METRIC

MIL-STD-2196(SH)
12 January 1989

MILITARY STANDARD

GLOSSARY, FIBER OPTICS

AMSC N/A

FSC 60GP

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

FOREWORD

1. This military standard is approved for use by the Department of the Navy and is available for use by all Departments and Agencies of the Department of Defense.

2. Every effort was made to ensure this glossary is consistent with published standards. Several glossaries in fiber optics have been prepared by standards organizations. In 1982 the National Institute of Standards and Technology, formerly the National Bureau of Standards, published PB82-166257, Optical Waveguide Communications Glossary. Two years later, The Institute of Electrical and Electronics Engineers approved IEEE Standard 812-1984, Definitions of Terms Relating to Fiber Optics, for the most part based on the contents of PB82-166257. In 1986, FED-STD-1037, Glossary of Telecommunication Terms, was issued by the General Services Administration. The U.S. Army Information Systems Engineering Support Activity was the preparing activity and the National Communications System was the assigned agency. With an orientation toward telecommunications, about 10 percent of its content is devoted to fiber optics. Shortly thereafter, the Electronic Industries Association published EIA-440A, Fiber Optic Terminology, again consisting primarily of PB82-166257. A glossary, IEC-Draft 731-Optical Communication, is being prepared by the International Electrotechnical Commission. Different areas of fiber optics were emphasized by each. None covered fiber optics science and technology in its entirety. Some emphasized theory while others covered technology or applications. Even if all of them were to be merged into one, fiber optics science and technology still would not be adequately covered, particularly in the areas of electromagnetic theory, fiber optic sensors, light sources, photodetectors, and other components used in fiber optic systems; and several application areas, such as telemetry, illumination, imaging, security systems, endoscopy, networking, and control systems. Format, deprecation, indexing, and cross referencing were handled differently by each.

3. Many fiber optics terms occurring in military standards, specifications, test methods, test procedures, handbooks, and manuals have not been covered by the published glossaries. This comprehensive standard attempts to bring together under one cover the advantages and benefits of all the published glossaries. The primary purpose of this standard is to standardize fiber optics terminology for improved communication. Information to adequately cover the theory, principles, and technology of fiber optics has been added to accomplish the secondary purpose of this standard, namely to provide information in the science and technology of fiber optics.

4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 55Z3, Department of the Navy, Washington, D.C. 20362-5101, by using the self-addressed Standardization Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

1. SCOPE

1.1 Scope. This standard provides terms and definitions pertaining to fiber optics science and technology.

1.2 Purpose. The purpose of this standard is to provide and standardize comprehensive and authoritative definitions of terms used in fiber optics military standards, specifications, handbooks, test methods, test procedures, and other fiber optics documents; standardize the use of fiber optics terminology in the Department of Defense; and provide information on fundamental theory, principles, and concepts in fiber optics science and technology. This standard covers fiber optics terminology used in describing, designing, fabricating, packaging, shipping, testing, evaluating, installing, operating, and maintaining fiber optic systems and components.

3. DEFINITIONS

A

aberration. See chromatic aberration.

absolute luminance threshold. The lowest limit of luminance necessary for visual perception to occur in a person with normal or average vision.

absolute luminosity curve. The plot of spectral luminous efficiency versus optical wavelength.

absorptance. See spectral absorptance.

absorption. In the transmission of signals, such as electrical, electromagnetic, optical, and acoustic signals, the conversion of the transmitted energy into another form of energy, such as heat. Signal attenuation is not only a consequence of absorption, but also of other phenomenon, such as reflection, refraction, scattering, diffusion, and spatial spreading. In the transmission of electromagnetic waves, such as lightwaves, absorption includes the transference of some or all of the energy contained in the wave to the substance or medium in which it is propagating or upon which it is incident. Absorbed energy from a transmitted or incident lightwave is usually converted into heat with a resultant attenuation of the power or energy in the wave. In optical fibers, intrinsic absorption is caused by parts of the ultraviolet and infrared absorption bands. Extrinsic absorption is caused by impurities, such as hydroxyl, transition metal, and chlorine ions; silicon, sodium, boron, calcium, and germanium oxides; trapped water molecules, and defects caused by thermal and nuclear radiation exposure. Synonymous with material absorption. See band-edge absorption; hydroxyl ion absorption; selective absorption.

absorption coefficient. The coefficient in the exponent of the absorption equation that expresses Bouger's law, namely the b in the equation

$$F = F_o e^{-bx}$$

where F is the electromagnetic (light) field strength at the point x and F_o is the initial value of field strength at x = 0.

absorption index. The ratio of the electromagnetic radiation absorption constant to the refractive index given by the relation

$$K' = K\lambda/4\pi n$$

where K is the absorption coefficient, λ is the wavelength in vacuum, and n is the refractive index of the absorptive material.

absorption loss. When an electromagnetic wave propagates in a propagation medium, the loss of wave energy caused by intrinsic absorption, that is, by material absorption, and by impurities consisting primarily of metal and hydroxyl ions in the medium. Absorption losses may also be caused indirectly when light scattered by atomic defects is also absorbed.

acceptance angle. In fiber optics, half the vertex angle of that cone within which optical power may be coupled into bound modes of an optical waveguide. For an optical fiber, it is the maximum angle, measured from the longitudinal axis or centerline of the fiber to an incident ray, within which the ray will be accepted for transmission along the fiber, that is, total (internal) reflection of the incident ray will occur for long distances within the fiber core. If the acceptance angle is exceeded, optical power in the incident ray will be coupled into leaky modes or rays, or lost by scattering, diffusion, or absorption in the cladding. For a cladded fiber in air, the sine of the acceptance angle is given by the square root of the difference of the squares of the refractive indices of the fiber core and the cladding, that is, by the relation

$$\sin A = (n_1^2 - n_2^2)^{1/2}$$

where A is the acceptance angle and n_1 and n_2 are the refractive indices of the core and cladding respectively. If the refractive index is a function of distance from the center of the core, then the acceptance angle at a given distance from the center is given by the relation

$$\sin A_r = (n_r^2 - n_2^2)^{1/2}$$

where A_r is the acceptance angle at a point on the entrance face of the fiber at a distance r from the center and n_2 is the minimum refractive index of the cladding. SinA and $\sin A_r$ are the numerical apertures. Acceptance angles and numerical apertures for optical fibers are usually given for the center of the endface of the fiber, that is, where the refractive index, and hence the NA, is the highest. Power may be coupled into leaky modes at angles exceeding the acceptance angle; that is, at internal incidence angles less than the critical angle. See maximum acceptance angle.

acceptance cone. In fiber optics, that cone within which optical power may be coupled into the bound modes of an optical waveguide. The acceptance cone is derived by rotating the acceptance angle, that is, the maximum angle within which light will be coupled into a bound mode, about the fiber axis. The acceptance cone for a round optical fiber is a solid angle whose included apex angle is twice the acceptance angle. Rays of light that are within the acceptance cone can be coupled into the end of an optical fiber and be totally internally reflected as it propagates along the core. Typically, an acceptance cone apex angle is 40 degrees. For noncircular waveguides, the acceptance cone transverse cross section is not circular, but is similar to the cross section of the fiber.

access coupler. A device placed between the ends of two waveguides to allow signals to pass from one waveguide to the other.

acoustic sensor. See optical fiber acoustic sensor.

acoustic transducer. See optoacoustic transducer.

acoustooptic effect. A variation of the refractive index of a material caused by acoustic waves. The changes are also produced in diffraction gratings or phase patterns produced in a propagation medium in which a lightwave is propagating when the medium is subjected to a sound wave, due to photoelastic changes that occur in the material composing the propagation medium. The acoustic waves may be created by a force developed by an impinging sound wave, for example by the piezoelectric effect, or by magnetostriction. The effect can be used to modulate a light beam in a material because of the changes that occur in light velocities, reflection and transmission coefficients, acceptance angles, critical angles, and transmission modes resulting from changes in the refractive index caused by the acoustic wave.

acoustooptics. The branch of science and technology devoted to the interactions between sound waves and light in a solid medium. Sound waves can be made to modulate, deflect, and focus lightwaves by causing a variation in the refractive index of the medium.

action. In quantum mechanics, the product of the total energy, E, in a stream of photons and the time during which the flow occurs, expressed by the relation

$$E = h\sum_{i=1}^{m} f_i n_i t_i$$

where f_i is the ith frequency; n_i is the number of photons of the ith frequency; t_i is the time duration of the ith frequency summed over all the frequencies, photons, and time durations of each in a given light beam or beam pulse; and h is Planck's constant. Also see electrooptics; magnetooptics; optooptics; photonics.

activated chemical vapor deposition process. See plasma-activated chemical vapor deposition (PACVD) process.

active connector. See optical fiber active connector.

active device. A device that contains a source of energy, or that requires a source of energy other than that contained in input signals, the output of which is a function of present and past input signals that modulate the output of the energy source. Examples of fiber optic active devices include operational amplifiers, repeaters, oscillators, phototransistors, lasers, optical masers, photomultipliers, and photodetectors.

active laser medium. The material in a laser, such as a crystal, gas, glass, liquid, or semiconductor, that emits optical radiation. Radiation from a laser is usually coherent, that is, has a high coherence degree, and results from stimulated electronic, atomic, or molecular energy transitions from higher to lower energy levels. The action is maintained by causing population inversion.

active material. See optically active material.

active optical device. A device capable of performing one or more operations on lightwaves with wavelengths in or near the visible region of the electromagnetic spectrum through the use of input energy, such as electrical or acoustic energy, in addition to that contained in the waves being operated upon. Examples of active optical devices include fiber optic transmitters, receivers, repeaters, switches, active multiplexers, and active demultiplexers.

active optical fiber. An optical fiber designed such that active laser medium is the fiber itself, that is, a fiber laser that serves as an optical fiber amplifier.

active optics. The development and use of optical components whose characteristics are controlled during their operational use in order to modify the characteristics of lightwaves propagating within them. Controlled lightwave characteristics include wavefront direction, polarization, modal power distribution, electromagnetic field strength, or the path they take. Also see fixed optics.

actuation method. The way in which a motive force must be applied to a switch to place it into its various states.

actuator. A device that provides the motive force that must be applied to a switch to place it into its various states.

acquisition time. In a device that puts out a signal as a result of an input signal, such as an optical transmitter or receiver, the time between the instant of application of the leading edge of an input signal and the stabilization of the corresponding output signal.

adjusting. See self-adjusting

advanced television system. A television system in which an improvement in performance has been made to an existing television system to create the advanced system. The improvement may or may not result in a system that is compatible with the original system or with other present systems. Some features and technical characteristics of the original system on which the advanced system is based may be included in the advanced system. Also see enhanced-definition television (EDTV) system; high-definition television (HDTV) system; improved-definition television (IDTV) system.

aerial optical cable. An optical cable designed for use in overhead suspension devices, such as towers or poles.

aligned bundle. A bundle of optical fibers in which the relative spatial coordinates of each fiber are the same at the two ends of the bundle. Synonymous with coherent bundle.

alignment sensor. See fiber axial-alignment sensor.

all-glass fiber. An optical fiber whose core and cladding consist entirely of glass.

all-plastic fiber. An optical fiber whose core and cladding consist entirely of plastic. Most fibers are of glass core and glass cladding.

alternative test method (ATM). In fiber optics, a test method in which a given characteristic of a specified class of fiber optic devices, such as optical fibers, fiber optic cables, connectors, photodetectors, and light sources, is measured in a manner that is consistent with the definition of this characteristic, gives reproducible results that are relatable to the reference test method, and is relatable to practical use. Synonymous with practical test method. Also see reference test method.

ambient light susceptibility. The optical power that enters a device from ambient illumination incident upon the device. It may be measured in absolute power, such as microwatts, or in dB relative to the incident ambient optical power. For example, in a fiber optic connector or rotary joint, it is the ambient optical power that leaks into the optical path in the component.

amplification by stimulated emission of radiation. See light amplification by stimulated emission of radiation.

amplifier. See fiber amplifier; photodetector transimpedance amplifier.

amplitude distortion. Distortion of a signal in a system, subsystem, or device when the output amplitude is not a linear function of the input amplitude under specified operating conditions.

amplitude modulation. See pulse-amplitude modulation (PAM).

amplitude. See pulse amplitude.

analog data. Data represented by a physical quantity that is considered to be continuously variable and whose magnitude is made directly proportional to the data or to a suitable function of the data. Also see digital data.

analog signal. A nominally continuous signal that varies in a direct correlation to the instantaneous value of a physical variable. For example, the optical output signal of a light source whose intensity is a function of a continuous acoustic or electrical input signal, or the continuous photocurrent output signal of a photodetector whose photocurrent is a function of a continuous optical input signal. Also see digital signal.

analyzer. See lightwave spectrum analyzer.

angle. See acceptance angle; borescope articulation angle; borescope axial viewing angle; Brewster angle; deviation angle; exit angle; critical angle; incidence angle; launch angle; maximum acceptance angle; radiation angle; refraction angle.

angle of incidence. See incidence angle.

angstrom (Å). A unit of wavelength. 1 Å = 10^{-10} m (meter). The angstrom is not an SI (Systemè International) unit.

angular misalignment loss. An optical power loss caused at a joint, such as at a splice or connector, because the axes of the optical fibers are not parallel, that is, there is an angular deviation of the optical axes of the two fibers being joined. There can be a light-source-to-fiber, fiber-to-fiber, or fiber-to-photodetector angular misalignment loss. The loss is considered extrinsic to the fiber.

anisotropic. Pertaining to material whose properties, such as electric permittivity, magnetic permeability, and electrical conductivity, are not the same in every direction in which they are measured, that is, not all of their spatial derivatives are 0 in every direction. Therefore, an electromagnetic wave propagating in the material will be affected in different ways depending on the direction of propagation and direction, or type, of polarization of the wave. Also see isotropic; birefringent medium.

anisotropic propagation medium. Pertaining to a propagation medium in which properties and characteristics of the medium are not the same in reference to a specific phenomenon, such as a medium whose electromagnetic properties, like the refractive index, at each point are different for different directions of propagation or for different polarizations of a wave propagating in the medium.

antireflection coating. One or more thin dielectric or metallic films, such as index-matching material films, applied to an optical surface to reduce the reflectance and thus increase the transmittance. Ideally, the value of the refractive index of a single-layered film is the square root of the product of the refractive indices on either side of the film. The ideal thickness of an antireflection coating is one quarter of the wavelength of the incident light. A precise thickness of coating will cancel the reflection from the interface surface by interference. Also see index-matching material.

APD. Avalanche photodiode.

aperture. The portion of a plane surface near a directional source of radiation, such as an antenna or an orifice, normal to the direction of maximum irradiation, that is, radiation intensity, through which the major part of the radiation passes. In the movement or passage of any entity, such as a fluid, an electromagnetic wave, a sound wave, or time, an aperture is an opening or window in the path or period of time through which or during which the entity is constrained to flow or occur. Apertures can be controlled so as to perform coupling, guidance, and control functions. The size of the aperture is a function of its physical dimension, the direction of flow, the boundary conditions, and parameters of the moving entity, such as the viscosity of fluids or the wavelength of light. The dimensions of an aperture may be expressed in terms of length, width, area, planar angle, solid angle, and time units as well as in terms of dimensionless or normalized numbers. The numerical values may be relative, that is, normalized, or they may be absolute. Apertures usually occur at interfaces or transitional points, such as at a radiating antenna or at the entrance to an optical fiber. Apertures usually introduce losses and restrict passage. For example, the aperture of a lens depends on the size of the uncovered portion of the lens, the refractive index of the glass, and the color (wavelength) of the incident light. The aperture presented by a device may also depend on the incidence angle of the entering light. The aperture of an electromagnetic wave antenna is limited by the wavelength and the dimensions of the feeder, antenna array, or dish. For a phased-array antenna, the aperture is limited by the dimensions of the array, the launch angle, and the wavelength. In an optical fiber, the aperture is the acceptance cone angle as determined by the numerical aperture. For a sound wave, the aperture may be determined by the size of the hole in an inelastic material and the wavelength. For fluids, the aperture might be the size of a hole in the side of a container or constriction in a pipe, in which case the size of the aperture may depend on the dimensions of the hole or constriction, turbulence, and viscosity. For granular substances, the hole must be large enough to sustain flow or else the effective aperture is zero. See launch numerical aperture (LNA); numerical aperture; output aperture.

application layer. In open systems architecture, the layer that is directly accessible to, visible to, and usually explicitly defined by, users. It provides all the functions and services needed to execute their programs, processes, controls, and data exchanges. It is considered the highest layer. Also see Open Systems Interconnection (OSI) Reference Model (RM).

application parameter. In the design of an optical station/regenerator section, a performance parameter specified by the manufacturer or the user, e.g., application type (aerial, buried, underwater (salt, fresh, or brackish), or underground) temperature range, cabled fiber reel length, nominal central wavelength, central wavelength range, type of splice, splice insertion loss, cable designation, maximum cable cutoff wavelength, maximum cable attenuation rates and expected increases, dispersion parameters, interconnection parameters (cladding diameter, cladding ovality, core/cladding concentricity errors, mode field diameter), and global fiber parameters (standard and extended).

architecture. See open systems architecture.

area. See cladding tolerance area; coherence area; coherent area; core area; core tolerance area.

area network. See local area network (LAN); metropolitan area network (MAN).

articulation angle. See borescope articulation angle.

assembly. See optical harness assembly.

