antenna an antenna that radiates power equally in all directions in at least one plane through its radiation center, but whose radiation pattern may vary for other such planes.

on-line error detection a real-time detection capability that is performed concurrently with useful work (e.g., parity checkers, comparators in duplicated systems).

on-line memory memory that is attached to a computer system.

on-line optimization interval time interval over which optimization of the decisions required to be made by the considered decision mechanism at a particular time instant during the control system operation is performed; setting of the on-line optimization interval is one of the essential decisions during design of a controller with the model-based predictive control mechanism.

on-line testing concurrent testing to detect errors while circuit is in operation.

on–off keying (OOK) a binary form of amplitude modulation in which one of the states of the modulated wave is the absence of energy in the keying interval (the "off" state). The "on" state is represented by the presence of energy in the modulated wave.

on-wafer measurements electrical measurements made using a wafer probe station by directly contacting the device under test using special test probes.

one decibel desensitization point a reduction in a device output signal power by one decibel due to one or more additional signals that compress the device output.

one's complement (1) a representation of integer numbers in which a data word is organized such that negative numbers all contain a binary "one" in the leftmost bit while positive numbers contain a "zero" in the leftmost bit, and in which the negative numbers are the bit-by-bit inverse of their positive equivalent.

(2) the operation of inverting a data word so that all ones become zeros and vice versa.

one-cycle control (OCC) the switched signal is sensed to control the pulse timing such that the error between the control reference and the average value of the switched signal is zero in each cycle. In a constant frequency implementation, the switch is turned on by a constant frequency clock. The output of the switch is integrated and compared to a reference; when the reference is reached, the switch is turned off and the integrator is reset. One-cycle control achieves zero error within each cycle under steady-state or transient conditions. In addition, this method effectively rejects input perturbations, corrects switching errors, and provides high linearity.

one-dimensional coding scheme a scheme in which a run of consecutive pixels of the same gray scale is combined together and represented by a single code word for transmission.

Scan lines are coded as "white" or "black," which alternate along the line. The scans are assumed to begin with white and are padded with white if this is not the case. Generally, run-length coding is a one-dimensional coding scheme.

one-dimensional correlator a correlator where both input signals are one dimensional, such as temporal signals.

one-dimensional space integrating correlator a correlator where a single lagged product of two input signals is performed at a given instant and integrated spatially, such as with a lens onto a single photodetector. A series of such operations are performed for each lag value to give a temporal sequence that is the correlation function.

one-gun color display a color CRT in which a single electron gun produces one electron beam that is controlled to produce the proper excitation of each of the three color phosphors.

one-level memory an arrangement of different (in terms of speed, capacity, and medium) types of memory such that the programmer has a view of a single flat memory space. *See also* hierarchical memory, virtual memory.

one-level storage *See* one-level memory.

one-line diagram an abbreviated schematic representation of a power system in which three-phase transmission lines are shown as single lines between principal circuit components and from which circuit parameters are often omitted.

one-out-of-N coding a method of training neural networks in which the input vector and/or the output vector have only one nonzero element (usually equal to unity) for each training example.

one-port device an electrical network in which only one external terminal is available for analysis. Antennas can be modeled as one-port devices.

one-port oscillator a device in a class of circuits in which the amplifying device and its nonlinearity are lumped into a single, reactance-free, controlled source. The oscillations in this approach are most successfully found using the harmonic balance method (especially when the nonlinearity can be approximated by a polynomial) or by the phase plane methods (for second-order systems).

one-shot multivibrator a circuit that is obtained from a closed-loop regenerative bistable system including two similar amplifiers connected by coupling circuits. In one-shot multivibrator, one of the circuits is purely resistive, another, which is frequently called "toggling" circuit, includes a reactance (capacitor or coil). The circuit is normally in its stable state; by an external pulse it is transferred in its quasi-stable state, and the toggling circuit helps to preserve the quasi-stable condition for the "timing-out" time. Then the circuit returns to its normal state.

one-step-ahead control the control method to drive the value of the d-step-ahead output, where d is the inherent time delay of the system, to its desired level in one step.

ontogenic network a network that adapts its topology during training through the addition or deletion, as appropriate, of connections and neurons, until the problem of interest is satisfactorily accommodated. Learning can be either supervised or unsupervised.

OOK *See* on–off keying.

op-amp *See* operational amplifier.

OPC *See* optical proximity correction.

opcode a part of an assembly language instruction that represents an operation to be performed by the processor. Opcode was formed from the contraction of "operational" and "code."

open circuit impedance the impedance into an N-port device when the remaining ports are terminated in open circuits.

open drip-proof (ODP) pertaining to a ventilated machine whose openings are constructed to prevent drops of liquid or solid particles falling on the machines at an angle less than 15° from the vertical from entering the machine either directly or by rolling along a horizontal or inwardly inclined surface of the machine.

open kinematic chain a chain that consists of one sequence of links connecting two ends of the chain.

open loop gain *See* open-loop gain.

open system architecture a layered architectural design that allows subsystems and/or components to be readily replaced or modified; it is achieved by adherence to standardized interfaces between layers.

open systems interconnection (OST) model a framework for organizing networking technology developed by the International Standards Organization (ISO). Generally called the OSI model.

open waveguide a type of waveguides whose cross section is not bounded by perfect electric conductor, i.e., a waveguide for which the boundary value problem is on an infinite domain. A few examples are optical fiber, microstrips, coplanar waveguides, dielectric waveguides.

open-circuit test a transformer test conducted by applying nominal voltage on the low voltage side while keeping the high voltage side open. By measuring the power in, current, and voltage, the magnetizing reactance of the transformer equivalent circuit can be determined.

open-circuit quarter-wave transmission line transmission line of ninety degrees electrical length where one end of the line is terminated in an open-circuit impedance. The properties of the transmission line result in the non-open circuited end to exhibit a short-circuit impedance.

open-delta transformer a connection similar to a delta–delta connection, except that one single-phase transformer is removed. It is used to deliver three-phase power using only two single-phase transformers. The normal capacity of the open-delta transformer is reduced to 57.7% of its delta rating.

open-loop control system a control system in which the system outputs are controlled by the system inputs only, and no account is taken of the actual system output.

open-loop gain the gain of an operational amplifier with no feedback applied (with the negative feedback loop "open").

open-loop-feedback control predictive control policy with repetitively used decision mechanism, that at a given time instant, considers current state of the controlled process — or the current estimate of this state — and computes the values of the control inputs for the next intervention instant or interval by performing an open-loop optimization of the process operation over specified prediction (optimization) interval. The open-loop optimization can be defined as an open-loop stochastic optimization problem or as a deterministic optimization problem using a single forecast of the free inputs over specified prediction interval; other forms of open-loop optimization problems can also be defined. Model-based-predictive control, widely used as an industrial standard, is usually realized in the form of the open-loop-feedback control.

opening for structuring element B, the composition of the erosion by B followed by the dilation by B; it transforms X into $X \circ B = (X \ominus B) \oplus B$. The opening by B is what one calls an algebraic opening; this means that: (a) it is a morphological filter; (b) it is anti-extensive, in other words it can only decrease an object. *See* dilation, erosion, morphological filter, structuring element.

operand specification of a storage location that provides data to or receives data from the operation.

operand address the location of an element of data that will be processed by the computer.

operand address register the internal CPU register that points to the memory loca-

tion that contains the data element that will be processed by the computer.

operating point *See* set point.

operating system a set of programs that manages the operations of a computer. It oversees the interaction between the hardware and the software and provides a set of services to system users.

operating temperature the ambient case temperature to which a device or circuit is exposed during operation under all supply bias and RF signal conditions, at which it must meet all specified requirements unless otherwise called out. The operating temperature range is the minimum to maximum operating temperatures of the device.

operation specification of one or a set of computations on the specified source operands placing the results in the specified destination operands.

operational amplifier a high-gain DC-coupled amplifier with a differential input and single-ended output. In nearly all amplifier applications, the op-amp is used with negative feedback ("closed-loop"), so that the closed-loop gain of the amplifier depends primarily on the feedback network components, and not on the op-amp itself. It is widely used as a basic building block in electronic designs. Abbreviated as "op-amp."

operational control control or decision making activity that requires, or in some instances may require, a human operator (dispatcher) to approve — or modify — automatically computed decisions before they are actually implemented; such a situation is typical in production management, in control of supply and environmental systems, at upper layers of process control systems.

operational impedance a representation in which the impedance of a system is expressed as a function of the Heaviside operator $p = d/dt$ or the Laplace operator $s = j\omega$. In the modeling of synchronous machines, the Park's transformed stator flux linkages per second are often expressed in terms of impedances $X_q(p)$, and $X_d(p)$, termed the quadrature- and direct-axis operational impedances, respectively. Using these, the dynamics of the rotor windings are represented within the operational impedances, and therefore the rotor of a synchronous machine can be considered as either a distributed or lumped parameter system.

operational space *See* external space.

operational space control *See* Cartesian-based control.

operator *See* Canny operator, Laplacian operator, Marr-Hildreth operator, morphological operator, Sobel operator.

opposition effect *See* weak localization of light.

optical adder an optical device capable of performing the function of arithmetic addition using binary signals. It can be constructed using a series of cascaded full adders where carry has to ripple through each full adder from least significant bit to most significant bit. It can also be constructed using cascaded layers. Each layer consists of a series of half adders. Carry also has to ripple through the cascaded layers. It is also known as digital adder.

optical addition adding operation using light. Two incoherent light beams have intensities A and B, respectively. When two beams are combined, i.e., illuminating the same area, the resultant intensity is $A + B$.

optical amplifier amplifier of electromagnetic waves at optical frequencies, usually by the process of simulated emission or nonlinear optics. *See* laser amplifier.

optical beam beam of electromagnetic power at optical frequencies.

optical bistability the property of certain nonlinear optical system to possess two possible output states for a given input state. In one typical example, the bistable optical device has the form of a third-order nonlinear optical material placed inside of an optical cavity, and the device can display two possible different transmitted intensities for certain values of the input intensity.

optical bus an optical channel used for transmitting a signal from a source to one or more detectors. A bus allows only the same interchange of information to take place at different detectors. A source is connected to many detectors.

optical cavity resonant structure for maintaining oscillation modes at optical frequencies.

optical character recognition (OCR) a process in which optically scanned characters are recognized automatically by machine. It is widely utilized in document storage, processing and management.

optical circulator a four-ports optical device that can be used to monitor or sample incident light (input port) as well as reflected light (output port) with the two other unidirectional coupling ports.

optical communications communication of information at optical carrier frequencies. There are two general categories:

1. free-space, such as with lasers and optical modulators, and

2. guided-wave, such as over optical fiber and using guided lightwave devices.

optical computer (1) a general purpose digital computer that uses photons as an electronic computer uses electrons. The technology is still immature. The nonlinear operations that must be performed by a processor in computer are difficult to implement optically.

(2) an analog optical processor capable of performing computations such as correlation, image subtraction, edge enhancement, and matrix-vector multiplication that are usually performed by an electronic digital computer. Such a computer is usually very specific and inflexible, but well adapted to its tasks.

optical computing the use of optics to aid in any type of mathematical computation. Categories of optical computing include.

1. analog processing such as using optical Fourier transforms for spectral analysis and correlation,

2. optical switching and interconnection using nonlinear, e.g., bistable, optical devices, and

3. use of optical devices in digital computers.

optical demultiplexer a device that directs an input optical signal to an output port depending on its wavelength.

optical disk a disk on which data are stored optically. Data are written by altering the reflectivity of the surface, and read by measuring the surface reflection of a light source. Storage is organized in the same way as on a magnetic disk, but higher storage density can be achieved.

optical disk track the region on a compact disk in which pits or other features are located to store digital data. CD-ROM pit sizes are approximately 0.5 microns in width and from 0.8 to 3.6 microns in length, depending on the number of ones and zeros represented by the length. The track-to-track spacing is 1.6 microns.

optical energy energy of an electromagnetic wave oscillating at optical frequencies. *See also* energy, electromagnet.

optical expert system an expert system that utilizes optical devices for performing

logic operations. An expert system mostly requires logic gates to perform inferences. In an optical expert system, not only discrete optical logic gates are used, but the parallelism and capability of performing matrix-vector multiplication of optical processor are exploited as well. Sequential reasoning in an electronic expert system is replaced by parallel reasoning in an optical expert system, so its speed can be increased substantially. As with the optical computer, it is still immature.

optical fiber a single optical transmission fiber usually comprised of a cylindrical core (5–100 mm diameter) in which the light is guided of higher index of refraction surrounded concentrically by a cladding (125–250 mm diameter) with a lower index of refraction. More properly defined as an optical waveguide. Some optical fibers may have multiple concentric cores and/or claddings. Optical fibers made be of all glass, all plastic, or a combination of glass core and plastic cladding construction. Optical glass fibers may be silica- or fluoride-based glass.

optical fiber signal distortion a change in the temporal shape of an optical signal transmitted through an optical fiber caused by a combination of wavelength effects (dispersion) and multimode and polarization effects. The wavelength effects include material dispersion, profile dispersion, and waveguide dispersion. The multi-mode effects cause distortion by the differential time delays between the various modes propagating in a multimode fiber. The polarization effect causes distortion by the differential time delay between the two polarizations of a single mode.

optical flow the 2-D field of apparent velocities of pixels on an image plane; i.e., the raw motion information arising from the displacement of points in the visual (optical) field. Let each image point p have an intensity I and a velocity $v = (v_x, v_y)$, which are both functions of p and time t, where the velocity represents the image plane projection of the point's 3-dimensional velocity. Under the assumption that the point's intensity does not change along its trajectory, it follows that

$$(\partial I/\partial x)v_x + (\partial I/\partial y)v_y + (\partial I/\partial z)v_z + \partial I/\partial t = \nabla I \cdot v + \partial I/\partial t = 0.$$

See also aperture problem.

optical flux *See* optical flow.

optical Fourier transform the implementation of the Fourier transform using the transform properties of a lens, spatial light modulators, such as acousto-optic modulators, to generate the optical input information, and photodetector arrays to detect the optical field representing the Fourier transform. *See also* Fourier transform, two-dimensional Fourier transform.

optical full adder an optical device forming part of an adder and able to receive three inputs, augend, addend, and carry from the previous stage, and deliver two outputs, sum and carry. Several logic gates are required to provide the sum and the carry.

optical gain increase in the amplitude of an optical signal with propagation distance in an optical amplifier.

optical guided-wave device an optical device that transmits or modifies light while it is confined in a thin-film optical waveguide.

optical half adder an optical device forming part of an adder and able to receive two inputs, augend and addend, and deliver two outputs, sum and carry. The sum is the XOR function of two inputs, and the carry is the AND function of two inputs. An optical half adder consists of an optical XOR gate and an optical AND gate. It is also known as one-digit adder.

optical inference engine *See* optical expert system.

optical integrated circuit guided wave optics on a single substrate. If also incorporating active and electrical devices, also known as opto-electronic integrated circuit (OEIC).

optical interconnect an optical communication system in an electronic computer that consists of three primary parts:

1. sources,

2. optical paths with switches or spatial light modulators, and

3. detectors.

An optical signal from a source of an array of sources is transmitted to a detector of an array of detectors in optical interconnects. The transmitted optical signal from the source is converted from an electronic signal. The detector in turn reverts the optical signal into an electronic signal. The merits of optical interconnects include large bandwidth, high speed of light propagation (the velocity of electric signals propagating in a wire depends on the capacitance per unit length), no interferences, high interconnection density and parallelism, and dynamic reconfiguration.

optical invariant a parameter that remains constant throughout an optical system. A consequence of the optical invariant is that the product of numerical aperture and magnification in the system is constant.

optical isolator a unidirectional optical device that only permits the transmission of light in the forward direction. Any reflected light from the output port is blocked by the device from returning to the input port with very high extinction ratio.

optical Kerr effect *See* Kerr effect.

optical linear algebraic processor (OLAP) an optical processor that performs specific matrix algebraic operations as fundamental building blocks for optical computation and signal processing.

optical lithography lithography method that uses light to print a pattern in a photosensitive material. Also called photolithography.

optical logic logic operations, usually binary, that are performed optically.

optical logic gate an optical device for performing Boolean logic operations. The basic idea is that since a computer is built by Boolean logic gates, if we can make optical logic gates, then we can eventually build a complete optical computer. Since light does not affect light, it cannot directly perform nonlinear operations represented by sixteen Boolean logic gates. A thresholding device is required if intensities of two input beams are simply added in the logic gate. For example, to perform AND operation, 00-0, 01-0, 10-0, 11-1, the threshold is set at 2. Only when both beams have high intensities, the output is 1. Otherwise, the output is 0. To perform OR operation, 00-0, 01-1, 10-1, 11-1, the threshold is set at 1. The gate can be constructed by directing two input light beams onto the same detector. After passing through an electronic thresholding device, the resulting electric signal from the detector shows the logic output. To implement optical logic gate without using electronic circuit, optical thresholding devices such as MSLM or nonlinear optic materials can be used.

optical logical etalon (OLE) pulsed nonlinear Fabry–Perot etalon that requires two wavelengths ($\lambda_1 =$ signal, $\lambda_2 =$ clock).

optical maser early equivalent name for laser.

optical matrix–matrix multiplication an operation performing matrix–matrix multiplication using optical devices. For two-by-two matrices A and B, the matrix–matrix multiplication produces two-by-two matrix C, whose elements are

$$lc_{11} = a_{11}b_{11} + a_{12}b_{21}$$

$$c_{12} = a_{11}b_{12} + a_{12}b_{22}$$
$$c_{21} = a_{21}b_{11} + a_{22}b_{21}$$
$$c_{22} = a_{21}b_{12} + a_{22}b_{22}$$

An optical implementation is as follows. Matrix elements b_{12}, b_{22}, b_{11}, and b_{21} are represented by four vertical lines on a spatial light modulator. Matrix A is represented by a two-by-two source array. Two images of matrix A are generated by an optical means, for example, two lenslets. An image of A covers two lines of b_{12} and b_{22}, another image of A covers lines b_{11} and b_{21}. Using two cylindrical lenses, light passing through the spatial light modulator is focused into four points at the four corners of a square representing c_{11}, c_{12}, c_{21}, and c_{22}. Various optical arrangements for implementing matrix–matrix multiplication have been proposed. Optical matrix–matrix multiplication is needed for solving algebraic problems, which could be faster than an electronic computer because of parallel processing.

optical matrix-vector multiplication an operation performing matrix–vector multiplication using optical devices. For matrix W and vector X, the matrix–vector multiplication produces vector Y, whose elements are

$$y_1 = w_{11}x_1 + w_{12}x_2 + w_{13}x_3$$
$$y_2 = w_{21}x_1 + w_{22}x_2 + w_{23}x_3$$
$$y_3 = w_{31}x_1 + w_{32}x_2 + w_{33}x_3$$

A simple coherent optical processor to implement this operation is as follows. Vector elements x_1, x_2, and x_3 are represented by the transmittance of three vertical lines on a first spatial light modulator. A collimated coherent light beam passes through the first spatial light modulator. The modulated light then passes through a second spatial light modulator displaying three-by-three squares with transmittances of w_{11} to w_{33}. Two spatial light modulators are aligned such that the vertical line x_1 covers three squares of w_{11}, w_{21}, w_{31}, line x_2 covers w_{12}, w_{22}, w_{32}, and line x_3 covers w_{13}, w_{23}, w_{33}. The light passing the second spatial light modulator is focused by a cylindrical lens to integrate light in horizontal direction. In other words, $w_{11}x_1$, $w_{12}x_2$, and $w_{12}x_3$ are summed up at a point on the focal line of cylindrical lens. A detector placed at this point will produce y_1. Two other detectors will provide y_2 and y_3 in a similar way. Various optical arrangements are possible to implement matrix–vector multiplication, including correlators. Optical matrix–vector multiplication is important for crossbar switch and neural networks. It can also be used for finding eigenvalues and eigenvectors, solving linear equations, and computing the discrete Fourier transform.

optical modulator device or system that modulates the amplitude or phase of an optical signal.

optical multiplication multiplying operation using light. A light beam has intensity-A. When the beam passes through a transparency with transmittance B, the intensity of transmitting light beam is AB.

optical neural network optical processor implementing neural network models and algorithms. A neural network is an information processing system that mimics the structure of the human brain. Two features of neural networks are recognition capability and learning capability. In recognizing process, the neural net is formulated as

$$z_j = f\left(\sum_{ji} x_i + \theta_j\right)$$

where z_j is the output of the jth neuron, w_{ji} is the interconnection weight between the ith input neuron and the jth neuron, x_i is the input coming from the ith input neuron, θ_j is the bias in the jth neuron, and f is a nonlinear transfer function. Notice that z_j and x_i are binary. Nonlinear transfer function f could simply be a threshold function. The formation of interconnection weight matrix is called learning process. It appears that in recognizing process, the neural network has to

perform a matrix–vector multiplication and a nonlinear operation. The matrix–vector multiplication can be easily performed using an optical system. However, the nonlinear operation can not be performed by optical means. It may be performed using electronic circuits. For two-dimensional neural processing, tensor–matrix multiplication is needed, which can also be realized by optical means.

optical parametric oscillator a nonlinear optical device that can produce a frequency-tunable output when pumped by a fixed-frequency laser beam. The device consists of a second-order nonlinear optical crystal placed inside of an optical resonator as well as additional components for precise control of the output characteristics. When pumped by a laser beam at the pump frequency ω_p, it produces two output frequencies, one at the signal frequency ω_s and one at the so-called idler frequency ω_i, where $\omega_p = \omega_s + \omega_i$.

optical path optical elements in the path of the laser beam in an optical drive. The path begins at the laser itself and contains a collimating lens, beam shaping optics, beam splitters, polarization-sensitive elements, photodetectors, and an objective lens.

optical path length the distance an incident photon travels within a material before it emerges and impinges on a detector. The path may be directly through the material, in which case the pathlength will equal the thickness of the light absorbing material, or may involve scattering due to heterogeneous structures, causing the pathlength to exceed the material's thickness (effective pathlength).

optical phase conjugation an optical process in which a time reversed replica of the incident wave is generated. The time-reversed replica is identical to the incident wave, except the direction of propagation. Optical phase conjugation can be achieved by using a deformable mirror whose mirror surface matches exactly the wavefront of the incident wave. For example, consider the reflection of a spherical wave from a spherical mirror with an identical radius of curvature. The reflected wave is a time-reversed replica of the incident wave. Optical phase conjugation can also be obtained by using optical four-wave mixing, stimulated Brillouin scattering (SBS) in nonlinear media. In optical phase conjugation via four-wave mixing, the nonlinear medium is pumped by a pair of counterpropagating beams. When a signal beam is incident into the medium, a phase conjugate beam is generated which is a time-reversed replica of the incident beam.

optical potential transformer (OPT) a potential transformer that uses a voltage-sensitive optical device, typically in conjunction with optical fibers, to avoid the need for the heavy insulation required of electromagnetic or capacitive potential transformers.

optical processing *See* optical signal processing.

optical proximity correction (OPC) a method of selectively changing the shapes of patterns on the mask in order to more exactly obtain the desired printed patterns on the wafer.

optical proximity effect proximity effect that occurs during optical lithography.

optical pumping excitation of an atom or molecule resulting from absorption of optical frequency electromagnetic radiation; the electromagnetically assisted accumulation of population into or out of one or more states of a quantum mechanical system. In practice, this generally involves selective absorption of the electromagnetic field to populate an excited state, followed by a less selective decay into more than one ground state. For example, a system having ground state spin sublevels can be optically pumped by circularly polarized light into a single ground state spin sublevel. In a multilevel system, more selective transfer of population from one state

to another can be achieved by adiabatic passage.

optical rectification the second-order nonlinear optical process in which a material develops a static electric field in response to and proportional to the square of the strength of an applied optical field.

optical repeater optoelectric device that receives a signal and amplifies it and retransmits it. In digital systems, the signal is regenerated.

optical representation of binary numbers the representation of binary numbers 0 and 1 using light. Since an optical detector is sensitive to light intensity, it is a very logical choice to represent binary numbers 0 and 1 with dark and bright states or low and high intensity, respectively. However, some difficulty would occur when 1 has to be the output from 0, because no energy can be generated for 1 from 0 without pumping light. Binary numbers 0 and 1 can be represented by a coded pattern instead of the intensity of a single spot. They can also be represented by two orthogonal polarizations, although the final states should be converted to intensity, which is the only parameter that can be detected by a detector.

optical resonator electromagnetic cavity designed to have low loss at optical frequencies.

optical signal processing the use of light with optical devices to process signals and images. These systems exploit the high bandwidths and inherent parallelism offered by optical components.