ATM. Alternative test method.

atmosphere laser. A laser in which the active laser medium is a gas. See longitudinally-excited atmosphere laser; transverse atmosphere laser.

atomic laser. A laser in which the active laser medium is an element in atomic form, such as sodium or boron. Also see molecular laser.

attenuate. To decrease the power of a signal, light beam, or lightwave propagating in an optical device, the decrease usually being the reduction that occurs between the input and output of the device, such as over the entire length of an optical fiber or between the input and output of a fiber optic connector. The device attenuates the signal by absorption, reflection, scattering, deflection, dispersion, or diffusion rather than by geometric spreading. Synonymous with pad.

attenuation. 1. In an optical component, the decrease in power of a signal, light beam, or lightwave measured from input to output, such as measured over the entire length of an optical fiber or between the input and output of a fiber optic connector. The attenuation can be in absolute power units, a fraction of a reference value, or in decibels. Attenuation in a fiber occurs as a result of absorption, reflection, scattering, deflection, dispersion, or diffusion rather than as a result of geometric spreading. Attenuation for an optical fiber is usually expressed as an attenuation rate, that is, in the units of decibels/kilometer (dB/km). 2. The loss of power that occurs between the input and output of a device, usually expressed in dB. See differential mode attenuation (DMA); induced attenuation; light attenuation; macrobend attenuation; optical dispersion attenuation; path attenuation; transient attenuation.

attenuation constant. See attenuation term.

attenuation-limited operation. The condition that prevails in a device or system when the magnitude of the optical power at a point in the device or system limits its performance or the performance of the device or system to which it is connected. For example, the condition that prevails in an optical link when the power level at the receiving end is the predominant mechanism that limits link performance. When an optical link is attenuation limited, the optical power level at the receiver is below the sensitivity threshold of the photodetector because the transmitter power is not high enough or the attenuation between transmitter and receiver is too high, or both. The attenuation is the sum of all the component insertion losses and the attenuation rate of the fiber times its length.

attenuation rate. In an electromagnetic wave that is propagating in a waveguide, such as a lightwave in an optical fiber, the attenuation in signal power that occurs per unit of distance along its length. In dB/km, the attenuation rate, α, is given by the relation

$$\alpha = [10 \log_{10}(P_i/P_o)]/L$$

where L is a given length of the waveguide in kilometers, P_i is the input power for the length L and P_o is the output power for the length L. In this form, the attenuation rate will be a positive value because P_i is the larger of the two powers. Also see attenuation.

attenuation-rate characteristic. See fiber global attenuation-rate characteristic; wavelength-dependent attenuation-rate characteristic.

attenuation term. In an electromagnetic wave that is propagating in a waveguide, such as a lightwave in an optical fiber, in the expression for the exponential variation characteristic of guided waves, the a in the relation

$$A = A_o e^{-pz} = A_o e^{-jb-az}$$

which represents the attenuation, or pulse amplitude reduction of the amplitude, A, experienced per unit of propagation distance, z, of the wave, where A_o is the amplitude at the point z = 0. The reduction in amplitude is in the form of an exponential decay. The attenuation term is the real part of the propagation constant, p. In a given guide, the phase term, b, is initially assumed to be independent of the attenuation term, a, which is then found separately, assuming b does not change with losses, for an optical fiber. The attenuation term, a, is supplied by the manufacturer because it can be measured experimentally. Synonymous with attenuation coefficient; attenuation constant.

attenuator. A device capable of reducing the power level of a signal, usually without also creating any other distortion of the signal. See continuously-variable optical attenuator; fiber optic attenuator; fixed attenuator; optical attenuator; pad; stepwise-variable optical attenuator.

audio. In communication systems, pertaining to a capability or characteristic to detect, transmit, or process signals having frequencies that lie within the range that can be heard by the human ear. Audio frequencies range from 30 to 15,000 Hz.

avalanche multiplication. In semiconductors, the sudden or rapid increase in the number or density of hole-electron pairs that is caused when the semiconductor is subjected to high, that is, near-breakdown, electric fields. This increase in charge carriers causes a further increase in their numbers and density. Incident photons of sufficient energy can further multiply the carriers. These effects are used in avalanche photodetectors.

avalanche photodetector. A photodetector that uses the avalanche multiplication effect to increase the output photocurrent.

avalanche photodiode (APD). A photodiode that operates with a reverse-bias voltage that causes the primary photocurrent to undergo amplification by cumulative multiplication of charge carriers. As the reverse-bias voltage increases toward breakdown, hole-electron pairs are created by absorbed photons. An avalanche effect occurs when hole-electron pairs acquire sufficient energy to create additional pairs when they collide with ions. Silicon and germanium APDs are inherently electrically noisy. Gallium indium arsenide phosphide on indium phosphide substrates and gallium antimonide APDs are being made.

average diameter. In a round optical fiber, the mean value of a measurable diameter, such as the core, cladding, or reference surface diameter.

AVPO. Axial vapor-phase oxidation.

AVPO process. See axial vapor-phase oxidation (AVPO) process.

axial alignment sensor. See fiber axial alignment sensor.

axial deposition process. See vapor-phase axial deposition (VAD) process.

axial displacement sensor. See fiber axial displacement sensor.

axial interference microscopy. See slab interferometry.

axial propagation constant. See propagation constant.

axial ratio. In an electromagnetic wave having elliptical polarization, the ratio of the major axis to the minor axis of the ellipse described by the tip of the electric field vector.

axial ray. A light ray that propagates along and is coincident with the optical axis of a waveguide. See paraxial ray.

axial slab interferometry. See slab interferometry.

axial vapor-phase oxidation (AVPO) process. A vapor-phase oxidation (VPO) process for making graded-index (GI) optical fibers in which the glass preform is grown radially rather than longitudinally as in other processes. The refractive-index profile is controlled in a spatial domain rather than in a time domain. The chemical gasses are burned in an oxyhydrogen flame, as in the outside vapor-phase oxidation (OVPO) process, to produce a stream of soot particles to create the graded refractive-index profile.

axial viewing angle. See borescope axial viewing angle.

axis. See optical axis; optic axis.

B

backscatter. 1. The deflection, by reflection or refraction, of a ray of an electromagnetic wave or signal in such a manner that a component of the ray is deflected opposite to the direction of propagation of the incident wave or signal. The term "scatter" can be applied to reflection or refraction by relatively uniform propagation media, but is usually taken to mean propagation in which the wavefront and direction are modified in a somewhat disorderly fashion. 2. The component of an electromagnetic wave or signal that is deflected by reflection or refraction opposite to the direction of propagation of the incident wave or signal. 3. To scatter or randomly reflect electromagnetic waves in such a manner that a component is directed back toward the source of the waves when resolved along a line from the source to the point of scatter. 4. The components of electromagnetic waves that are directed back toward their source when resolved along a line from the source to the point of scatter. Backscatter occurs in optical fibers because of the reflecting surfaces of particles or occlusions in the propagation medium, resulting in attenuation. Backscatter of lightwaves and radio waves also occurs in the atmosphere and the ionosphere. Also see forward scatter.

backscattering. Lightwave and radio wave propagation in which the direction of the incident and scattered waves, resolved along a reference direction, usually horizontal, are oppositely directed. A signal received by backscattering is often referred to as "backscatter".

backscattering technique. See optical time domain reflectometry.

backshell. In a fiber optic connector, the portion of the shell (housing) immediately to the rear of the fastening mechanism which is considered the front. The backshell contains the optical fibers and attaches to the bend limiter.

bait tube. The basic structure upon which a fiber optic preform is built.

band. 1. In communication, the frequency spectrum between two defined frequency limits. 2. In an atom, the difference between two electron energy levels. See frequency band; narrow-band; stop-band; wideband.

band-edge absorption. Absorption of energy in lightwaves that occurs in the visible region and extends from the ultraviolet to the infrared regions. In glass, band-edge absorption is usually caused by oxides of silicon, sodium, boron, calcium, germanium, and other elements, and by the hydroxyl ion.

band-gap energy. The difference between any pair of allowable energy levels of the electrons of an atom. An electron that absorbs a photon absorbs the energy equivalent to one or more band-gaps. When an electron loses energy, a photon is emitted with energy equivalent to the energy of one or more band-gaps.

bandwidth. 1. The difference between the limiting frequencies within which performance of a device, in respect to some characteristic, falls. The particular performance characteristic, such as the gain of an amplifier, the responsivity of a device, or the bit error ratio (BER), and the limiting frequencies must be specified. 2. The difference between limiting frequencies of a continuous frequency band. 3. A range of frequencies, in a given frequency spectrum, usually specifying the number of hertz of the band or of the upper and lower limiting frequencies. 4. The range of frequencies that a device is capable of generating, handling, passing, or allowing, usually the range of frequencies in which the responsivity is not reduced greater than 3 dB from the maximum response. 5. In fiber optics, the value numerically equal to the lowest modulation frequency at which the magnitude of the baseband transfer function of an optical fiber decreases to a specified fraction, generally to one half of the zero-frequency value. In multimode fibers, bandwidth is limited mainly by multimode distortion and material dispersion, which cause intersymbol interference at the receiving end of an optical fiber and thus places a limit on the bit error ratio (BER). In single-mode fibers, it is limited mainly by material and waveguide dispersion. In fiber optics, the concept of bandwidth, as applied to electronic systems, is not entirely useful in describing the data signaling rate capability or the transmission capacity of an optical fiber because the optical frequencies involved range over a spectrum about a decade wide near 10^{15} Hz, or 1 PHz (petahertz). The bandwidth-distance factor, that is, the bit-rate-length product (BRLP), is a better measure of the signal-carrying capacity of an optical fiber than the bandwidth. However, the modulation scheme must also be specified in order to make the value of the BRLP meaningful. See fiber bandwidth; Nyquist bandwidth.

bandwidth compression. A reduction of the bandwidth needed to transmit a given amount of information in a given time or a reduction of the time needed to transmit a given amount of information in a given bandwidth. The reduction must be accomplished by a means that does not reduce the information content of a signal and that usually does not increase the bit error ratio (BER).

bandwidth-distance factor. In fiber optics, a figure of merit used to express the signal-carrying capacity of an optical fiber. The figure indicates that bandwidth and distance may be reciprocally related, though the trade-off is not necessarily linear, especially for short lengths, and thus the operating values, namely bandwidth and distance, should both be specified. The band-width-distance factor is usually expressed as the product of the bandwidth and the distance between end-points, normally expressed in megahertz-kilometers. The associated bit-error-ratio (BER) should also be given along with the bandwidth-distance factor. Synonymous with bandwidth-length product. Also see bit-rate-length product (BRLP).

bandwidth-length product. See bandwidth-distance factor.

bandwidth-limited operation. See bit-rate-length-product-limited operation.

bandwidth rule. See Carson bandwidth rule (CBR).

barrier layer. In the manufacture of optical fibers, a layer that prevents hydroxyl ion diffusion into the fiber core.

baseband. 1. In fiber optics, the spectral band occupied by a signal that neither requires carrier modulation nor describes the signal state prior to modulation or following demodulation. It is usually characterized by being much lower in the frequency spectrum than the resultant signal after it is used to modulate a carrier or subcarrier. 2. The band of frequencies associated with or comprising an original signal from the source that generated it. In the process of modulation, the baseband is occupied by the aggregate of the transmitted signals used to modulate a carrier. In demodulation, it is the recovered aggregate of the transmitted signals.

baseband response function. See transfer function.

baud. 1. A unit of modulation rate. One baud corresponds to a rate of one unit interval per second, where the modulation rate is expressed as the reciprocal of the duration in seconds of the shortest unit interval. 2. A unit of signaling speed equal to the number of discrete signal conditions, variations, or events, per second.

beam. See Gaussian beam; laser beam.

beam diameter. 1. The distance between two diametrically opposed points in a plane normal to the beam axis at which the irradiance, that is, the optical power density, is a specified fraction of the beam peak irradiance. The specified fraction of the beam peak irradiance is typically stated as being 1/2, 1/e, $1/e^2$, or 1/10 of the peak irradiance at the point where the beam diameter is measured. The beam profile of the emission from a multimode optical fiber is assumed to be Gaussian and the beamwidth (diameter) is given by the relation

$$D = [2d\tan(\sin^{-1}NA]/1.73 \approx 2d(NA)/1.73$$

where d is the distance from the end of the fiber and NA is the numerical aperture measured at the 5-percent-of-peak irradiance points. Single-mode fiber beam diameters are given by the relation

$$D = 2d\lambda/\pi d_o$$

where d_o is the mode field (core) diameter and λ is the wavelength. The numerical aperture is defined at the 5-percent-of-peak irradiance. To calculate the axial beam irradiance of a Gaussian beam, the beam cross-sectional area at the 1/e points is used. The 1.73 accounts for the difference. Synonymous with beam width.

beam divergence. 1. In an electromagnetic beam, such as a light beam, the increase in diameter with increase in distance along the beam axis from the appropriate aperture. 2. For beams that are circular or nearly circular, the angle subtended by the far-field beam diameter. Generally, for noncircular beams, only the maximum and minimum divergences corresponding to the major and minor diameters of the far-field irradiance need be specified. 3. The far-field angle subtended by two diametrically opposed points in a plane perpendicular to the beam axis, at which points the irradiance, that is, the power density, is a specified fraction of the beam peak irradiance. The divergence, usually expressed in milliradians, is measured at specified points along the beam and radially from the beam central axis, such as where the energy density is 1/2 or 1/e of the maximum value at that point along the beam. The divergence must be specified as the half angle or as the full angle. Generally, only the maximum and minimum divergences, corresponding to the major and minor diameters of the far-field irradiance, need by specified. The emission from a multimode optical fiber is assumed to be Gaussian in which case the beam divergence is given by the relation

$$\Phi = [\tan(\sin^{-1}NA]/1.73 \approx NA/1.73$$

where NA is the numerical aperture, measured at the 5-percent-of-peak irradiance points. The corresponding beam divergence for a single-mode fiber is given by the relation

$$\Phi = 2\lambda/\pi d_o$$

where d_o is the mode field (core) diameter and λ is the wavelength.

beam splitter. A device that divides a beam, such as a light beam, into two or more beams whose total power is less than or equal to the original beam. For example, a beam splitter might consist of a flat parallel transparent plate coated on one side with a dielectric or metallic material that reflects a portion and transmits the remaining portion of a light beam. Also see partial mirror.

beam width. See beam diameter.

beat length. See polarization beat length.

bend. See E-bend; H-bend; microbend.

bending. See macrobending; microbending.

bending loss. In an optical fiber, the radiation emitted at bends due to the escape of discrete modes of the transmitted light. The bends may be microbends that occur along the core-cladding interface, causing incidence angles to occur that are greater than the critical angle for total reflection; or they may be macrobends with radii of curvature less than the critical radius, in which case evanescent waves can no longer remain coupled to bound modes and hence radiate laterally away from the fiber. The outside edges of the evanescent waves will radiate because their wavefronts cannot exceed the velocity of light as they sweep around the outside of the bend, that is, they cannot maintain a constant phase relationship with the wave inside the fiber. Thus, they become uncoupled or unbound and hence radiate away.

bend limiter. In fiber optic cable systems, a device, such as a rod, bracket, fixture, or tube, that reduces the tendency of a fiber optic cable to bend when bending forces are applied. The purpose of the bend limiter is to assist in preventing the cable from bending at a radius of curvature less than the critical radius or the minimum bend radius, whichever is greater.

bend sensor. See microbend sensor.

BER. See bit error ratio.

bidirectional optical cable. A fiber optic cable that can handle signals simultaneously in both directions and has the necessary components to operate successfully and avoid crosstalk between the oppositely directed signals. Components used in or with bidirectional cables include beam splitters, entrance and exit ports, mixing rods, couplers, and interference filters.

bidirectional transmission. In an optical waveguide, signal transmission in both directions.

binder. A string or tape used to tie together a number of fibers, buffered fibers, or OFCCs.

birefringence. 1. That property of a material which causes a light beam passing through the material to be split into two beams with orthogonal polarizations. 2. The splitting of a light beam into two divergent components upon passage into and through a doubly-refracting propagation medium, with the two components propagating at different velocities in the medium. The medium is characterized by having two different refractive indices in the same direction, which causes the existence of the different velocities of propagation for the different orthogonal polarizations.

birefringence fiber. See high-birefringence fiber; low-birefringence fiber.

birefringence noise. See polarization noise.

birefringence sensor. A fiber optic sensor in which light entering an optical fiber of birefringent material, that is, material demonstrating two refractive indices, is split into two beams, each propagating in a different path of different optical path length. When the beams are recombined, interference patterns are produced. External stimuli to be sensed are used to alter the optical path lengths to produce reinforcement or cancellation of the lightwaves at a photodetector. Thus, the output signal of the photodetector is a function of the type and degree of applied stimuli, such as force, pressure, electric field, and temperature. Examples include the Pockels-effect sensor and the Kerr-effect sensor.

birefringent medium. A material that exhibits different refractive indices for orthogonal linear polarizations of incident light. The phase velocity of a wave in a birefringent medium depends on the polarization of the wave. Optical fibers may be made of birefringent material. Thus, if light in a propagation medium can be decomposed into two perpendicular directions of polarization which propagate at different velocities, the medium is said to be birefringent. Also see anisotropic; isotropic.

bit error rate (BER). See bit error ratio (BER).

bit error ratio (BER). The number of erroneous bits divided by the total number of bits in a propagating signal over some stipulated period of time. For example, the number of erroneous bits received divided by the total number of bits transmitted. The BER is usually expressed as a coefficient and a power of ten. For example, 2.5 bits that are erroneously detected by a photodetector out of 100,000 bits properly transmitted by a signal source would correspond to a system or link BER of 2.5×10^{-5}. Synonymous with bit error rate (BER).

bit-rate-length product (BRLP). For an optical fiber or cable, the product of the bit rate, that is, the data signaling rate, the fiber or cable can handle for tolerable dispersion or for a given bit error ratio (BER). The BRLP is usually stated in units of megabit-kilometers/second. A typical value for graded-index fibers with a numerical aperture (NA) of 0.2 is 1000 Mb-km/s, higher values to be expected in the future. The value of the product is a good indicator of fiber performance in terms of transmission capability. Another useful measure of optical fiber performance or transmission capacity is the bit rate at which full-wave-half-power point occurs at the receiving end of a given length of the fiber.

bit-rate-length-product-limited operation. The condition that prevails in a device or system when distortion of the signal caused by dispersion, that is, waveguide and material dispersion, limits its performance or the performance of the device or system to which it is connected. For example, the condition that prevails in an optical link when intersymbol interference at the receiving end is the predominant mechanism that limits link performance. Synonymous with bandwidth-limited operation.

blank. See optical blank; optical fiber blank.

bobbin-wound sensor. A distributed-fiber sensor in which the optical fiber is wound on a bobbin in such a manner as to be differentially, sequentially, or selectively stimulated by the parameter to be measured, such as a spatially-shaded winding or a segmented in-line winding of many coils on a single bobbin, the bobbin serving only to support the distributed fiber but plays no other role, such as stretching or squeezing the fiber.

bolometer. A device used to measure the radiant energy from an emitter by measuring the change in resistance of a temperature-sensitive element exposed to the radiation. The bolometer is usually used to measure temperatures high above ambient, such as that of a furnace or other body heated to incandescence.

Boltzmann's constant. A physical constant defining the ratio of the universal gas constant to Avogadro's number. Usually represented by the symbol k, it is equal to 1.38042×10^{-16} erg/K. For example, in a photoemissive photodetector, the dark current, I_d, is given by the relation

$$I_d = AT^2e^{qw/kT}$$

where A is the surface area constant, T is the absolute temperature, q is the electron charge, w is the work function of the photoemissive surface material, and k is Boltzmann's constant; the signal-to-noise ratio for a photodetector is given by the relation

$$SNR = (N_p/B)(1 - e^{-hf/kT})$$

where N_p/B is the number of incident photons per unit of bandwidth, h is Planck's constant, f is the frequency of the incident photons, k is Boltzmann's constant, and T is the absolute temperature; and for the noise generated by thermal agitation of electrons in a conductor, the noise power, P, in watts, is given by the relation

$$P = kT(\Delta f)$$

where k is Boltzmann's constant, T is the conductor temperature in kelvins, and Δf is the bandwidth in hertz.

borescope. See fiber optic borescope; flexible borescope; rigid borescope.

borescope articulation angle. In a flexible borescope, the angle between the axis of the articulating tip of the borescope at its maximum deflection and the axis of the tip at the undeflected position, i.e., when the tip is collinear with the straight-line working length. A typical articulation angle is 90 degrees, though borescopes with larger articulation angles are available.

borescope axial viewing angle. The angle by which the axis of the view field deviates from the nominal straight forward axis of the working section of a borescope.

borescope magnification. The ratio of the apparent size of an object seen through a borescope to that of the size of the same object viewed directly by the unaided eye, with the object-borescope distance equal to the object-eye-distance.

borescope overall length. The length of a borescope, including the working length, which is the length of fiber optic cable to the tip, the tip length, and the eyepiece assembly length, combined.

borescope target resolution. The resolving power of a borescope, usually given in line pairs per millimeter of a back-lighted high-contrast resolution target (object) placed a selected nominal operating distance from the objective end (distal tip).

borescope tip length. The distance between the center objective window and the objective end (distal tip) of a flexible or rigid borescope. This distance determines how close to the bottom of a cavity an image can be observed when the borescope is completely inserted. The tip length should be compatible with the diameter of the probe.

borescope view field. The area or solid angle that can be viewed through a borescope. The solid angle is determined by the aperture. The area is determined by the aperture and the focal length.

borescope working diameter. The diameter of the working section, i.e., the diameter of the fiber optic cable and tip, of a flexible borescope or the diameter of the probe of a rigid borescope. The diameter must be sufficiently smaller than the smallest size opening it must pass through so that it reaches the object to be viewed without undue friction or binding.

borescope working length. The distance between the distal end of the hand-held body portion and the optical axis of the tip. The tip length is not included.

Bouger's law. In the transmission of electromagnetic radiation through a propagation medium, the attenuation of the irradiance, that is, the electromagnetic field strength or optical power density, as an exponential function of the product of a constant coefficient, which is dependent upon the material and its thickness, given by the relationship

$$I = I_o e^{-ax}$$

where I is the irradiance at distance x, I_o is the irradiance at x = 0, and a is a material constant coefficient that depends upon the scattering and absorptive properties of the propagation medium. If only absorption takes place, a is the spectral absorption coefficient and is a function of wavelength. If only scattering takes place, it is the scattering coefficient. If both absorption and scattering occur, it is the extinction coefficient, being then the sum of the absorption and scattering coefficients. The irradiance, or optical power density, is usually measured in watts per square meter.

bounce time. See switch bounce time; switch operating bounce time; switch release bounce time.

bound mode. In an optical waveguide, a mode whose field decays monotonically in the transverse direction everywhere external to the core and which does not lose power to radiation. For an optical fiber in which the refractive index decreases with distance from the optical axis and where there is no central refractive-index dip, a bound mode is governed by the relation

$$n_a k < \beta < n_o k$$

where β is the imaginary part, that is, the phase term, of the axial propagation constant; n_a is the refractive index at r = a, the core radius; n_o is the refractive index at r = 0, the core axis; k is the angular free space wavenumber, $2\pi/\lambda$, and λ is the wavelength. Bound modes correspond to guided rays in geometric optics. When more than one mode is propagating in a fiber, the optical power in bound modes is largely confined to the core. Synonymous with guided mode; trapped mode. Also see cladding mode; guided wave; leaky mode; leaky ray; unbound mode.

bound ray. See guided ray.

box. See optical fiber distribution box; optical fiber interconnection box; optical mixing box.

branch. In network topology, a direct path, such as a bus, joining two adjacent nodes of a network.

branching device. See fiber optic branching device; optical branching device.

Brewster angle. The angle, measured with respect to the normal, at which an electromagnetic wave incident upon an interface surface between two dielectric media of different refractive indices, is totally transmitted from one propagation medium into another. The reflectance will be zero only for light that has its electric field vector in the plane defined by the direction of propagation, that is, the direction of the Poynting vector, and the normal to the surface. This implies that the magnetic field component of the incident wave must be parallel to the interface surface. The Brewster angle is given by the relation

$$\tan B = (e_1/e_2)^{1/2} = n_1/n_2$$

where B is the Brewster angle, e_1 is the electric permittivity of the incident-wave propagation medium and e_2 is the electric permittivity of the transmitted-wave propagation medium and n_1 and n_2 are their corresponding refractive indices. The Brewster angle is a convenient angle for transmitting all the energy in an optical fiber to a photodetector, or from a source to a fiber. There is no Brewster angle when the electric field component is parallel to the interface, except when the electric permittivities are equal, in which case there is no interface. For entry into a more dense medium, such as from air into an optical fiber, B is less than 45 degrees; and from a more dense medium into a less dense medium, such as fiber to air, B is greater than 45 degrees. The Brewster angle is measured with respect to the normal to the interface surface.

Brewster's law. When an electromagnetic wave is incident upon a surface and the angle between the refracted and reflected ray is 90 degrees, maximum polarization occurs in both rays. The reflected ray has its maximum polarization in a direction normal to the incidence plane and the refracted ray has its maximum polarization in the incidence plane.

brightness. An attribute of the physiological sensation of light, that is, a visual perception or appearance of a higher or lower level of light. In photometrics, brightness was used as a synonym for luminance. In radiometrics, brightness was incorrectly used as a synonym for radiance. See radiance.

brightness conservation. See radiance conservation.

brightness theorem. See radiance conservation.

Brillouin diagram. A diagram showing the allowable and unallowable frequencies or energy levels of electromagnetic waves that can pass through materials that have certain periodic microstructures. When an electric field is applied to the material, electrons experience periodic attractive and repulsive forces as they approach and depart from atomic nuclei in their path as they move through the material. The resulting electron vibration results in a field that interacts or resonates with the propagating electromagnetic wave, causing energy from the wave to be absorbed by the electrons at the resonant frequencies. The net result is that electromagnetic waves of the resonant frequencies are absorbed while others are passed. Crystals and certain glasses have these periodic microstructures and therefore Brillouin diagrams can be drawn for them.

Brillouin scattering. The scattering of lightwaves in a propagation medium caused by thermally-driven density fluctuations that cause frequency shifts of several gigahertz at room temperature.

BRLP. Bit-rate-length product.

broadcast satellite. See direct broadcast satellite (DBS).

broadening. See pulse broadening.

budget. See error budget; loss budget; optical power budget; power budget.

budget constraint. See loss budget constraint.

buffer. 1. Material placed on or around an optical fiber to protect it from mechanical damage. Buffers can be bonded to the cladding. 2. In a fiber optic cable, material used to cushion and protect the optical fibers, particularly from mechanical damage, such as microbends and macrobends, caused during manufacture, spooling, subsequent handling, and when pressure is applied during use. 3. A data storage device used to compensate for differences in the rate of flow of data, or the time of occurrence of events, when transferring data from one device to another. 4. An isolating circuit used to prevent a driven circuit from influencing the driving circuit. 5. To allocate and schedule the use of buffers. See fiber buffer.

buffered fiber. An optical fiber that has a coating over the cladding for protection, increased visibility, and ease of handling.

bundle. A group of conductors, such as wires, optical fibers, or coaxial cables, associated together and usually in a single sheath. Optical fibers are nonconductors of electric currents, but when properly designed, will transmit optical signals. See aligned bundle; cable bundle; unaligned bundle; optical fiber bundle; ray bundle. Also see cable.

bundle jacket. See cable bundle jacket.

bundle of rays. See ray bundle.

bundpack. In fiber optics, an optical fiber wound in a spherical or conical shape after the fiber drawing process in such a manner that it can be payed out, that is, unwound, from either the inside or the outside of the winding. The conical shape permits easy removal of the collapsible winding mandrel after winding. The bundpack can be wrapped in a tight plastic skin for protection during storage, shipping, and handling. There are no spools or reels involved during payout, though one may be used for outside payout if convenient to do so. A light bonding cement is used to control payout so that payout is steady and without bunching. A twist is placed in the fiber when winding so that payout is without strain and hockels, that is, kinks, do not occur.

Burrus diode. See surface-emitting LED.

Burrus LED. See surface-emitting LED.

bus. One or more conductors, such as wires, coaxial cables, or optical waveguides, that serve as a common connection for a related group of devices. See optical data bus.

butt coupling. In fiber optics, the coupling of one optical fiber, or other optical element, to another by placing the end face of one against the end face of the other so that an electromagnetic wave can be transmitted with a minimum loss of power and a maximum transmission coefficient at the interface. The interface is usually transverse to the direction of propagation. The Brewster angle can be used for maximum coupling and total transmission, that is, zero reflection, when lightwaves pass from one propagation medium to another, each medium having a different refractive index. However, when butt coupling optical fibers, the end faces are perpendicular to the optical axis because they are easy to make and the joint can be rotated and shifted for maximum coupling, with Fresnel reflection normally being about 4 percent of the incident irradiance, that is, the incident optical power.

C

c. The symbol used for the speed of an electromagnetic wave, such as a lightwave, in a vacuum, that is, 3×10^8 m/s (meters per second). The speed in a material propagation medium is given by the relation

$$v = c/n$$

where n is the refractive index of the medium relative to that of a vacuum.

cable. In fiber optics, an assembly of one or more optical fibers, strength members, buffers, and perhaps other components all within an enveloping sheath or jacket, constructed so as to permit access to the fibers singly or in groups. See aerial optical cable; bidirectional optical cable; central-strength-member optical cable; fiber optic cable; filled cable; grooved cable; hybrid cable; loose-tube cable; multifiber cable; optical station cable; optoelectrical cable; peripheral-strength-member optical cable; ribbon cable; Tempest-proofed fiber optic cable; tight-jacket cable. Also see bundle.

cable assembly. See fiber optic cable assembly.

cable bundle. A number of fibers, buffered fibers, ribbons, or OFCCs grouped together in the cable core within a common protective layer.

cable bundle jacket. The material that forms a protective layer around a bundle of fibers, buffered fibers, ribbons, or OFCCs.

cable component. See optical fiber cable component (OFCC).

cable core. See fiber optic cable core.

cable core component. A cable core part, such as a buffered fiber, OFCC, cable bundle, ribbon.

cable cutoff wavelength. For a cabled optical fiber, the wavelength region above which the fiber supports the propagation of only one mode and below which multiple modes are supported. Operation of the fiber below the cutoff wavelength usually results in modal noise, modal distortion (increased pulse broadening), and unsatisfactory operation of connectors, splices, and wavelength-division multiplexing (WDM) couplers. The operating wavelength range, as determined by the transmitter nominal central wavelength and the transmitter spectral width, must be less than the maximum cutoff wavelength and greater than the minimum cutoff wavelength to ensure the cable operates entirely in the fiber single-mode region. Usually, the highest value of cabled fiber cutoff wavelength occurs in the shortest cable length. A criterion that will ensure a system is free from high cutoff wavelength problems is given by the relation

$$\lambda_{cc\ max} > \lambda_{t\ min}$$

where $\lambda_{cc\ max}$ is the maximum cutoff wavelength and $\lambda_{t\ min}$ is the minimum value of the transmitter central wavelength range, which is also caused by the worst-case variations introduced by manufacturing, temperature, aging, and any other significant factors determined when the cable is operated under standard or extended operating conditions. See maximum cable cutoff wavelength; minimum cable cutoff wavelength. Also see fiber cutoff wavelength.

cable facility. See optical cable facility.

cable facility loss. See optical cable facility loss; statistical optical cable facility loss.

cable feed-through. See fiber optic cable feed-through.

cable interconnect feature. See optical cable interconnect feature.

cable pigtail. See optical cable pigtail.

cable splice. In fiber optics, a connection between two cables, consisting of one or more optical fiber splices within a cable splice closure. It provides optical continuity between cables, protection against environmental conditions, and mechanical strength to the cable joint. The cable splice is used primarily to complete a cable span or to repair a cable.

cable splice closure. The portion of a fiber optic cable splice that covers the fiber splice housings, seals against the outer jackets of the joined cables, provides protection against the environment, and provides mechanical strength to the joint.

cabling process. In the manufacture of fiber optic cables, starting with one or more reels of optical fiber or fiber ribbon, usually with appropriate coatings and buffers already applied, the assembly of a fiber optic cable by wrapping additional buffers, strength members, jackets, and perhaps other materials, such as overarmor and harnesses. The process includes putting coatings on the jacket, adding markings to indicate the type of cable, and winding the finished cable on spools or other forms for internal or external payout. Care must be taken to ensure the cabling process does not introduce microbends in the optical fibers and does not bend the fibers with a radius of curvature less than the minimum bend radius.

carrier. A wave, pulse train, or other signal suitable for modulation by an information-bearing signal in a modulator for the purpose of representing information and capable of being transported or transmitted by a communication system.

Carson bandwidth rule (CBR). A rule defining the approximate bandwidth requirements of communication system components for a carrier signal that is frequency modulated by a continuous, that is, a broad spectrum of frequencies rather than a single frequency. The rule is expressed by the relation

$$CBR = 2(\Delta f + f_m)$$

where Δf is the carrier peak deviation frequency, and f_m is the highest modulating frequency. Bandwidth requirements for modulated carriers and equipment capabilities impose limits on the extent of multiplexing that can be accommodated. The Carson bandwidth rule is often applied to transmitters, antennas, light sources, receivers, photodetectors, and other communication system components.

cavity mirror sensor. See optical cavity mirror sensor.

cavity. See optical cavity; resonant cavity.

CBR. Carson bandwidth rule.

cell. See Kerr cell; Pockels cell.

cement. See optical cement.

center. See cladding center; core center; network control center; processing center; reference surface center; scattering center; switching center.

central-strength-member optical cable. A cable containing optical fibers that are wrapped around a high-tensile-strength material, such as stranded steel, Kevlar, and Nylon, with a crush-resistant jacket wrapped around the outside. Also see peripheral-strength-member optical cable.

central wavelength. See nominal central wavelength.

central wavelength measurement. For the transmitter terminal/regenerator facility of an optical station/regenerator section, the measurement of the wavelength that identifies where the effective optical power of the transmitter resides using either the peak mode or the power weighted method.

central wavelength range. See transmitter central wavelength range.

change in transmittance. See induced attenuation.

channel. 1. A connection between initiating and terminating nodes of a circuit. 2. A single path provided by a transmission medium either by physical separation, e.g., multipair cable, or by electrical separation, e.g., frequency or time-division multiplexing. 3. A single unidirectional or bidirectional path for transmitting or receiving, or both, of electrical or electromagnetic signals, usually distinct from other parallel paths. 4. Used in conjunction with a predetermined letter, number, or codeword to reference a specific radio or video frequency. 5. A path along which signals can be sent, e.g., data channel or output channel. 6. The portion of a storage medium that is accessible to a given reading or writing station, e.g., a track or band. 7. In information theory, that part of a communication system that connects the message source to the message sink.

characteristic. See fiber global dispersion characteristic; fiber global attenuation-rate characteristic; wavelength-dependent attenuation rate characteristic.

characteristic impedance. 1. In a uniform electromagnetic plane wave propagating in free space, or in dielectric propagation media, the ratio between the electric and magnetic field strengths, given by the relation

$$Z = E/H$$

in which E and H are orthogonal and are in a direction perpendicular to the direction of propagation, namely perpendicular to the Poynting vector, which is the vector obtained from the cross (vector) product of the electric and magnetic field vectors, with the direction of a right-hand screw obtained when rotating the electric vector into the magnetic vector over the smaller angle. 2. From Maxwell's equations, the impedance of a linear, homogeneous, isotropic, dielectric, and electric-charge-free propagation medium, given by the relation

$$Z = (\mu/\epsilon)^{1/2}$$

where μ is the magnetic permeability and ϵ is the electric permittivity. In free space, and approximately in air, $\mu = 4\pi \times 10^{-7}$ H/m (henries per meter) and $\epsilon = (1/36\pi) \times 10^{-9}$ F/m (farads per meter) from which 120π, or 377 ohms, is obtained. For dielectric media, the permittivity is the dielectric constant, which for glass, ranges from about 2 to 7. However, the refractive index is the square root of the dielectric constant. Thus, the characteristic impedance of dielectric materials is 377/n ohms, where n is the refractive index.

chemical vapor deposition (CVD) process. A method of making optical fibers in which silica and other glass-forming oxides and dopants are deposited at high temperatures on the inner wall of a fused silica tube, called a bait tube, which is then collapsed into a short, thick, preform from which a long thin fiber is pulled at a high softening temperature using a fiber-pulling machine. See modified chemical vapor deposition (CVDP) process; plasma-activated chemical vapor deposition (PACVD) process.

chemical vapor-phase oxidation (CVPO) process. A method of making low-loss (less than 10 dB/km), high bit-rate-length product (greater than 300 Mb-km/s), multimode, graded index (GI), optical fiber involving either the inside vapor phase oxidation (IVPO) process, the outside vapor phase oxidation (OVPO) process, the modified chemical vapor deposition (MCVD) process, the plasma-activated chemical vapor deposition (PCVD) process, the axial vapor phase oxidation (AVPO) process, or a combination or variation of these, by soot deposition on a glass substrate followed by oxidation and pulling of the fiber.

chief ray. The central ray of a ray bundle.

chirp. See laser chirp.