optical soliton a pulse that propagates without change in shape through a dispersive nonlinear optical medium as a consequence of an exact balance between dispersive and nonlinear effects. The propagation of such a pulse is described by the nonlinear Schrödinger equation.

optical switching a process in which one optical beam is controlled by another optical wave or by an electro-optical signal.

optical tensor–matrix multiplication an operation performing tensor–matrix multiplication using optical devices. For tensor W and matrix X, the tensor–matrix multiplication produces matrix Y, whose elements are

$$\begin{aligned} y_{11} &= w_{1111}x_{11} + w_{1112}x_{12} + w_{1211}x_{21} \\ &\quad + w_{1212}x_{22} \\ y_{12} &= w_{1121}x_{11} + w_{1122}x_{12} \\ &\quad + w_{1221}x_{21} + w_{1222}x_{22} \\ y_{21} &= w_{2111}x_{11} + w_{2112}x_{12} + w_{2211}x_{21} \\ &\quad + w_{2212}x_{22} \\ y_{22} &= w_{2121}x_{11} + w_{2122}x_{12} \\ &\quad + w_{2221}x_{12} + w_{2222}x_{22} \end{aligned}$$

An incoherent optical processor can implement this operation as follows. The two-by-two matrix

$$\begin{pmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \end{pmatrix}$$

represented by four LEDs is imaged by a lenslet onto a part of the tensor that is a two-by-two matrix

$$\begin{pmatrix} w_{1111} & w_{1112} \\ w_{1211} & w_{1212} \end{pmatrix}$$

represented by a spatial light modulator. Light passing through the spatial light modulator is integrated by another lenslet to provide y_{11}. Thus, two sets of two-by-two lenslet arrays with four LEDs and a spatial light modulator displaying all tensor elements as four matrices are sufficient to perform this tensor–matrix multiplication. Various optical arrangements can implement tensor–matrix multiplication. Optical tensor–matrix multiplication is important for two-dimensional neural networks.

optical time domain reflectometry (OTDR) device used to locate faults or determine attenuation in a length of optical fiber. The

technique relies on launching a pulse of light into the fiber and measuring the backward scattered power with time, which is then related to distance along the fiber.

optical transfer function the normalized Fourier transform of the incoherent point spread function, i.e.,

$$H(\omega_x, \omega_y) = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x, y)\exp[-i(\omega_x x + \omega_y y)]dxdy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x, y)dxdy}$$

where $h(x, y)$ is a point spread function which represents the image intensity response to a point source of light. *See also* modulation transfer function, impulse response, point spread function.

optical time-domain reflectometer optical fiber an instrument capable of launching optical pulses into an optical fiber transmission link or network, detecting the backscattered optical pulses, and displaying these backscattered pulses as a function of distance. Used to measure optical fiber length, attenuation, connector and splice losses, and to detect faults in optical fiber networks.

optically inhomogeneous medium a medium whose refractive index randomly varies either in space, in time, or in both. It produces scattering of the light transmitted or reflected at it.

optimal decision the best decision, from the point of view of given objectives and available information, that could be taken by the considered decision (control) unit; the term optimal decision is also used in a broader sense — to denote the best decision that can be worked out by the considered decision mechanism, although this decision mechanism may itself be suboptimal. An example is model-based optimization as a decision mechanism at the upper layer of a two-layer controller for the steady-state process — the results of this optimization will be referred to as the optimal decisions.

optimal sensitivity minimal, in the sense of the H_∞ norm, value of the sensitivity function found using H infinity design (H_∞) techniques. For single-input–single-output systems, the H_∞ norm is simply the peak magnitude of the gain of the sensitivity function. In the multi-input–multi-output case, it is expressed by the maximal singular value of the sensitivity matrix function. To meet the design objectives, the optimal sensitivity is found for the sensitivity function multiplied by left and right weighting functions. It enables one to specify minimum bandwidth frequency, allowable tracking error at selected frequencies, the shape of sensitivity function over selected frequency range, and maximum allowed peak magnitude.

optimization determining the values of the set of free parameters that minimizes or maximizes an objective function. The minimization or maximization may be subject to additional constraints. *See also* gradient descent, graph search, genetic algorithm, minimax estimate, relaxation labeling, simulated annealing.

optimization of microwave networks the procedure used in the design of a microwave system in order to maximize or minimize some performance index. May entail the selection of a component, of a particular structure, or a technique. *See also* objective function.

optimizing control layer operation or structure of the control layer of a multilayer controller, usually situated above the direct control layer, where the objective of the decision mechanism is to minimize (or maximize) a given performance function associated with the control system operation; typical example of optimizing control is the set point control of an industrial process concerned with optimal operation of this process in the steady state conditions. *See also* steady-state control.

optimum combining a technique for weighted addition of the output of several communication channels where the weights are chosen to maximize the ratio between the desired signal and the sum of the interference and noise in combined output. Used in adaptive antenna systems. *See also* angle diversity, antenna diversity.

optimum coupling choice of output coupling mirror reflectivity that yields the largest output power from a laser oscillator.

optimum distance profile (ODP) code a convolutional code with superior distance profile given the code rate, memory, and alphabet size. Optimum distance profile codes are suitable if, e.g., sequential decoding is used.

optimum free distance (OFD) code a convolutional code with the largest possible free distance given the code rate, memory, and alphabet size.

optode a fiber optic sensor used to determine the concentration of a particular chemical species present in the sensor's environment by utilizing spectroscopic changes in a sensing element placed at the end of the optical fiber.

optoelectronic integrated circuit (OEIC) opto-electronic device combining optical and electrical devices on a common substrate. This includes combinations of semiconductor lasers, modulators, photodetectors, and electrical processing circuitry.

optoelectronics the interaction of light and electrons in which information in an electrical signal is transferred to an optical beam or vice versa, e.g., as occurs in optical fiber communications components.

optrode *See* optode.

opus sweep an amplifier large signal stability test in which a signal within the passband is held constant in both frequency and power such that compression is achieved. A second signal operated at a much smaller level is then injected and swept across the entire frequency band, observing the gain of this small signal through the compressed amplifier. Sharp gain peaks in this small signal response are indications of large signal stability problems. The test is dependent on bias conditions, large signal frequency, large signal compression, and amplifier source and load impedance.

OR the Boolean operator that implements the disjunction of two predicates. The true table for $\vee \equiv X$ OR Y is

X	Y	$X \vee Y$
F	F	F
F	T	T
T	F	T
T	T	T

n-ary ORs can be obtained as disjunction of binary ORs.

OR gate a logic circuit that performs the OR operation. The output of the gate is high if one or all of its inputs are high.

oral cavity the human cavity where speech is produced and where the articulations of the speech organs makes it possible to produce different sounds.

Orange book *See* IEEE Color Books.

ordinary refractive index the refractive index that is invariant with light direction, affecting one particular optical polarization component.

ordinary wave polarization component of a light wave that is affected by the ordinary refractive index.

organic LED *See* organic light emitting diode.

organic light emitting diode a group of recently developed organic material that emits light in response to electrical input. Although lower in efficiency, they have greater manufacturing flexibility than semiconductor LED.

orientation for an orthonormal coordinate frame attached to an object, the direction of the three axes of the frame relative to the base orthonormal coordinate frame.

orthogonal for two signals or functions, the condition that their inner product is zero. For example, two real continuous functions $s_1(t)$ and $s_2(t)$ are orthogonal if

$$\int s_1(t)s_2(t)\,dt = 0$$

orthogonal code division multiple access scheme a code division multiple access scheme (CDMA), i.e., a spread spectrum system with multiple users, where the PN sequences utilized by the different users are orthogonal sequences. In such a system, the multiple access interference is zero. The orthogonal sequences can be obtained from the rows of a Hadamard matrix, for example.

orthogonal CDMA *See* orthogonal code division multiple access scheme.

orthogonal filter bank a biorthogonal filter bank whose polyphase transfer functions of the analysis and synthesis filters satisfy $F(z) = H^T(z^{-1})$.

orthogonal frequency division multiplex (OFDM) a frequency division multiplex scheme where the subcarriers for each of the frequency divided bands (subbands) are orthononal to each other. This allows for spectral overlap between successive subbands.

orthogonal hopping sequences a set of frequency hopping sequences (hopping patterns) for which no two sequences have the same value for a given position in the sequence. The set of sequences can be represented as the rows of a matrix. In such a case for a given column of the matrix, the elements are distinct.

orthogonal matrix a matrix A whose inverse is A^T; that is, $A^TA = I$, where I is the identity matrix. More generally, A is a unitary matrix if its inverse is A^H (that is, the complex-conjugate transpose); consequently a real unitary matrix is an orthogonal matrix. Although not recommended, the phrase "orthogonal matrix" is sometimes used to refer to a unitary matrix.

orthogonal projection for a vector $\mathbf{c}$ onto a vector $\mathbf{b}$, the orthogonal projection is

$$\mathbf{c_b} = \left(\frac{\mathbf{b}^T\mathbf{c}}{\mathbf{b}^T\mathbf{b}}\right)\mathbf{b}$$

orthogonal set of functions for real signal set $f_m(t)$ over $[t_1, t_2]$ such that

$$\int_{t_1}^{t_2} f_m(\tau)\,f_n(\tau)d\tau = \begin{cases} 0 & m \neq n \\ 1 & m = n \end{cases}$$

orthogonal functions are necessary for transforms such as the FFT, or the DCT.

orthogonal transform a transform whose basis functions are orthogonal. *See* orthogonalset of functions.Thetransformmatrixofa discrete orthogonal transform is an orthogonal matrix. Sometimes orthogonal transform is used to refer to a unitary transform. Orthogonal real transforms exhibit the property of energy conservation.

orthogonal wavelet wavelet functions that form orthogonal basis by translation and dilation of a mother wavelet.

orthographic projection a form of projection in which the rays forming an image are modeled as moving along parallel paths on their way to the image plane: usually the paths are taken to be orthogonal to the image plane. Orthographic projection suppresses

information on depth in the scene. A limiting case of perspective projection.

orthonormal functions an orthogonal signal set $f_m(t)$ on $[t_1, t_2]$ such that

$$\int_{t_1}^{t_2} |f_m(t)|\, dt = 1$$

for all m.

orthonormal transform *See* orthogonal transform.

oscillation condition (1) condition that must be satisfied for an active circuit or device to exhibit a stable frequency oscillation. For a stable oscillation to be achieved, a condition is placed on the impedance presented to the active device, the impedance exhibited by the active device, and the derivative of these impedances with respect to both frequency and voltage.

(2) requirement that the electromagnetic field in a laser oscillator be self-sustaining including all loss and gain elements; also subconditions on self-consistency of amplitude, phase, polarization, and frequency.

oscillation frequency frequency produced by a laser oscillator, including effects of the optical cavity, active medium, and any other elements in the cavity.

oscillation threshold condition under which unsaturated gain is equal to loss.

oscillator (1) a circuit that generates a repetitive series of pulses at a certain frequency.

(2) an amplifier that has an output for zero input, i.e., it is providing an output signal even though there is no signal applied at the input.

oscillatory transient a rapid change in frequency (not power frequency) during steady state that is bipolar for voltage or current.

oscillograph a continuous recording of the waveforms of an electric power line, formerly made with a cathode-ray tube but currently with a digital signal recorder, kept updated to record abnormalities during switching operations and fault conditions.

OSI model *See* open systems interconnection model.

OTDR *See* optical time domain reflectometry.

OTDR optical fiber *See* optical time domain reflectometry, optical fiber.

OTP one-time programmable. *See* programmable read-only memory.

out-of-order issue the situation in which instructions are sent to be executed not necessarily in the order that they appear in the program. An instruction is issued as soon as any data dependencies with other instructions are resolved.

out-of-step an abnormal condition when generators in a power system cannot operate in synchronism.

out-of-step relay a protective relay that senses that a synchronous generator has pulled out of step, and is operating at a frequency different than the system frequency.

outage (1) the percentage of time or area for which a communication system does not provide acceptable quality.

(2) loss of power from all or part of a power system.

outage inferencing the act of identifying the probable location of an outage based on information received from customer trouble calls and power monitoring units.

outlier a statistically unlikely event in which an observation is very far (by several standard deviations) removed from the mean.

Also refers to points which are far removed from fitted lines and curves. In experimental circumstances, "outlier" frequently refers to a corrupt or invalid datum.

output backoff *See* backoff.

output block when the processor writes a large amount of data to its output, it writes one block, a certain amount of data, at a time. That amount is referred to as an output block.

output buffer when the processor writes to its output device, it must make sure that device will be able to accept the data. One common technique is that the processor writes to certain memory addresses, the output buffer, where the output device can access it.

output dependency the situation when two sequential instructions in a program write to the same location. To obtain the desired result, the second instruction must write to the location after the first instruction. Also known as write-after-write hazard.

output device a device that presents the results sent to the user, and typical output devices are the screen and the printer. (According to some interpretations, it also includes the stable storage where the processor saves data.)

output filter a lowpass filter used to attenuate the switching ripple at the output of switching circuits to a tolerable level.

output impedance the ratio of the drop in voltage to the current drawn is known as the output impedance of the electric source and is measured in units of ohms.

output neuron layer a neuron (layer of neurons) that produces the network output (outputs). In feedforward networks, the set of weights connected directly to the output neurons is often also referred to as the output layer.

output power (1) the difference in the power available under perfectly matched conditions and the reflected power taking the output return loss into account, expressed in watts.

(2) in lasers, the useful output from a laser oscillator.

output return loss negative ratio of the reflected power to the incident power at the output port of a device, referenced to the load or system impedance, expressed in decibels. The negative sign results from the term "loss." Thus an output return loss of 20 dB results when 1/100th of the incident power is reflected.

output routine low-level software that handles communication with output devices. Handles the formatting of data as well as eventual protocols and timings with the output devices.

output swing for a semiconductor device, the difference between the output high voltage and the output low voltage.

output vector a vector formed by the output variables of a network.

outstar configuration consists of neurons driving a set of outputs through synaptic weights. An outstar neuron produces a desired excitation pattern to other neurons whenever it fires. *See also* outstar training, instar configuration.

outstar rule a learning rule that incorporates both Hebbian learning and weight decay. A weight is strengthened if its input signal and the activation of the neuron receiving the signal are both strong. If not, its value decays. A similar rule exists for instars, but has found less application.

outstar training neuron training where the weights are updated according to

$$w_i(t+1) = w_i(t) + \nu\,(y_i - w_i(t))$$

where ν is the training rate starting from about 1 and gradually reduced to 0 during the training. *See also* instar configuration.

over-compounded a compound DC generator in which the terminal voltage increases as load current increases. Extra turns are added in the series winding to generate the additional voltage after compensating for the armature voltage drop and the armature resistance drop.

overcurrent (1) current in a circuit that exceeds a preset limit.

(2) motor current magnitude in the normal circuit path exceeding the full-load current.

overcurrent protection (1) the act of protecting electrical and electronic devices or circuits from a dangerous amount of input current.

(2) the effect of a device operative on excessive current.

overcurrent relay a protective relay that operates when fed a current larger than its minimum pick-up value.

overdamped more damping than a critically damped system. For a characteristic equation of the form:

$$s^2 + 2\zeta\omega_n s + \omega_n^2$$

the system is overdamped if $\zeta < 1.0$; the roots of the characteristic equation are complex conjugate pairs.

overexcited the condition where the field winding current is greater than a rated value that produces the rated MMF in the armature. With a synchronous or a DC machine, the excitation current is a direct current in the field windings.

If a machine is overexcited, the excess MMF must be counterbalanced in the armature. In the case of a DC motor, the overexcitation is counterbalanced by the increase of armature current, which is translated by the increase of both torque and speed. In the case of synchronous motor, a leading component of the armature current is present and the machine operates at a leading power factor.

overflow a data condition in arithmetic operations of signed numbers where the magnitude of a result exceeds the number of bits assigned to represent the magnitude. The result changes the sign bit, thus, making the result incorrect.

overlap angle *See* commutation angle.

overlapped execution processing several instructions during the same clock pulses.

overlay (1) in wireless communications, refers to a modulated signal (communication scheme) that occupies an RF channel that is already occupied by other signals. The classical example is that of a spread spectrum signal that is (spectrally) placed on top of a set of narrow band channels that carry narrow band signals. The wideband spread spectrum signal has a low power spectral density; hence the overlay scheme can coexist with the narrow band signals occupying the frequency band.

(2) a vector describing the positional accuracy with which a new lithographic pattern has been printed on top of an existing pattern on the wafer, measured at any point on the wafer. Also called registration.

overload a situation that results in electrical equipment carrying more than its rated current. Placing too much electrical load on a generator or too much mechanical load on a motor would cause an overload.

overload heater a term used to describe the thermal sensors that detect motor overload currents. Usually located on the motor starter, the heaters cause the overload relay to operate.

overload protection a protective device which opens the circuit to a piece of electri-

cal equipment or power line in the event of current exceeding the upper design limit.

overload relay a device designed to detect and interrupt motor overload conditions. Motor overload relays may be actuated by thermal (temperature), magnetic (current), or electronic (voltage and current) sensors.

overmoded the condition of a waveguide at a frequency where two or more modes are above cutoff (propagating).

overmodulation technique used in pulse-width-modulated (PWM) switching schemes to obtain a higher output voltage. Overmodulation occurs when the control (or modulation) signal magnitude exceeds the magnitude of the triangle carrier signal that it is being compared to and the number of pulses begin to drop out. This does introduce greater output voltage distortion.

oversampling sampling a continuous-time signal at more than the Nyquist frequency.

oversampling converter A/D converter that samples frequencies at a rate much higher than the Nyquist frequency. Typical oversampling rates are 32 and 64 times the sampling rate that would be required with the Nyquist converters.

overshoot the amount by which an output value momentarily exceeds the ideal output value for an underdamped system.

overstress failure failure mechanisms due to a single occurrence of a stress event when the intrinsic strength of an element of the product is exceeded.

overvoltage a voltage having a value larger than the nominal voltage for a duration greater than 1 minute.

overvoltage relay a protective relay that operates on overvoltage.

over-excitation limiter *See* maximum excitation limiter.

oxidation for a semiconductor manufacturing process, the process of growing silicon dioxide on a silicon wafer subjected to elevated temperature in an oxygen-containing environment.

oxide charge the charge in the oxide, which may be grown in, or may be introduced by charge injection from, external sources or by ionizing radiation. Its presence in the oxide of a MOS device causes a shift in the flatband voltage and the threshold voltage.

oxide trap a defect, impurity, or disordered bond in the oxide that can trap an electron or a hole.

P

P commonly used symbol for power in watts or milliwatts.

P_{DC} common symbol for DC power in watts.

P_{input} common symbol for power input to a device in watts.

P_{load} common symbol for power delivered to the load.

P_{ref} common symbol for power reference level in watts or milliwatts.

p-channel MOSFET a MOSFET where the source and drain are composed of heavily doped p-type semiconductor regions in a n-type surface. Holes form drain-source current when the applied gate and substrate potentials invert the n-type surface between them.

P-I-N photodiode a photodiode (detector) in which a layer of intrinsic (undoped) material is added between the p-n junction. This has the effect of increasing the amount of incident optical power absorbed in the device and hence the efficiency in converting optical power into electrical current.

p-n junction (1) a junction between regions of the same bulk material that differ in the concentration of dopants, n-type on one side and p-type on the other.

(2) metallurgical interface of two regions in a semiconductor where one region contains impurity elements that create equivalent positive charge carriers (p-type) and the other semiconductor region contains impurities that create negative charge carriers (n-type).

(3) a physical region where n-type and p-type materials are in contact (*See* doping). The diode is based on a single p-n junction.

P-well a region of p-type semiconductor located at the surface of a n-type substrate (or larger N-well) usually created in order to contain n-channel MOSFETs.

P1dB acronym for 1 dB compression power. This gives a measure of the maximum signal power level that can be processed without causing significant signal distortion or saturation effects. Technically, this refers to the power level at the input or the output of a component or system at which the saturation of active devices like transistors causes the gain to be compressed by 1 dB from the linear gain.

PAC learning a supervised learning framework in which training examples x are randomly and independently drawn from a fixed, but unknown, probability distribution on the set of all examples. Each example is labeled with the value $f(x)$ of the target function to be learned. A PAC (probably, approximately correct) learning algorithm is one which, on the basis of a finite number of examples, is able, with high probability, to learn a close approximation to the target function.

package in MMIC technology, die or chips have to ultimately be packaged to be useful. An example of a package is the T07 "can." The MMIC chip is connected within the can with bond wires connecting from pads on the chip to lead pins on the package. The package protects the chip from the environment and allows easy connection of the chip with other components needed to assemble an entire system, such as a DBS TV receiver.

packed decimal a data format for the efficient storage and manipulation of real numbers, similar to BCD, with digits stored in decimal form, two per byte.

packet a unit of data which is sent over a network. A packet comprises a payload containing some data, and either a header or a trailer containing control information.

packet reservation multiple access (PRMA) a user transmitting a packet in a particular slot will have the corresponding slot reserved in the next frame. The base station will broadcast the state of the slots (reserved and free for contention) at the beginning of each frame.

packet switching means of switching data among the ports (inputs and outputs) of a switch such that the data is transferred in units of variable size.

packet-switched bus *See* split transaction.

pad (1) a device (network) that impedance matches and/or attenuates. Typically used to refer to a coax attenuator.

(2) a concrete foundation, usually prefabricated and used to support power transformers in underground residential distribution work.

pad-mount transformer a heavily-enclosed distribution transformer mounted at grade level upon a concrete slab or pad.

Pade approximation a pole-zero approximation of deadtime based on the expansion

$$e^{-s\tau} = \frac{1 - \theta + \frac{1}{2!}\theta^2 - \frac{1}{3!}\theta^3 + \ldots + \frac{1}{n!}\theta^n + \ldots}{1 + \theta + \frac{1}{2!}\theta^2 - \frac{1}{3!}\theta^3 + \ldots + \frac{1}{n!}\theta^n + \ldots}$$

where $\theta = s\tau/2$. When the infinite series in both numerator and denominator are truncated to m terms, the approximation contains m zeros and m poles and is known as the mth order Pade approximation to deadtime. This formula allows pole-zero methods like root locus or pole placement which cannot normally deal with system containing deadtime, to be applied to such systems.

page *See* virtual memory.

page fault event that occurs when the processor requests a page that is currently not in main memory. When the processor tries to access an instruction or data element that is on a page that is not currently in main memory, a page fault occurs. The system must retrieve the page from secondary storage before execution can continue.

page frame a contiguous block of memory locations used to hold a page. *See also* virtual memory.

page miss penalty when a page miss occurs, the processor will manage the load of the requested page as well as the potential replacement of another page. The time involved, which is entirely devoted to the page miss, is referred to as the page miss penalty.

page offset the page offset is the index of a byte or a word within a page, and is calculated as the physical as well as virtual address modulus of the page size.

page printing a printing technique where the information to be printed on a page is electronically composed and stored before shipping to the printer. The printer then prints the full page nonstop. Printing speed is usually given in units of pages per minute (ppm).

page replacement at a page miss, when a page will be loaded into the main memory, the main memory might have no space left for that page. To provide space for that new page, the processor will have to choose a page to replace.

page table a mechanism for the translation of addresses from logical to physical in a processor equipped with virtual memory capability. Each row of the page table contains a reference to a logical block of addresses and a reference to a corresponding block of physical storage. Every memory reference is translated within the CPU before storage is

accessed. The page table may itself be stored in standard memory or may be stored within a special type of memory known as associative memory. A page table stored in associative memory is known as a translation lookaside buffer.

page-fault-frequency replacement a replacement algorithm for pages in main memory. This is the reciprocal of the time between successive page faults. Replacement is according to whether the page-fault frequency is above or below some threshold.

page-mode DRAM a technique that uses a buffer like a static RAM; by changing the column address, random bits can be accessed in the buffer until the next row access or refresh time occurs.

This organization is typically used in DRAM for column access. Additional timing signals allow repeated accesses to the buffer without a row-access time. *See also* two-dimensional memory organization.

page-printing printer a human-readable output device used for producing documents in a written form. The printer stores a whole page in memory before printing it (e.g., a laser printer).

paged segmentation the combination of paging and segmentation in which segments are divided into equal sized pages. Allows individual pages of a segment rather than the whole segment to be transferred into and out of the main memory.

paged-segment a segment partitioned into an integral number of pages.

paging the process of transferring pages between main memory and secondary memory.

paging channel a channel in a wireless communication system used to send paging messages. Paging messages are typically used to set up telephone calls and also to send control messages to terminals that are involved in a communication session.

Pagourek–Witsenhausen paradox the best known result concerning comparison of performance sensitivity between open-loop and closed-loop nominally optimal systems. The result provides the somewhat deceptive answer to a question of what is the deviation of the performance index for a closed-loop and open-loop implementations of nominally optimal control systems due to parameter deviations from its nominal value (for which the optimal control has been calculated). The answer considered either obvious or paradoxical can be expressed as follows: the infinitesimal sensitivity of the performance index expressed by its first variation caused by a variation of the parameter vector is the same whether an open-loop or a closed-loop implementation of the nominally optimal control is used. The result primary found for linear-quadratic problem has been generalized for nonlinear time-varying sufficiently smooth optimal control problems with free terminal state.

PAL *See* phase alternate line or programmable array logic.

PAM *See* pulse amplitude modulation.

PAM system *See* prism | air | metal system.

panelboard an assembly of one or more panel units containing power buses, automatic overcurrent protective devices, that is placed in a cabinet or cutout box located in or flush on a wall. The assembly can only be accessed from the front and may contain switches for operation of light, heat, or power circuits. *See* switchboard.

pantograph an apparatus for applying sliding contacts to the power lines above an electric railroad locomotive.

paper tape strips of paper capable of storing or recording information, most often in the form of punched holes representing the values. Now obsolete.

Papoulis' generalization a sampling theory applicable to many cases wherein signal samples are obtained either nonuniformly and/or indirectly.

parabolic index profile quadratic transverse variation of the index of refraction; leads to analytic solutions of the paraxial equations for rays and beams.

parabolic reflector a reflecting surface defined by a paraboloid of revolution or section of a paraboloid of revolution.

paraelectric the nonpolar phase into which the ferroelectric transforms above T_c, frequently called the paraelectric phase.

parallel adder a logic circuit that adds two binary numbers by adding pairs of digits starting with the least significant digits. Any carry generated is added with the next pair of digits. The term "parallel" is misleading, since all the digits of each numbers are not added simultaneously.

parallel architecture a computer system architecture made up of multiple CPUs. When the number of parallel processors is small, the system is known as a multiprocessing system; when the number of CPUs is large, the system is known as a massively parallel system.

parallel bus a data communication path between parts of the system that has one line for each bit of data being transmitted.

parallel computing computing performed on computers that have more then one CPU operating simultaneously.

parallel computing system a system whose parts are simultaneously running on different processors.

parallel data transfer the data transfer proceeds simultaneously over a number of paths, or a bus with a width of multiple bits, so that multiple bits are transferred every cycle. A technique to increase the bandwidth over that of serial data transfer.

parallel feed *See* corporate feed.

parallel I/O *See* parallel input/output.

parallel I/O interface I/O interface consisting of multiple lines to allow for the simultaneous transfer of several bits. Commonly used for high-speed devices, e.g., disk, tape, etc. *See also* serial I/O interface.

parallel input/output generic class of input/output (I/O) operations that use multiple lines to connect the controller and the peripheral. Multiple bits are transferred simultaneously at any time over the data bus.

parallel interference cancellation a multiple access interference cancellation strategy for CDMA based on multistage detection. In the first stage, tentative decisions are made for each user in parallel. For each user, an estimate of the resulting multiple access interference is made and substracted from the received signal. In the succeeding stage, a more reliable tentative decision can then be made for each user. This proceeds successively for a predetermined number of stages.

parallel manipulator manipulator that consists of a base platform, one moving platform and various legs. Each leg is a kinematic chain of the serial type, whose end links are the two platforms. Parallel manipulators contain unactuated joints, which makes their analysis more complex than those of serial type. A paradigm of parallel manipulators is the flight simulator consisting of six legs actuated by hydraulic pistons.

parallel paths the number of separate paths through the armature winding that exist between the brushes of a DC machine. In a DC machine's armature, the conductors and coils are placed in their slots and connected to the commutator using either the lap winding method or the wave winding method. The number of conductors that are connected in parallel depend on the number of poles the machine has, and whether the winding connections are lap or wave. For the lap wound armature, the number of parallel paths is found by multiplying the number of poles by the number of revolutions it takes to fill all the slots of the armature. The number of revolutions it takes to fill the slots is known as the machine's "plex" value. In a simplex wound armature, the "plex" value is 1, duplex has a "plex" value of 2, triplex has a "plex" value of 3, and so on. For the wave wound armature, the number of parallel paths is two times the "plex" value. This same concept can also be applied to AC machinery.

parallel plate waveguide a type of waveguide formed by two parallel metallic plates separated by a certain distance. It supports propagation of several types of modes: the TEM mode and the TE and TM mode families.

parallel port a data port in which a collection of data bits are transmitted simultaneously.

parallel processing (1) an environment in which a program is divided into multiple threads of control, each of which is capable of running simultaneously, at the same time instant.

(2) processing carried out by a number of processing elements working in parallel, thereby speeding up the rate at which operations on large data sets such as images can be achieved. Often used in the design of real-time systems.

parallel transmission the transmission of multiple bits in parallel.

parallel-to-serial conversion a process whereby data, whose bits are simultaneously transferred in parallel, is translated to data whose bits are serially transferred one at a time. During the translation process, some timing information may be included (such as start and stop bits) or is implicitly assumed.

parallel-transfer disk a disk in which it is possible to simultaneously read from or write to multiple disk surfaces. Advantageous in providing high data transfer rates.

parallelism the possibility to simultaneously execute different parts of a system on different processors.

Although parallelism can be found in many electronic computing systems, parallelism is the inherent property of an optical system. For example, a lens, the simplest optical system, forms the whole image at once and not point-by-point or part-by-part. If the image consists of one million points, the lens processes one million data in parallel.

parallelogram mechanism a manipulator that has a kinematic chain of the serial type and part of its kinematic chain forms a closed kinematic chain.

paramagnetic materials with permeability slightly greater than unity. Sodium, potassium, and oxygen are examples.

parameter coding also called vocoding. In parameter coding, the signal is analyzed with respect to a model of the vocal mechanism and the parameters of the model are transmitted.

parameter estimation the procedure of estimation of model parameters based on the model's response to certain test inputs.

parameter matrix an $N \times N$ matrix of complex linear parameters which describe the behavioral relationships between the N ports of a circuit or network. The most commonly utilized parameter matrices are con-

ductance (G), impedance (Z), admittance (Y), (H), scattering (S), chain ($ABCD$) and scattering chain (Φ), all of which can be readily transformed from one to another through simple algebraic manipulations. Any set of these parameters are referenced to given port source and/or load impedance, at fixed input frequencies and fixed power levels.

parameter space a domain formed by all possible values of the given parameters.

parametric amplification a nonlinear optical process in which a signal wave of frequency ω_s and a higher-frequency pump wave of frequency ω_p propagate through a second-order nonlinear optical material, leading to the amplification of the signal wave and the generation of an idler wave of frequency $\omega_p - \omega_s$. *See also* optical parametric oscillator.

parametric coding refers to the class of signal compression methods that are based on a criterion where parameters, or features, of the signal are extracted and coded. Contrasts waveform coding techniques, since the reproduced waveform can be (analytically) quite different from the input, but will still be a subjectively (in terms of vision or hearing) good, even indistinguishable, replica of the input signal.

parametric fixed form control rule control rule given in a predeclared form, with a number of parameters to be tuned; tuning of those parameters can be performed either off-line, prior to control rule implementation, or on-line. A classical example of a parametric fixed form control rule is PID industrial controller; another example is a neural network based control rule with a number — usually large — of parameters of the network to be tuned.

parametric oscillator *See* optical parametric oscillator.

parasitic capacitance the generally undesirable and not-designed-for capacitance between two conductors in proximity of one another.

parasitic inductance the generally undesirable and not-designed-for inductance associated with a conductor, or path of current on a conductor.

parasitic reactance the generally undesirable and not-designed-for reactance associated with one or more conductors in a circuit.

parasitic resistance the generally undesirable and not-designed-for resistance associated with a conductor, or path of current on a conductor.

paraxial approximation neglect of the second derivative of the nearly plane-wave amplitude in the direction of propagation; makes possible analytic solutions for diffracting beams.

paraxial optics formalism for optics in which the paraxial approximation is employed.

paraxial ray ray propagating so nearly parallel to the z axis that its length can be considered equal to the z propagation distance.

paraxial ray equation set of second-order differential equations in the propagation distance for the trajectory of a light ray propagating almost parallel to a fixed axis.

paraxial wave solution of the scalar wave equation in the paraxial approximation.

PARCOR coefficients *See* partial-correlation parameters.

parity property of a binary sequence that determines if the number of 1's in the sequence is either odd or even.

parity bit an extra bit included in a binary sequence to make the total number of 1's (including itself) either odd or even. For instance, for the following binary sequence 101, one would insert a parity bit *P(odd)=1* to make the total number of 1's odd; a parity bit *P(even)=0* would be inserted to make this number even. *See also* error detecting code.

parity check matrix a matrix whose rows are orthogonal to the rows in the generator matrix of a linear forward error control block code. A nonzero result of element-wise finite field multiplication of the demodulated word by this matrix indicates the presence of symbol errors in the demodulated word.

Is generated from the parity check polynomial of any linear (n, k) code and has dimension of $(n - k \times n)$. It is used by the decoder for error detection by checking the parity bits.

parity detection circuit a parity check logic incorporated within the processor to facilitate the detection of internal parity errors (reading data from caches, internal buffers, external data, and address parity errors).

parity-check code a binary linear block code.

Park's transformation a change of variables represented by a linear matrix multiplication used in the analysis of electric machines. *See* rotor reference frame.

parking on a bus, a priority scheme that allows a bus master to gain control of the bus without arbitration.

parse tree the tree that is used for parsing strings of a given language.

Parseval's equation *See* Parseval's theorem.

Parseval's theorem a relationship that states that the integral of the square of the magnitude of a periodic function is the sum of the square of the magnitude of each harmonic component.

Rigorously, suppose that two continuous time signals $f_1(t)$ and $f_2(t)$ have corresponding Fourier transforms $F_1(\omega)$ and $F_2(\omega)$, and that $\overline{F_2(\omega)}$ is the complex conjugate of $F_2(\omega)$. Then Parseval's theorem states that

$$\int_{-\infty}^{\infty} f_1(t) f_2(t) dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} F_1(\omega) \overline{F_2(\omega)} d\omega \, .$$

If $f_1(t) = f_2(t)$, then the left-hand side of the above equation provides an expression of the energy of a signal, which can be related to its Fourier transform as follows:

$$\int_{-\infty}^{\infty} f(t)^2 dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} |F(\omega)|^2 d\omega \, .$$

parsing the process of detecting whether a given string belongs to a given language, typically represented by grammars.

partial coherence the ratio of the sine of the maximum half-angle of illumination striking the mask to the numerical aperture of the objective lens. Also called the degree of coherence, coherence factor, or the pupil filling function, this term is usually given the symbol s.

partial element equivalent method an integral equation technique in which the electromagnetic problem is reduced to a lumped circuit problem by defining some regions in space associated with a node in the lumped circuit. This method takes electric field interactions in the original problem into account by finding (through the integral equations) either a capacitor to ground at infinity and a summation of current controlled current sources or a capacitor connected in series to a summation of voltage controlled voltage sources. The magnetic field interactions are taken into account by finding an inductance in series with a summation of current controlled voltage sources which is placed between nodes.

partial fraction expansion the method of partial fraction expansion consists of taking a function that is the ratio of polynomials and expanding it as a linear combination of simpler terms of the same type. This tool is useful in inverting Fourier, Laplace or z-transforms and in analyzing linear time invariant systems described by linear constant-coefficient differential or difference equations.

partially coherent illumination a type of illumination resulting from a finite size source of light that illuminates the mask with light from a limited, nonzero range of directions.

partial restoration refers to the situation where not all customers who are part of a larger outage can have power restored.

Utilities typically make efforts to restore power to all customers, but situational factors may dictate that the restoration process proceed in stages.

partial-correlation parameters the parameters that are obtained when solving the autocorrelation equations for the problem of linear prediction.

partially decorrelating noise whitening the process of transforming the matched-filtered sufficient statistic of a CDMA signal into a corresponding sufficient statistic which is affected by uncorrelated (white) noise and is partially decorrelated, i.e., the resulting sufficient statistic for a K-user system is described by

$$\mathbf{x} = \mathbf{F}\mathbf{d} + \mathbf{n} \ ,$$

where $\mathbf{x}$ is a length K column vector of sufficient statistics, $\mathbf{F}$ is a $K \times K$ lower left triangular matrix, $\mathbf{d}$ is a length K column vector of data symbols, and $\mathbf{n}$ is a length K column vector of AWGN noise samples.

participation factor the ratio of the change in the power output of a generator versus the total change in power demand. The participation factor of each generator in a power system is found in the solution of the economic dispatch problem.

partition noise electrical noise generated within a vacuum tube when the electron stream hits obstacles and is divided.

partition table a table that enables the grouping of states into equivalent sets.

partitioned process controlled process that is considered as consisting of several sub-processes that can be interconnected; process partitioning is an essential step in control problem decomposition — for example, before decentralized or hierarchical control can be introduced. The term "partitioned system" is used when one is referring to the partitioned control system, but is also often used to denote just the partitioned controlled process.

passband (1) the range of frequencies, or frequency band, for which a filter passes the frequency components of an input signal.

(2) the frequency difference between the higher and lower band edges, expressed in radians/second. The band edges are usually defined as the highest and lowest frequencies within a contiguous band of interest at which the loss equals the maximum attenuation loss across the band. *Compare with* stopband.

passband edge the frequency at which the signal becomes significantly attenuated; typically the frequency at which the signal is attenuated at 3 dB from the maximum response.

passband ripple difference between the maximum attenuation loss and the minimum attenuation loss across the band, expressed in decibels. This parameter is also known as the loss attenuation in ratio form. The band edges are usually defined as the highest and lowest frequencies within a contiguous band of interest at which the loss equals the maximum attenuation loss across the band.

passivation the process in which an insulting dielectric layer is formed over the surface of the die. Passivation is normally achieved by thermal oxidation of the silicon and a thin layer of silicon dioxide is obtained in this manner. Other passivation dielectric coatings may also be applied, such as silicon glass.

passive backplane in printed circuit boards, a circuit board in which other boards are plugged, which contains no active circuit elements to control signal quality.

passive filter a filter circuit that uses only passive components, i.e., resistors, inductors, and capacitors. These circuits are useful at higher frequencies and as prototypes for ladder filters that are active.

passive magnetic bearing a magnetic bearing that does not require input energy for stable support during operation. Generally implemented using permanent magnets.

passive network an electronic circuit made up of passive elements. Passive elements are capacitors, resistors and inductors, and have no gain characteristics.

passive optical network a network where the optical fiber plays the role of a broadband, passive interconnect, and the functions of switching and control are made using electronics.

passive redundancy a circuit redundancy technique which assures fault masking by error correcting codes or N-modular redundancy with voting.

passivity naturally associated with power dissipation. It can be defined for linear as well as nonlinear systems. A formal definition of passivity requires a representation of systems by an operator mapping signals to signals. The signal space under consideration is assumed to be extended L_2 space with a scalar product defined by

$$\langle x|y\rangle = \int_0^\infty x(s)y(s)ds$$

A system with input u and output y is passive if

$$\langle x|y\rangle \geq 0$$

The system is input strictly passive if there exists $\varepsilon > 0$ such that

$$\langle x|y\rangle \geq \varepsilon\|u\|^2$$

and output strictly passive if there exists $\varepsilon > 0$ such that

$$\langle x|y\rangle \geq \varepsilon\|y\|^2$$

path the space curve that the manipulator end-effector moves along from the initial location (position and orientation) to the final location is called the path. Notice that the path is a pure geometric description of motion. Path can be specified in the joint space or in the operational space.

path-delay testing any one of several possible techniques to verify that signal transitions created by one clock event will travel through a particular logic/path in a subcircuit, IC component, or system and will reach their final steady-state values before a subsequent clock event.

path-set the set of all edges in a path.

patrolling in overhead power lines, action taken when the location of a fault is not known. The crew will typically follow overhead spans until the location of the outage is found.

pattern a plot of the distribution of radiated power. Typically, the pattern consists of a main lobe (major lobe), in which most of the radiated power is confined, and a number of progressively weaker sidelobes (minor lobes).

pattern classification assignment of a pattern (typically a vector of measurements or a feature derived from measurements) to a class.

pattern matching (1) the detection, in an image, of a subimage in which pixel values are structured according to a predefined schema.

(2) a process by which patterns may be recognized, potentially and sometimes in practice by template matching, but otherwise by inference following the location of features. Typically, inference is carried out by application of Hough transforms or association graphs.

pattern recognition the feature extraction, clustering, and classification processes associated with assigning meaning to measurements. There are statistical, syntactic and structural methods for pattern recognition, and neural network methods are often considered as a subset of pattern recognition.

pattern sensitive integrated circuits in which an error may result from a certain data pattern being encountered.

pattern synthesis the process of designing an antenna such that its radiation characteristics meet desired specifications.

patterning the processes of lithography (producing a pattern that covers portions of the substrate with resist) followed by etching (selective removal of material not covered by resist) or otherwise transferring the pattern into the substrate.

pause instruction an assembly language instruction whose execution causes a momentary pause in program execution.

Pawlak's information system a system model denoted S can be viewed as a pair $S = (U, A)$, where $U = \{x_1, \ldots, x_n\}$ is a nonempty finite set of objects. The elements of U may be interpreted, for example, as concepts, events, goals, political parties, individuals, states, etc. The set U is called the universe. The elements of the set A, denoted $\mathbf{a}_j$, $j = 1, \ldots, m$, are called the attributes. The attributes are vector-valued functions. For example,

$$\mathbf{a}_j : U \to \{-1, 0, 1\} .$$

An example of a simple information system is shown in the following table.

	$\mathbf{a}_1$	$\mathbf{a}_2$	$\mathbf{a}_3$
x_1	-1	0	0
x_2	0	0	1
x_3	0	1	1
x_4	1	1	1

The first component of $\mathbf{a}_1$ being -1 may mean that x_1 is opposed to the issue $\mathbf{a}_1$, while x_4 support $\mathbf{a}_1$, etc. Such data can be collected from newspapers, surveys, or experts.

payload the portion of a packet that is neither the header nor the trailer and is either user- or protocol-specific data.

PC *See* program counter, personal computer.

PC-relative addressing an addressing mechanism for machine instructions in which the address of the target location is given by the contents of the program counter and an offset held as a constant in the instruction added together. Allows the target location to be specified as a number of locations from the current (or next) instruction. Generally only used for branch instructions.

PCA *See* principal component analysis.

PCB *See* printed circuit board. polychlorinated biphenyls.

PCBA acronym for printed circuit board assembly.

PCM *See* pulse-code modulation.

PCN *See* personal communications network.

PCS *See* personal communications services.

PDC *See* personal digital cellular.

PDF *See* probability density function.

PDF-optimized scalar quantization *See* Lloyd–Max scalar quantization.

PDMA *See* polarization division multiple access.

PDP *See* piecewise deterministic process.

PDU *See* protocol data unit.

PE *See* processing element.

peak accumulation mode an operating feature of digital storage oscilloscope in which the maximum and minimum excursions of the waveform are displayed for a given point in time.

peak detector an electronic circuit which outputs a DC voltage which indicates the peak amplitude of an alternating waveform.

peak let-through current the maximum value of the available short-circuit current that is let through a current-limiting fuse. *See also* current limiting fuse.

peak output power the instantaneous peak power delivered to a load, expressed in watts. It is simply the maximum power at any instant in time taken during the total time period being considered. This term is often used when a device or application is subjected to time-varying signals such as pulse modulation.

peak power the maximum value of the square of the absolute value of a signal over the duration of the signal; i.e., for the signal $x(t)$, $\max_t |x(t)|^2$. The maximum instantaneous power of a signal.

peak signal to noise ratio (PSNR) objective distortion measure of the difference between a discrete time signal x_i, defined over $[1 \ldots n]$, and a degraded, restored or otherwise processed version of the signal $\hat{x_i}$, defined as

$$PSNR = 10log_{10}\frac{x_{max}^2 n}{\sum_{i=1}^{n}(x_i - \hat{x_i})^2}\ dB$$

PSNR differs from the standard signal to noise ratio by using the square of the signal's maximum value rather than its variance in the numerator. In image coding, this value is often assumed to be 255, for 8-bit images.

peaking generator (1) a utility generating unit, typically driven by a gas-fired turbine, available to rapidly come on line when the system demand reaches its highest levels.

(2) a generator used by a plant to reduce the peak demand drawn in a given period of time (typically during a one-month interval).

peaking unit a generator used only to supply peak periods of electric power demand.

Pearl Street Station the first investor-owned electric utility plant, started by Edison in 1882 in New York City. It provided low-voltage, DC electric service to 85 customers with an electric load of 400 lamps.

PEB *See* post-exposure bake.

PEC *See* perfect electric conductor.

pel a picture element that has been encoded as black or white, with no gray scale in between.

pellicle a thin, transparent membrane placed above and/or below a photomask to protect the photomask from particulate contamination. Particles on the pellicle are significantly out of focus, and thus have a much reduced chance of impacting image quality.

penalty function *See* cost function.

penstock a water tube that feeds the turbine. It is used when the slope is too steep for using an open canal.

pentode vacuum tube with five active electrodes: cathode, control grid, screen grid, suppressor grid, plate.

per-unit system a dimensionless system for expressing each quantity in terms of a fractional part of a "base" value, often the nominal or rated value of the system. Typical electrical calculations require four base quantities (voltage, current, impedance, and apparent power), any two of which may be chosen arbitrarily. The per-unit system greatly simplifies calculations in electrical systems containing transformers with non-unity turns ratios, making the voltage differences transparent.

percent impedance the per-unit impedance expressed as a percentage on a certain MVA and voltage base.

percent system a variation of the per-unit system in which the ratios expressing system quantities are expressed as a percentage of the base quantity.

perceptron one of the earliest neural algorithms demonstrating recognition and learning ability. Since the output of neuron is binary, the neuron can classify an input into two classes, A and B. The perceptron model containing a single neuron is expressed as follows: $z = 1$, if $\sum w_i x_i > T$ and $z = 0$, if $\sum w_i x_i < T$ where z is the output, x_i is an input, w_i is an element of the interconnection weight matrix, and T is a generalized threshold. If the interconnection weight matrix is known, an input vector (x_i) can be classified into A or B according to the result of z. On the other hand, the interconnection weight matrix can be formed if a set of input vectors (x_i) and their desired outputs z are known. The process of forming the interconnection weight matrix from known input–output pairs is called learning. The perceptron learning is as follows. First, the weight w_i and the threshold T are set to small random values. Then the output z is calculated using a set of known input. The calculated z is compared with the desired output t. The change of weight is then calculated as follows: $\delta w_i = \eta(t - z)x_i$ where η is the gain term that controls the learning rate, which is between 0 and 1. The learning rule determines that the corrected weight is

$$w_i = w_i(\text{old}) + \delta w_i$$

The process is repeated until $(t - z) = 0$. The whole learning process is completed after all input–output pairs have been tested with the network. If the combination of inputs are linearly separable, after a finite number of steps, the iteration is completed with the correct interconnection weight matrix. Various optical systems have been proposed to implement the perceptron, including correlators.

The original perceptron was a feedforward network of linear threshold units with two layers of weights, only one layer of which (the output layer) was trainable, the other layer having fixed values.

perceptron convergence procedure a supervised learning technique developed for the original perceptron. If the output y_i of unit i in the output layer is in error, its input weights, w_{ij}, are adjusted according to $Dw_{ij} = h(t_i - y_i)x_j$, where t_i is the target output for unit i and h is a positive constant (often taken to be unity); x_j is the output of unit j in the previous layer which is multiplied by weight w_{ij} and then fed to unit i in the output layer.

perceptual coding involves the coding of the contextual information of the image features by observing the minimum perceptual levels of the human observer.

perfect code a t-error correcting forward error control block code in which the number of nonzero syndromes exactly equals the

number of error patterns of t or fewer errors. Hamming codes and Golay codes are the only linear nontrivial perfect codes.

perfect electric conductor (PEC) a conductor that has infinite conductivity or zero resistivity.

perfect reconstruction the condition states that the output of a filter bank is a delayed version of the corresponding input. In other words, there are no aliasing and (phase and magnitude) distortions for the output of this filter bank.

perfect shuffle interconnects that connect sources 1, 2, 3, 4, 5, 6, 7, 8 to detectors 1, 5, 2, 6, 3, 7, 4, 8, respectively. The operation divides 1, 2, 3, 4, 5, 6, 7, 8 into two equal parts 1, 2, 3, 4 and 5, 6, 7, 8 and then interleaves them. The size of the array must be 2^n. The array returns to its original order after n operations. When the option to exchange pairs of neighboring elements is added to a perfect shuffle network, any arbitrary permutation of the elements is achievable.

performability the probability that a system is performing at or above some level of performance, L, at the instant of time t.

periodic convolution a type of convolution that involves two periodic sequences. Its calculation is slightly different from that of discrete linear convolution in that it only takes summations of the products within one period instead of taking summations for all possible products. Circular convolution is an operation applied to two finite-length sequences. In order to make its result equal to that of the linear convolution, the two sequences have to be zero-padded appropriately. These two zero-padded sequences can then serve as periods to formulate two periodic sequences. At this time, the result of the periodic convolution is equal to circular convolution.

periodic coordination coordination process occurring when a sequence of control decisions is required over a given time interval and these decisions are directly made by the local units but the operation of these units is periodically adjusted by the coordinator; an example is operation of an industrial process controller with several independent regulators, which at specified time instants are provided with new parameters or additive compensation signals so as to achieve better results from the overall point of view, for example, to achieve better transient responses to the changes of the free inputs.

periodic signal a continuous time signal $f(t)$ with period $T \geq 0$ such that

$$f(t) = f(t+T) \text{ for all } -\infty < t < \infty .$$

The smallest such T is its *fundamental* period. For example, the signal

$$f(t) = A\sin(\omega t + \phi)$$

is periodic with fundamental period $2\pi/\omega$.