chirping. Rapid fluctuations in frequency or wavelength of an electromagnetic wave, usually caused by some form of modulation at the source or of the wave after emission. For example, a sudden shift from one set of spectral lines, that is, in the wavelengths emitted by a source, to another set of lines. Chirping is often observed when sources are pulsed, that is, modulated by pulses.

chopper. See optical chopper.

chromatic aberration. Image imperfections caused by light of different wave-lengths following different paths through an optical system due to the dispersion caused by the optical elements of the system.

chromatic dispersion. Dispersion or distortion of a pulse in an optical waveguide due to differences in wave velocity caused by variations in the refractive indices in different portions of the guide. The propagation velocity varies inversely with the refractive index. The propagation time from the beginning to a point in the guide varies directly as the optical path length, the rate of change of refractive index with respect to wavelength, and the spectral line width of the source. Differences in delay, that is, differences in propagation time, cause the distortion.

chromatic dispersion coefficient. The derivative with respect to wavelength of the normalized group delay of a waveguide, such as an optical fiber, given by the relation

$$D(\lambda) = d\tau(\lambda)/d\lambda$$

where $\tau(\lambda)$ is the normalized group delay and λ is the wavelength at which the normalized group delay is taken. Also see Sellmeier equation.

chromatic dispersion slope. The derivative with respect to wavelength of the chromatic dispersion coefficient of a waveguide, such as an optical fiber, given by the relation

$$S(\lambda) = dD(\lambda)/d\lambda$$

where $D(\lambda)$ is the chromatic dispersion coefficient and λ is the wavelength at which the slope is taken.

chromatic distortion. Synonymous with intramodal distortion.

chromaticity. The frequency, or wavelength, composition of electromagnetic waves in the visible region of the spectrum. Chromaticity is normally characterized by the dominant frequencies or wavelengths, which describe the quality of color. It affects propagation in filters, attenuation in optical fibers, and the sensitivity of photographic film.

chromatic radiation. See polychromatic radiation.

chromatic resolving power. 1. The ability of an instrument to separate two electromagnetic waves of different wavelengths. It is equal to the ratio of the shorter wavelength divided by the difference between the wavelengths. 2. A measure of the ability of an optical component to separate or differentiate two or more object points that are close together relative to the distance between the optical component and the object points.

circuit. See integrated optical circuit (IOC).

circular dielectric waveguide. A waveguide consisting of a long circular cylinder of concentric dielectric materials, capable of sustaining and guiding an electromagnetic wave in one or more propagation modes. For example, most optical fibers are circular dielectric waveguides that are capable of transmitting, or transporting, lightwaves. Some polarization-preserving (PP) fibers are somewhat elliptical or rectangular in cross section, especially the core.

circularity. See cladding noncircularity; core noncircularity.

circular polarization. Polarization of the electric and magnetic field vectors in a uniform plane-polarized electromagnetic wave, such as some lightwaves or radio waves, in which the two arbitrary sinusoidally-varying rectangular components of the electric field vector are equal to each other in amplitude but are 90 degrees out of phase. This causes the electric field vector to rotate, with the direction of rotation depending on which component leads or lags the other, that is, the tip, or head, of the electric field vector rotates in a circle. The magnetic field vector is at the center of this circle and perpendicular to the plane of the circle. See left-hand circular polarization; right-hand circular polarization.

clad. See cladding.

cladding. A layer of a lower refractive-index material, in intimate contact with a core of higher refractive-index material, used to achieve reflection. The cladding confines lightwaves to the core, provides some protection to the core, and also transmits evanescent waves that are usually bound to waves in the core. These evanescent waves will propagate in the cladding and even extend beyond. They will not radiate away if the cladding is sufficiently thick. They will radiate away if the fiber is bent too sharply, that is, bent sharper than a certain radius called the critical radius. Synonymous with clad. See depressed cladding; extramural cladding; fiber cladding; homogeneous cladding; matched cladding.

cladding center. In a round optical fiber, the center of the circle that best fits the outer limit of the cladding. The cladding center may not be the same as cladding and reference surface centers.

cladding concentricity. See core-cladding concentricity.

cladding diameter. In a round optical fiber, the diameter of the circle that best fits the outer limit of the cladding. The center of this circle is the cladding center.

cladding guided mode. See cladding mode.

cladding mode. In an optical waveguide, a propagation mode supported by the cladding, that is, a mode in which the electromagnetic field is confined to the cladding and the core because there is a lower refractive-index propagation medium surrounding the outermost cladding. These modes are in addition to the modes supported only by the core. Cladding modes may be attenuated by using lossy media to absorb the energy propagating in the mode thus preventing reconversion of energy to core-guided modes and thereby reducing dispersion. Synonymous with cladding guided mode; cladding ray. Also see bound mode; leaky mode; leaky ray; unbound mode.

cladding mode stripper. A device in which cladding modes are converted to radiation modes. A material is usually applied to cladding to allow electromagnetic energy propagating in the cladding to leave the cladding by having its refractive index be equal to or greater than that of the cladding.

cladding noncircularity. 1. In the cross section of a round optical fiber, (1) the difference between the diameters of the smallest circle that can circumscribe the core area and the largest circle that can be inscribed within the cladding, both circles concentric with the cladding center, (2) divided by the cladding diameter. 2. In a round optical fiber, the percent deviation of the cladding cross section from a circle. Synonymous with cladding ovality. Also see optical fiber concentricity error.

cladding ovality. See cladding noncircularity.

cladding power distribution. See core-cladding power distribution.

cladding ray. See cladding mode.

cladding tolerance area. In the cross section of a round optical fiber, the region between the smallest circle that can circumscribe the core area and the largest circle that can be inscribed within the cladding, both circles concentric with the cladding center.

clad fiber. See quadruply clad fiber.

clad silica fiber. See hard-clad silica (HCS) fiber.

clockwise polarized wave. An elliptically or circularly polarized electromagnetic wave in which the direction of rotation of the electric vector is clockwise as seen by an observer looking in the direction of propagation of the wave. Also see counterclockwise polarized wave.

closed waveguide. A waveguide that has electrically conducting, or optically reflecting, walls, thus permitting an infinite but discrete set of propagation modes of which relatively few are practical. Each discrete mode has its own propagation constant. The electric and magnetic fields at any point can be described in terms of these modes. There is no radiation from the guide. Examples of a closed waveguide include a metallic rectangular-cross-section pipe not unlike an ordinary rectangular rain downspout on a house and an optical fiber with a reflective coating to obtain internal reflection and used as a light pipe for interior illumination. Also see open waveguide.

closure. See cable splice closure.

coated fiber sensor. A fiber optic sensor in which a special coating is used to apply stress to an optical fiber resulting in fiber strain. For example, a magnetostrictive coating may be used to elongate the fiber proportionally to an applied longitudinal magnetic field. The variations in length can be measured using interferometric techniques. If the magnetic field is made proportional to an electric current, the electric current can be measured. If the coating is thermally sensitive, the coefficient of thermal expansion can be used to measure temperature, or the thermal expansion effect of an electric current in the coating can be used to measure the electric current. A narrow spectral-line-width light source; a length of optical fiber, serving as a sensing leg, with a bonded coating sensitive to the parameter being measured; a shielded length of optical fiber, serving as a reference leg, that is not exposed to the parameter being measured to serve as a reference; a fiber optic splitter to split the same wave into both legs; a coupler to combine the waves from both legs; and a photodetector responsive to the light intensity produced by the two interfering waves, all connected together constitute a coated fiber sensor.

coated optics. The use of optical elements or components whose optical refractive and reflective surfaces have been coated with one or more layers of dielectric or metallic material for reducing or increasing reflection from the surfaces, either totally or for selected wavelengths, and for protecting the surfaces from abrasion and corrosion. Some antireflection coating materials that can serve as optical coatings are magnesium fluoride, silicon monoxide, titanium oxide, and zinc sulfide.

coating. See antireflection coating; optical protective coating; optical fiber coating; primary coating; secondary coating.

coating offset ratio. See fiber/coating offset ratio.

coefficient. See absorption coefficient; chromatic dispersion coefficient; dispersion coefficient; extinction coefficient; global dispersion coefficient; scattering coefficient; spectral absorption coefficient; reflection coefficient; transmission coefficient; worst-case dispersion coefficient.

coherence. 1. The phenomenon pertaining to a correlation between the phase points of two waves at the same instant or at the same point in space. 2. The phenomenon pertaining to a correlation between the phase points of one wave at two different instants of time at the same point in space or at two points in space at the same instant. In practice, coherence is a matter of degree. If coherence were perfect, the phase relationships within a wave, and the phase relationships among waves, would be always and everywhere precisely predictable. See spatial coherence; coherence degree; partial coherence; time coherence.

coherence area. In and optical fiber, the area in a plane perpendicular to the direction of propagation over which light may be considered highly coherent. It is usually considered to be the area over which the coherence degree exceeds 0.88.

coherence degree. A measure of the coherence of a light source, equal to the visibility, V, given by the relation

$$V = (I_{max} - I_{min})/(I_{max} + I_{min})$$

where V is the visibility of the fringes of a two-beam interference test, I_{max} is the irradiance, that is, the optical power density, at a maximum of the interference pattern, and I_{min} is the irradiance at a minimum of the interference pattern. Light may be considered to be coherent if the coherence degree exceeds 0.88 and incoherent if significantly less than 0.88. Synonymous with degree of coherence.

coherence length. The propagation distance over which a light beam may be considered coherent. The coherence length in a propagation medium, such as an optical fiber or integrated optical circuit (OIC) element, is given by the relation

$$L_c = \lambda_o^2/n\Delta\lambda$$

where λ_o is the central wavelength of the source, n is the refractive index of the medium, and $\Delta\lambda$ is the spectral line width of the source.

coherence time. The time over which a propagating electromagnetic wave may be considered coherent. It is equal to the coherence length divided by the phase velocity of light in a propagation medium; approximately given by the relation

$$T_c \approx \lambda_o^2/c\Delta\lambda$$

where λ_o is the central wavelength, $\Delta\lambda$ is the spectral line width, and c is the velocity of light in vacuum. In long-distance transmission systems, the coherence time may be degraded, that is, reduced, by many other propagation factors, such as refractive index, temperature, impurity, and pressure variations at various points in the propagation medium.

coherent. 1. Pertaining to a fixed phase relationship between points on an electromagnetic wave. A truly coherent wave would be perfectly coherent at all points in space. In practice, however, the region of high coherence may extend only a finite distance from a source. 2. Pertaining to an electromagnetic wave in which the electric and magnetic field vectors are uniquely and specifically definable always and everywhere within specified tolerances. An electromagnetic wave of single frequency, that is a purely monochromatic wave, would be coherent at all points in free space and in a homogeneous isotropic propagation medium. Thus, the electric and magnetic field values could be precisely predicted at every point in space and time using the solutions to Maxwell's equations. In actual practice monochronism is not perfect. There is a spectral width. The region of high coherence may extend only a short distance from the source. The area on the surface of a practical wavefront over which the wave may be considered highly coherent is the coherent area or is a coherence patch. The distance in the direction of propagation in which the wave is highly coherent is the coherence length, in which case the wave is phase or length coherent. This coherence length divided by the velocity of the light in the propagation medium is the coherence time. Thus, phase and time coherence are related. Phase coherence may also be called time coherence because both are taken in the direction of propagation rather than transverse to the direction of propagation as is area coherence. Area coherence is taken at an instant of time. Time, or temporal, and phase coherence of a wave occurs over the period of time that corresponds to its coherent length.

coherent area. The area in a plane perpendicular to the direction of propagation over which radiation may be considered to be coherent, that is, the locus of all points in a plane at which the coherence degree is greater than 0.88.

coherent bundle. See aligned bundle.

coherent detection. In fiber optics, optical detection in which a low-power phase-modulated lightwave is coherently mixed with an optical signal to produce an amplitude modulated signal that can be directly detected downstream by conventional means.

coherent light. Light in which all parameters are predictable and correlated at any point in time or space, particularly over an area in a plane perpendicular to the direction of propagation or over time at a point in space. See time-coherent light.

coherent radiation. At a given point, electromagnetic radiation that has a coherence degree greater than 0.88.

collimation. The process by which divergent or convergent light, that is, a beam of electromagnetic radiation, is converted into a beam with the minimum divergence or convergence possible for that system. Ideally, a bundle of parallel rays is a collimated radiation. 2. The process of making electromagnetic rays, such as light rays, parallel. For example, the use of a lens system to make divergent or convergent rays parallel. Light rays from a very distant not necessarily point source are practically parallel.

collimator. An optical device that renders diverging or converging light rays parallel. The degree of collimation, that is, the extent to which they are parallel, should be stated in terms of an angle of convergence or divergence.

color. 1. The sensation produced by light of a given wavelength, or group of wavelengths, in the visible region of the electromagnetic spectrum. 2. A given wavelength, or set of wavelengths, in the visible spectrum.

color-division multiplexing. See wavelength-division multiplexing.

combiner. See optical combiner.

communication network. See long-haul communication network; short-haul communication network.

communications. See optical fiber communications.

compensated optical fiber. An optical fiber whose refractive-index profile has been adjusted so that light rays propagating in the higher-refractive-index portion of the core, that is, near the core center, thus propagating a shorter distance at lower speeds due to the high-index material, and the rays propagating in the outer lower index material, thus undergoing total (internal) reflection, or bending back and forth, and thus traversing a longer path but propagating faster due to the lower index, arrive at the end of the fiber at the same time, along with the skew rays that travel a helical path, thus reducing modal dispersion to nearly zero. Higher-order modes have higher eigenvalues in the wave equation solutions, higher frequencies, and shorter wavelengths than lower-order modes. Also see overcompensated fiber; undercompensated fiber.

component. See magnetic field component; optical fiber cable component (OFCC); optical path component.

compression. See bandwidth compression; optical fiber pulse compression.

compression sensor. See fiber longitudinal compression sensor; fiber trans-verse compression sensor.

computer. See optical computer.

concatenation. The linking of a series of devices or components, such as optical waveguides, in such a manner that the output of the first is the input to the second, the output of the second is the input to the third, and so on.

concentrator. See optical fiber concentrator.

concentric-circle near-field template. See four-concentric-circle near-field template.

concentric-circle refractive-index template. See four-concentric-circle refractive-index template.

concentricity. See core reference-surface concentricity; core-cladding concentricity.

concentricity error. See optical fiber concentricity error.

condition. See extended operating condition; launch condition; standard operating condition.

conduction. See optical conduction.

conductivity. See electrical conductivity; photoconductivity.

conductor. See optical conductor.

cone. See acceptance cone.

configuration scattering. Scattering of electromagnetic radiation caused by variations in the configuration of a propagation medium, such as scattering caused by variations in geometry and refractive-index profile of an optical fiber. Synonymous with fiber scattering.

confinement factor. For a given guided mode of an electromagnetic wave propagating in a waveguide, the ratio between the power within the guiding layer, such as the core of an optical fiber or inner layer of a planar waveguide, and the total guided power.

connection. See fiber optic cross-connection; fiber optic interconnection.

connector. See expanded-beam connector; fiber optic connector; fixed connector; free connector; heavy-duty connector; hybrid connector; light-duty connector; optical waveguide connector; optical fiber active connector; receiver optical connector; transmitter optical connector; wet-mateable connector.

connector set. See optical fiber connector set.

connector variation. See optical connector variation.

conservation law. See radiance conservation law.

conservation of radiance law. Synonymous with radiance conservation law.

constant. See Boltzmann's constant; Planck's constant; propagation constant; transverse propagation constant; Verdet's constant.

constitutive relations. A set of three equations pertaining to the properties of a propagation medium in which electric and magnetic fields, electric currents, and electromagnetic waves exist and propagate. The relations are given as $D = \epsilon E$, $B = \mu H$, and $J = \sigma E$, where D is the electric flux density or electric displacement vector, E is the electric field strength, B is the magnetic flux density, H is the magnetic field strength, J is the electric current density, ϵ is the electric permittivity, μ is the magnetic permeability, and σ is the electrical conductivity. The relations are used in conjunction with Maxwell's equations for electromagnetic wave propagation. In dielectric materials, such as optical fibers, $\sigma = 0$ and $\mu = 1$.

constraint. See loss budget constraint.

contact. See terminus.

continuously-variable optical attenuator. A device that attenuates the irradiance, that is, the power density, of lightwaves over a continuous range rather than in discrete steps. The attenuator may be inserted in an optical link to control the irradiance of light at the receiving photodetector. Also see stepwise-variable optical attenuator.

contrast. See refractive-index contrast.

control center. See network control center.

control link. A dedicated data link in which the transmitted information is used to control the operation of a device, such as a ship or aircraft propulsion system or subsystem. Usually the control link is used to transmit data from the device being controlled to a control point, such as a control panel, or to transmit data, usually in the form of a control signal, to the device where the signal is converted to an electric current or mechanical actuating device of some type to control the operation of that device and hence the system.

convergent light. Light consisting of a bundle of rays each of which is propagating in such a direction as to be approaching every other ray, that is, they are not parallel to each other and are propagating toward a line, or are heading toward a point of intersection or focus. The wavefront of convergent light is somewhat spherical, that is, convex on the incidence side. If a collimated beam enters a convex lens, the emerging light is convergent. Also see divergent light.

conversion. See mode conversion.

core. The center region of an optical waveguide through which light is transmitted. In a dielectric waveguide, such as an optical fiber, the refractive index of the core must be higher than that of the cladding. Most of the optical power is confined to the core. Unlike the magnetic material at the center of a relay or coil winding, the core of an optical fiber is a dielectric, that is, it is an electrically nonconducting, nonmagnetic, transparent material such as glass. See fiber core; fiber optic cable core.

core area. That part of the cross-sectional area of a dielectric waveguide, within which the refractive index is everywhere greater than that of the adjacent, that is, innermost, homogeneous cladding by a given fraction of the difference between the maximum refractive index of the core and the refractive index of the homogeneous cladding. Any refractive-index dip is excluded. Thus, the core area is the smallest cross-sectional area within which the refractive index is given by the relation

$$n_3 = n_2 + m(n_1 - n_2)$$

where n_1 is the maximum refractive index of the core, n_2 is the refractive index of the homogeneous cladding adjacent to the core, and m is a fraction, usually not greater than 0.05. Thus, in an optical fiber, the core area is the cross-sectional area enclosed by the line that connects all points nearest to the optical axis on the periphery of the core where the refractive index exceeds that of the homogeneous cladding by m times the difference between the maximum refractive index in the core and the refractive index of the homogeneous cladding, where m is a positive or negative constant such that $|m| < 1$.