Let T be a positive integer. A discrete time signal $f[k]$ is periodic with period T if

$$f[k] = f[k+nT] \text{ for all integers } k.$$

The smallest such T is its fundamental period. For example, $f[k] = \cos[\frac{\pi}{2}k]$ is periodic with period 4. On the other hand, $f[k] = \cos(k)$ is not periodic, as a positive *integer* T does not exist to satisfy the definition.

If a signal is not periodic, then it is *aperiodic*.

periodic structure structure consisting of successive identically similar sections, similarly oriented, the electrical properties of each section not being uniform throughout. Note that the periodicity is in space and not in time. The analysis of infinite periodic structure is significantly simplified by the Floquet's theorem. *See also* Floquet's theorem.

periodic waveform phrase used to describe a waveform that repeats itself in a uniform, periodic manner. Mathematically, for

the case of a continuous-time waveform, this characteristic is often expressed as $x(t) = x(t \pm kT)$, which implies that the waveform described by the function $x(t)$ takes on the same value for any increment of the kT, where k is any integer and the characteristic value $T > 0$, describes the fundamental period of $x(t)$. For the case of the discrete-time waveform, we write $x(n) = x(t \pm kN)$, which implies that the waveform $x(n)$ takes on the same value for any increment of sample number kN, where k is any integer and the characteristic value integer $N > 0$ describes the fundamental period of $x(n)$.

peripheral an ancillary device to a computer that generally provides input/output capabilities.

peripheral adapter a device used to connect a peripheral device to the main computer; sometimes called an I/O card, I/O controller, or peripheral controller.

peripheral control unit a device used to connect a peripheral device to the main computer; sometimes called an I/O card, I/O controller, or peripheral controller.

peripheral controller *See* peripheral control unit.

peripheral device a physical mechanism attached to a computer that can be used to store output from the computer, provide input to the computer, or do both. *See also* I/O device.

peripheral processor a computer that controls I/O communications and data transfers to peripheral devices. It is capable of executing programs much like a main computer. *See also* I/O channel.

peripheral transfer a data exchange between a peripheral device and the main computer.

peripheral unit a physical mechanism attached to a computer that can be used to store output from the computer, provide input to the computer, or do both. *See also* I/O device.

permalloy a family of ferromagnetic alloys consisting of iron, nickel, and molybdenum that saturate at moderate flux density levels and have a low coercive force.

permanent fault a fault that remains in existence indefinitely if no corrective actions are taken.

permanent magnet (PM) a magnet that produces an external magnetic field by virtue of the alignment of domains inside the material and retains its magnetism after being subjected to demagnetizing fields.

permanent magnet AC motor a generic term used to describe both permanent magnet synchronous motors and brushless DC motors.

permanent magnet brushless DC machine a machine that is similar in structure to a permanent magnet synchronous machine, containing armature windings on the stator and permanent magnets on the rotor. The permanent magnet brushless DC machine, however, is characterized by a trapezoidal flux density distribution in the airgap instead of the sinusoidal distribution of the synchronous machine. In operation, a DC voltage is applied sequentially to the stator coils to create a rotating field that pulls the rotor with it. To correctly operate, the brushless DC machine requires sensors to determine the rotor position so that the proper stator phases may be excited.

permanent magnet DC machine a DC machine in which the field excitation in the stator is provided by permanent magnets instead of electromagnets.

permanent magnet DC motor *See* permanent magnet DC machine.

permanent magnet machine a machine that uses permanent magnets to establish the field. In DC machines, the permanent magnets are placed on the stator, while on AC synchronous machines they are placed on the rotor.

permanent magnet stepper motor a stepper motor that has a permanent magnet assembly on the rotor.

permanent magnet synchronous machine a polyphase AC motor with rotor mounted permanent magnets and sinusoidal distribution of stator phase windings. The field windings in the rotor are replaced by permanent magnets to provide the field excitation in these machines.

permanent split-capacitor (PSC) motor a induction motor that operates from a single-phase supply. The motor contains two phase windings in quadrature; however, one of them has a capacitor in series with it to create a phase shift between the winding currents. Both windings and the capacitor operate continuously so the machine acts like a two-phase machine when running at its operating speed, producing less vibration and noise than a single-phase motor. Since the capacitor runs continuously, it is sized smaller than the capacitor used in a capacitor-start induction motor (CSIM). Thus, the PSC motor produces a lower starting torque than the CSIM.

permeability tensor relationship between the magnetic field vector and the magnetic flux density vector in a medium with no hysteresis; flux density divided by the magnetic field in scalar media. Permeability indicates the ease with which a magnetic material can be magnetized. An electromagnet with a higher permeable core material will produce a stronger magnetic field than one with a lower permeable core material. Permeability is analogous to conductance, when describing electron flow through a material. *See also* reluctance.

permeameter making use of Hall effect gaussmeters, search coils, and flux meters, the permeameter, or hysteresigraph, records the major hysteresis loop of a material, from which its basic material properties can be determined: residual induction, coercivity, energy product, saturation flux density, and recoil permeability.

permeance the magnetic analog for conductance, indicating the ease with which magnetic flux will follow a certain path, which can be approximated by calculations based purely on magnetic circuit geometry.

permeance coefficient the slope of the load line for a magnetic circuit, determined solely by physical geometry of the magnet and permeable materials around it; the ratio of magnetic induction (B) and applied field (H) at the operating point.

permission *See* access right.

permittivity *See* electric permittivity.

persistent current a current circulating in a closed structure without applied potential. Examples are the supercurrent in a superconducting magnet and the current in a closed mesoscopic ring in a magnetic field.

persistent spectral hole burning spectral hole burning with a long lifetime, usually on the scale of seconds or longer.

personal computer a general term for a microcomputer used for such purposes as word processing, email, financial management, and game playing. While, the acronym "PC" is applied to microcomputers used both for business and personal use, the term "personal computer" is more usually applied to those used by individuals or families at home.

personal communications network (PCN) a telecommunications network designed to provide services to a person rather than a geographic location. The network may comprise a range of different technologies from end to end and contains within it intelligence to enable the communication to be directed to the appropriate terminal or device carried with the person.

personal communications services (PCS) a mobile telephone service with an essential urban and suburban coverage characterized by low cost pocket terminals, communications at a price comparable to a cable telephone, and distribution of the services and products to the general public. This definition is independent of the technology used.

PCS is the proposed next generation of wireless network services, providing voice communication services similar to today's cellular services, only with smaller cells, lower power, and cheaper rates.

personal digital cellular (PDC) one type of digital cellular phone system. PDC is 800 MHz/1.5 GHz band, FDD, TDMA system, and it handles 1/4p shift QPSK modulated signal with 32 kbit/s. This cellular system was developed and operated in Japan.

personal handy phone system (PHS) a digital microcell system designed in Japan that operates in the 1.9 GHz band. PHS provides cordless telephone or telepoint services similar to other digital cordless technologies, such as CT2. The spectrum allocation for PHS is 1895–1918 MHz. There are 77 radio channels, each 300 kHz wide and divided into 2×4 time slots. This provides a total of 308 duplex traffic channels, with duplexing via TDD. The carrier bit rate is 384 kb/s, and PHS terminals have a peak transmit power of 80 mW.

perspective distortion a type of object distortion that results from projecting 3-D shapes onto 2-D image planes by convergence of rays towards a center of projection: *See also* perspective projection. This type of distortion is also called foreshortening.

perspective inversion a property of perspective projection in which planar (typically silhouetted) objects that are not perpendicular to the axis of projection will appear, in the absence of additional information, to have either of two possible orientations in space.

perspective projection projection of a 3-D object on a plane, termed "projection plane," as if it were imaged by an ideal pinhole camera located in a point termed "center of perspective."

perspective transformation a matrix transformation that represents the perspective projection of objects in 3-D scenes into 2-D images or the projection of one 2-D image into another 2-D image. Perspective transformations are conveniently carried out using 4×4 matrices representing homogeneous co-ordinate transformations.

perturbations of controllable systems the set of controllable linear stationary continuous-time finite-dimensional dynamical systems is dense and open in the set of all linear stationary continuous-time finite-dimensional dynamical systems with the same state and input dimensions.

PET *See* positron emission tomography.

Petersen coil another term for a ground fault neutralizer.

petticoat another name for shed, a feature of an insulator.

PFN *See* pulse forming network.

PGA *See* field-programmable gate array.

phantom an artificial target, sometimes designed to mimic the size, shape, and attenuation characteristics of actual tissue, that is

used to test and calibrate imaging hardware and software.

phase (1) a notion used extensively in interpreting complex quantities such as Fourier series, Fourier transforms etc. Given a complex number $c = x + iy = r\cos\phi + ir\sin\phi$, then r represents the magnitude of c and ϕ the phase.

(2) a horizontal translation parameter of the signal. Given a sinusoidal signal $s(t) = Asin(2\pi ft + \phi)$, then f represents the frequency (in Hz) of s and ϕ the phase.

phase alternate line (PAL) a color television system that inverts the (R-Y) color signal on alternate lines. The color burst is located on the back porch of the composite video signal and the phase alternates every line for identification of the (R-Y) difference signal phase. The color demodulator uses the shift in the color burst phase and the (R-Y) phase reversals to eliminate any hue changes caused by phase errors. The PAL color demodulation method eliminates the tint control but does cause desaturated colors.

The vertical scan parameters for the PAL television system are based on the European power line frequency of 50 Hz. The different PAL standards in existence in different countries allow for a slightly wider video bandwidth. The primary PAL system parameters (with the allowed bandwidth variance) are

Vertical Fields Frequency	50 Hz
Number of Interlaced Fields	2
Vertical Frame Frequency	25 Hz
Number of Horizontal Lines/Frame	625
Horizontal Scan Frequency	15,625 Hz
Video Bandwidth	5 to 6 MHz
Color Subcarrier Frequency	4.433618 MHz
Sound Modulation	FM
RF Channel Bandwidth	7 to 8 MHz

[* Alternative definitions for the 3 television systems that you may enjoy]

[NTSC - Never Twice the Same Color, SECAM - System Essentially Contrary to the American Method, PAL - Perfect At Last]

phase angle the angle in the complex plane of a complex value $x = a + jb$ calculated as

$$\angle x = \arctan\frac{b}{a}.$$

phase angle meter meter used to measure the phase angle difference between two AC quantities. In power systems, typical meters use perpendicular moving coils to measure the phase angle between an AC current and an AC voltage. More accurate devices typically measure the time interval between zero crossings of the two input signals.

phase breaking the process by which the quantum mechanical phase, which is related to energy, of a particle is destroyed. The most common example is the inelastic scattering due to electron–electron and electron–phonon interactions.

phase coded modulation (PCM) a form of angle modulation. The modulated wave, $s(t)$, is given by:

$$s(t) = A_c\cos[2\pi f_c t + k_p m(t)],$$

where $m(t)$ is the message signal, f_c is the carrier frequency, and k_p is the phase sensitivity of the modulator.

phase comparator often referred to as a phase detector; a three-port device that produces an analog output proportional to the phase difference between its two inputs. Since both inputs are periodic, the relative output voltage (or current) as a function of input phase difference (i.e., the transfer function) is also periodic; the shape of the transfer function (sometimes called the "output characteristic" of the phase detector) depends upon the particular technique used to accomplish the phase detection. These include sinusoidal, triangula, and sawtooth shape factors. Analog/digital implementation, required linearity, and range of input phase difference are primary factors in determining a suitable output characteristic for a specific phase comparator application.

phase comparison relay a phase comparison relay is a protective relay used on transmission lines which operates by comparing phase angles of signals generated at opposite ends of the line. They employ a dedicated communications channel to make the comparison. The signals compared are typically corresponding phase currents or sequence currents.

phase conjugate mirror *See* phase conjugator.

phase conjugation a technique for providing dispersion compensation that relies on spectral inversion of the optical signal using a nonlinear process known as four-wave-mixing.

phase conjugator an optical set-up or system that can generate the time-reversed replica of the incident wave. Phase conjugators play an important role in many optical systems that require the transmission of optical waves through scattering media such as atmosphere, optical fibers. Photorefractive crystals such as $BaTiO_3$, SBN, BSO are by far the most efficient media for the generation of phase conjugate waves.

phase constant a constant, which is generally complex, that is important in the study of electromagnetic waves. The phase constant is equal to the frequency of excitation of the wave times 2 times pi times the square root of the product of the permeability and the permittivity of the medium that the wave is traveling in. Also called propagation constant or wavenumber.

phase control a method for controlling the amount of power delivered to a load by varying the delay angle. This controls the delay between the instant when the voltage across the power semiconductor goes positive and the actual start in conduction of the device.

phase delay the difference in the absolute angles between a point on a wavefront at the device output and the corresponding point on the incident input wavefront, expressed in seconds or degrees. The delay can exceed 360 degrees.

phase detector gain the ratio of the DC output voltage of the phase detector to the input phase difference. This is usually expressed in units of volts per radian.

phase deviation the peak difference between the instantaneous angle of the modulated wave and the angle of the carrier. In the case of a sinusoidal modulating function, the value of the phase deviation, expressed in radians, is equal to the modulation index.

phase discriminator a device for detecting the phase deviation of a phase modulated signal.

phase distortion problem that occurs when the phase shift in the output signal of an amplifier is not proportional to the frequency.

phase error the difference in phase between two sinusoidal waveforms having the same frequency.

phase grating an optical grating characterized by a spatially periodic variation in the refractive index of a medium.

phase interrupting collision a collision that interrupts the phase of the wavefunctions of lasing atoms and consequently broaden their emission spectra.

phase locked loop a device containing a voltage controlled oscillator, a synchronous detector and a low-pass filter, arranged in a feedback loop so that the oscillator output can be made to lock onto a weak incoming periodic signal such as a radio wave. Also of use in frequency synchronization.

phase matching the condition that the phase of the nonlinear polarization bears a spatially fixed relation to that of the optical field generated by the polarization. This condition is a requirement for high efficiency in nonlinear optical generation processes.

phase modulation a type of angle modulation whereby information is encoded onto a carrier wave by modifying its phase angle as a function of time in proportion to the intelligence signal amplitude.

phase modulator a device that alters the phase of a signal.

phase noise frequency variation in a carrier signal that appears as energy at frequencies other than the carrier frequency.

phase only binary filter transmission or reflection phase plate in which neighboring regions differ in phase shift by pi radians.

phase parameter complex parameter representing corrections to the gain and phase of a Gaussian beam.

phase plane a two-dimensional state space.

phase plate transparent medium that introduces different phase shifts to different transverse regions of an optical wave for the purpose of introducing or reducing phase or amplitude structure on the wave; often having only two phase shift values differing by π.

phase portrait many different trajectories of a second-order dynamical system plotted in the phase plane.

phase response the way in which a system alters the phase of an input sinusoid.

phase ripple the variation in phase response across the operating bandwidth of an optical or electrical device.

phase sensitive detection *See* synchronous detection.

phase sensitive measurement measurement in which the phase of an AC signal is tracked in a feedback loop in order to improve detection sensitivity. The most common examples are phase-locked loops in control systems and lock-in amplifier measurements in electronics. In the latter, a small AC signal is added to the bias voltage supply, and this signal is then detected in any measured quantity with an amplifier whose phase can be varied to "lock onto" that of the initial AC signal. This effectively mixes the two AC signals, and their difference (at DC) is used to characterize the measurement. The effective bandwidth is determined by the bandwidth at the DC level.

phase sequence describes the rotational orientation of the voltage phasors in a 3-phase electrical power system. A positive phase sequence, designated by the nomenclature ABC, indicates a 3-phase connection in which the B phase voltage lags the A phase voltage by 120 degrees, and the C phase voltage leads the A phase voltage by 120 degrees. A negative phase sequence, designated by ACB, reverses this relationship so that the B phase leads the A phase, and the C phase lags the A phase. *See also* phase sequence indicator.

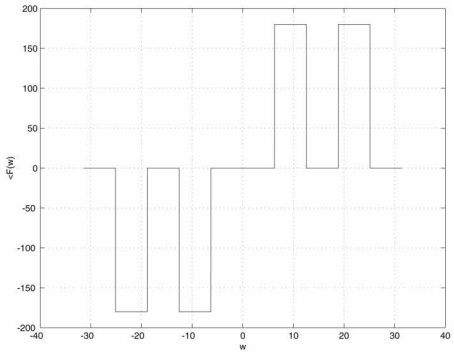
phase sequence indicator device used to detect the phase sequence of a 3-phase electrical power system. *See also* phase sequence.

phase shift a time displacement of a waveform with respect to another waveform of the same frequency.

phase shifter a device that changes the phase angle between two buses in a power system. Conventional phase shifters are special autotransformers in with each phase voltage in connected in series with a variable component of voltage from another phase.

By adjusting the variable component, the phase angle can be changed. Newer phase shifters are built with power electronic devices. Phase shifters are often used in antenna arrays.

phase spectrum the phase angle of the Fourier transform $\angle F(\omega), -\infty < \omega < \infty$ of a signal $f(t)$. For example, the phase spectrum of a rectangular pulse of unit width is given in the figure. *See also* Fourier transform.



Phase spectrum.

phase velocity the velocity, at a given frequency, and for a given mode, of an equiphase surface in the direction of propagation. In other words, it is the velocity at which an observer travelling in the propagation direction should move in order to see the phase unchanged. It can be greater than the speed of light, since no transportation of energy is actually involved.

phase-controlled converter converter in which the power devices are turned off at the natural crossing of zero voltage in AC to DC conversion applications.

phase-controlled oscillator a voltage controlled oscillator whose output frequency is determined by some type of phase difference detecting circuitry. *See also* phase error.

phase-locked loop (PLL) (1) a circuit for synchronizing a variable local oscillator with the phase of a feedback portion of that oscillator so as to operate at a constant phase angle relative to the reference signal source. May be categorized as 1st, 2nd, 3rd, and so on, order loops according to the number of integrators in the so-called loop filter. The number of integrators is one less than the order of the loop. This loop is used for demodulators, frequency synthesizers, and timing recovery circuits.

(2) a closed-loop feedback control system where the feedback signal is a phase variation of the signal frequency rather than a voltage or a current.

phase-only filter an optical mask imposes a pattern of phase variations over an image passing through it; used frequently in image correlators.

phase-matching conditions in waveguides formed by two or more different media, the phase-matching condition states the phase velocity along the propagation direction in the different media should be the same.

phase-shift keying (PSK) an information encoding method that uses changes in the phase of the signal carrier.

phase-shifting mask a mask that contains a spatial variation not only in intensity transmittance but phase transmittance as well.

phase-to-phase fault a fault with two transmission lines being short circuited.

phased array *See* phased array antenna.

phased array antenna an antenna composed of an aperture of individual radiating elements. Beam scanning is implemented by changing the phases of the signals at the antenna elements with the weights remaining fixed as the beam is steered.

phasor a complex number representing the amplitude and phase of a sinusoidal function.

phoneme the smallest units in phonemics. Phonemes are produced by different manners of articulation (e.g., plosives, fricatives, vowels, liquids, nasals). The automatic speech recognition on large lexicons is often based on the recognition of units like phonemes in order to break the complexity of the global recognition process, from speech frames to words and sentences.

phonemics the study of sound units in the framework of descriptive linguistics. Basically, unlike phonetics, the sounds are studied by taking into account the language and not only observable features in the signal.

phones the smallest units in phonetics, where the emphasis is placed on observable, measurable characteristics of the speech signal.

phonetic knowledge knowledge of the acoustic structure of phones. It is of fundamental importance for the design of effective automatic speech recognition systems.

phonetics the study of the acoustic sounds where the emphasis is placed on observable, measurable characteristics of the speech signal.

phonon a quantized packet of energy associated with material lattice vibrations that have been excited by an incident photon.

phonon maser *See* acoustic laser.

phosphorescence emission of light from a long-lived electronically excited state. Phosphorescent emission is a quantum mechanically forbidden transition between electronic levels of different spin states.

photochemistry chemical reactions that occur as a result of electronically exciting at least one of the reactant molecules with light.

photodetector device capable of producing or modifying an electrical signal in proportion to the amount of light falling on the active area of the device.

photoelastic effect mechanical strain in a solid causes a change in the index of refraction that can affect the phase of a light wave traveling in the strain medium.

photoelectric effect the phenomenon whereby light of sufficiently short wavelength falls on the emitter electrode of a photocell and causes electrons to be emitted from the electrode.

photogalvanic effect *See* photovoltaic effect.

photolithography *See* optical lithography.

photoluminescence the process by which light is emitted from solids, atoms, gases, after excitation by an additional light source. The input light excites electrons to higher energy states, and as they relax they emit light (through electron-hole recombination) whose frequency is characteristic of the statistical properties of the carriers.

photomask *See* mask.

photon a minimum energy quantum of light energy proportional to the frequency of the radiation.

photon echo (1) an optical field emitted by a macroscopic polarization that has been generated by reversing the dephasing process in a material having an inhomogeneously broadened spectrum.

(2) complex output pulses that are generated when two intense input pulses interact

with the same semiclassically described laser medium.

photon lifetime *See* cavity lifetime.

photon noise fundamental noise due to the quantum nature of light; a statistical variation in optical intensity due to measurements of discrete number of photons.

photopic formally, a description of luminances under which human cone cells are active. Informally, describing daylight luminances.

photorefractive beam fanning a photorefractive phenomenon in which a beam of coherent light is scattered into a fanned pattern by a photorefractive crystal (e.g., barium titanate, lithium niobate). When a laser beam passes through a photorefractive crystal, significant scattering often occurs. The scattered light appears to be asymmetrical with respect to the beam except for propagation along the c-axis. For laser beams of moderate power, the scattered light appears to develop slowly in time and eventually reaches a steady-state scattering pattern. This is known as photorefractive beam fanning. The beam fanning originates from an initial scattering due to crystal imperfections. The initially scattered light is amplified due to the physical overlap and the energy coupling between the incident beam and the scattered beam. Beam fanning often occurs in highly efficient photorefractive media, even if the material is near-perfect. Photorefractive beam fanning plays an important role in the initiation of many phase conjugators and resonators, even through the fanning itself can be a source of noise in many experimental measurements.

photorefractive crystal crystalline solids that exhibit photorefractive effect. The photorefractive effect is observed in many electro-optic crystals, including $BaTiO_3$, $KNbO_3$, $LiNbO_3$, $Sr_{1-x}Ba_xxNb_2O_6$ (SBN), $Ba_{2-x}Sr_xK_{1-y}Na_y$ Nb_5O_{15} (KNSBN), $Bi_{12}SiO_{20}$ (BSO), $Bi_{12}GeO_{20}$ (BGO), GaAs, InP, CdTe, etc. These crystals are referred to as photorefractive crystals. They are by far the most efficient medium for the generation of phase conjugation and real-time holography using relatively low intensity levels (e.g., 1 W/cm^2). In addition to the efficient holographic response, beam coupling known as two-wave mixing also occurs naturally in photorefractive crystals.

photorefractive effect in the broad sense, any optical process in which the refractive index of a material system is modified by an optical field. More precisely, a particular nonlinear optical process in which loosely bound charges are redistributed within a crystalline material in response to an incident light field, thereby producing a static electric field, and modifying the refractive index of the material by the linear electro-optic effect. Changes in refractive index upon exposure to a light pattern in certain materials such as BSO, lithium niobate, and barium titanate. A manifestation of the electro-optic effect on a microscopic scale due to spatial charge transport.

photorefractive grating a refractive index grating often produced by using the illumination of two coherent laser beams, having sufficient photon energy, in photorefractive crystals.

photoresist a photosensitive material that forms a three-dimensional relief image by exposure to light and allows the transfer of the image into the underlying substrate (for example, by resisting an etch).

photoresist contrast a measure of the resolving power of a photoresist, the photoresist contrast is defined in one of two ways. The measured contrast is the slope of the standard H-D curve as the thickness of resist approaches zero. The theoretical contrast is the maximum slope of a plot of log-development rate versus log-exposure energy (the theoretical H-D curve). The photoresist contrast is usually given the symbol g.

photovoltaic effect a photoelectric phenomenon in certain photorefractive crystals, for example, $LiNbO_3$, $BaTiO_3$, $LiTaO_3$, in which the illumination of light leads to the generation of electric current along certain direction in the crystals. This leads to the accumulation of charges on the surfaces of the crystals, causing an open circuit voltage.

photovoltaics conversion of insolation into DC electricity by means of solid state p-n junction diodes.

PHPS *See* personal handy phone system.

PHS *See* personal handy phone system.

physical address *See* real address.

physical medium the communication channel over which signals are transmitted. Broadcast media, in which all stations receive each transmission, are primarily used in local-area networks. Common media are optical fibers, coaxial cable, twisted copper-wire pairs, and airwaves.

physical model a mathematical model based on device physics. Physical models generally have a mid-range to high modeling valuation coefficient.

physical optics a high-frequency technique to approximate electromagnetic scattering from an object by representing the smooth, electrically large parts of the object by equivalent currents at the object's surface.

physical page number the page-frame address (in main memory) of a page from virtual memory.

physical placement of logic (PPL) a design entry method between full custom and standard cell. It begins at the block diagram level where the detailed block specification and the corresponding layout are done simultaneously. PPL is targeted at the occasional designer.

physical sensor an interface device at the input of an instrumentation system that quantitatively measures a physical quantity such as pressure or temperature.

physical theory of diffraction a correction to physical optics that includes diffracted fields due to edges and corners.

physical vapor deposition a process in which a conductive or insulating film is deposited on a wafer surface without the assistance of chemical reaction. Examples are vacuum evaporation and sputtering.

pickup current the specified value that, if exceeded, causes the relay to act on its contact and cause a circuit breaker action. It is the threshold current for system protection, and a magnitude above this is considered a fault or abnormal condition.

pickup voltage *See* pickup current.

picocell cell with radius of a few meters. *See also* cell.

picture description language a language in which parts of scenes are labelled and their relative positions are described in a special symbolic form. Typical relationships between objects are "inside," "adjacent to," "underneath," and so on. Such a language can be parsed and interpreted symbolically to build up a meaningful understanding of the picture.

picture–carrier the carrier frequency of 1.25 MHz above the lower frequency limit of a standard NTSC television signal (luminance carrier in color TV).

PID control *See* proportional-integral-derivative control.

piecewise deterministic process (PDP) a class of Markov stochastic processes that follow deterministic dynamics between random jumps. A generator of piecewise determin-

istic process (PDP) is an integro-differential operator. Roughly speaking PDPs may be characterized by three functions:

1. deterministic dynamics between jumps driven by a differential equation,

2. jump intensity,

3. jump magnitude probabilistic distribution.

PDPs can be used to describe some queueing, storage, and renewal processes. Moreover, they may also be applied in modeling control processes in the presence of failures, abrupt changes of working conditions, jumping deterioration of quality of working plants, as well as inventory and maintenance systems. The important class of PDPs is produced by linear systems with Markov jumps.

Pierce gun an electron gun with which the focusing electrode is tilted 67.5° from the axis of the electron beam and the accelerator anode is also tilted forward to produce a rectilinear flow of an electron beam.

Pierce oscillator usually, an FET crystal oscillator where the crystal is connected between gate and drain. The crystal is used like an inductor, the source of the FET is AC grounded, and the gate-source capacitance of the device and drain-source capacitance are used as parts of the LC-oscillator similar to Colpitts oscillator.

piezoelectric pertaining to a material that possesses a noncentrosymetric crystal structure that will generate charge on the application of a mechanical stress. As in the case of a pyroelectric materials, this can be detected as either a potential difference or as a charge flowing in an external circuit.

piezoelectric transducer device that converts electric signals to ultrasonic waves, and vice versa, by means of the piezoelectric effect in solids.

pig slang for line hose *See* line hose.

pig tail a type of hot stick that can slide over an overhead conductor.

piggyback board *See* daughter board.

pigtail short electrical conductor used to connect the brushes of an electrical motor or generator to the external electrical connections of the machine.

pilot carrier a means of providing a carrier at the receiver, which matches the received carrier in phase and frequency. In this method, which is employed in suppressed carrier modulation systems, a carrier of very small amplitude is inserted into the modulated signal prior to transmission, extracted and amplified in the receiver, and then employed as a matching carrier for coherent detection.

pilot sequence a spreading code sequence used in a CDMA cellular network such as IS-95 to facilitate the PN code synchronization and coherent demodulation of the received signal. In the most typical case, the pilot sequence is utilized in the forward channel, i.e., transmission by the base station.

pin the electronic connection that allows connection between an integrated circuit or circuit board and some socket into which it is plugged.

PIN diode a diode with a large intrinsic region sandwiched between p- and n-doped semiconducting regions.

pin insulator an electric insulator which is concentric with a hollow, threaded hole so that it can be screwed onto a steel pin mounted on a utility pole or crossarm.

pinch effect the collapse of a hollow conductor due to the magnetic effects of very large currents. Sometimes observed in cable shields which have been struck by lightning.

pinch resistance the resistance of a fully depleted channel of a junction field effect transistor (JFET).

pinch-off region *See* ohmic region.

pinch-off voltage the gate-to-source voltage at which the channel current is reduced to a very small predetermined level specified in milliamperes per millimeter. The effect is caused by carrier depletion of the channel area.

pincushion distortion the geometric distortion present in an image in which both horizontal and vertical lines appear to collapse toward the display center. For a CRT image system, pincushion distortion is a result of the interaction of the long face plate radius of curvature and the short radius from the deflection center to the face plate. The interaction causes the top, bottom, left, and right raster center points to be closer to the center of the CRT face plate deflection than the top left, top right, bottom left, and bottom right raster corners. Consequently, a square grid has the appearance of a pin cushion.

pipe cable a paper-insulated high-voltage electric power transmission cable laid within a rigid steel pipe containing pressurized insulating oil.

pipe flush systems that fetch streams of data or instructions sometimes have to interrupt the stream when an unusual event occurs. When this happens, the pipeline containing the stream of instructions or data must be emptied before execution can continue; this is called flushing the pipe.

pipeline chaining a design approach used in computers whereby the output stream of one arithmetic pipeline is fed directly into another arithmetic pipeline. Used in vector computers to improve their performance.

pipeline interlock a hardware mechanism to prevent instructions from proceeding through a pipeline when a data dependency or other conflict exists.

pipeline processor a processor that executes more than one instruction at a time, in pipelined fashion.

pipelined bus *See* split transaction.

pipelined cache a cache memory with a latency of several clock cycles that supports one new access every cycle. A new access can be started even before finishing a previous one. The access to the cache is divided into several stages whose operation can be overlapped. For instance, the cache can be pipelined to speed up write accesses: tags and data are stored in independently addressable modules so that the next tag comparison can be overlapped with the current write access. Read accesses are performed in a single cycle (tag and data read at the same time).

pipelining a technique to increase throughput. A long task is divided into components, and each component is distributed to one processor. A new task can begin even though the former tasks have not been completed. In the pipelined operation, different components of different tasks are executed at the same time by different processors. Pipelining leads to an increase in the system latency, i.e., the time elapsed between the starting of a task and the completion of the task.

pitch commonly used by physicists and musicians, defined with reference to the frequency. Given two signals with frequencies f_1 and f_2, the difference in pitch is defined by $1200 \log_2 \frac{f_2}{f_1}$. *See also* coil pitch.

pitch angle an angle between a tangent to a helix and another tangent to a cylinder that contains the helix and is perpendicular to the cylinder axis at a common tangential point on the helix.

pitch factor in an electric machine, the ratio of the fractional pitch in electrical degrees to the full pitch, also in electrical degrees.

pivoting when applying Gaussian elimination to solve a set of simultaneous linear equations, the natural solution order is sometimes varied. The process of varying the natural solution order is termed pivoting. Pivoting is used to avoid fill-in and to maintain the accuracy of a solution.

pixel contraction of "picture element:" each sample of a digital image, i.e., a square or rectangular area of size $\Delta x \times \Delta y$ of constant intensity, located at position $(k\Delta x, l\Delta y)$ of the image plane. Also called pel.

pixel adjacency the property of pixels being next to each other. The adjacency of pixels is ambiguous and is defined several ways. Pixels with four-adjacency or four-connected pixels share an edge. Pixels with eight-adjacency or eight-connected pixels share an edge or a corner. *See also* chain code, connectivity, pixel.

pixel density a parameter that specifies how closely the pixel elements are spaced on a given display, usually a color display.

PLA *See* programmable logic array.

placement a placement routine determines an optimal position on the chip for a set of cells in a way that the total occupied area and the total estimated length of connections are minimized.

planar array in addition to placing elements along a line to form a linear array, one can position them on a plane to form a planar array. For example, a circular array is a special form of planar array, where the elements are placed along a circle that is usually located on a horizontal plane. Planar arrays provide additional variables that can be used to control and shape the array's beam pattern. The main beam of the array can be steered towards any point in its half space.

planar doped barrier a material growth technique that allows control of doping on a single atomic layer, rather than the more conventional doping over a thicker region. This technique is used for bandstructure control in heterojunction transistors and is also used in the fabrication of planar doped barrier detector diodes.

planar magnetron a permanent magnet arrangement consisting of a steel base on which an outer ring of one polarity surrounds an inner ring or island of the opposite polarity, creating a magnetic flux "tunnel" for trapping electrons in the sputtering process.

planar mirror an optically flat mirror, the flatness generally specified as a fractional number of optical wavelengths.

planar–optic interconnect an interconnect in which optical signals travel along zigzag path in a transparent substrate with a source and a detector array, and other optical elements such as mirrors, gratings, and holograms. All optical elements on the substrate can be fabricated by lithographic techniques. The merits are compact packaging, easy alignments, large heat removal capacity, and suitability for integration with optoelectronic devices.

plane earth loss the propagation loss experienced when isotropic transmit and receive antennas are operated in the vicinity of a flat reflecting plane. Frequently used as an approximation for propagation over Earth's surface.

plane wave (1) an electromagnetic wave in which each wavefront (surface of constant phase) forms a plane of infinite extent and propagates in a direction perpendicular to the wavefront. A uniform plane wave has the same amplitude over an entire wavefront; a

nonuniform plane wave has varying amplitude.

(2) a wave having as equiphase surface a plane. It is commonly represented by the functional dependence $\exp^{j(\omega t - \mathbf{k}\cdot\mathbf{r})}$ where ω is the angular frequency, t is the time, $\mathbf{r}$ is the position vector, and $\mathbf{k}$ is the wave vector. Sometimes monochromaticity is also implied.

plane-parallel resonator a laser resonator in which the mirrors are flat and parallel to each other.

planned outage an interruption in service to consumers which has been caused by a sequence of events which were pre-planned by the utility, for example to perform maintenance or construction.

plasma the fourth state of matter comprised of positive ions and negative electrons of equal and sufficiently high density to nearly cancel out any applied electric field. Not to be confused with blood plasma.

plasma frequency a critical frequency in a plasma (e.g., ionosphere) below which radio waves cannot propagate through the plasma. Usually, in the ionosphere for an $f > f_p$ the wave gets refracted towards Earth.

plasmon a polariton in a plasma medium.

plastic a term for a flexible roll-on polymer insulation layer.

plate the positive electrode or anode in a vacuum tube.

platinotron a strap feed starting radial M-type backward wave oscillator.

platter *See* disk platter.

plausibility function a function that gives a measure of plausibility or belief.

PLC *See* programmable logic controller, power line conditioner.

PLD *See* programmable logic device.

PLL *See* phase-locked loop.

plosives sounds produced when the vocal tract, completely shut off at a certain point, is subsequently reopened so as a small explosion occurs. The "silence" that precedes the explosion can either be voiced or voiceless. In the first case we have voiced plosives (/*b*/, /*d*/, /*g*/), while in the second case we have voiceless plosives (/*p*/, /*t*/, /*k*/).

plossl an eyepiece consisting of four lens elements, a pair of cemented doublets facing each other in a symmetrical configuration.

Plotkin's upper bound for any (n, k) linear block code, the minimum distance is bounded asymptotically as, for $n \to \infty$

$$\left(1 - \frac{k}{n}\right) \geq 2\frac{d}{n}$$

plug fuse a small fuse with a threaded base designed to be installed in a mated screw-type receptacle. Plug fuses are rated 125 V and are typically applied on branch circuits in ratings of 15 A, 20 A, and 30 A. Type S plug fuses are designed to prevent overfusing.

plug-in board a printed-circuit board that can be plugged into another board or module to provide some functionality.

plugging a procedure to bring a three-phase motor to an abrupt stop by reversing the direction of the rotating magnetic field in the airgap. The reversal is accomplished by reversing two of the phase connections to the motor.

Plumbicon tube a type of camera tube first developed in the 1960s by Philips.

PLZT *See* lead lanthanum zirconium titanate.

PM *See* permanent magnet.

PMA *See* post-metal anneal.

PMA system *See* prism | air | metal system.

PMN generic name for electrostrictive materials of the lead (Pb) magnesium niobate family.

PMOS acronym for P-channel MOSFET.

PMU *See* power monitoring unit.

PN *See* pseudo-noise.

PN code *See* pseudo-noise code tracking.

PN code tracking *See* pseudo-noise code tracking.

PN sequence pseudo-noise sequence. *See* spreading sequence.

Pockels coefficients denotes the strength of the linear effect in electro-optic materials. Named after the pioneer researcher F. Pockels.

Pockels effect change in refractive index in noncentrosymmetric materials upon application of an electric field. Same as the linear electro-optic effect. Named after the pioneer researcher F. Pockels. *See also* electro-optic effect.

Pockels readout optical modulator (PROM) an optically addressed spatial light modulator device using the electro-optic effect in BSO.

Poincaré sphere a conceptual aid in which the state of polarization is represented by a point on a sphere. For example, points along the equator correspond to linear polarization (horizontal, vertical, or slant), the poles correspond to circular polarization (right-hand for upper pole and left-hand for lower pole), and all other points correspond to elliptical polarization.

point feature a small feature that can be regarded as centered at a point, so that inter-feature distances can be measured, as part of a process of inspection, or prior to a process of inference of the presence of an object from its features. Commonly used point features include corners and small holes, or fiducial marks (e.g., on printed circuit boards). *See also* salient feature, key point detection.

point operation an image processing operation in which individual pixels are mapped to new values irrespective of the values of any neighboring pixels.

point process a type of image processing in which the enhancement at any pixel depends only on the gray level at that pixel. This is in contrast to an operation whose value depends on the location of the pixel or on the values of neighboring pixels. *See also* gray level, neighborhood operation.

point source a light source so small that its size and shape cannot be determined from the characteristics of the light emanating from it. The light emitted has a spherical wave front and is spatially coherent.

point spread function (PSF) multidimensional impulse response. Output of a multidimensional system when a point function ($\delta-$function) is input.

point-to-point bus a bus that connects and provides communication capability between two, and only two, components. It should be noted that buses support communications within the CPU, as well as external to the CPU. Most internal buses are point-to-point buses. In contrast, see also multipoint bus.

point-to-point motion in the point-to-point motion, the manipulator has to move

from an initial to a final joint configuration in a given time t_f.

pointer in programming languages, a variable that contains the address of another variable.

poison any material or process which absorbs neutrons and thus dampens a nuclear fission reaction, e.g., control rods.

Poisson counting process *See* Poisson process.

Poisson distribution a probability distribution widely used in system modeling. A non-negative integer-valued random variable X is Poisson-distributed if $Prob(X = k) = e^{-a}a^k/k!$, where a is a positive parameter sometimes called the intensity of the distribution. For example, the number of 'purely' random events occurring over a time interval of t often follows a Poisson distribution with parameter a proportional to t.

Poisson process a random point process denoting the occurrence of a sequence of events at discrete points in time. The time difference between the different events is a random variable. For a given time interval of length T, the number of events (points in the process) is a random variable with Poisson distribution given by the following probability law $P[N = k] = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$, where N is the number of events that occur in the interval of length T, and λ is the expected number of occurrences of events per unit time. The time interval between any two events is a random variable with exponential distribution given by $F(\tau) = 1 - e^{-\lambda\tau}$, $\tau > 0$.

Poisson's equation a partial differential equation that expresses the relation between the scalar potential V and the charge density at any point ρ. Mathematically described by $\nabla^2 V = \frac{\rho}{\epsilon}$, where ∇^2 is the Laplacian, ρ is the forcing function, V is the equation's solution, and ϵ is the dielectric constant of the medium.

polariton term originally used to designate the polarization field particles analogous to photons. It is currently used to denote the coupling of the electromagnetic field with the polar excitations in solids.

polarity the notation used in the assignment of voltages. In DC generators, the polarity of the armature voltage can be reversed by either reversing its field current or by rotating the generator in reverse direction.

polarization (1) the shape traced out by the tip of the electric field vector as a function of time and the sense in which it is shaped.

(2) a description of the form of the temporal variation of the electric field vector of a light field. In general, the polarization state can be described by the ellipse that tip of the electric field vector traces each optical cycle. Commonly encountered limiting forms are linear polarization and circular polarization.

(3) the response of material systems, an applied light field by developing a time varying dipole moment. The response is described quantitatively in terms of the dipole moment per unit volume, which is known as the polarization vector.

(4) description of the direction and motion of the electric field vector of a wave. Plane waves may be linearly or elliptically (including circularly) polarized.

polarization controller a device that alters only the polarization state of the incident light.

polarization distortion distortion in the temporal shape of an optical signal transmitted through an optical fiber caused by the differential time delay between the two polarizations of each propagating mode. Usually of significance only in a single mode fiber.

polarization diversity the use of at least two antennas with different polarization characteristics in a depolarizing medium so as to produce communication channels with substantially uncorrelated fading characteristics.

polarization division multiple access (PDMA) a multiple access technique where user channels are separated in the polarization domain of the transmitted signal (horizontal–vertical for linear polarization and left–right for circular polarization).

polarization ellipse the most general form of polarization specification in which the polarization of an electromagnetic wave is completely specified by the orientation and axial ratio of the polarization ellipse and by the sense of rotation (right-hand or left-hand).

polarization logic gate an optical logic gate using polarization modulating devices. Polarization modulating devices include MOSLM (magneto-optic spatial light modulator), LCTV (liquid crystal television), LCLV (liquid crystal light valve), MSLM (microchannel-plate spatial light modulator). These devices are very useful in performing XOR and XNOR operations. The basic operation is as follows. Two devices represent inputs A and B, respectively. When a beam of light passes through the first device, its polarization is rotated according to input A. The beam then passes through the second device resulting that its polarization is either rotated further away or rotated back according to input B. To perform other logic operations, an additional thresholding device is necessary whether it is based on optical addition or multiplication.

polarization loss also called polarization mismatch. It occurs when the polarization of the incident wave is different than the polarization of the receiving antenna.

polarization maintaining fiber a "single mode" fiber that supports two (linearly polarized) orthogonal modes.

polarization mismatch *See* polarization loss.

polarization vector that part of the flux density attributable to orientation of bound charges inside a dielectric by an applied electric field. It is also the electric dipole moment per unit volume inside the dielectric and is equal to the product of the electric susceptibility and the applied electric field intensity.

polarization-sensitive device device that exhibits behavior dependent on the polarization of the incident electromagnetic wave. A polarizing filter exhibits transmission as a function of the polarization of the light incident on it.

polarized capacitor an electrolytic capacitor in which the dielectric film is formed on only one metal electrode. The impedance to the flow of current is then greater in one direction than in the other. Reversed polarity can damage the part if excessive current flow occurs.

pole (1) the root s of the denominator $D(s) = 0$, for irreducible rational function $X(s) = \frac{N(s)}{D(s)}$ at which points $X(s)$ become unbounded. Rational functions important to signal processing applications include Laplace transforms; the pole locations of Laplace transforms provide valuable information on system stability and other behaviors.

(2) the values of a complex function which cause the value of the function to equal infinity (positive or negative). The poles are all natural frequencies of vibration, or resonances of the circuit described by the equation, but occur at infinite (finite if loss is present) attenuation. They are properties of the function itself, and are not influenced by any other elements in the system (immune to load pulling).

(3) one end of a magnet or electromagnet in electrical machines, created by the flux of the machine.

pole line any power line which is carried overhead on utility poles.

pole of 2-D transfer matrix a pair of complex numbers (p_1, p_2)

$$T(z_1, z_2) = \frac{N(z_1, z_2)}{d(z_1, z_2)}$$
$$N(z_1, z_2) \in R^{p \times m}[z_1, z_2]$$

that are the root of the 2-D polynomial $d(z_1, z_2)$, i.e., $d(p_1, p_2) = 0$, where $R^{p \times m}[z_1, z_2]$ is the set of $p \times m$ polynomial matrices in z_1 and z_2 with real coefficients.

pole pitch the angular distance (normally in electrical degrees) between the axes of two poles in an electrical machine.

pole top pin a steel pin onto which a pin insulator is screwed.

pole-coefficient sensitivity when a coefficient d_k of the polynomial $D(s) = d_0 + d_1 s + d_2 s^2 + \ldots$ is a variable parameter then the roots of the polynomial are functions of this parameter. If these roots are simple, one can use the pole-coefficient sensitivity

$$\mathbf{S}_{d_k}(p_i) = \frac{\partial p_i}{\partial d_k / d_k} = -d_k \frac{p_i^k}{D'(p_i)}$$

The pole-coefficient sensitivity is frequently used in evaluation of active circuit stability.

pole-top transformer generally a distribution transformer which is mounted atop a utility pole near the customer.

pole-zero plot a graphical representation of a Laplace transform is known as a pole-zero plot. Except for a scale factor, the numerator and denominator polynomials in a rational Laplace transform $X(s) = \frac{N(s)}{D(s)}$ can be specified by their roots. Thus, marking the location of the roots of $N(s)$ and $D(s)$ in the s-plane provides a powerful way of visualizing a Laplace transform. Pole-zero plots are used extensively in signal processing design and analysis, e.g., to determine the stability of a system function.

polled interrupt a mechanism in which the CPU identifies an interrupting device by polling each device. *See also* vectored interrupt.

polling sequencing through a group of peripheral devices and checking the status of each. This is typically done to determine which device(s) are ready to transfer data.

polychlorinated biphenyls chemical compounds added to insulating oils to improve stability and insulating capability.

polygon detection the detection of polygon shapes, often from corner signals or from straight edges present in an image. Polygon detection is important when locating machined parts in images, e.g., prior to robot assembly tasks. *See also* rectangle detection, square detection.

polygonalization a method of representing a contour by a set of connected straight line segments; for closed curves, these segments form a polygon.

polymer membrane type of structure used to mechanically modulate light.

polynomial warp polynomial warping is a type of commonly used image processing operation designed to modify an image geometrically. This type of operation is useful when an image is subject to some unknown physical spatial distortion, and then measured over a rectangular array. The objective is then to perform a spatial correction warp to produce a corrected image array.

polyphase filter bank a filter bank where the filters are implemented in terms of their polyphase representation. The decimators can be moved ahead of the polyphase filters in the analysis section, thereby reducing computation.

polyphase representation a sequence representation. A sequence $H(z)$ can be represented by the summation of M sequences

$E_k(z)$ or $R_k(z)$ as

$$H(z) = \sum_{k=0}^{M-1} z^{-k} E_k(z^M) \quad \text{Type I polyphase.}$$

or

$$H(z) = \sum_{k=0}^{M-1} z^{-(M-1-k)} R_k(z^M)$$

Type II polyphase.

polyphase system electrical system that has more than one phase, which are separated by angles of $360°/n$, where n is the number of phases. For example, three phase systems are polyphase systems where the three phases are separated by 120 electrical degrees from each other. A six-phase system is a polyphase system where each successive phase is separated by 60 electrical degrees from the other.

polysalicide a variation in the formation of polysilicide where the metal is deposited after the polysilicon and reacted with the silicon during a subsequent thermal annealing cycle.

polysilicon a polycrystalline or amorphous form of silicon deposited on the surface of a wafer during integrated circuit fabrication. In modern technologies, it most often forms the MOSFET gate, the bipolar emitter, the plates of a capacitor or a resistor.

pop instruction an instruction that retrieves contents from the top of the stack and places the contents in a specified register.

popcorning a plastic package crack or delamination that is caused by the phase change and expansion of internally condensed moisture in the package during reflow soldering, which results in stress the plastic package cannot withstand.

population dynamics a variety of models used to describe evolution, growth, kinetics, and dynamics of diverse populations. Population dynamics models may be stochastic or deterministic, discrete or continuous, differential or integral, and cover a number of mathematical tools from ordinary differential and difference equations, through partial differential, integro-differential, functional and integral equations to particle systems, cellular automata, neural networks and genetic algorithms. The type of the model depends on the type of population, the objective of modeling, available data, knowledge of phenomena, etc. The most often modeled and analyzed populations include human and animal populations for demographic and epidemiologic purposes, cell populations including cancer, blood, bone marrow, eukaryotic cells, virus, bacteria, fungi, genomes, and biomolecules. Control problems in population dynamics may be formulated in terms of optimal treatment protocols (for example cell-cycle-specific control), vaccination, harvesting strategies, modulation of growth and so on. The simplest models are found by clustering distributed in reality systems into lumped compartments. It leads to compartmental models of population dynamics. Linear models could be obtain under hypotheses of Malthusian (exponential) growth of the population. If, however, such a model is used to describe the evolution of the population under control (for example treatment by drugs, vaccination, harvesting), the model is no longer linear, and the simplest class of control models that could be used is given by bilinear control systems. Since real populations never grow unboundedly, more realistic models are given by nonlinear models with saturation effects. The simplest nonlinear differential models represent logistic, Pearl–Verlhurst, Michaelis–Menton, and Gompertz dynamics.

population inversion usually the density of atoms or molecules in the higher state of a laser transition minus the density in the lower state.

population of energy level number or density of atoms or molecules in an energy state.

population trapping optical pumping into a noninteracting state or states of a quantum mechanical system.

porous silicon noncrystalline silicon grown so as to produce porous, sponge-like structures that seem to enhance optical emission.

port (1) a terminal pair.