core center. In a round optical fiber, the center of the circle that best fits the outer limit of the core area. The core center may not be the same as cladding and reference surface centers.

core-cladding concentricity. 1. In a multimode round fiber, the distance between the core and cladding centers, divided by the core diameter. 2. In a single-mode fiber, the distance between the core and cladding centers.

core-cladding power distribution. For a given mode of an electromagnetic wave propagating in an optical fiber, the fraction of the total power in the mode that is within the core. The remaining fraction is in the cladding. The fraction of power in the core is given by the relation

$$P_{core}/P_T = 1 - P_{clad}/P_T$$

where P_{clad} is the modal power in the cladding and P_T is the total power in the mode. The power distribution for a given mode can change with distance along the guide, especially for the higher-order modes wherein the cladding power can be lost to lateral radiation.

core diameter. In a round optical fiber, the diameter of the circle that best fits the outer limit of the core area. The center of this circle is the core center.

core eccentricity. See optical fiber concentricity error.

core mode filter. A device, such as one turn of an optical fiber wrapped around a mandrel, that removes high-order propagation modes from the core of the optical fiber.

core noncircularity. 1. In a round optical fiber, the difference between the diameters of the smallest circle that can circumscribe the core area and the largest circle that can be inscribed within the core area, divided by the core diameter. 1. In a round optical fiber, the percent deviation of the core cross section from a circle. Synonymous with core ovality. Also see optical fiber concentricity error.

core ovality. See core noncircularity.

core reference-surface concentricity. 1. In a multimode round optical fiber, the distance between the core and reference surface centers, divided by the core diameter. 2. In a single-mode round optical fiber, the distance between the core and reference surface centers.

core tolerance area. In the cross section of a round optical fiber, the region between the smallest circle that can circumscribe the core area and the largest circle that can be inscribed within the core area, both circles concentric with the core center.

cosine emission law. See Lambert's cosine law.

cosine law. See Lambert's cosine law.

counterclockwise polarized wave. An elliptically or circularly polarized electromagnetic wave in which the direction of rotation of the electric vector is counterclockwise as seen by an observer looking in the direction of propagation of the wave. Also see clockwise polarized wave.

coupled mode. In fiber optics, a mode that shares energy propagating in an electromagnetic wave with one or more other modes in such a manner that the coupled modes propagate together. The propagating energy is distributed among the coupled modes. The energy distribution among the modes changes with distance along an optical fiber, especially before the equilibrium length, that is, the equilibrium modal power distribution length.

coupled power. See source-to-fiber coupled power.

coupler. 1. In fiber optics, a device that enables the transfer of optical energy from one optical waveguide to another. 2. A passive optical device that distributes or combines optical power among two or more ports, including protective housing and pigtails. See directional coupler; fiber optic coupler; fiber optic multiport coupler; nonuniformly distributive coupler; optical waveguide coupler; optoelectronic directional coupler; reflective star coupler; star coupler; tee coupler; wye coupler; uniformly distributive coupler. 3. In electronics, the means by which energy is transferred from one conductor, including a fortuitous conductor, to another. Types of coupling include: (a) capacitive coupling--the linking of one conductor with another by means of capacitance (also known as electrostatic coupling); (b) inductive coupling--the linking of one conductor with another by means of magnetic inductance; (c) conductive coupling--hard wire connection of one conductor to another.

coupler excess loss. Fiber optic coupler loss given by the relation

$$P_{ex} = \sum_{i}^{1} P_j - \sum_{i}^{1} P_{ij(id)}$$

where P_{ex} is the coupler excess loss, i is the number of input ports, P_j is the output power at port j, and $P_{ij(id)}$ are the transmittances that would be obtained from an ideal coupler in which all of the input power is coupled to the non-isolated output ports.

coupler loss. The insertion loss, that is, the power loss, that occurs when power is transferred from a given input port to a given output port with all other ports properly terminated.

coupler transmittance. For a fiber optic coupler, the optical transmittance measured between an input port and an output port of the coupler by launching a known optical power level into each input port i, one at a time, and measuring the power at each of the j output ports for each of the i input ports. For example, in a 2 x 4 coupler there are 6 ports. For each of the two input ports, the power at each of the 4 output ports would be measured to determine the 8 coupler transmittances. Also see coupler transmittance matrix.

coupler transmittance matrix. For a fiber optic coupler, a matrix of L x L dimensions, where L is the total number of ports, no distinction being made between input and output ports. For example, in a 2 x 4 coupler L would be 6, there would be six ports, numbered 1 to 6. Each of the transmittances, in dB, in the matrix is represented by the relation

$$P_{ij} = 10 \log_{10}(P_i/P_j)$$

where P_{ij} is the transmittance in dB from the input port i to the output port j, P_i is the optical power launched into port i, and P_j is the output power at port j. The subscripts of the elements of the transmittance matrix correspond to the numbers labelled on the coupler. The format of the transmittance matrix is defined as

$$P = \begin{matrix} P_{11} & \cdots & P_{1L} \\ P_{21} & \cdots & P_{2L} \\ \vdots & & \vdots \\ P_{L1} & \cdots & P_{LL} \end{matrix}$$

coupling. 1. In fiber optics, the transferring of optical power or energy from one device to another, for example, the transferring of an optical signal from one optical fiber to another. 2. In fiber optics, the part of a fiber optic connector that aligns the optical termini. See butt coupling; free-space coupling; mode coupling; proximity coupling.

coupling coefficient. See coupling efficiency.

coupling efficiency. In fiber optics, the efficiency with which optical power is transferred between two components. Coupling efficiency is usually expressed as the percentage of power output from the transmitting component that is actually received at the receiving component. If the coupling efficiency is expressed in dB, it corresponds to the coupling loss. The maximum light coupling efficiency, E, from a Lambertian radiator, that is, a light source, such as an LED and a graded-index optical fiber, is given by the relation

$$E = A_c(NA)^2/2A_s n_o^2$$

where A_c is the core area, A_s is the source area, n_0 is the refractive index of the propagation medium between the source and fiber, and NA is the numerical aperture. Synonymous with coupling coefficient. See source coupling efficiency.

coupling loss. The power loss that occurs when power is transferred from one optical waveguide to another. Coupling loss may be expressed in absolute units, such as watts, or as a ratio, that is, a fraction or percentage of the power in the originating circuit. If expressed as 10 times the logarithm to base 10 of the ratio, that is, in dB or dBm, it is called coupling efficiency. See intrinsic coupling loss; extrinsic coupling loss.

covering. See protective covering.

crack. See microcrack.

criterion. See Nyquist criterion.

critical angle. In optics, the least incidence angle between one medium and another at which total reflection takes place, that is, total (internal) reflection, wherein the incidence medium is considered as the inside. The critical angle varies with the refractive indices of the two media according to the relationship

$$\sin A_1 = n_2/n_1$$

where A_1 is the critical angle; n_2 the refractive index of the less dense medium, that is, the lower-refractive-index material; and n_1 the refractive index of the denser medium, that is, n_1 is greater than n_2, and the incident wave is in the denser medium. Thus, when an electromagnetic wave is incident upon an interface surface between two dielectric media, the critical angle is the angle at which total reflection of the incident ray first occurs as the incidence angle is increased from zero, and beyond which total internal reflection continues to occur. Also, the incident ray must be in the medium with the greater refractive index. For angles less than the critical angle, there will be a refracted ray that is bent away from the normal in the less dense medium. If the incidence angle is equal to the critical angle, the reflection coefficient becomes unity, all the incident power is reflected, the transmission coefficient becomes zero, and none of the incident power is transmitted into the less dense medium. In an optical fiber, the wave will be confined to the fiber for all incidence angles greater than the critical angle. Some bound modes will remain and propagate in the cladding. However, the bulk of the optical power will be confined to the core. In an optical fiber, the incidence angles are measured with respect to the normal to the core-cladding interface surface.

critical-angle sensor. A fiber optic sensor in which the amount of light coupled into an optical fiber is a function of the angle at which the light enters the fiber's end-face. The light intensity that reaches a photodetector at the end of the fiber will depend on the entry angle, permitting the angle between the direction of the source beam and the fiber axis to be measured.

critical radius. In an optical fiber, the radius of curvature of the fiber at which the field of a propagating electromagnetic wave detaches itself from the fiber and radiates out into space because the velocity of the portion of the wavefront on the outside part of the curve must increase beyond the speed of light in order to maintain the proper phase relationship with the wave inside the fiber and thus no longer can remain bound to the inside wave. After the velocity of an evanescent wavefront element farthest from the central axis of the fiber begins to exceed the velocity of light as it sweeps around the bend can no longer keep up with the part of the wave inside the fiber, the energy begins to radiate out from the fiber, resulting in attenuation of the energy in the propagating wave. If the radius is less than the critical radius, the incidence angles at the bend become less than the critical angle, causing part of the energy in the wave to enter the cladding. For radii of curvature, that is, macrobends below the critical radius, nearly all of the energy radiates from the fiber. Below the critical radius, mode conversion also occurs, because of the many reflections at the bend. Also see critical-radius sensor.

critical-radius sensor. A fiber optic sensor in which an optical fiber is bent in such a manner that increased energy in a lightwave propagating within it is radiated out of the fiber as the bend radius is decreased. The amount of light radiated away at the bend increases sharply from zero to 100 percent as the radius of the bend is decreased to and passes through the critical value. The loss is due to mode conversion loss in the transition from the straight fiber to the curved fiber and to separation of the evanescent wave into space when the outer edge of the wave cannot keep up with the internal wave, that is, the outer edge has reached the speed of light as it swings around the bend. A photodetector is used to detect the variation in light intensity at the end of the fiber, which is a function of the bend radius. Thus, the displacement that is causing the bend can be measured after the device is calibrated. Also see critical radius.

cross-connection. See fiber optic cross-connection.

crosstalk. 1. In fiber optics, the undesired optical power that is transferred from, that is, leaks from, one optical waveguide to another. It is often a measure of the optical power picked up by an optical fiber from an adjacent energized fiber. The crosstalk, X_T, in dB (decibels), is then given by the relation

$$X_T = 10 \log_{10}(P_d/P_o)$$

where P_o is the optical power at the receiving end of the energized fiber and P_d is the power in the disturbed fiber at the corresponding end. Because P_d is always less than P_o, the crosstalk is always negative. The negative sign is commonly ignored, for example, the crosstalk may be given as simply 90 dB. 2. The phenomenon in which a signal transmitted on one circuit or channel of a transmission system, creates an undesired effect in another circuit or channel. See fiber crosstalk.

crystal. See multirefracting crystal.

current. See dark current; noise current; photocurrent; threshold current.

curvature loss. In fiber optics, the optical power loss caused by macrobends in an optical fiber. Power will radiate away from the fiber if the radius of the bend is less than the critical radius. Synonymous with macrobend loss.

curve. See spectral loss curve.

cut. See runner-cut.

cutback technique. A technique for measuring certain optical fiber transmission characteristics, such as the attenuation rate, insertion loss, bit-rate-length-product, bandwidth, and dispersion, by performing two transmission measurements. One measurement is made at the output of a length of the fiber and the other is made at the output of a shorter length of the same fiber without changing the launching conditions, that is, without changing the entrance-end conditions; or one measurement is made without an inserted component and another measurement is made after a component whose insertion loss is to be measured, is inserted, that is, spliced in. Access to the shorter length is obtained simply by cutting off a length of the exit end of the fiber. The two transmission measurements and the measured lengths can be used to calculate the transmission characteristic, such as the attenuation rate or the insertion loss. Several cutback measurements can be made on the same fiber for the same or different measurements, all measurements being made with the same entrance-end launch conditions.

cutoff. See low-frequency cutoff.

cutoff frequency. 1. In an optical fiber, the frequency below which a specified propagation mode fails to exist. As the frequency is decreased, the wavelength increases until the wavelength is too long for the dimensions of the fiber to support the wave. 2. The frequency above which, or below which, the output electrical current in a circuit, such as a line or a filter, is reduced to a specified level. 3. The frequency below which a radio wave fails to penetrate a layer of the ionosphere at the incidence angle required for transmission between specified points by reflection from the layer.

cutoff mode. The highest order mode that will propagate in a given waveguide at a given frequency.

cutoff wavelength. In a waveguide, the wavelength corresponding to the cut-off frequency, that is, the free-space wavelength above which a given bound mode cannot exist in the guide. Thus, it is the wavelength greater than which a particular mode ceases to be a bound mode, that is, the mode ceases to propagate within the guide. In a single-mode waveguide, concern also is with the cutoff wavelength of the second-order mode, in order to ensure single-mode operation. For single-mode operation, the fiber cut-off wavelength can be determined from the relation

$$V = (2\pi a/\lambda)(n_1^2 - n_2^2)^{1/2}$$

where a is the core radius, λ is the operational wavelength, n_1 is the core refractive index, and n_2 is the cladding refractive index. For single-mode operation $V = 2.405$ and λ will be the cutoff wavelength. For a short uncabled single-mode optical fiber with a specified large radius of curvature, that is, macrobend, the cutoff wavelength is the wavelength at which the presence of a second order mode introduces a significant attenuation increase when compared to a fiber whose differential mode attenuation is not changing at that wavelength. Because the cutoff wavelength of a fiber is dependent upon length, bend, and cabling, the cabled fiber cutoff wavelength may be a more useful value for cutoff wavelength from a systems point of view. In general, the cable cutoff wavelength is less than the fiber cutoff wavelength. See cable cutoff wavelength; maximum cable cutoff wavelength; minimum cable cutoff wavelength.

cutting tool. See fiber-cutting tool.

CVD. Chemical vapor deposition.

CVD process. See chemical vapor deposition (CVD) process.

CVPO. Chemical vapor-phase oxidation.

CVPO process. See chemical vapor-phase oxidation (CVPO) process.

D

D*. See specific detectivity.

damage. See optical fiber radiation damage.

dark current. The external current that, under specified biasing conditions, flows in a photodetector when there is no incident radiation. The dark current usually increases with increased temperature for most photodetectors. For example, in a photoemissive photodetector, the dark current is given by the relation

$$I_d = AT^2e^{qw/kT}$$

where A is the surface area constant, T is the absolute temperature, q is the electron charge, w is the work function of the photoemissive surface material, and k is Boltzmann's constant.

data. 1. Representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means. 2. Any representations, such as characters or analog quantities, to which meaning is or might be assigned. See analog data; digital data.

data bus. See optical data bus.

data interface standard. See fiber distributed data interface (FDDI) standard.

data link. 1. A communication link suitable for transmitting data. 2. A link capable of transmitting analog or digital data, or both, from one point to another, such as a connection by wire, optical fiber, radio, microwave, or other propagation medium, that allows information to be transferred between two locations. See dedicated data link; fiber optic data link.

data link layer. In open systems architecture, the layer that provides the functions, procedures, and protocol needed to establish, maintain, and release data link connections between user end-instruments and switching centers and between two switching centers of a network. It is a conceptual level of data processing or control logic existing in the hierarchical structure of the station that is responsible for maintaining control of the data link. Data link layer functions provide an interface between the station high-level logic and the data link, including bit injection at the transmitter and bit extraction at the receiver; address and control field interpretation; command-response generation, transmission and interpretation; and frame check sequence computation and interpretation. Also see Open Systems Interconnection (OSI) Reference Model (RM).

data network. See integrated services digital (or data) network (ISDN).

data processing. See optical data processing.

data rate. See data signaling rate.

data signaling rate (DSR). The aggregate signaling rate in the transmission path of a data transmission system, usually expressed in bits/second. The data signaling rate is given by the relation

$$DSR = \sum_{i=1}^{m}(1/T_i)\log_2 n_i$$

where m is the number of parallel channels, T_i is the minimum time interval for the ith channel expressed in seconds, and n_i is the number of significant conditions of the modulation signal in the ith channel. Each significant condition occurs at a significant instant. Thus, for a single channel, the DSR reduces to $(1/T)\log_2 n$. With a two-condition channel, n=2, the DSR is 1/T. For a parallel transmission with equal minimum intervals and equal number of significant conditions on each channel, the DSR is $(m/T)\log_2 n$. Synonymous with data transmission rate. Also see range designation of data signaling rates (DSRs).

data signaling rates (DSRs). See range designation of data signaling rates (DSRs).

data transfer network (DTN). A network that transports data in any form among a group of interconnected stations or users. The stations or users may be switching centers, switchboards, devices being controlled, or other systems, subsystems, or user end-instruments, such as telephones, computers, video terminals, and control panels. See fiber optic data transfer network.

data transmission rate. See data signaling rate.

dB. Decibel.

dBm. Abbreviation for dBmW, that is, dB referred to 1 mW (milliwatt). The unit is used in communication work as a measure of absolute power values. Zero dBm equals 1 milliwatt. To avoid ambiguity, dBmW is the preferred term.

dBmW. See dBm.

DBS. Direct broadcast satellite.

DC. Double crucible.

DC process. See double-crucible (DC) process.