(2) a place of connection between one electronic device and another.

(3) a point in a computer system where external devices can be connected.

port protection device device in line with modem that intercepts computer communication attempts and requires further authentication.

portability the possibility to move software to another hardware/operating system environment without changes.

position error the final steady difference between a step function 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 maintain a constant position. *See also* acceleration error and velocity error.

position error constant a gain K_p from which the position error e_p 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

$$e_p = \frac{1}{1 + K_p} \text{ and } \quad K_p = \lim_{s \to \infty} q(s)$$

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 velocity error constant.

position sensor a device used to detect the position of the rotor with respect to the stator. The most commonly used position sensors for electric motors are Hall effect devices, encoders, and resolvers with resolver-to-digital converters.

position servo a servo where mechanical shaft position is the controlled parameter. *See also* servo.

positioner a mechanical device used to move an antenna or target to a desired position for measurement purposes. Positioners can be single or multi-axis and are usually controlled by computers and automated measurement equipment.

positive 2-D Roesser model the 2-D Roesser model

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

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

$i, j \in Z_+$ (the set of nonnegative integers) is called positive if for all boundary conditions $x^h_{0j} \in R^{n_1}_+$, $j \in Z_+$, and $x^v_{i0} \in R^{n_2}_+$, $i \in Z_+$ and all inputs sequences $u_{ij} \in R^m_+$, $i, j \in Z_+$ we have $x^h_{ij} \in R^{n_1}_+$, $x^v_{ij} \in R^{n_2}_+$ for $i, j \in Z_+$ and $y_{ij} \in R^p_+$ for $i, j \in R^p_+$ where R^n_+ is the set of n-dimensional vectors with nonnegative components and x^h_{ij} and x^v_{ij} are horizontal and vertical state vectors, respectively. The 2-D Roesser model is positive if and only if all entries of the matrices A_1, A_2, A_3, A_4, B_1, B_2, C, and D are nonnegative.

positive definite function a scalar function $V(x)$ with continuous partial derivatives with respect to the components of the vector x where

1. $V(0) = 0$.

2. $V(x) > 0$ whenever $x \neq 0$.

positive definite matrix a symmetric matrix A such that $x^T Ax > 0$ for any vector x not identically zero. The eigenvalues of a positive definite matrix are all strictly greater than zero.

positive photoresist a photoresist whose chemical structure allows for the areas that are exposed to light to develop at a faster rate than those areas not exposed to light.

positive real (PR) function a rational function $H(s)$ of the complex variable $s = \sigma + j\omega$ is said to be positive real (PR) if it satisfies the following properties:

1. $H(s)$ is a real number whenever s is a real number, and

2. $Re[H(s)] \geq 0$ whenever $Re[s] > 0$, where $Re[\cdot]$ represents the real part of $[\cdot]$.

positive semidefinite a scalar function $V(x,t)$ with continuous partial derivatives with respect to all of its arguments is said to be positive semi-definite if

1. $V(0,t) = 0$.

2. $V(x,t) \geq 0$ whenever $x \neq 0$.

positive semi-definite matrix a symmetric matrix A such that $x^T Ax >= 0$ for any vector x. The eigenvalues of a positive semidefinite matrix are all greater than or equal to zero.

positive sequence the set of balanced normal (abc) sequence components used in symmetrical components. Balanced load currents, for example, are strictly positive sequence.

positive transition angle the angular portion of the time-based output signal (in degrees) that has a positive slope. This quantity could be loosely interpreted as the "leading edge" angle.

positive-sequence reactance the inductive reactance offered by a circuit to the flow of positive-sequence currents alone. The positive-sequence reactance is a function of the operating frequency of the circuit and the inductance of the circuit to positive-sequence currents.

positivity a system $H : X \to X$ where

$$\langle x, Hx \rangle \to \geq 0 \qquad \forall x \in \mathcal{X}$$

See also inner product space, and passivity.

positron emission tomography (PET) (1) a form of tomographic medical imaging based upon the density of positron-emitting radionuclides in an object.

(2) an imaging modality that uses injected positron-emitting isotopes as markers for physiological activity. The isotopes emit pairs of gamma photons which are detected using a gamma camera and coincidence detector.

possibility theory a theory evolved from the concepts of fuzzy sets and approximate reasoning which provides a mathematical framework for possibility analysis.

POST *See* power on self-test.

post insulator an electrical insulator which is supported by its firmly-bolted base, either in an upright position or cantilevered out horizontally from a utility tower.

post-apply bake *See* prebake.

post-compensator a compensator positioned on the process output signal. For MIMO systems, a given compensator will have a different effect depending on whether it is positioned before or after the process. Hence the importance of the prefix "post." *See also* compensation, compensator, and pre-compensator.

post-exposure bake (PEB) the process of heating the wafer immediately after exposure in order to stimulate diffusion of the products

of exposure and reduce the effects of standing waves. For a chemically amplified resist, this bake also causes a catalyzed chemical reaction.

post-metal anneal (PMA) a process used in semiconductor processing after metallization to improve device properties and circuit performance. Typically it is performed at a modest temperature (300–450 C°) in a forming gas (e.g., 5% hydrogen with 95% nitrogen) ambient.

postbake *See* hard bake.

posterior statistics the empirical statistics of a random quantity (scalar, vector, process, etc.), based on the a priori statistics supplemented with experimental or measured observations. *See also* prior statistics, Bayes' rule.

postfix *See* postfix notation.

postfix notation a notational or programming scheme in which both operands of a two-operand operation are written before the operator is specified. Example: $ab+$ is the postfix representation of a sum; this could be implemented in a programming model based upon an evaluation stack by the operation sequence PUSH a, PUSH b, ADD. Postfix notation is used in programming zero-address computers.

postincrementation an assembly language addressing mode in which the address is incremented after accessing the memory value. Used to access elements of arrays in memory.

pot head a fork-shaped transition between a three-phase buried cable and an overhead three-phase electric power line.

potassium dihydrogen phosphate (KDP) a strong linear electro-optic material, belonging to the same crystal class as ammonium dihydrogen phosphate (ADP). Its chemical form is KH_2PO_4.

potential an auxiliary scalar or vector field that mathematically simplifies the solution process associated with vector boundary value problems. *See also* Hertzian potential.

potential coil a long, finely wound, straight coil, similar in operation to a Chattuck coil, that is used with a fluxmeter to measure magnetic potential difference between a point in a magnetic field and a flux-free point in space.

potential source rectifier exciter a source of energy for the field winding of a synchronous machine obtained from a rectified stationary AC potential source. The AC potential can be obtained from the machine phase voltages, or from an auxiliary source. The components of the exciter are the potential source transformer and the rectifiers (including possible gate-circuitry).

potential transformer (PT) a device which measures the instantaneous voltage of an electric power line and transmits a signal proportional to this voltage to the system's instruments. *See* voltage transformer.

potentially unstable active circuit or device, where particular impedance termination placed on its input and/or output ports causes it to become unstable and oscillates.

potentiometric sensor a chemical sensor that measures the concentration of a substance by determining the electrical potential between a specially prepared surface and a solution containing substance being measured.

Potier reactance the leakage reactance obtained in a particular manner from a test on a synchronous machine at full load with a power factor of zero lagging. The test requires little power but supplies the excitation for short circuit and for normal rated volt-

age both at full-load current at zero power factor. The Potier reactance is determined by a graphical manner from the open circuit characteristic and the short circuit point for full-load current.

power (1) a measurable quantity that is the time rate of increase or decrease in energy. Units are in watts.

(2) ratio of energy transferred from one form to another (i.e., heat, radio waves, light, etc.) to the time required for the transfer, expressed in watts.

power added efficiency dimensionless ratio of RF power delivered from a device to the load minus the input incident RF power versus the total DC power dissipated in the device.

power amplifier amplifier operating at either audio or radio frequency range delivering power to a termination such as speaker, antenna, or resistive load.

power angle the angular displacement of the rotor from the stator rotating magnetic field while the machine is on load. The power angle is also the angle between the terminal voltage V_t of a synchronous machine and the generated voltage E_g or E_m, respectively, for a generator or motor. This angle denoted by δ is also referenced as power angle or torque angle or the load angle in a synchronous machine. It signifies the limits of the machine to remain in synchronism. *See also* torque angle.

power angle curve a curve shown the relationship between the active power output of a generator and its power angle.

power broadening increase in linewidth of a homogeneously broadened transition due to stimulated emission.

power conditioner a device designed to suppress some or all electrical disturbances including overvoltages, undervoltages, voltage spikes, harmonics, and electromagnetic interference (EMI). Example power conditioners are active filters for the reduction of harmonics, metal-oxide varistors (MOVs) and isolation transformers for the protection against voltage spikes, and EMI filters.

power control (1) the use of a mechanism to adjust a transmitter's power, usually in order to improve the overall performance of a communications network.

(2) in CDMA, a technique to increase the radio capacity. This is due to the fact that a CDMA system is interference-limited and that all users in a cell operate at the same frequency. The power control scheme used at the forward link of each cell can reduce the interference to the other adjacent cells. The less the interference generated in a cell, the higher the capacity.

(3) in a TDMA system, used to reduce cochannel interference or interference in adjacent cells. By having all cells (which operate at different frequencies with a cell reuse factor of 7 for a TDMA system) at approximately the same power, interference is reduced.

power density generally refers to the average power density, which is a measure of the power per unit area of a propagating EM wave. Mathematically, it is defined as the time average of the Poynting vector.

power disturbance a variation of the nominal value of the voltage or current.

power divider passive electronic circuit consisting of one input and two or more outputs. A signal applied to the input is divided into equiphase output signals, generally of equal amplitude.

power factor in an AC system, the ratio of the (active component) real power P to the apparent power S; it is given by the cosine of the angle subtended by S on the real, P axis. *See also* apparent power, real power, reactive power.

power factor correction the addition of reactive load to bring the combined power factor nearer unity. Since most industrial loads are inductive, capacitors are often employed as passive devices for power factor correction.

power fault arc an arc through soil extending from a power lines's lightning ground to a buried, grounded structure. These may form when lightning strikes an energized overhead electric power line.

power flow studies solutions of transmission line active and reactive power flow and bus voltages giving system load.

power flow study the circuit solution of an electric power system which yields the voltage of each bus and thus the power flows throughout the system.

power follow a fault condition, especially through a lightning arrester, in which power line current flows along a path through air or other insulation broken down by a high voltage impulse such as a lightning stroke to a conductor. *See* power fault arc.

power follow transformer a rugged, high-current power transformer used in tests of lightning arresters to test the arrester's power follow arc suppression capability.

power flux density a vector that gives both the magnitude and direction of an electromagnetic field's power flow. The units are watts per square meter.

power fuse a protective device that consists of a fusible element and an arc quenching medium. An overload or fault current in the fuse melts the fusible element, which creates an arc. The quenching medium then interrupts the current at a current zero, and prevents the arc from restriking.

power gain dimensionless ratio of RF power delivered to a load versus the input incident RF power, normally expressed in decibels. Thus a power gain of 100 is expressed as 20 dB.

power line conditioner (PLC) equipment installed on the customer's side of the meter to eliminate momentary over- and undervoltages to critical loads.

power monitoring unit (PMU) a device that is installed in at a consumer's site that will indicate to the utility whether or not an outage condition exists. The units commercially available at the present time typically have the facility to call power off and power on status to a central facility via a telephone link.

power noise factor for a photodetector, the ratio of signal-to-noise power ratio at the input ($\mathrm{SNPR}_{\mathbf{in}}$) to the signal-to-noise power ratio at its output ($\mathrm{SNPR}_{\mathbf{out}}$). If the power noise factor is denoted by k, then

$$k = \frac{\mathrm{SNPR}_{\mathbf{in}}}{\mathrm{SNPR}_{\mathbf{out}}}$$

power on self-test (POST) a series of diagnostic tests performed by a machine (such as the personal computer) when it powers on.

power optical power carried by an optical frequency beam.

power output useful output from a laser oscillator.

power quality (1) the concept of maintaining appropriate voltage and current waveforms and frequency in transmission, distribution, and generation systems, and usually taken to mean undistorted and balanced waveforms.

(2) a measure of an electric supply to meet the needs of a given electrical equipment application. As delivered by the utility, power quality is the faithfulness of the line voltage to maintain a sinusoidal waveform at rated voltage and frequency.

power signal suppose that $f(t)$ is a continuous time signal and let

$$P_T = \frac{1}{2\pi}\int_{-T}^{T} f(t)^2 dt$$

represent the power dissipated by $f(t)$ during the interval $[-T, T]$. The signal $f(t)$ is a power signal if $\lim_{T\to\infty} P_T$ exists and satisfies

$$0 < P \lim_{T\to\infty} P_T < \infty .$$

Furthermore, $\lim_{T\to\infty} P_T$ is the average power of the signal. Notice that an energy signal is not a power signal since necessarily $\lim_{T\to\infty} P_T = 0$.

Suppose that $f[k]$ is a discrete time signal and let

$$P_T = \frac{1}{2T}\sum_{k=-T}^{T} f(tk)^2 .$$

The signal $f[k]$ is a power signal if $\lim_{T\to\infty} P_T$ exists and satisfies

$$0 < P \lim_{T\to\infty} P_T < \infty .$$

Furthermore, $\lim_{T\to\infty} P_T$ is the average power of the signal. All discrete time periodic signals are power signals. *See also* energy signal, periodic signal.

power spectral analysis computation of the energy in the frequency distribution of an electrical signal.

power spectral density (1) a function associated with a random process that specifies the distribution of the signal power over the different frequency components of the spectrum of the random process. The integral of the power spectral density function is the average power of the signal. The Wiener–Khinchine theorem states that the power spectral density $S_X(\omega)$ of a random process $X(t)$ is equal to the Fourier transform of the autocorrelation function $R_X(\tau)$ of the process; i.e., for the process $X(t)$ $S_X(\omega) = \int_{-\infty}^{\infty} R_X(\tau)e^{-j\omega\tau}d\tau$, where $j^2 = -1$.

(2) the power spectral density function of a signal is its power spectrum.

power spectrum (1) a representation of power contributed by each harmonic of the spectrum.

(2) for a wide sense stationary random process is the Fourier transform of the autocorrelation function. The power spectrum is a measure of the average power of a random process as a function of frequency. The expected value of the periodogram tends to the power spectrum as the periodogram window length tends to infinity.

power splitter passive device that accepts an input signal and delivers multiple outputs with equal power.

power supply an electronic module that converts power from some power source to a form which is needed by the equipment to which power is being supplied.

power supply unit (PSU) *See* power supply.

power system damping a torque action which works to reduce power system oscillations as time progresses.

power system oscillation variations in the machine rotor angle caused by small disturbances in the system. The oscillations are usually at low frequency.

power system security an operational index that determines the capability of a system to withstand equipment failures and external disturbances. It could be measured by the reserve capacity available or the number of operating constraint violations under a given prevailing condition or under a contingent probability of disturbances.

power system stabilizer a control device that provides an additional input signal to the AVR to damp power system oscillations.

power transfer function any function of input to output power in ratio form, expressed as a dimensionless ratio.

power transformer a transformer that is used to transmit power from one voltage level to another. Power transformers can be of either single phase or three phase design, and include either two or three windings.

Poynting vector a vector, proportional to the cross product between the electric and magnetic field intensity vectors, indicating the density and flow of electromagnetic power.

PPL *See* physical placement of logic.

PR function *See* positive real function.

practical intrafield predictor technique used to improve the image quality. In practical intrafield predictors, several issues are considered. For example, in two-dimensional images, prediction may not lead to significant improvements in entropy of the prediction error; however, there is a decrease in the peak prediction error. By choosing proper coefficients, it is possible to get improved prediction and a decay of the effects of the transmission bit errors in the reconstructed picture.

practical stability *See* uniform ultimate boundedness.

practical stabilization deterministic approach to robust systems design based on the use of Lyapunov functions. Design feedback control law ensures desirable behavior of the systems for all admissible variations of bounded uncertainty in the following sense.

There exists a neighborhood of the origin $\mathbf{B}(d)$ such that

1. For any initial condition there exists a solution of the state equation for the closed-loop system in the given time interval.

2. All solutions for a given set of initial conditions can be extended over infinite time interval.

3. All solutions are uniformly bounded for the given set of initial conditions (*See* uniform boundedness).

4. All solutions for the given set of initial conditions are uniformly ultimately bounded with respect to a ball $\mathbf{B}(d_0)$ with $d_0 > d$ (*See* ultimate boundedness).

5. All solutions from the ball $\mathbf{B}(d_0)$ are uniformly stable.

If the given set of initial conditions could be extended to the whole state space, then the closed-loop system is globally practically stable for the designed control law.

PRAM model a multiprocessor model in which all the processors can access a shared memory for reading or writing with uniform cost.

Prandtl number a nondimensional characteristic of fluids, relating the rate of momentum diffusion to heat diffusion.

praseodymium doped fiber amplifier optical amplifier based on the rare-earth element praseodymium used to amplify signals in the 1310 nm telecommunications window. The region of useful gain is 1300–1350 nm.

preamplifier an amplifier connected to a low level signal source to present suitable input and output impedances and to provide gain so that the signal may be further processed without appreciable degradation in the signal-to-noise ratio. A preamplifier may include provisions for equalization and frequency discrimination.

prebake the process of heating the wafer after application of the resist in order to drive off the solvents in the resist. Also called soft-bake and post-apply bake.

pre-compensator a compensator positioned on the process input signal. For MIMO systems, a given compensator will

have a different effect depending on whether it is positioned before or after the process. Hence the importance of the prefix "pre-." *See also* compensation, compensator, and post-compensator.

pre-emphasis a technique of processing baseband signals through a network that provides a frequency-dependent amplitude transfer characteristic.

precise interrupt an implementation of the interrupt mechanism such that the processor can restart after the interrupt at exactly where it was interrupted. All instructions that have started prior to the interrupt should appear to have completed before the interrupt takes place and all instructions after the interrupt should not appear to start until after the interrupt routine has finished. *Compare with* imprecise interrupt.

predecrementation an addressing mode using an index or address register in which the contents of the address are reduced "decremented" by the size of the operand before the access is attempted.

predicate a logical expression that is to be evaluated, often to determine whether an important condition is satisfied. For example, "IF speed is high THEN reduce input supply."

prediction (1) an estimation procedure in which a future value of the state (see the definition) is estimated based on the data available up to the present time.

(2) in branching, the act of guessing the likely outcome of a conditional branch decision. Prediction is an important technique for speeding execution in overlapped processor designs. Increasing the depth of the prediction (the number of branch predictions that can be unresolved at any time) increases both the complexity and speed.

predictive coding compression of a signal by coding differences between samples and predictions from previously coded values. For example, in still image coding, a predictive encoder may predict a pixel by taking the average of the pixel's left neighbor and its above neighbor. With raster-order coding these values are already available in the decoder, which can form the same prediction. The difference or prediction error values may be quantized. Their probability density function is approximately Laplacian, and further compression can therefore be achieved with entropy coding. Also called *differential pulse code modulation.*

predictive control control policy (scheme), realized at a given control layer, involving repetitive usage of a decision mechanism based upon considering, at each intervention instant, the future operation of the controlled process (or the control system as a whole) over specified period of time (prediction interval). Usually, predictive control involves the use of optimization-based decision tools and of the free input forecasting; predictive control is the term describing a variety of possible control schemes, in particular open-loop-feedback control and limited-look-ahead-control.

predictive pyramid a limited amount of data is used to form a prediction image, and then the difference between the predicted image and the original image is used to form a residual image. This can then further be iterated to form a pyramid of residuals called the Laplacian pyramid.

predictive scalar quantization *See* differential pulse code modulation.

predictive SQ *See* differential pulse code modulation.

predictive vector quantization the generalization of scalar predictive coding to vector coding. *See* differential pulse code modulation.

predictive VQ *See* differential pulse code modulation.

predistorter predistortion type linearizer used to compensate the distortion component generating at high power amplifier (HPA). Since the predistorter adds the distortion component to the signal at 180 degrees out of phase, the distortion components, generated in predistorter and HPA, are canceled out at the output of the HPA.

prefetch *See* fetch policy.

prefetch queue in the CPU, a queue of instructions that has been prefetched prior to being needed by the CPU.

prefetching in the CPU, the act of fetching instructions prior to being needed by the CPU. *See also* fetch policy.

preformat information such as sector address, synchronization marks, servo marks, etc., embossed permanently on the optical disk substrate.

preincrementation an assembly language addressing mode in which the address is incremented prior to accessing the memory value. Used to access elements of arrays in memory.

preliminary breakdown an electrical discharge in the cloud that initiates a cloud-to-ground flash.

preprocessing a series of image enhancements and transformations performed to ease the subsequent image analysis process through, e.g., noise removal or feature extraction/enhancement.

pressure broadening spectral broadening of a transition in a laser medium due to elastic or inelastic collisions.

pressure vessel a steel tank which encloses the core of a nuclear reactor and is generally filled with coolant under pressure.

pressurized water reactor (PWR) a nuclear reactor which uses liquid water under pressure for a primary coolant and moderator.

preventive congestion control protocols that control the system and user traffic parameters so that the probability of a congestion is minimized. *See also* congestion.

price method coordination coordination by the price method amounts to iterating the coordination variables (dual coordination instruments) defined as the vector of prices by which the local interaction inputs to the subprocesses as well as their outputs are multiplied and added to the local performance criteria; these local criteria are then minimized with respect to the local decisions and the results are passed to the coordinator. The coordinator iterates the values of prices until the interaction equations and, if needed, any other coupling constraints are satisfied.

primal sketch a hierarchical image representation that makes explicit the amount and disposition of the intensity changes in the image. At the lowest levels of the representation, primitives just describe raw intensity changes and their local geometrical structure; at the higher levels they represent groupings and alignments of lower-level ones.

primary (1) the source-side winding.

(2) refers to the portion of a nuclear power plant containing the reactor and its equipment.

primary coolant the medium used to remove energy, in the form of heat, from a nuclear reactor core, e.g., water, helium, or liquid metal.

primary feeder *See* feeder.

primary system of equations a system of algebraic and differential equations obtained by applying the Kirchhoff's current and voltage laws and the element I-V relations.

primary voltage in power distribution the voltage at the primary winding of the distribution transformer.

primary winding the transformer winding connected to the energy source.

prime mover the system that provides the mechanical power input for a mechanical-to-electrical energy conversion system (generator), e.g., the diesel engine of an engine–generator set.

prime-number interleaving *See* interleaved memory.

primitive polynomial a polynomial $p(x)$ of degree m that gives a complete table of 2^m distinct symbols containing 0 and 1. The reciprocal of the primitive polynomial is also primitive. *See also* irreducible polynomial.

primitive-based coding edges, lines, and other local features of images. Schemes to detect such primitives, then use them to code the image. For example, edges may be used to segment the image into regions which are then independently coded as simple surfaces, while the boundaries are compressed with a chain code.