DDS. Doped-deposited silica.

dead zone. The region in an optical waveguide, such as an optical fiber, in which a measurement cannot be made with a given optical time domain reflectometer (OTDR). In an optical fiber, the distance is usually from immediately beyond the light source, or the entrance face of the fiber to which the OTDR is connected for the fiber portion of the dead zone, to a point, some distance into the fiber, where the measurement is 3 dB (decibel) down from measurements made a much greater distance into the fiber where measurements are their normal values. Dead zones are of the order of 1 m (meter).

decibel (dB). A gain or an attenuation measured as 10 times the logarithm to the base 10 of a power ratio or 20 times the logarithm to the base 10 of the voltage or electric field strength ratio. Attenuation in dB in optical fibers is measured as an optical power ratio between two points and therefore is expressed as dB/km.

decollimation. In optics, that effect wherein a beam of parallel light rays is caused to diverge or converge from parallelism. Any of a large number of factors may cause this effect, such as refractive index inhomogeneities, occlusions, scattering, deflection, diffraction, reflection, and refraction.

dedicated data link. A data link used for one and only one purpose. For example, a data link from a sensor to a display panel or a data link between a control panel and a motor control actuator. No other connections are made to the dedicated data link.

defect. See vacancy defect.

degree. See coherence degree.

degree of coherence. See coherence degree.

delay. See group delay; multimode group-delay; propagation delay.

delay distortion. The distortion of a wave form or signal made up of two or more different frequencies, caused by the difference in arrival time of each frequency at the output of a transmission system. In an optical fiber, the spectral width gives rise to delay distortion because the different wavelengths in an optical pulse arrive at the end of a fiber at different times. See waveguide delay distortion.

delay line. See optical fiber delay line.

delta-beta switch. A fiber optic switch in which a two-branch Y-splitter lithium niobate waveguide is made so that one path is made of titanium lithium niobate and the other of just lithium niobate. An applied voltage can be manipulated to cause one path to shift the wavelength of light passing though relative to the other path. The switch thus acts as a fast wavelength division multiplexer. Electrons line up preferentially along the length of the titanium-doped channel, which changes its refractive index from n_1 to n_2, the nonlinear refractive index. This shifts the wavelength of light down that channel. If a specific voltage is guided to one waveguide, the polarization state of light in that waveguide is shifted. The shifted mode is coupled instantly with the wave going down the second waveguide, thus shutting off the first channel. Because this switch operates by change of beta, the nonlinear coefficient of the waveguide, it is referred to at a delta-beta switch. In another variety of lithium niobate electrooptic behavior, the device can be made into a picosecond-speed on-off switch. Also, by replacing the Y-splitters on a common Mach-Zehnder intensity modulator with 3-dB couplers, a 2-by-2 high-speed balanced-bridge switch can be mass produced to perform the same function as the delta-beta switch.

demodulate. The opposite of modulate, that is, to recover an intelligence-bearing signal from a wave that has been modulated by the signal. Also see modulate.

demodulation. The process wherein a signal resulting from previous modulation is processed to derive a signal having substantially the characteristics of the original modulating signal.

demultiplexer. See fiber optic demultiplexer (active); fiber optic demultiplexer (passive); optical demultiplexer (active); optical demultiplexer (passive).

demultiplexing. See time-division demultiplexing.

density. See electromagnetic energy density; optical energy density; optical density; packing density; reflectance density; spectral density; transmittance density.

departure. See phase departure.

departure angle. See launch angle.

dependent attenuation rate characteristic. See wavelength-dependent attenuation rate characteristic.

deposition. See inside vapor deposition (IVD); outside vapor deposition (OVD).

deposition process. See plasma-activated chemical vapor deposition (PACVD) process; modified chemical vapor deposition (MCVD) process; vapor-phase axial deposition (VAD) process; chemical vapor deposition (CVD) process; plasma-activated chemical vapor deposition (PACVD) process.

depressed cladding. Cladding in which the region adjacent to the core has a refractive index less than that of outer regions.

depressed-cladding fiber. An optical fiber, usually a single-mode fiber, that has two claddings, the outer cladding having a refractive index intermediate between that of the core and the inner cladding. Also see doubly-clad fiber.

descriptor. See receiver information descriptor; transmitter information descriptor.

designation of data signaling rates (DSRs). See range designation of data signaling rates (DSRs).

designation of frequency. See spectrum designation of frequency.

detection. See coherent detection; fiber optic illumination detection; homodyne detection.

detection threshold. See sensitivity.

detectivity. The reciprocal of the noise equivalent power. See specific detectivity.

detector. 1. A transducer. 2. A signal conversion device that converts power from one form to another, such as from optical power to electrical power, from sound power to electrical power, or mechanical power to electrical power, while preserving the information in, or extracting the information from, the input signal. For example, a device that accepts a modulated carrier and emits only the modulation signal. See fiber optic photodetector; internal photoeffect detector; optical detector; optoelectronic detector; phase detector; photodetector (PD); photoelectromagnetic photodetector; photoemissive photodetector; photon detector; photovoltaic photodetector; video optical detector.

detector-emitter (DETEM). An optoelectronic transducer in which the functions of an optical detector and an optical emitter are combined in a single device or module. Synonymous with detem; DETEM.

detector signal-to-noise ratio. See photodetector signal-to-noise ratio.

detector type. See optical detector type.

detem. Detector-emitter.

DETEM. Detector-emitter.

device. See active device; active optical device; linear device; network interface device; nonlinear device; optical branching device; passive optical device.

diagram. See Brillouin diagram.

diameter. See average diameter; beam diameter; borescope working diameter; cladding diameter; core diameter; fiber diameter; mode field diameter.

diameter tolerance. In a round optical fiber, the maximum allowable deviation from the nominal values of the core, cladding, or reference surface diameters.

dichroic filter. An optical filter capable of transmitting all frequencies in an electromagnetic wave above a certain cutoff frequency and reflecting all lower frequencies, being either a high-pass or low-pass filter, depending on whether the transmitted or reflected wave is used. Thus, the dichroic filter is designed to separate radiation into two spectral bands.

dichroic mirror. A mirror that reflects light selectively according to its wavelength and not its polarization plane.

dichroism. 1. In anisotropic propagation media, the absorption of light rays propagating in only one particular plane relative to the crystalline axes of the material media. 2. In isotropic propagation media, the selective reflection and transmission of light as a function of wavelength regardless of the direction of the polarization plane. The color of such materials, as seen by transmitted light, varies with the thickness of the material examined. Synonymous with dichromatism; polychromatism.

dielectric. Pertaining to material composed of atoms whose electrons are so tightly bound to their atomic nuclei that electric currents are negligible even when high electric field strengths, that is, near-breakdown voltages, are applied to the material. Thus, in the constitutive relation $J = \sigma E$, where J is the electric current density, σ is the electrical conductivity, and E is the electric field strength. However, $\sigma = 0$ for dielectric materials. Therefore $J = 0$ for these materials.

dielectric constant. See electric permittivity.

dielectric waveguide. A waveguide consisting of dielectric material surrounded by air or other material having a lower refractive index than that of the surrounded material. Electromagnetic waves propagate through the waveguide similar to the way sound waves propagate through a speaking tube. In fiber optics, the cladding is considered to be a part of the waveguide. In an all-dielectric fiber optic cable, strength members, sheaths, buffers, and jackets, if any, consist only of dielectric materials. Some fiber optic cables may use metals as electrical conductors, strength members, jackets, sheathing, and over-armor. If there are electrical conductors in the cable, it is considered to be an optoelectrical cable. See slab dielectric waveguide; circular dielectric waveguide.

differential mode attenuation (DMA). In an electromagnetic wave propagating in a waveguide, such as an optical fiber, the differences in attenuation that occur to each of the modes comprising the wave. For example, high-order modes experience a higher attenuation in a given fiber than low-order modes.

differential mode delay. See multimode group delay.

differential quantum efficiency. In a quantum device, the derivative, or slope, of the characteristic graph or equation that defines the countable elementary events at the output as a function of the countable events at the input. The function is the device transfer function for the countable events. For example, in a photodetector, the slope at a given point in the curve in which the number of electrons generated per unit time for the photocurrent is plotted against the number of incident photons per unit time.

diffraction. The deviation of a wavefront from the optical path predicted by geometric optics when a wavefront is restricted by an opening, edge, obstruction, or inhomogeneity in a propagation medium. Diffraction is usually most noticeable for apertures of about a wavelength. However, diffraction may still be important for apertures many orders of magnitude larger than the wavelength.

diffraction grating. An array of fine, parallel, equally-spaced reflecting or transmitting ruled lines that mutually enhance the effects of diffraction at the edges of each so as to concentrate light diffracted from an incident beam in a few directions characteristic of the spacing of the lines and the wavelengths in the incident beam. Diffraction gratings produce diffraction patterns of many orders, each numbered. The order number is given by the relation

$$N = (s/\lambda)(\sin i + \sin d)$$

where N is the order number of the spectrum, s is the center-to-center distance between successive rulings, λ is the wavelength of the incident light, i is the incidence angle, and d is the diffraction angle. If a large number of narrow, close, equally spaced rulings are made on a transparent or reflecting substrate, the grating will be capable of dispersing incident light into its wavelength component spectrum like the dispersion of white light into its constituent colors caused by a prism.

diffraction-limited. 1. In ordinary optics, pertaining to a light beam in which the divergence is equal to that predicted by diffraction theory. 2. In focusing optics, pertaining to a light beam in which the resolving power, that is, the resolution limit, is equal to that predicted by diffraction theory.

diffraction pattern. See Fraunhofer diffraction pattern; Fresnel diffraction pattern; far-field diffraction pattern; near-field diffraction pattern.

diffused optical waveguide. An optical waveguide consisting of a substrate into which one or more dopants have been diffused to a depth of a few microns, thus producing a lower refractive-index material on the outside, as in an optical fiber. The result is an optical waveguide with a graded refractive index profile. Diffused optical waveguides can be made using single crystals of zinc selenide or cadmium sulfide. Dopants include cadmium for the zinc selenide and zinc for the cadmium sulfide.

diffuse relection. Reflection of an incident group or bundle of light rays from a rough surface, such that different parts of the same group, whether or not the rays are collimated or coherent, are reflected in different directions, as Snell's laws of reflection and refraction are microscopically obeyed at each undulation of the rough surface. Diffuse reflection prevents formation of a clear image of the light source or of the illuminated object.

diffused waveguide. See planar diffused waveguide.

digital data. 1. Data represented by discrete values or conditions, as opposed to analog data. 2. A discrete representation of a quantized value of a variable, for example, the representation of a number by numerals or the representation of a letter of the alphabet by a pattern of pulses. Also see analog data.

digital network. See integrated services digital (or data) network (ISDN).

digital signal. A nominally discontinuous signal that changes from one state to another in discrete steps. For example, the electromagnetic wave pulses, phase shifts, or frequency shifts that represent zeros or ones; or electrical output pulses from a photodetector caused by light input pulses. Also see analog signal.

diode. See laser diode; light-emitting diode (LED); PIN diode; PIN photodiode; restricted edge-emitting diode (REED); stripe laser diode.

diode laser. See laser diode.

diode photodetector. See photodiode.

dip. See refractive index dip.

direct broadcast satellite (DBS). Pertaining to the broadcasting of television programming via satellite to terrestrial receiving antennas. The programming may be rebroadcast on earth to conventional receiving antennas at homesites, received directly from satellites at home-site receiving antennas, or distributed locally via coaxial cable (CATV). Fiber optic cables could handle the television programming.

directional coupler. A coupler in which optical power applied to certain input ports is transferred to only one or more specified output ports. See optoelectronic directional coupler.

direct ray. A ray of electromagnetic radiation that follows the path of least possible propagation time between transmitting and receiving antennas. The least time path is not always the shortest distance path. For example, in a graded-index optical fiber, a light ray propagating in the lower refractive index regions propagates faster than light rays propagating in higher-index regions, but the higher-speed ray might travel a longer distance, particularly if it is a skew ray and takes a helical path around the fiber optical axis.

discontinuity. 1. A sudden or step-change of a value, such as an interruption or drop out of an optical signal. 2. A break in an optical fiber that causes a step-change in power level of an optical signal at the break. See optical impedance discontinuity.

disk. See optical disk; optical video disk (OVD).

dispersion. 1. The phenomenon in which electromagnetic wave propagation parameters are dependent upon frequency or wavelength. For example, an electromagnetic signal may be distorted because the various frequency components of the signal have different propagation characteristics. The variation of refractive index with frequency (or wavelength) also causes dispersion. In optical fibers, the total dispersion is the combined result of material dispersion, waveguide dispersion, and profile dispersion. Dispersion will cause distortion of a transmitted signal because of the different times at which different wavelengths that comprise a pulse arrive at the end of a waveguide. 2. Pulse broadening, that is, the spreading of a signal in time and space as a result of traversing transmission paths of different physical, electrical, or optical path lengths. 3. The process by which electromagnetic waves of different wavelength are deviated angularly by different amounts because the refractive index and other optical properties vary with wavelength, as occurs in a prism. For example, if a lightwave pulse of given pulse duration and given spectral line width is launched into an optical fiber, the different wavelengths experience different refractive indices and therefore take different paths as well as propagate at different speeds, causing pulse broadening as it propagates along the fiber because the different wavelengths that make up the spectral line width arrive at the far end at different times (material dispersion). At the same time, energy in the different wavelengths distributes among different modes, also causing pulse broadening (modal dispersion). Dispersion imposes a limit on the bit-rate-length product for digital data and bandwidth for analog data transmitted in an optical fiber for a given bit error ratio (BER) at the limit of intersymbol interference. 4. In communication systems, the allocation of circuits between two points over more than one geographical or physical route. See chromatic dispersion; fiber dispersion; intermodal dispersion; material dispersion; maximum transceiver dispersion; modal dispersion; optical multimode dispersion; profile dispersion; waveguide dispersion; zero dispersion.

dispersion attenuation. See optical dispersion attenuation.

dispersion characteristic. See fiber global dispersion characteristic.

dispersion coefficient. For a lightwave propagating in an optical fiber, a value that expresses the dispersion, usually in picoseconds per kilometer of fiber for each nanometer of spectral width of the lightwave launched into the fiber. The unit for the dispersion coefficient usually is psec/nm-km. See chromatic dispersion coefficient; global dispersion coefficient; worst-case dispersion coefficient. Also see material dispersion parameter.

dispersion equation. An equation that indicates the dependence of the refractive index of a propagation medium on the free-space wavelength of the light transmitted by the medium. The adjustment of the index for wavelength permits more accurate calculation of reflection and refraction angles, phase shifts, and propagation paths that are dependent upon the refractive index and the refractive-index gradient. Often it is necessary to obtain a value of the rate of change of refractive index with respect to the wavelength. There are several useful dispersion equations. In one, the refractive index, n, is given by the relation

$$n = n_o + C/(\lambda - \lambda_o)$$

which is attributed to Hartmann. In another relation

$$n = A + B/\lambda^2 + C/\lambda^4$$

which is attributed to Cauchy. In these relations, λ_o is the free-space wavelength, n is the refractive index, and the other symbols are material dependent and empirically determined.

dispersion-flattened fiber. An optical fiber that has a dispersion value that is low over the wavelength region from 1.29 to 1.57 μ (micron).

dispersion-limited length. The sheathed length of fiber optic cable, such as might be in the cable facility of an optical station/regenerator section, whose length is limited by dispersion. The dispersion arises from the combined effects of chromatic dispersion and modal noise. The dispersion limited length, ℓ_D, is given by the relation

$$\ell_D = D_{TR}/D_{max}$$

where D_{TR} is the maximum transceiver dispersion (psec/nm) and D_{max} is the absolute value of the worst-case chromatic dispersion coefficient (in psec/(nm-km)) over the range of transmitter wavelength and over the specified variation in cable dispersion. A regenerator section will not be limited by dispersion as long as the relation

$$D(\lambda_t)\bullet\ell < D_{TR}$$

holds, where ℓ is the fiber length in km, $D(\lambda_t)$ is the fiber chromatic dispersion coefficient evaluated at λ_t in psec/(nm-km), and D_{TR} is the maximum transceiver dispersion in psec/nm. Generally for single-mode systems operating at bit rates (data signaling rates) under 0.5 Gbps, the length of the cable facility of a regenerator section can be expected to be limited by attenuation (loss) rather than by dispersion. At higher bit rates the optical link length can be expected to be limited by dispersion. In the design of an optical station/regenerator section, the effect of dispersion is accounted for in the equation for the terminal/regenerator system gain, G, via the dispersion power penalty, P_D, in dB. Also see terminal/regenerator system gain.

dispersion parameter. See material dispersion parameter; profile dispersion parameter.

dispersion power penalty. In an optical transmitter, the worst-case increase in receiver input optical power (dB) needed to compensate for the total pulse distortion due to intersymbol interference and mode partition noise at the specific bit rate (data signaling rate), bit error ratio (BER), and maximum transceiver dispersion specified by the manufacturer when operated under standard or extended operating conditions as measured under standard test procedures.

dispersion-shifted fiber. A single-mode optical fiber that has a nominal zero-dispersion wavelength near 1.55 μm. The fiber refractive-index profile is designed in such a manner that because of the variation in refractive index with various wavelengths in the spectral width of the pulse and because of the various lengths of the paths taken by the various propagation modes, at a certain median wavelength and particular refractive-index profile, all modes can be made to have the same end-to-end propagation time, thus reducing signal pulse distortion caused by material dispersion to an absolute minimum, actually nearly zero. A fiber can be designed such that the zero-material-dispersion wavelength is also at the minimum attenuation wavelength, that is, at a spectral window, or trough, in the attenuation rate versus wavelength curve. Also see dispersion-unshifted fiber.

dispersion slope. See chromatic dispersion slope; zero-dispersion slope.

dispersion-unshifted fiber. 1. A single-mode fiber that has a nominal zero-dispersion wavelength near 1.3 μ (microns). 2. A single-mode fiber whose dispersion curve increases monotonically, with a single crossing of the zero-dispersion axis in the vicinity of 1.30 μ. Synonymous with dispersion-unshifted single-mode fiber. Also see dispersion-shifted fiber.

dispersion-unshifted single-mode fiber. See dispersion-unshifted fiber.

dispersion wavelength. See zero-dispersion wavelength.

dispersive medium. In the propagation of electromagnetic waves in material media, a medium in which the phase velocity varies with frequency. Thus, if an optical pulse consisting of more than a single wavelength is passed through a dispersive medium, the different wavelengths will arrive at the end at different times. Thus, the phase velocity and the group velocity are not the same thing. All materials are dispersive to some extent. Also see nondispersive medium.

displacement sensor. See fiber axial displacement sensor.

display device. See fiber optic display device.

distance resolution. 1. In an optical time domain reflectometer (ODTR), a rating based on the shortest distance along the length of an optical waveguide, such as an optical fiber, that the OTDR can distinguish on its display screen, usually a cathode ray tube. It is a measure of how close together two events, or faults, can be distinguished as separate events. 2. See spatial resolution. Also see dynamic range; measurement range.

distortion. Any departure of an output signal shape from an input signal shape over a range of frequencies, amplitudes, or phase shifts during a given time interval. In a signal transmission system, it is the undesirable amount that an output wave shape or pulse differs from the input form. It may be expressed as the undesirable difference in amplitude, frequency composition, phase, shape, or other attribute between an input signal and its corresponding output signal. See delay distortion; intermodal distortion; intramodal distortion; multimode distortion; optical distortion; optical pulse distortion; pulse-width distortion; total harmonic distortion; waveguide delay distortion.

distortion-limited operation. The condition that prevails in a device or system when any form of distortion of a signal limits its performance or the performance of the device or system to which it is connected. For example, the condition that prevails in an optical link when a combination of attenuation, dispersion, and delay distortion all contribute toward limiting link performance.

distributed data interface standard. See fiber distributed data interface (FDDI) standard.

distributed-fiber sensor. A fiber optic sensor that uses a spatial distribution of optical fiber to sense a parameter, such as a planar distribution, a bobbin wound with spatial shading, a series of windings in line, two or more parallel coils, or an array of wound bobbins. Distributed sensors can sense many parameters, such as a pressure point at a cartesian coordinate, a formed beam direction, a pressure gradient, and an electric field gradient using optical time domain reflectometry (OTDR), interferometry, and other optical techniques to modulate irradiance, that is, the power density or intensity of light, incident upon a photodetector.

distributed star coupled bus. See star-mesh network.

distributed thin-film waveguide. See periodically-distributed thin-film waveguide.

distribution. See core-cladding power distribution; modal distribution; nonequilibrium modal power distribution; Rayleigh distribution.

distribution frame. See fiber optic distribution frame.

distribution length. See nonequilibrium modal power distribution length.

distributive coupler. See nonuniformly distributive coupler; uniformly distributive coupler.

divergence. See beam divergence.

divergent light. Light consisting of a bundle of rays each of which is propagating in such a direction as to be departing from every other ray, that is, they are not parallel to each other, but are spreading and hence are not collimated or convergent, and their wavefront is somewhat spherical or concave on the incidence side. If a collimated beam enters a concave lens, the emerging light is divergent. Also see convergent light.

diversity. See polarization diversity.