Princeton architecture a computer architecture in which the same memory holds both data and instructions. This is contrasted with the Harvard architecture, in which the program and data are held in separate memories.

principal axis the optical axis of a lens or camera, usually normal to the image plane.

principal component notionally, the direction of greatest variability of a random vector or among a set of sample vectors. More specifically, the principal component is the direction of the eigenvector associated with the largest eigenvalue of the covariance matrix of the random vector (or the sample covariance of a sample set). More generally, the n principal components of a distribution are the eigenvectors corresponding to the n largest eigenvalues. Principal components are frequently used for data clustering, pattern analysis, and compression.

principal component analysis (PCA) a technique applied to n-dimensional data vectors with the aim of finding a set of m-orthogonal vectors (typically $m \ll n$) that account as much as possible for the data's variance. PCA can be carried out in an unsupervised fashion by implementing a normalized version of Hebb's rule on m-linear neural units.

principal point the point at which the optical axis of the lens in a camera meets the image plane: also, the corresponding point in the image.

principle of locality *See* locality. *See also* sequential locality.

principle of superposition in a linear electrical network, the voltage or current in any element resulting from several sources acting together is the sum of the voltages or currents from each source acting alone.

printed circuit board (PCB) a substrate made from insulating material that has one or more sandwiched metallic conductor layers applied that are etched to form interconnecting traces useful for interconnecting components.

printer an output device for printing results on paper.

prior statistics the statistics of a random quantity (scalar, vector, process etc.) before any experimental or measured knowl-

edge of the quantity is incorporated. *See also* posterior statistics.

prioritization coding a coding scheme whereby the position of the symbol in the data steam indicates its weight.

priority encoder an encoder with the additional property that if several inputs are asserted simultaneously, the output number indicates the numerically highest input that is asserted.

prism | air | metal (PAM) system the two-interface model of an ATR (attenuated total reflection) system comprised of prism | air | metal. Commonly known as PAM system.

prismatic joint a joint characterized by a translation that is the relative displacement between two successive links. This translation is sometimes called the joint offset.

private key cryptography also known as secret key cryptography. In such a cryptographic system, the secret encryption key is only known to the transmitter and the receiver for whom the message is intended. The secret key is used both for the encryption of the plaintext and for the decryption of the ciphertext. *See also* public key cryptography.

privileged instruction an instruction that can be executed only when the CPU is in privileged mode.

privileged mode a mode of execution of machine instructions in the CPU in which certain special instructions can be executed or data accessed that would otherwise be prohibited. *See also* user mode.

PRMA *See* packet reservation multiple access.

probabilistic metric space a generalization of the notion of metric spaces onto the uncertain systems by replacing a metric on a given set S by a distance distribution function F, and a triangle inequality by a generalized inequality defined by triangle function τ. A distance distribution functions between two elements $p, q \in S$ is defined as a real function F_{pq} whose value $F_{pq}(x)$ for any real number x is interpreted as the probability, the membership function, or the grade of membership (depending on the type of the uncertainty model) that the distance between p and q is less than x. The simplest distance distribution function is given by the unit step (Heaviside) function **1** as follows:

$$F_{pq}(x) = \mathbf{1}(x - d(p, q))$$

where d is a standard metric. Then a probabilistic metric space reduces to the standard metric space. More precisely, a probabilistic metric space (PMS) is defined as a triple (S, F, τ) endowed with the following properties:

$$F_{pq}(x) = \mathbf{1}(x) \iff p = q$$
$$F_{pq} = F_{qp}$$
$$F_{pr} \geq \tau\left(F_{pq}, F_{qr}\right)$$

for all $p, q, r \in S$. The types of the distribution function and the triangle function are related to the model of uncertainty and the way of composition of the standard operations in the model.

probabilistic neural network a term applied loosely to networks that exhibit some form of probabilistic behavior but also applied specifically to a type of network developed for pattern classification based upon statistical techniques for the estimation of probability densities.

probability density function (PDF) (1) a function describing the relative probability of outcomes of an experiment. For experiments with discrete outcomes, the PDF is analogous to a relative frequency histogram. For experiments with continuous outcomes, the PDF analogous to a relative frequency histogram where the category bin widths are reduced to

zero. The total area underneath a PDF must always be unity.

(2) the derivative of the cumulative distribution function (when the derivative exists). More formally, for a random $\boldsymbol{x}$ and any probabilistic event A, the probability density function $p_x(\boldsymbol{x})$ satisfies

$$\Pr(\boldsymbol{x} \in A) = \int_A \mathrm{d}p_x(\boldsymbol{x}).$$

See also cumulative distribution function.

procedure a self-contained code sequence designed to be re-executed from different places in a main program or another procedure. *See also* call instruction, return instruction.

procedure call in program execution, the execution of a machine-language routine, after which execution of the program continues at the location following the location of the procedure call.

process the context, consisting of allocated memory, open files, network connections, etc., in which an operating system places a running program.

process control block (PCB) an area of memory containing information about the context of an executing program. Although the PCB is primarily a software mechanism used by the operating system for the control of system resources, some computers use a fixed set of process control blocks as a mechanism to hold the context of an interrupted process.

process environment part of the control scene that is outside of the controlled process; within this environment are formed the uncontrolled, free inputs to the process. Specified quantities related to the environment may be observed and used by the controller, for example, when performing free input forecasting.

process interaction a stream of energy, material, or information exchanged between the sub-processes of a large-scale process. Relevant attributes of those streams are, respectively, interaction inputs or interaction outputs. Interactions are described by the interaction equations, which relate interaction inputs to a given subprocess to interaction outputs from other subprocesses.

process monitor in semiconductor manufacturing, wafers processed at a particular process step to permit the quality or some other attribute of the step to be monitored. For example, in a photolithographic etching process, a process monitor would be a wafer exposed and etched that permits the physical dimensions of the resulting etched layer to be monitored and measured.

process state the set of information required to resume execution of a process without interfering with the results of the computation.

process swap the act of changing the execution point from one process to another.

process window a window made by plotting contours corresponding to various specification limits as a function of exposure and focus. One simple process window, called the critical dimension (CD) process window, is a contour plot of the high and low CD specifications as a function of focus and exposure. Other typical process windows include sidewall angle and resist loss. Often, several process windows are plotted together to determine the overlap of the windows.

process-oriented analysis a method of analyzing application transformation processing as the defining characteristic of applications.

processing amplifier high-performance amplifier that regenerates as well as amplifies the signal being processed.

processing element (PE) a processing module, comprising at least a control section, registers, and arithmetic logic, in a multiprocessor system. A processing element may be capable of operating as a stand-alone processor.

processing ensemble a collection of processors under control of a single control unit.

processing gain *See* spreading gain.

processor element *See* processing element.

processor farm a collection or ensemble of processing elements to which parallel processing tasks are assigned and distributed for concurrent execution. In this model, tasks are distributed, "farmed out," by one "farmer" processor to several "worker" processors, and results are sent back to the farmer. This arrangement is suitable for applications that can be partitioned into many separate, independent tasks. The tasks are large and the communications overhead is small.

processor status word a register in the CPU that stores a collection of bits that, taken as a group, indicate the status of the machine at a given period of time.

product code two-dimensional burst and random error correcting code in the form of a matrix with each row and column are code words of two different linear codes.

product of sums (PS) the AND combination of terms, which are OR combinations of Boolean variables.

program counter (PC) a CPU register that contains the address in memory of the next instruction to be fetched and executed.

program status word (PSW) a combination program counter and status-flag register provided in IBM mainframe computers.

programmable array logic (PAL) a programmable logic array with no OR array, but with a fixed set of OR gates into which are fed sets of product terms.

programmable gate array (PGA) *See* field-programmable gate array.

programmable logic array (PLA) a programmable logic device that consists of an AND array forming logical products of the input literals and an OR array that sums these products to form a set of output functions.

programmable logic controller (PLC) a microprocessor based system comprised of a set of modules for acquiring signals from environment and other for producing effects on the environment. These effects are typically used for controlling electromechanical machines by means of actuators (motors, heating element, etc.). The rules for specifying the control law are Boolean expressions. These sequentially and cyclically are executed. More complex PLCs allow the description of the control law by means of ladder diagram.

programmable logic device (PLD) an integrated circuit able to implement combinational and/or sequential digital functions defined by the designer and programmed into this circuit.

programmable radio system radios based on digital waveform synthesis and digital signal processing to allow simultaneous multiband, multiwaveform performance.

programmable read-only memory (PROM) a semiconductor memory device that has a primary function of storing data in a nonvolatile fashion that can be programmed to contain predetermined data by means other than photomasking. PROMs may be one-time programmable (OTP) or may be either UV or electrically eraseable, depending on the particular semiconductor process technology used for manufacturing.

programmed I/O transferring data to or from a peripheral device by running a program that executes individual computer instruction or commands to control the transfer. An alternative is to transfer data using DMA.

progressive coding ordering of coded values such that the original signal can be recovered progressively. For example, in transform coding of a picture, transmission of the zero sequency coefficients for all blocks first, rather than transmission of all coefficients for the first block first. This allows the receiver to generate an approximate reconstruction early in the reception of data.

progressive scan method of scanning a display on a horizontal line-by-line basis in strict sequence during one vertical sweep of the scanning beam/element. Each scan provides one complete video frame, and interlaced fields do not occur in either the production or display of the picture element sequence. Also known as sequential scan.

progressive transmission partial information of an image is transmitted. At each stage, an approximation of the original image is reconstructed at the receiver. The quality of the reconstructed image improves as more information is received.

projection in signal and image processing, the conversion of an n-dimensional signal into an $n-1$ dimensional version through some integration in the continuous case, or some summation in the discrete case. For instance, a 2-D image can be viewed as a (perspective) projection of 3-D scene via a camera. Another example exists in computed tomography. There a projection is a line integral along a straight ray.

projection of a fuzzy set for fuzzy set Q in a Cartesian product X^n, $X^n = X_1 \times \cdots \times X_n$, the, fuzzy set subspace R in X^i of X^n, $(i < n)$. The projection is usually denoted $R = \text{proj}\,(Q; X^i)$, in X^m with membership function obtained as the supremum of the membership function for the dimensions to be eliminated. *See also* cylindrical extension of a fuzzy set, fuzzy set, membership function.

projection printing a lithographic method whereby the image of a mask is projected onto a resist-coated wafer.

projection receiver multiple-access receiver technique in which users are estimated by first projecting the received signal onto the null space of the unwanted or interfering users.

projection television system a TV system in which a small but very bright image is optically projected onto a large viewing screen.

projective invariant a measure that is independent of the distance and direction from which a particular class of object is viewed, under perspective projection. The cross ratio is an important type of projective invariant, which is constant for four collinear points viewed under perspective projection from anywhere in space. Projective invariants are important in helping with egomotion (e.g., automatic guidance of a vehicle) and for initiating the process of object recognition in 3-D scenes.

PROM *See* programmable read-only memory, Pockels readout optical modulator.

prompt critical a nuclear reaction which can maintain criticality without the contribution of delayed neutrons, i.e., the sort of reaction which takes place in nuclear weapons.

propagating mode pattern of electromagnetic field with most of the energy contained in the core of the fiber that is sustained for long distances in an optical fiber (a few kilometers to 10's of kilometers) with only the amplitude of the electromagnetic field gradually decreasing while the shape of the mode remains constant.

propagating wave a wave that exhibits a spatial shift as time advances. Mathematically, a propagating wave is described by $f(t - r/v_p)$, where f is some function, t is the temporal variable, r is the spatial variable, and v_p is the phase velocity of the wave.

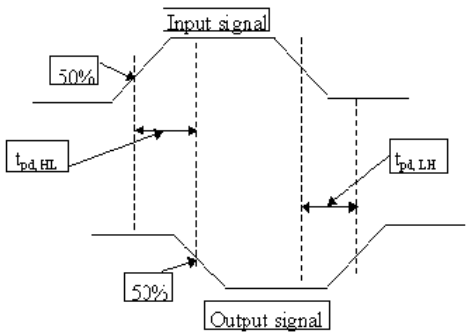
propagation the motion of electromagnetic waves through a medium or free space.

propagation constant a complex constant whose real part is the wave attenuation constant (nepers attenuation per unit length) and whose imaginary part is the wave phase constant (radian phase shift per unit length). *See also* phase constant.

propagation delay (1) the delay between transmission and reception of a signal. Caused by the finite velocity of electromagnetic propagation.

(2) the delay time between the application of an input signal to a chain of circuit elements and the appearance of the resulting output signal.

(3) the time it takes for a transistor switch to respond to an input signal, symbolized t_{pd}. It is calculated between the 50% rise point to the 50% fall point or vice-versa (see graph of typical inverter gate).



Propagation delay for a typical inverter gate.

The time from when the input logic level to a device is changed until the resultant output change is produced by that device.

propagation delay time *See* propagation delay.

propagation factor the ratio of the electric field intensity in a medium to its value if the propagation took place in free space.

propagation mode (1) in radio communication, refers to the manner in which radio signals propagate from the transmitting antenna to the receiving antenna. Radio waves can be reflected from the ionized layers within the ionosphere. Scatter modes of propagation also exist, and in these modes, propagation from the transmitting to receiving antennas is largely the result of scattering of the radio waves by dust and other particles in the troposphere. The ionized trails of meteors can also act as scatterers.

(2) in waveguides, used at microwave frequencies, propagation mode refers to the arrangement of electrical and magnetic fields within the waveguide. Modes can be classified as being transverse electric (TE) or transverse magnetic (TM), depending on whether the electric field or magnetic field is transverse to the direction of wave propagation within the waveguide. The mode that exists for the lowest frequency that can be transmitted by the waveguide is known as the dominant mode of the waveguide.

propagation path the route along which a radio wave propagates from the transmitting antenna to the receiving antenna. If this is a straight line, the path is a line of sight path. Otherwise, reflection, diffraction, and other phenomena may change the direction of propagation so that the path can be envisioned as made up of several straight-line segments. *See also* line of sight, multipath propagation.

proper 2-D transfer matrix the 2-D transfer matrix

$$T(z_1, z_2) = \frac{N(z_1, z_2)}{d(z_1, z_2)}$$
$$N(z_1, z_2) \in R^{p \times m}[z_1, z_2]$$

$$d_{z_1,z_2} = \sum_{i=0}^{n_1} \sum_{j=0}^{n_2} d_{ij} z_1^i z_2^j$$

is called proper if $d_{n_1,n_2} \neq 0$ ($d(z_1, z_2)$ is acceptable) and

$$\begin{aligned} &\deg_{z_1} n_{ij}(z_1, z_2) \leq n_1 \\ &\deg_{z_2} n_{ij}(z_1, z_2) \leq n_2 \\ &\text{for } i = 1, \ldots, p; \quad j = 1, \ldots, m\ ; \end{aligned}$$

where $n_{ij}(z_1, z_2)$ are the entries of $N(z_1, z_2)$ and $\deg_{z_1}(\deg_{z_2})$ denotes the degree with respect to z_1 (z_2).

proper mode a mode as obtained from a boundary value problem defined over a finite interval and relative to a second-order differential equation with real coefficients. *See also* improper modes.

proper subgraph a subgraph that does not contain all of the edges of the given graph.

proportional control control scheme whereby the actuator drive signal is proportional to the difference between the input/desired output and measured actual output.

proportional-integral-derivative (PID) control a control scheme whereby the signal that drives the actuator equals the weighted sum of

1. the difference,

2. time integral of the difference, and

3. time derivative of the difference between the input and the measured actual output.

It is a widely used control scheme in industry that can be tuned to give satisfactory performance based on knowledge of dominant system time constant.

protection control access to information in a computer's memory, consistent with a particular policy or mechanism. Ring numbering was introduced in the Multics system as one basis for limiting access and protecting information. The term "security" is used when the constraints and policies are very restrictive.

protection fault an error condition detected by the address mapper when the type of request is not permitted by the object's access code.

protective relay a device that monitors the condition of the electric power system and determines the presence of faults or other system anomalies. The protective relay monitors current flow, voltage level, or other parameter. When it operates due to a fault or other event, it initiates a trip signal intended to open the appropriate circuit breaker(s) or other protective devices.

protective relaying a unit for discriminating normal operating condition from faulted conditions in power systems.

protocol *See* bus protocol.

protocol data unit (PDU) the unit of exchange of protocol information between entities. Typically, a PDU is analogous to a structure in C or a record in Pascal; the protocol in executed by processing a sequence of PDUs.

protocol spoofing a technique used by VSAT networks to reduce the network delay. The satellite network emulates the host computer front-end processor at the VSAT locations and emulates the multiple cluster controllers at the hub location.

prototype filter a low-pass filter that is modulated to form a modulated filter bank.

prototyping building an engineering model of all or part of a system to prove that the concept works.

proximity effect a variation in the size of a printed feature as a function of the sizes and positions of nearby features.

proximity printing a lithographic method whereby a photomask is placed in close proximity (but not in contact) with a photoresist coated wafer and the pattern is transferred by exposing light through the photomask into the photoresist.

pruning self-generating neural network a methodology for reducing the size of self-generating neural network (SGNN).

During SGGN training, the network may grow very quickly, and some parts of the network may become useful in neither training nor classification, and the weights of these parts of the neurons of the network never change after some training stage. We call these parts of the network dead subnets. It is obvious that the dead subnets of the network should be pruned away to reduce the network size and improve the network performance. One way to achieve this is to check the weights of each neuron in the network to see whether they have been changed since last training epoch (or during the last few epochs). If they are unchanged, the neuron may be evidently dead and should be removed from the network. If a neuron is removed from an SGNN, all of its offspring should also be removed. *See also* self-generating neural network, training algorithm of self-generating neural network.

PS *See* product of sums.

PSC *See* permanent split-capacitor motor.

PSC motor *See* permanent split-capacitor motor.

pseudo code a technique for specifying the logic of a program in an English-like language. Pseudo code does not have to follow any syntax rules and can be read by anyone who understands programming logic.

pseudo color the display in color of gray-level pixels to make certain gray-level pixels or gray level patterns more visible. Typical pseudocoloring schemes are

1. displaying all pixels in a range of gray levels in one color;

2. displaying each gray level at a fixed interval in a different color to produce colored contour lines;

3. displaying the entire gray-level range as a rainbow. Pseudocoloring is usually carried out by look-up tables. *See also* false color, look-up table model (LUT).

pseudo-exhaustive testing a testing technique that relies on various forms of circuit segmentation and application of exhaustive test patterns to these segments.

pseudo-noise (PN) describes a class of pseudo-randomly generated processes that exhibit the statistical properties of noise.

pseudo-noise code phase the starting symbol of a pseudo-noise (PN) code with respect to some time reference in the system. In the IS-95 CDMA system, the same PN code with different PN code phases (typically multiples of 64 code symbols, or chips) is assigned as the pilot sequence for different base stations. *See also* spreading code.

pseudo-noise code tracking the act of accurately generating a local pseudo-noise (PN) code signal whose phase (timing relative to some reference time) accurately tracks the phase of an incoming PN code signal.

pseudo-noise sequence *See* spreading sequence.

pseudo-operation in assembly language, an operation code that is an instruction to the assembler rather than a machine-language instruction.

pseudo-QMF a cosine-modulated filter bank with the prototype filter being even-length symmetric spectral factor of an M-th band filter. The aliasing of the adjacent

bands is cancelled while the aliasing of non-adjacent bands is very small.

pseudo-random describes a process that has the statistical properties of being random, but is deterministic and can be recreated given the requisite properties of its generator.

pseudo-random pattern generator device that generates a binary sequence of patterns where the bits appear to be random in the local sense (1 and 0 are equally likely), but they are repeatable (hence only pseudo-random).

pseudo-random skewing *See* interleaved memory.

pseudo-random testing (1) a testing technique (often used in BISTs) that bases on pseudo-randomly generated test patterns. Test length is adapted to the required level of fault coverage.

(2) a technique that uses a linear feedback shift register (LFSR) or similar structure to generate binary test patterns with statistical distribution of values (0 and 1), across the bits; these patterns are generated without considering the implementation structure of the circuit to which they will be applied.

PSK *See* phase-shift keying.

PSNR *See* peak signal to noise ratio.

PSU power supply unit. *See* power supply.

PSW *See* program status word.

psychovisual redundancy the tendency of certain kinds of information to be relatively unimportant to the human visual system. This information can be eliminated without significantly degrading image quality, and doing so is the basis for some types of image compression. *See also* image compression, Joint Photographic Experts Group (JPEG), quantization matrix.

PT potential transformer. *See* voltage transformer.

PU-239 a man-made, fissile element suitable for use in nuclear weapons as well as power reactors.

public key cryptography two different keys are used for the encryption of the plaintext and decryption of the ciphertext. Whenever a transmitter intends sending a receiver a sensitive message that requires encryption, the transmitter will encrypt the message using a key that the receiver makes available publically to anyone wanting to send them encrypted messages. On receiving the encrypted message, the receiver applies a secret key and recovers the original plaintext information sent by the transmitter. In contrast to secret key cryptography, public key cryptography does not suffer from the problem of having to ensure the secrecy of a key. *See also* private key cryptography.

public key cryptosystem system that uses a pair of keys, one public and one private, to simplify the key distribution problem.

pull-in time the time required by an automatic frequency control (AFC) system to lock or stabilize after a frequency change.

pull-in torque the amount of torque needed to change a synchronous motor's operation from induction to synchronous when self-started.

pull-out torque the maximum value of torque that an AC motor can deliver. An induction motor operating at the pull-out torque will operate at maximum slip, and loading it beyond the pull-out torque will cause the motor to stall. Synchronous motors remain at synchronous speed up to the pull-out torque. Exceeding the pull-out torque for a synchronous machine will lead to pole slipping and destruction of the machine.

pull-up torque the minimum torque generated by an AC motor as the rotor accelerates from rest to the speed of breakdown torque. For an induction motor, this value usually is less than the locked-rotor torque, and thus establishes the maximum load that can be started.

pulse a sudden change of an electrical value of short duration with a quick return to the original value. A pulse injects a short sharp burst of energy into a system and is usually quantified by its area rather than its amplitude or its duration. In the limit as the amplitude tends to infinity and the duration to zero, it approaches the Dirac delta function whose Laplace transform is unity.

pulse amplitude modulation (PAM) a process in which an analog signal is sampled, the sampled values are then used to modulate the amplitudes of pulses. PAM is one type of analog pulse modulation, which is different from pulse code modulation.

pulse broadening *See* pulse distortion.

pulse code modulation (PCM) a process in which an analog signal is sampled, the sampled value is then quantized, the quantized level is (usually binary) encoded, and finally the code is represented by pulses exhibiting amplitude, phase or frequency modulation.

pulse compression technique of correlating identically coded signals, such as chirp signals, to produce a sharply peaked correlation function, the peak width being much shorter than that of the original coded pulses by a ratio equal to the time-bandwidth of the coded signals.

pulse distortion a spreading or lengthening of the temporal shape of an optical signal transmitted through an optical fiber caused by a combination of wavelength effects (dispersion) and multimode and polarization effects. Also called pulse broadening.

pulse Doppler a coherent radar, usually having high pulse repetition rate and duty cycle and capable of measuring the Doppler frequency from a moving target. Has good clutter suppression and thus can see a moving target in spite of background reflections.

pulse forming network (PFN) (1) a transmission line with different impedance along its length.

(2) a lumped element circuit consisting of inductors and capacitors designed to deliver a square pulse.

pulse number of a converter number of ripples in DC voltage per cycle of AC voltage. A three-phase, two-way bridge is a six-pulse converter.

pulse propagation time and space dependence of a travelling electromagnetic pulse.

pulse shape refers to the time domain characteristics of a pulse that is typically used to transmit data symbols over a channel. In most cases the pulse is shaped using a transmitter filter so that it satisfies the Nyquist I criterion for zero intersymbol interference.

pulse spreading increase with time or distance of the length of a propagating electromagnetic pulse.

pulse width width of the temporal region over which a pulse has significant amplitude; sometimes represented more specifically as, for example, full width at half maximum.

pulse width modulated inverter an inverter that uses pulse width modulation to create AC voltages from a DC supply. *See also* pulse-width modulation.

pulse-code modulation (PCM) (1) a digital encoding technique whereby an analog signal is converted into a sequence of digital

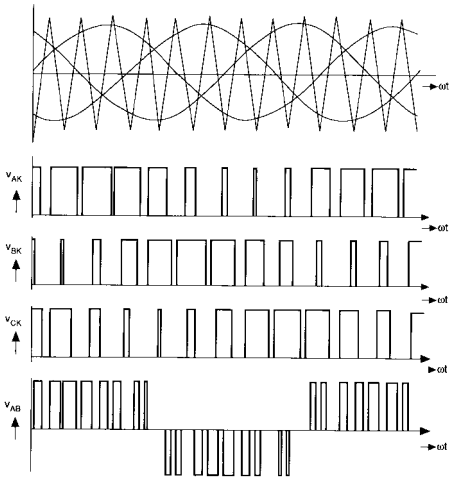
words in a periodic pulse train. The PCM process starts by bandlimiting the analog input waveform to one half the sampling rate (*See* aliasing). The analog signal is periodically sampled, using flat-top PAM (*See* pulse amplitude modulation). The height of each pulse is then quantized (estimated at an integer value) using an analog-to-digital converter, with the number of discrete quantizing levels determined by the resolution of the ADC used. The integer number associated with each sample is converted into binary format, then serially transmitted (MSB first). Note that for an 8-bit resolution ADC, each amplitude sample from the original analog waveform requires a sequence of 8 data bits in the output pulse train to represent it; as such, the output data clock rate must be at least eight times faster than that of the clock used to sample the analog input waveform. *See also* analog-to-digital conversion and quantization.