DMA. Differential mode attenuation.

domain reflectometry. See optical time domain reflectometry.

dopant. A material mixed, fused, amalgamated, crystallized, or otherwise added to another in order to achieve desired characteristics of the resulting material. The germanium tetrachloride or titanium tetrachloride added to pure glass to control the refractive index of glass for optical fibers, or the gallium or arsenic added to germanium or silicon to produce p-type or n-type semiconducting material for making diodes and transistors, are examples of dopants.

doped-deposited silica (DDS) process. A process for making optical fibers in which dopants are deposited in inside or outside walls of silica glass tubes or cylinders and fused to produce desired refractive-index profiles.

dosimeter. See fiber optic dosimeter.

double-crucible (DC) process. In the production of optical fibers, a fiber drawing process in which two concentric crucibles are used, one for the core glass and one for the cladding glass. The cladded fiber is pulled out of the bottom at the convergence or apex of the two crucibles. Diffusion of the dopant materials in the glasses produces a graded-refractive-index profile.

double refraction. That property of a material in which a single incident light beam is refracted into two transmitted beams as though the material had two distinct refractive indices.

doubly-clad fiber. An optical fiber, usually a single-mode fiber, that has a core covered by an inner low-refractive-index material, which, in turn, is covered by a second cladding of a higher-refractive index material, but not higher than that of the core. This is in contrast to an optical fiber having only one lower-refractive-index cladding covering the higher (step or graded) refractive-index core. In the doubly-clad fiber, inner cladding modes are stripped off because the outer cladding refractive index is higher than the inner cladding refractive index so that when rays are incident upon the inter-cladding interface surface, they are bent toward the normal to the intercladding interface surface and hence escape. Also see depressed-cladding fiber.

drawing. See fiber drawing.

drawn glass fiber. A glass fiber formed by pulling a strand from a heat-softened preform through a die or from a mandrel with a pulling machine.

drop. See fiber optic drop.

dry glass. Glass from which as much water as possible has been driven out, for example, glass with a water concentration less than 1 ppm (part per million). Drying is done primarily to reduce hydroxyl ion absorption loss. Drying can be accomplished by many days of drying of starting powders in a 250°C (celcius) vacuum oven, followed by many hours of dry-gas melt bubbling to dry out water to extremely low levels.

DSR. Data signaling rate.

D-star. See specific detectivity.

DTN. Data transfer network.

duration. See pulse duration; pulse half-duration; root-mean-square (rms) pulse duration.

dynamic range. In an optical time domain reflectometer (OTDR), a measure of how far into an optical waveguide, such as an optical fiber, a measurement can be made. Thus, the dynamic range may be a measure of the optical power rating of an OTDR based on the inherent loss in dB/km of the waveguide, the pulse width of the light source, the operational wavelength, the length of waveguide being tested, the number of times the source pulse is launched, and whether the rating is based on a one-way or a round trip of the pulse; or the dynamic range may be the loss through the waveguide that can be measured based on the guide's inherent attenuation rate, e.g., if a multimode optical fiber has an attenuation rate of 0.8 dB/km (decibels per kilometer) and the goal is to measure a 40-km piece of fiber, or it is 40 km to a break, the OTDR has to have a dynamic range of at least 32 dB in order to measure the length of fiber, or the distance to the break. Also see distance resolution; measurement range.

E

E-bend. A gradual change in the direction of the optical axis of a waveguide throughout which the axis remains in a plane parallel to the direction of the electric field vector (E) transverse polarization. Synonymous with E-plane bend. Also see H-bend.

edge absorption. See band-edge absorption.

edge-emitting diode. See restricted edge-emitting diode (REED).

edge-emitting LED (ELED). A light-emitting diode, with a spectral output emanating from between the heterogeneous layers. Thus, the light is emitted parallel to the plane of the junction. It has a higher output radiance, greater coupling efficiency to an optical fiber or integrated optical circuit than the surface-emitting LED, but not as great as the injection laser diode. Edge-emitting and surface-emitting LEDs provide several milliwatts of optical power output in the 0.8-1.2-μ (micron) wavelength range at drive currents of 100 to 200 mA (milliampere). Diode lasers at these currents provide tens of milliwatts.

EDTV system. Enhanced-definition television system.

effect. See acoustooptic effect; electrooptic effect; internal photoelectric effect; Kerr effect; knife-edge effect; magnetooptic effect; photoconductive effect; photoelastic effect; photoelectric effect; photoelectromagnetic effect; photoemissive effect; photovoltaic effect; Pockels effect; speckle effect.

effective mode volume. In a waveguide, the square of the product of the diameter of the near-field radiation pattern and the sine of the radiation angle of the far-field radiation pattern. The diameter of the near-field radiation pattern is the full-width-half-maximum diameter and the radiation angle at half maximum intensity. In a multimode optical fiber, the effective mode volume is proportional to the breadth of the relative distribution of power among the modes propagating in the fiber. The effective mode volume is not an actual spatial volume but rather an optical volume having the units of the product of area and solid angle.

efficiency. See coupling efficiency; differential quantum efficiency; optical power efficiency; quantum efficiency; radiant efficiency; radiation efficiency; response quantum efficiency; source coupling efficiency; source power efficiency.

electric. See transverse electric (TE).

electrical cable. See optoelectrical cable.

electrical conductivity. A measure of the ability of a material to conduct an electric current when under the influence of an applied electric field. The conductivity is the constant of proportionality in the constitutive relation between the electrical current density and the applied electric field strength at a point in a material. It is expressed mathematically as $J = \sigma E$, where J is the current density, ϵ is the electrical conductivity, and E is the electric field strength. For example, if J is in amperes per square meter and E is in volts per meter, the electrical conductivity is given as $\sigma = J/E$ amperes/volt-meter, $(\text{ohm-meter})^{-1}$, or mhos/meter.

electrical length. The length of a sinusoidal wave expressed in wavelengths, radians, or degrees. When expressed in angular units, it is the length in wavelengths multiplied by 2π to give radians, or by 360 to give degrees.

electric field. The effect produced by the existence of an electric charge, such as an electron, ion, or proton, in its surrounding volume of space or material medium. Each of a distribution of charges contributes to the whole field at a point on the basis of superposition. A charge placed in an electric field has a force exerted upon it by the field. The magnitude of the force is the product of the electric field strength and the magnitude of the charge. Thus, $\mathbf{E} = \mathbf{F}/q$, where **E** is the electric field strength, **F** is the force the field exerts on the charge, and q is the charge. The direction of the force is in the same direction as the field for positive charges, and in the opposite direction for negative charges. Moving an electric charge against the field requires work, that is, energy, and increases the potential energy of the charge. Electric field strength is measurable as force per unit charge or as potential difference per unit distance, that is, a voltage gradient, such as volts/meter. It is also expressible as a number of electric lines of flux per unit of cross-sectional area. The force and the electric field are vector quantities. The charge is a scalar quantity.

electric field intensity. See electric field strength.

electric field strength. The intensity, that is, the amplitude or magnitude, of an electric field at a given point. The term is normally used to refer to the rms value of the electric field, expressed in volts per meter. An instantaneous electric field strength is usually given as a gradient, and therefore is a vector quantity, because it has both magnitude and direction. For example, the units of electric field strength may be volts per meter, kilograms per coulomb, or electric lines of flux per square meter divided by the electric permittivity of the medium at the point it is measured. Synonymous with electric field intensity. Also see magnetic field strength.

electric field vector. In an electromagnetic wave, such as a lightwave propagating in a propagation medium, the vector that represents the instantaneous amplitude and direction of the electric field strength at a given point in the medium in which the wave is propagating.

electric permittivity. A parameter of free space or a material that serves as the constant of proportionality between the magnitude of the force exerted between two point electric charges of known magnitude separated by a given distance. The magnitude of the force is defined by the relation

$$F = q_1 q_2 / 4\epsilon\pi d^2$$

where q_1 and q_2 are the point electric charges, F is the force between them, d is their distance of separation, ϵ is the electric permittivity of the medium in which they are embedded, and π is approximately 3.1416. The direction of the force is along the line joining the two point charges, being one of attraction if the charges are of opposite polarity and repulsion if they are of the same polarity. The electric permittivity, magnetic permeability, and electrical conductivity determine the refractive index of a material. However, for dielectric materials, that is, electrically nonconducting media, such as the glass and plastic used to make optical fibers, the electrical conductivity is zero, the relative velocities of electromagnetic waves, such as lightwaves, propagating within them, are given by the relation

$$v_1/v_2 = [(\mu_2\epsilon_2)/(\mu_1\epsilon_1)]^{1/2}$$

where v is the velocity and μ and ϵ are the magnetic permeability and electric permittivity, respectively, of media 1 and 2. If propagation medium 1 is free space, the above equation becomes the relation

$$c/v = [(\mu\epsilon)/(\mu_0\epsilon_0)]^{1/2}$$

where c is the velocity of light in a vacuum, v is the velocity in a material medium, the non-subscripted values of the constituent constants are for the material medium and the subscripted values for free space. However, c/v is the definition of the refractive index of a medium relative to free space. From this is obtained the relation

$$n = (\mu_r\epsilon_r)^{1/2}$$

where n is now a dimensionless number and relative to free space. The magnetic permeability and electric permittivity are also relative to free space, or air. As stated above, for dielectric materials, μ_r is approximately 1, being very much greater than one only for ferrous substances and slightly greater than 1 for a few metals, such as nickel and cobalt. Hence, for the glass and plastics used to make optical fibers and other dielectric waveguides, the refractive index, relative to a vacuum, or air, is given by the relation

$$n \approx \epsilon_r^{1/2}$$

where ϵ_r is the electric permittivity of the propagation medium. Refractive indices are usually given relative to a vacuum, or relative to 1.0003 for air near the earth's surface and closer to one as the air gets thinner in the upper atmosphere and outer space. In absolute units for free space, the electric permittivity is $\epsilon = 8.854 \times 10^{-12}$ F/m (farads per meter) and the magnetic permeability is $\mu = 4\pi \times 10^{-7}$ H/m (henries per meter). The reciprocal of the square root of the product of these values yields approximately 2.998×10^8 m/s (meters per second), the velocity of light in a vacuum. Because the refractive index for a propagation medium is defined as the ratio between the velocity of light in a vacuum and the velocity of light in the medium, the ratio becomes unity when the propagation medium is a vacuum. See relative electric permittivity. Also see refractive index.

electroluminescence. The direct conversion of electrical energy into light, for example, photon emission caused by electron-hole recombination in a pn junction of a light-emitting diode (LED). The conversion process does not produce incandescence in the emitting material. The emitted optical radiation is in excess of the radiation caused by thermal emission that would result from the application of electrical energy.

electromagnetic effect. See photoelectromagnetic effect.

electromagnetic energy density. The amount of energy contained per unit volume of free space or propagation medium at a point at which an electromagnetic wave is propagating. The density is scalar and is a function of the electric and magnetic field strengths at the point. When the propagation velocity is taken into account, the energy flow rate can be considered as the energy per unit volume times velocity, that is, distance per unit time, thus becoming the vector quantity of energy crossing per unit cross-sectional area per second, that is, the power density, more properly called the irradiance, usually expressed as watts per square meter, or joules/second-meter^2.

electromagnetic field. A field characterized by both electric and magnetic field vectors that interact with one another rather than exist independently of each other, as in electrostatic, staticmagnetic, and electromagnetostatic fields. The electromagnetic field varies with time at a point and propagates as a wave from its source, whereas the others, although they may be made to vary, do not exist very far from their sources and decay rapidly with distance.

electromagnetic photodetector. See photoelectromagnetic photodetector.

electromagnetic radiation (EMR). Radiation made up of oscillating electric and magnetic fields that propagate with the speed of light. It includes gamma radiation; x-rays; ultraviolet, visible, and infrared radiation; and radar and radio waves. The radiation is propagated with a phase velocity, v, in the propagation medium, given by the relation

$$v = \lambda f = c/n$$

where λ is the wavelength in the propagation medium, f is the frequency generated by the source, c is the velocity of light in a vacuum (approximately 3×10^8 m/s), and n is the refractive index of the propagation medium.

electromagnetic spectrum. 1. The frequencies, or wavelengths, present in given electromagnetic radiation. A particular spectrum could include a single frequency or a wide range of frequencies. 2. The entire range of electromagnetic wavelengths that can be physically generated, extending from nearly infinite length to the shortest possible wavelength. It includes the optical portion of the spectrum, which includes the visible and near-visible portion of the spectrum, that is, lightwaves. The optical portion extends from the shorter-wavelength far-ultraviolet to the longer-wavelength far-infrared, while the visible portion extends from violet to red. Also see optical spectrum.

electromagnetic wave. The effect obtained when a time-varying electric field and a time-varying magnetic field interact, causing electrical and magnetic energy to be propagated in a direction that is dependent upon the spatial relationship of the two interacting fields that are interchanging their energies as the wave propagates. The two fields define the polarization plane as well as the wavefront. The cross-product of the two fields, with the electric field vector rotated into the magnetic field vector, define a vector, called the Poynting vector, that indicates the direction of propagation and defines a ray, which is perpendicular to the wavefront. See left-hand-polarized electromagnetic wave; plane (electromagnetic) wave; plane-polarized electromagnetic wave; right-hand polarized electromagnetic wave; trapped electromagnetic wave; uniform plane-polarized electromagnetic wave.

electron energy. See emitted-electron energy.

electronic. See optoelectronic.

electronic directional coupler. See optoelectronic directional coupler.

electronics. See optoelectronics.

electrooptic. Pertaining to the effect that an electric field has on a lightwave, such as rotating the direction of the polarization plane as the lightwave passes through the field, or, if the wave is propagating in material media, the effect the electric field has on the refractive index of the material. Electrooptic is often erroneously used as a synonym for optoelectronic. Also see optoelectronic.

electrooptic effect. 1. The change in the refractive index of a material when subjected to an electric field. The effect can be used to modulate a lightwave propagating in a material because many lightwave propagation properties, such as propagation velocities, reflection and transmission coefficients at interfaces, acceptance angles, critical angles, and transmission modes, are dependent upon the refractive indices of the media in which the lightwave is propagating. 2. The effect an electric field has on the polarization of a lightwave, such as rotating the polarization plane. In any case, the applied electric field strength adds to the electric field strength of the electromagnetic wave, causing rotation as it propagates. Pockels and Kerr effects are electrooptic effects that are linear and quadratic respectively in relation to the applied electric field. Also see magnetooptic effect; optoelectronic.

electrooptics. The branch of science and technology devoted to the interaction between optics and electronics leading to the transformation of electrical energy into light, or vice-versa, with the use of an optical device, such as devices whose operation relies on modification of a material's refractive index by electric fields, particularly the generation and control of lightwaves by electronic means and vice versa. For example, in a Kerr cell, the refractive index change is proportional to the square of the electric field strength. The material is usually a liquid. In a Pockels cell, a crystal is used whose refractive index change is a linear function of the electric field strength.

electrooptic transmitter. An optoelectronic transmitter in which the electrooptic effect is used in its operation.

ELED. See edge-emitting LED (ELED).

elliptical polarization. In an electromagnetic wave, polarization such that the tip, that is, the extremity, of the electric field vector describes an ellipse in any fixed plane intersecting the wave and normal to the direction of propagation. An elliptically-polarized wave may be resolved into two linearly-polarized waves in phase quadrature with their polarization planes at right angles to each other.

emission. Electromagnetic energy propagating from a source. The energy thus propagated may be either desired or undesired and may occur at a frequency, or wavelength, anywhere in the electromagnetic spectrum. See spontaneous emission; spurious emission; stimulated emission.

emission of radiation. See light amplification by stimulated emission of radiation (laser).

emission wavelength. See peak emission wavelength.

emissivity. 1. The ratio of power radiated by a source to the power radiated by a blackbody at the same temperature. Power and area units for both bodies must be the same or normalized. 2. The ratio of the radiant emittance of, or radiated flux from, a source to the radiant emittance of, or radiated flux from, a blackbody having the same temperature. Emissivity depends on wavelength and temperature.

emittance. See radiant emittance; spectral emittance.

emitter. See detector-emitter (DETEM); optical emitter.

emitted-electron energy. In a photoemissive detector, the remaining energy of an electron that escapes from the emissive material due to the energy imparted to it by an incident photon, given by the relation

$$E_e = hf - qw$$

where E_e is the remaining energy of the electron, h is Planck's constant, f is the photon frequency, q is the charge of an electron, and w is the work function of the emissive material. Actually, hf is the photon energy and qw is the energy required for an electron to escape from the emissive material, that is, to overcome the boundary effects.

emitting diode. See light-emitting diode (LED).