(2) in image processing, a system that transmits quantized amplitudes of each pixel. Each pixel is assigned a unique binary word of finite length. Coding of image intensity samples in this manner is called pulse code modulation or PCM. In the case of the DPCM, the difference resulting from the subtraction of the prediction and the actual value of the pixel is quantized into a set of L discrete amplitude levels. *See also* differential pulse code modulation.

(3) in color signal encoding, PCM digitization of R, G, and B using full bandwidth for each component is common practice, as the PCM signals can be used for filtering, storage, compression, etc. But PCM encoding of color signals may not always use all the R, G, and B signals. However, if all the components R, G, B have the same bandwidth then fewer bits are used to quantize the red and blue compared with the green signal.

pulse-echo ultrasound using a probe containing a transducer to generate a short ultrasound pulse and receive echoes of that pulse, associated with specular reflection from interfaces between tissues or scattering from inhomogeneities within the tissue, to form a display of tissue backscatter properties.

pulse-width modulated inverter a self-commutated inverter where the amplitude and frequency of the output are controlled by PWM. The switching frequency is generally much higher than the output frequency to ensure a smooth output waveform. In the following example, PWM is performed by comparing a sine reference with a triangle carrier. The output before and after the low-pass filter is shown in the figure.



Waveforms of a PWM inverter.

pulse-width modulated switch an active switch driven by a pulse-width modulated (PWM) pulse train.

pulse-width modulation (PWM) a control technique used in variable speed DC, AC, or other electrical variable speed drives to control the harmonic content of the applied voltage or current. Typically, the pulse width is modulated in three ways, trailing-edge modulation, leading-edge modulation, and double-edge modulation. Most popular is sinusoidal PWM for AC drives.

PWM is most frequently used in switching converter technology as the drive signal for active switching elements.

pulsed laser laser designed to produce its output in the form of isolated or periodic pulses that may be either long or short compared to the length of the laser cavity.

pulsed network a network that conveys information between neurons by means of pulse streams. The information may be coded using conventional pulse modulation techniques or by using random bit streams, in which case the information is coded into the statistics of the stream.

pulsed response the response of a system, or circuit to a pulsed input signal.

pumping process for achieving population inversion and gain in a laser medium; process for providing energy to an arbitrary nonlinear optical system; process in which input energy is used to obtain a population inversion in a laser medium.

punched card a method, now obsolete, used to represent data and programs as cardboard cards where the values were represented by punched holes at appropriate places.

punctured code a code constructed from another code by deleting one or more coordinates from each codeword. Thus an (n, k) original code becomes an $(n-1, k)$ code after the puncturing of one coordinate.

punctured convolutional code a code where certain symbols of a rate $1/n$ convolutional code are periodically punctured or deleted to obtain a code of higher rate. Because of its simplicity, it is used in many cases, particularly in variable rate and high-speed applications. *Compare with* punctured code.

puncturing periodic deletion of code symbols from the sequence generated by a forward error control convolutional encoder, for purposes of constructing a higher rate code. Also, deletion of parity bits in a forward error control block code.

pure ALOHA type of multiple access protocol. Any user is allowed to transmit at any time. The possible collisions result in destroyed packets. Destroyed packets are retransmitted at a later time. *See also* ALOHA.

pure longitudinal wave ultrasonic plane wave in which the particle motion is parallel to the wave vector and for which energy flow is parallel to the wave vector.

pure procedure a procedure that does not modify itself during its own execution. The instructions of a pure procedure can be stored in a read-only portion of the memory and can be accessed by many processes simultaneously.

pure shear wave ultrasonic plane wave in which the particle motion is parallel to the wave vector and for which energy flow is perpendicular to the wave vector.

purity in a color display, the production of red image content (only) by the red picture signal, blue image content (only) by the blue picture signal, and green image content (only) by the green picture signal. Picture impurity may be due to a color phosphor being excited by an inappropriate color electron beam.

Purkinje region the region of light intensity where, as illumination is reduced slowly enough to allow the eye to adapt, sensitivity to long wave light (red–orange) decreases more rapidly than sensitivity to short wave light (blue–violet).

pursuit behavior the human operator's outputs depend on system errors, as in com-

pensatory behavior, but may also be direct functions of system inputs and outputs. The human response pathways make the man–machine system a combined open-loop, closed-loop system.

pursuit display in the simplest case, a display that shows input command, system output, and the system error as separable entities.

push brace a rigid brace, typically another utility pole, which is angled against a utility pole to serve the purpose of a guy where a guy cannot be placed.

push instruction an instruction that stores the contents of specified register/s on the stack.

push–pull amplifier an amplifier made up of two identical class B amplifiers operated as a balanced pair (180 degrees out of phase with each other) into a common load, resulting in each amplifier operating over alternating half cycles of the input signal, and having the output signal combined such that full cycles are dissipated across the load. Odd order harmonics are present at the load, while even order harmonics are suppressed, resulting in an output signal that is an odd order multiple of the input frequency (either a fundamental frequency amplifier or an odd order frequency multiplier).

push–push amplifier an amplifier made up of two identical class B amplifiers operated as a balanced pair (180 degrees out of phase with each other) into a common load, resulting in each amplifier operating over alternating half cycles of the input signal, and having the output signal combined such that rectified half cycles are dissipated across the load. Even order harmonics are present at the load, while odd order harmonics are suppressed, resulting in an output signal that is an even order multiple of the input frequency (even order frequency multiplier).

pushdown stack a data structure containing a list of elements that are restricted to insertions and deletions at one end of the list only. Insertion is called a push operation and deletion is called a pull operation.

PV bus *See* voltage-controlled bus.

PWM *See* pulse-width modulation.

PWM inverter *See* pulse-width modulated inverter.

PWM switch *See* pulse-width modulated switch.

PWR *See* pressurized water reactor.

pyramid coding any compression scheme that repeatedly divides an image into two subbands, one, a lowpass representation that is subsampled and used as input for the next level, and the other an error (difference) image. A small lowpass image plus a pyramid of difference images of increasing size is generated, allowing the lowpass information to be coded accurately with few codewords, and the highpass information to be coded with coarse quantization. *See also* Laplacian pyramid.

pyramidal horn a horn antenna where the aperture is formed by flaring the walls in both the E-plane and the H-plane. The flare angles for the E-plane and H-plane can be adjusted independently.

pyroelectric a polar dielectric material in which the internal dipole moment is temperature dependent. This leads to a change in the charge balance at the surface of the material which can be detected as either a potential difference or as a charge flowing in an external circuit.

pyrolytic grid a grid structure made of pyrolytic (oriented) graphite that is laser-cut

to the proper geometry for use in a power vacuum tube.

pyrosensitive smart material material that self-adaptively (smartly) manages the electromagnetic surface characteristics of active surfaces constituted by pyrosensitive inclusions, in response to an external temperature-inducing stimulus applied per the feedback information on electromagnetic characteristics.

PZT generic name for piezoelectric materials of the lead (Pb) zirconate titanate family.

Q

q unit of electric charge. $q = 1.602 \times 10^{-19}$ coulombs.

Q *See* quality factor.

q axis *See* quadrature axis.

Q_L common symbol loaded quality factor. Q_L is dimensionless.

Q_U common signal for unloaded quality factor. Q_U is dimensionless. *See also* quality factor.

Q-factor a figure of merit that represents the ratio of stored to dissipated energy per cycle.

Q-switching rapid increase in the quality of a laser cavity from below threshold to above threshold for the purpose of obtaining a large output optical pulse; also called loss-switching.

QAM *See* quadrature amplitude modulation.

QOS *See* quality of service.

quad tree a tree data structure used to represent an image, where each node is a square subset of the image domain. The root represents the whole image domain, which is subsequently subdivided in square subsets until all pixels in each node have the same value, i.e., until all nodes become "pure."

quadratic detector a detector that makes use of the second-order statistical structure (e.g., the spectral characteristics) of measurements. The optimum structure for detecting a zero-mean Gaussian signal in the presence of additive Gaussian noise is of this form.

quadratic gain profile gain that varies quadratically with distance away from the axis of an optical medium.

quadratic index profile index of refraction that varies quadratically with distance away from the axis of an optical medium.

quadratic measure of sensitivity when the multiparameter sensitivity row vector is known and the components x_i have tolerance constants ϵ_i (these are considered to be positive numbers), i.e.,

$$x_{i0}\,(1-\epsilon_i) \le x_i \le x_{i0}\,(1+\epsilon_i)$$

then the quadratic measure of sensitivity is defined as

$$M_Q = \int_{\omega_1}^{\omega_2} \Big[\sum_{i=1}^{n} (\mathrm{Re}\mathbf{S}_{x_i}^{F(j\omega,\mathbf{x})})^2 \epsilon_i^2\Big] d\omega$$

quadratic media propagation media in which the gain and/or index of refraction vary quadratically with distance away from the axis.

quadratic phase coupling a measure of the degree to which specific frequencies interact to produce a third frequency.

quadratic stabilizability a property of a dynamical (possibly uncertain) system that could be stabilized using state feedback designed via a quadratic Lyapunov function. If the system is linear, then it is usually required that it could be quadratically stabilizable via linear feedback. It means that there exists such a linear in state x feedback control law and a positive definite matrix P that the resulting closed-loop system has the property that the derivative of the Lyapunov function $V(x) = x'Px$ is negative definite for all possible uncertainties. The suitable matrix P may be found, for example, by solving a respective game type Riccati equation or parametrically scaled linear matrix inequalities.

quadrature a condition where there is a 90 degree separation between items. That is, they are at right angles to one another.

quadrature amplitude modulation (QAM) a modulation technique in which the incoming symbols are split into two substreams, which are modulated in quadrature. In the conventional implementation, the "in-phase" symbols are modulated by $\cos 2\pi f_c t$, and the "quadrature" symbols are modulated by $\sin 2\pi f_c t$, so that the transmitted phases associated with the two substreams differ by $\pi/2$.

quadrature axis (q axis) an axis placed 90 degrees ahead of the direct axis of a synchronous machine. *See* direct axis.

quadrature axis magnetizing armature reactance a reactance that represents all the inductive effects of the q-axis stator current of a synchronous machine, except for that due to the stator winding leakage reactance. In Park's q-axis equivalent circuit of the synchronous machine, this reactance is the only element through which both the stator and rotor currents flow. Its value may be determined by subtracting the stator winding leakage reactance from the steady-state value of the q-axis operational impedance or from the geometric and material data of the machine, using expressions described in.

quadrature axis magnetizing reactance *See* quadrature axis magnetizing armature reactance.

quadrature axis subtransient open circuit time constant a constant that characterizes the initial decay of transients in the q-axis variables of the synchronous machine with the stator windings open-circuited. The interval characterized is that immediately following a disturbance during which the effects of all amortisseur windings are considered. A detailed (derived) closed-form expression for the subtransient open-circuit time constant of a machine with two q-axis amortisseur windings is obtained by taking the reciprocal of the smallest root of the denominator of the q-axis operational impedance. An approximate (standard) value is often used, in which it is assumed one amortisseur winding resistance is very small relative to the other and the detailed expression simplified. Expressions for the q-axis subtransient open-circuit time constant of a machine with two q-axis amortisseur windings are derived in.

quadrature axis subtransient reactance the high-frequency asymptote of the q-axis operational impedance of a synchronous machine. The reactance characterizes the equivalent reactance of the q-axis windings of the machine during the initial time following a system disturbance. In models in which the rotor windings are represented as lumped parameter circuits, the q-axis subtransient reactance is expressed in closed form as the sum of the stator winding leakage reactance, and the parallel combination of the q-axis magnetizing reactance and the q-axis rotor amortisseur leakage reactances.

quadrature axis synchronous reactance the sum of the stator winding leakage reactance and the q-axis magnetizing (armature) reactance of a synchronous machine. This reactance represents the balanced steady-state value of the q-axis operational impedance of the synchronous machine.

quadrature axis transient reactance a value that characterizes the equivalent reactance of the q-axis windings of the synchronous machine between the initial time following a system disturbance (subtransient interval) and the steady state. This reactance cannot be directly mathematically related to the q-axis operational impedance. However, in models in which the q-axis contains two amortisseur windings and the rotor windings are represented as lumped parameter circuits, the q-axis transient reactance is expressed in closed form as the sum of the stator winding leakage reactance, and the parallel combination of the q-axis magnetizing reactance and

the primary q-axis amortisseur winding leakage reactances.

quadrature detector mixer in a FM receiver where the output voltage is a function of the original modulation of two carrier inputs that are 90 degrees apart in phase.

quadrature distortion interference in signal transmission caused by phase error in the reference carrier.

quadrature FM demodulator FM demodulation of two carrier inputs that are 90 degrees apart in phase.

quadrature hybrid a directional coupler that accepts an input signal and delivers two equal power outputs that are 90 degrees out of phase.

quadrature modulation a modulation scheme that involves the modulation of two sinusoidal carriers with a 90-degree phase difference by two independent message signals. The two carriers are typically represented as $A\cos(\omega_c t)$ (the in-phase carrier) and $A\sin(\omega_c t)$ (the quadrature carrier), where ω_c is the carrier frequency. The modulated signal is written as $s(t) = Am_c(t)\cos(\omega_c t+\phi)+Am_s(t)\sin(\omega_c t+\phi)$, where $m_c(t)$ and $m_s(t)$ are the in-phase and quadrature modulating signals and ϕ is a random phase.

quadrature multiplexing a type of multiplexing technique, in which two message signals $m_1(t)$ and $m_2(t)$ are transmitted on the same carrier frequency with two quadrature carriers $A_c\cos 2\pi f_c t$ and $A_c\sin 2\pi f_c t$. That is, the quadrature multiplexed signal, also known as quadrature amplitude modulated signal, is

$$v(t) = A_c m_1(t)\cos 2\pi f_c t + A_c m_2(t)\sin 2\pi f_c t.$$

It is noted that the term quadrature indicates a 90° phase difference between the two carriers. For the demodulation refer to quadrature demodulation. The term quadrature multiplexing is sometimes also referred to as quadrature carrier multiplexing.

quadrature phased signals two independent signals that have identical frequencies and have a fixed 90-degree phase difference.

quadrature signal in quadrature modulation, the signal component that multiplies $\sin 2\pi f_c t$, where f_c is the carrier frequency.

quadrature spreader a device that takes an information signal and two independent PN sequences (two spreading codes) to produce two baseband direct sequence spread spectrum signals. These signals constitute the modulation signals for a quadrature modulation scheme.

quadrature-axis subtransient short-circuit time constant a constant that characterizes the initial decay of transients in the q-axis variables of the synchronous machine with the stator windings short-circuited. The interval characterized is that immediately following a disturbance, during which the effects of all amortisseur windings are considered. A detailed (derived) closed-form expression for the subtransient short-circuit time constant of a machine with two q-axis amortisseur windings is obtained by taking the reciprocal of the largest root of the numerator of the q-axis operational impedance. An approximate (standard) value is often used, in which it is assumed one amortisseur winding resistance is small relative to the other and the detailed expression simplified.

quadrature-axis transient open-circuit time constant a constant that charaterizes the decay of transients in the q-axis variables of the synchronous machine with the stator windings open-circuited. The interval characterized is that following the subtransient interval, but prior to steady-state, during which the fastest q-axis rotor circuit dynamics have subsided. A detailed (derived) closed-form expression for the transient short-circuit time

constant of a machine with two q-axis amortisseur windings is obtained by taking the reciprocal of the smallest root of the denominator of the q-axis operational impedance. An approximate (standard) value is often used, in which it is assumed one amortisseur winding resistance is infinite and the detailed expression simplified.

quadrature-axis transient short-circuit time constant a constant that characterizes the decay of transients in the q-axis variables of the synchronous machine with the stator windings short-circuited. The interval characterized is that following the subtransient interval, but prior to steady-state, during which the transients of the fastest dynamic q-axis rotor circuits have subsided. A detailed (derived) closed-form expression for the transient short-circuit time constant of a machine with two q-axis amortisseur windings is obtained by taking the reciprocal of the smallest root of the numerator of the q-axis operational impedance. An approximate (standard) value is often used, in which it is assumed one amortisseur winding resistance is infinite and the detailed expression simplified.

quadrupole a magnet system that produces a pair of dipoles with like poles opposite each other.

quadrupole illumination a type of off-axis illumination where four circles of light are used as the source. These four circles are spaced evenly around the optical axis.

quadtree a quadtree represents structure in an image by repeatedly subdividing squares into quarters until each square is homogeneous. Quadtrees can be used for facsimile coding, for representing contiguous regions in primitive-based coding or for representing motion vector distributions. In facsimile, where the image consists of black and white values only, three codewords are required: S, B, W, meaning split-block, black-block and white-block. Starting from large squares, each is analyzed and an appropriate codeword generated. If the codeword is S, then the same process is applied recursively to the four quarter-size blocks.

quadword a data unit formed from four words.

qualification all activities that ensure that the nominal design and manufacturing specifications will meet or exceed the reliability goals.

qualitative robustness an estimation scheme in which we optimize performance for the least favorable statistical environment among a specified statistical class.

quality factor (Q) measure of the persistence of damped oscillations in a resonator; 2π times the energy stored in an oscillating system divided by the energy lost in one cycle of the oscillations. Q is a measure of the precision of the frequency selectivity of an electrical resonator or filter. Q is dimensionless.

quality of service (QOS) a means of specifying the level of service provided by a network or required by a user of the network. Typical QOS parameters include bandwidth, delay, jitter, and error rate.

quantization (1) the process of converting amplitude values that can take on many different values (infinitely many for analog signals) into a finite (or more coarse) representation. Quantization is necessary in digital processing of inherently analog signals, such as voice or image. *See also* lossy source coding, analog-to-digital conversion.

(2) aspects of particle properties related to their wavelike nature as described by quantum mechanics.

(3) dividing a signal value into equally sized portions, known as quanta.

(4) conversion of a continuous range of values into a number of discrete levels, for example in analog-to-digital conversion; con-

version of finely spaced discrete values into more coarsely spaced values, e.g., in data compression.

quantization matrix a matrix of numbers in the JPEG compression scheme that specifies the amount by which each discrete cosine transform coefficient should be reduced. The numbers are based on the human contrast sensitivity to sinusoids and are such that coefficients corresponding to frequencies that people are not very sensitive to are reduced or eliminated. *See also* contrast sensitivity, discrete cosine transform, Joint Photographic Experts Group, human visual system, psychovisual redundancy.

quantization of transform coefficients technique that exploits the statistical redundancy in transform coefficients and also the subjective redundancy in pictures using transform coding. Unlike DPCM, quantization of transform coefficients affects every pixel in the transformed block. There is a spreading of the quantization error, thus making the design of transform coefficients quantizers quite different from that of DPCM.

quantizer a device that performs quantization (sense (1)). A quantizer takes an analog input signal and produces a discrete valued output signal. The number of possible levels in the output signal typically determines the error incurred in the quantization process. The output of the quantizer is typically encoded into a binary number.

quantizer characteristics the performance of a scalar quantizer Q is typically characterized by its mean-squared quantization error

$$E\left[(Q(x)-x)^2\right] = \int (Q(x)-x)^2 f_X(x)dx,$$

where $f_X(x)$ represents the probability distribution of the input X. In the special case where X is uniformly distributed, and where Q is a uniform quantizer (that is, the interval between successive quantization levels is Δ, and $Q(x)$ is the rounding of x to the nearest level), then the mean-squared quantization error is $\frac{\Delta^2}{12}$.

quantum coherence a condition that exists when a quantum mechanical system is in a linear combination of two or more basis states. The polarization produced when a 2-level atom interacts with a resonant electromagnetic field is an example of a quantum coherence.

quantum dot a particle of semiconductor material having all dimensions comparable to an average free carrier Bloch wavelength.

quantum effect macro effect on carrier movement created by the confinement of the carriers within very small dimensions along the direction of current flow (length). When the length dimension starts to approach an appreciable portion of the mean-free carrier path length, then odd things start to happen. This effect is somewhat analogous to the transition between low RF and microwave theory.

quantum efficiency the ratio of the average number of free electrons produced in the photodetector per photon. Since this is a quantized process, some photons produce no free electrons, while other photons produce one or more free electrons when their energy is absorbed in the photodetector. Quantum efficiency is usually denoted Q_e.

quantum electronics the field of study of the interactions of electromagnetic fields with matter, with emphasis placed on interactions that cannot be described classically.

quantum hall effect quantization of the Hall resistivity observed in two-dimensional high-mobility semiconductor systems, caused by novel many-body effects.

quantum interference the enhancement or suppression of a transition in a quantum mechanical system that arises when there are

multiple paths from the initial to the final state.

quantum limit the minimum number of photons that on average must be received in an optical communication system for a specified error probability (usually 10^{-9}). Using on–off keying and an ideal photon counting receiver, the quantum limit is approximately 10 photons/bit.

quantum mottle *See* speckle.

quantum numbers a group of integrating constants in a solution of Schrödinger's equation.

quantum well infrared photodetector mid- to long-wavelength photodetector exploiting optically induced transitions between confined quantum well states. Amenable to focal plane array manufacture due to compatibility with GaAs epitaxial growth and processing techniques.

quantum well laser a laser that uses quantum wells as the gain medium.

quantum wire a piece of semiconductor having two dimensions comparable to an average free carrier Bloch wavelength, the other dimension being much larger.

quarter-wave symmetry a periodic function that displays half-wave symmetry and is even symmetric about the 1/4 and 3/4 period points (the negative and positive lobes of the function).

quarter-wave transformer a piece of transmission line with an electrical length of 1/4 of the operating frequency wave length (or odd multiple) used for impedance matching.

quasi-ballistic motion in a metal or semiconductor in which the scattering is infrequent, and for which the phase coherence is mostly maintained during the time in which the carrier is in the active volume.

quasi-Fermi levels energy levels that specify the carrier concentration inside a semiconductor under nonequilibrium conditions.

quasi-linear nearly linear, easily approximated as linear with insignificant errors. Many circuits, elements and devices operated under small signal conditions are considered quasi-linear for many parameters or applications. A low noise amplifier under small signal operation still exhibits signal distortion (nonlinearity), but the gain characteristics can be determined from S-parameters, which are linear, with little or no error.

quasi-optics a low loss method of transmission and manipulation of millimeter and sub-millimeter waves.

quasi-TEM a mode of a structure comprising multiple dielectrics that behaves like the TEM mode of an equivalent structure comprising a single material with an appropriate effective dielectric constant. In certain types of transmission lines, for example, microstrip lines, the propagating waves are not pure TEM waves. Therefore, the general static approximations cannot be applied; however, in most practical cases one can make an approximation by assuming that the fields are quasi-TEM. In this case, good approximation for the phase velocity, propagation constant, and impedance is obtained.

quasiquantum device electron device in which the principle of the device function is more easily explainable by quantum mechanics than by Newtonian classical dynamics.

queue a data structure maintaining a first-in-first-out discipline of insertion and removal. Queues are useful in many situations,

particularly in process and event scheduling. *See also* FIFO memory.

quick gun a tool for installing crimped wire connectors.

quincunx five points, four at the corners of a square and one in the center.

quincunx lattice a horizontally and vertically repeated pattern of quincunxes, which is identical to a square lattice oriented at 45 deg.

quincunx sampling the downsampling of a 2-D or 3-D signal on a quincunx lattice by removing every even sample on every odd line and every odd sample on every even line. In the frequency domain, the repeat spectrum centers also form a quincunx lattice. Quincunx sampling structures have been used for TV image sampling on the basis that they limit resolution on diagonal frequencies but not on horizontal and vertical frequencies.