EMR. See electromagnetic radiation (EMR).

end finish. At the end of an optical fiber, the condition of the end surface, that is, the surface perpendicular to the optical axis.

end-instrument. See user end-instrument.

endoscope. See endoscopic device; fiber optic endoscope.

endoscopic device (endoscope). A device used to observe specific surfaces, particularly areas that are relatively inaccessible to photographic and television cameras, such as interior parts of functioning equipment and internal organs of the human body. The device usually consists of a lens that focuses an image on a fiber faceplate consisting of the originating end faces of an aligned bundle of optical fibers; the aligned bundle itself that transmits the image to another fiber faceplate at the other end of the bundle, made from the originating end face of the bundle; and perhaps another lens for displaying the image. Arrangements must be made for the object, whose image is to be transmitted, to be illuminated. This can be accomplished with additional optical fibers placed in the same fiber optic cable with the aligned bundle and energized by a light source to illuminate the object.

end-point node. 1. In network topology, a node connected to one and only one branch.

end-to-end separation sensor. See fiber end-to-end separation sensor.

energy. See band-gap energy; emitted-electron energy; radiant energy.

energy band. A specified range of energy levels that a constituent particle or component of a substance may have. The particles may be electrons, protons, ions, neutrons, atoms, molecules, mesons, or others. Some energy bands are allowable and others are unallowable. For example, electrons of a given element at a specific temperature can occupy only certain energy bands, such as the conduction and valence bands. When radiation strikes an electron and imparts enough energy to the electron to cause its energy to rise to a higher energy band, energy is absorbed. If the electron energy level is reduced to that of a lower energy band, energy is emitted in the form of electromagnetic radiation, namely a photon is emitted. Statistical laws apply to the number of electrons in each of the possible bands, the density of these electrons in the material, and the energies of the emitted photons.

energy density. See optical energy density; electromagnetic energy density.

enhanced-definition television (EDTV) system. A television system in which improvements are made that are not compatible with present receivers. Some features and technical characteristics of the original system on which the EDTV system is based may be included in the enhanced system. See advanced television system; high-definition television (HDTV) system; improved-definition television (IDTV) system.

E-plane bend. See E-bend.

equation. See dispersion equation; photoelectric equation; Sellmeier equation; wave equation.

equations. See Fresnel equations; Helmholtz equations; Maxwell's equations.

equilibrium coupling length. See equilibrium length.

equilibrium distance. See equilibrium length.

equilibrium length. The distance within a multimode waveguide, measured from the input end, necessary to attain electromagnetic wave equilibrium modal power distribution for a specific excitation condition, that is, a specific set of launch conditions at the input end. After the equilibrium length is reached, the fraction of total radiant power in each mode remains a constant with respect to distance. Usually the equilibrium length is the longest distance obtained from a worst-case, but undefined, excitation condition. Synonymous with equilibrium coupling length; equilibrium distance; equilibrium modal power distribution length.

equilibrium modal power distribution. In an electromagnetic wave propagating in a waveguide, such as a lightwave in an optical fiber, the distribution of radiant power among the various modes such that the fraction of total power in each mode is stable and does not redistribute as a function of distance. Equilibrium modal power distribution will not occur at the beginning of the guide until the wave has propagated a distance called the equilibrium length, because the launch conditions, wavelength, and refractive indices cannot be controlled with sufficient precision. Synonymous with equilibrium mode distribution; steady state condition. See nonequilibrium modal power distribution.

equilibrium modal power distribution length. See equilibrium length.

equilibrium mode distribution. See equilibrium modal power distribution.

equilibrium mode simulator. A component or system used to create an approximate equilibrium modal power distribution.

equilibrium radiation pattern. The radiation pattern at the output end of an optical fiber that is long enough so that equilibrium modal power distribution has been reached, that is, the fiber is longer than the equilibrium length.

equipment identification. Information that uniquely characterizes a product and provides a traceable indicator for determining its specifications, features, issue or revision, and manufacturer, e.g., Common Language Equipment Identification.

equivalent power. See noise equivalent power (NEP).

equivalent step-index (ESI) profile. The refractive-index profile of a hypothetical step-index optical fiber that has the same propagation characteristics as a given single-mode fiber. The refractive index of the cladding material has the same value everywhere in the cladding.

error. See optical fiber concentricity error.

error budget. The allocation of a bit error ratio (BER) requirement to the various segments of a link, circuit, or trunk, such as trunk lines, switches, access lines, and terminal devices, in a manner that permits the specified system end-to-end error ratio requirements to be satisfied for message traffic transmitted over a real circuit or a postulated reference circuit.

error ratio. See bit error ratio (BER).

ESI. Equivalent step-index.

ESI profile. See equivalent step-index (ESI) profile.

ESI refractive-index difference. For an optical fiber, the difference between the refractive index of the core and the refractive index of the cladding in its equivalent step-index (ESI) profile.

evanescent field. A time-varying electromagnetic field, propagating outside a waveguide but coupled or bound to an electromagnetic wave or mode propagating inside a waveguide, whose amplitude decreases monotonically without an accompanying phase shift, as a function of distance from the axis of the waveguide. In fiber optics, this field may provide coupling of signals from one optical fiber to another by means of proximity coupling or evanescent field coupling.

evanescent-field coupling. Coupling between two waveguides achieved by allowing evanescent waves of one to penetrate, and be trapped by, the other. Transfer of energy will take place if the guides are placed parallel and close together for a short distance. Evanescent field coupling is achieved between optical fibers by etching away the cladding of both fibers and placing their cores close together or locally modifying their refractive indices.

evanescent wave. In a transverse electromagnetic wave propagating in a waveguide, a wave in the cladding or on the outside of the guide. Evanescent waves are bound, that is, remain coupled to modes in the guide. They will radiate away at sharp bends in the guide if the radius of the bend is less than the critical radius. They usually have a frequency less than the cut-off frequency, above which true propagation occurs and below which the waves decay exponentially with radial distance from the guide. Evanescent wavefronts of constant phase may be perpendicular, or at an angle less that 90°, to the surface of the guide. Evanescent waves will not remain bound to modes inside a guide if the internal modes to which they are bound propagate faster than the evanescent waves propagate in the medium they are in, in which case they will radiate away.

exahertz (EHz). A unit of frequency that is equal to one million trillion hertz, that is, 10^{18} Hz.

excess loss. See coupler excess loss.

exchange process. See ion exchange process.

exitance. See radiant emittance.

exit angle. When a light ray emerges from a surface of a material, the angle between the ray and a normal to the surface at the point of emergence. For an optical fiber, the exit angle is the angle between the fiber optical axis and the emerging ray. The exit angle of a light source is the launch angle.

expanded-beam connector. A fiber optic connector in which the diameter of the light beam and the launch angle are increased, so that the losses caused by longitudinal off-set, angular misalignment, and lateral off-set are reduced to a minimum. In many cases, special lenses and other passive optical devices are built into the connector to optimize coupling. In some cases, the glass in the fiber itself is used to form the optical elements in the connector. Synonymous with lensed connector.

extended operating condition. In the design of an optical station/regenerator section, a condition that is more severe, e.g., a higher or lower temperature condition, a higher or lower humidity condition, than a standard operating condition, or any other environmental condition not included in the set of standard conditions, such as high pressures, corrosive atmospheres, severe abrasion, and high tensile stress, that may not result in the specified parameters having the specified performance as given for standard operating conditions. Also see standard operating condition.

external photoelectric effect. See photoemissive effect.

extinction coefficient. 1. The sum of the absorption coefficient and the scattering coefficient. The extinction coefficient may be expressed as a fraction or in decibels. 2. The ratio of two optical power levels, P_1/P_2, of a digital signal generated by a light source, where P_1 is the optical power level generated when the light source is "on" and P_2 is the power level generated when the light source is "off". Synonymous with extinction ratio. Also see Bouger's law.

extinction ratio. See extinction coefficient.

extramural cladding. A layer of dark or opaque absorbent coating placed over the cladding of an optical fiber to increase total (internal) reflection, protect the smooth reflecting wall of the cladding, and absorb scattered or escaped stray light rays that might penetrate the cladding.

extraordinary ray. A light ray that has an anisotropic velocity in a doubly-refracting crystal, that is, the crystal is an anisotropic propagation medium. An extraordinary ray does not necessarily obey Snell's law of refraction at the crystal surface. Also see ordinary ray.

extrinsic coupling loss. In fiber optics, the coupling loss that is caused when two optical fibers are imperfectly joined, such as by longitudinal off-set, angular misalignment, and lateral offset. Synonymous with extrinsic joint loss. Also see intrinsic coupling loss.

extrinsic joint loss. See extrinsic coupling loss.

eye pattern. A pattern obtained by applying a digital data stream to the vertical amplifier of an oscilloscope and triggering the scope with the system's clock pulse. The eye pattern qualitatively describes the proper functioning of a digital system, whereas the bit error ratio (BER) quantitatively describes the proper functioning. The quality of the eye pattern, critical for achieving a low BER, is influenced by two phenomenon, namely noise, which is proportional to the receiver's bandwidth, and intersymbol interference, which arises from other bits interfering with the bit of interest. The lower level of the eye pattern and the zero level of the oscilloscope are not identical. Intersymbol interference is inversely proportional to the bandwidth. A bandwidth compromise has to be made in order to obtain the best possible eye pattern aperture.

F

Fabry-Perot fiber optic sensor. A high-resolution multiple-beam interfero-metric sensor in which two optically flat parallel transparent plates are held a short distance apart and the adjacent surfaces of the plates, that is, interferometric flats, are made almost totally reflective by a thin silver film or a multilayer dielectric coating. If one plate is moved relative to the other, interference patterns can be made to occur when a lightwave is directed at the plates. If the ends of an optical fiber are made reflective, moving one end relative to the other will produce an output signal proportional to the relative motion when monochromatic light, that is, light with a narrow spectral linewidth, is inserted into the fiber.

faceplate. See fiber faceplate.

facility. See optical cable facility; optical station facility.

facility loss. See optical cable facility loss; statistical optical cable facility loss.

factor. See bandwidth-distance factor; confinement factor; intrinsic quality factor (IQF).

fading. See Rayleigh fading.

failure. See mean time to failure (MTTF).

failures. See mean time between failures (MTBF).

fall time. The time it takes for the amplitude of a pulse to decrease from a specified value, usually near the peak value, to a specified value, usually near the lowest or zero value. Values of fall time are often specified as the time interval between the 90 percent and 10 percent values of the peak value of a pulse. If other than 10 percent and 90 percent values are used, they should be specified. Synonymous with pulse decay time. Also see rise time.

Faraday effect. See magnetooptic effect.

far-field diffraction pattern. The diffraction pattern of a source, such as a light-emitting diode (LED), injection-laser diode (ILD), or the output of an optical waveguide observed at an infinite distance from the source, that is, in the far-field region of the source. A far-field diffraction pattern is considered to exist at distances larger than that given by the relation

$$d_i = s^2/\lambda$$

where s is the characteristic dimension of the source and λ is the wavelength. For example, if the source is a uniformly illuminated circle, then s is the radius of the circle. The far-field diffraction pattern is an approximation, for finite distances, for a diffraction pattern of a source observed from infinity or in the focal plane of a well-corrected lens, except for scale. The far-field diffraction pattern of a diffracting screen illuminated by a point source may be observed in the image plane of the source. Synonymous with Fraunhofer diffraction pattern.

far-field pattern. See far-field radiation pattern.

far-field radiation pattern. The radiation pattern of a source of electromagnetic radiation in the far field region, for example, the radiation pattern for an optical fiber that describes the distribution of irradiance as a function of angle in the far-field region of the radiation from the exit face of the fiber. Synonymous with far-field pattern.

far-field region. The region far from an electromagnetic radiation source or aperture where the radiation pattern and the irradiance, that is the incident optical power per unit area, or the electric field strength, is negligibly dependent upon the distance from the source, such as where the field strength varies inversely as the first power of the distance and the propagation times from the source to points within the region are not negligible compared to propagation times to points in the near-field region. However, because all the points in the far-field region are far from the source, the change in pattern from point to point within the far-field region is negligible.

far-infrared. Pertaining to the region of the electromagnetic spectrum that lies between the longer-wavelength end of the middle-infrared region and the shorter-wavelength end of the radio region, that is, from about 30 to 100 μ (micron). Thus, the far-infrared region is included in the optical spectrum. However, the near-infrared region lies between the longer-wavelength end of the visible spectrum and the shorter-wavelength end of the middle-infrared region, that is, from about 0.8 to 3.0 μ. Thus, the near-infrared is included in the near-visible region but the middle-infrared and far-infrared regions are not included in the near-visible region. None of the infrared regions-- near, middle, or far-- are included in the visible spectrum.

FDDI. See fiber distributed data interface (FDDI) standard.

FDHM. Full-duration half-maximum.

FDM. Frequency-division multiplexing.

feature. See optical cable interconnect feature.

feed-through. See fiber optic cable feed-through.

Fermat's principle. A light ray follows the path that requires the least time to propagate from one point to another, including reflections and refractions that may occur. The optical path length is an extreme path in the terminology of the calculus of variations. Thus, if all rays starting from point A propagate via a propagation medium to the same point B, the optical paths from A to B are the same optical length though their geometric lengths may be different. In optical fibers, different rays launched into the fiber take different paths. Thus, they arrive at the end at different points, giving rise to dispersion.

ferrule. A mechanical device or fixture, generally a rigid tube, used to hold the stripped end of an optical fiber or fiber bundle. Typically, individual fibers of a bundle are cemented together within a ferrule that has a diameter designed to hold the fibers firmly with a maximum packing fraction. Non-rigid materials, such as shrink tubing, may also be used for ferrules. Generally, a ferrule provides a means of positioning fibers within a connector by performing the function of a bushing.

fiber. See active optical fiber; all-glass fiber; all-plastic fiber; buffered fiber; compensated optical fiber; depressed-cladding fiber; dispersion-flattened fiber; dispersion-shifted fiber; dispersion-unshifted fiber; doubly-clad fiber; drawn glass fiber; fully-filled fiber; graded-index (GI) fiber; hard-clad silica fiber; high-birefringence fiber; launching fiber; Lorentzian fiber; low-birefringence fiber; medium-loss fiber; multimode fiber; optical fiber; overcompensated optical fiber; plastic-clad silica (PCS) fiber; polarization-preserving (PP) fiber; quadruply clad fiber; self-focusing optical fiber; single-mode fiber; step-index fiber; superfiber; tapered fiber; transition fiber; triangular-cored optical fiber; ultralow-loss fiber; undercompensated optical fiber; weakly guiding fiber; W-type fiber.

fiber acoustic sensor. See optical fiber acoustic sensor.

fiber active connector. See optical fiber active connector.

fiber amplifier. An optooptic (optically pumped) fiber laser used as an amplifier to boost optical signals. The fiber amplifier can be used in lieu of an optoelectronic repeater in local loops, LANs, and long-haul systems, thus allowing more sequential switching stages between repeaters and an increased number of nodes for a single transmitter in a network. Characteristics include high gain, low noise, wideband, relatively low cost device for traveling-wave optical amplification. The amplifier can be used for signal processing in the logic devices of integrated optical circuits (IOCs).

fiber-and-splice organizer. A device that provides for (1) accommodation of optical fibers and splices in an orderly manner, (2) protection of all types of fibers and splices, such as mechanical, fusion, and multiple-fiber arrays, (3) fiber splice identification, (4) fiber rearrangement, (5) storage of excess fibers, optical fiber cable cores, and fiber ribbons, and (6) modularity to allow for additional capacity for fibers and splices. Synonymous with fiber organizer; optical fiber organizer.

fiber axial alignment sensor. A fiber optic sensor in which the amount of light coupled from a source optical fiber mounted on one platform to a photodetector optical fiber mounted on another platform, decreases as the angular misalignment of the axes of the two fibers increases. Axial alignment is considered to have occurred when the output signal of the photodetector becomes a maximum as the alignment is varied. The sensor can be used to measure angular alignment of the two platforms, one attached to each fiber. When the angle between the axes is greater than half the apex angle of the acceptance cone, light is no longer coupled from the source fiber to the detector fiber, at which point the output of the photodetector is reduced to zero.

fiber axial displacement sensor. A fiber optic sensor in which the amount of light coupled from a source optical fiber mounted on one platform to a photodetector fiber mounted on another platform decreases as the axes of the two fibers are moved laterally, that is, transversely farther apart, even though the axes remain parallel, thus causing increasing lateral offset loss. The output signal from the photodetector is a function of the amount of displacement, varying from zero to a maximum. The time rate of change of the signal is proportional to the velocity at which the fibers are displaced laterally relative to each other. If the fibers oscillate with respect to each other, an oscillating signal will be produced by the photodetector.

fiber bandwidth. That value numerically equal to the lowest frequency at which the magnitude of the modulation transfer function of an optical fiber decreases to a specified function, generally to one-half of the zero frequency value. It is a not a good measure of the information-carrying capacity of an optical fiber at a specified optical wavelength. Fiber bandwidth for an optical fiber should not be considered in the same terms as for other types of communication systems, such as electronic systems. It is a function of the modulation transfer characteristic of the fiber and not the optical frequency transfer function. The bandwidth is limited by several mechanisms: (a) in multimode fibers--primarily by modal distortion and material dispersion; (b) in single-mode fibers--primarily by material and waveguide dispersion. A better measure of the information-carrying capacity of an optical fiber is the bit-rate-length product (BRLP), which is limited by the modulation scheme and the desired bit-error ratio (BER). The BER is limited by the tolerable level of intersymbol interference caused by all forms of dispersion, attenuation, and jitter; the dynamic range; photodetector sensitivity; and other factors. The dispersion is a function of the spectral width of the source, the refractive indices of the core and cladding, and the length of the fiber. Step-index fiber can be made with zero dispersion at specific wavelengths. With the proper refractive-index profile and wavelength, graded-index fibers can also be made with zero dispersion. Another measure of the data signaling rate (DSR) or information-carrying capacity of an optical fiber is the full-wave half-power point.

fiber blank. See optical fiber blank.

fiber buffer. A material that is used to protect an optical fiber from physical damage and provide mechanical strength and protection. Some fiber fabrication techniques result in firm contact between the fiber and its protective buffering material. Other techniques result in a loose fit, permitting the fiber to slip in the buffer tube. Added protection may be obtained by using several buffer layers. Some fiber fabrication techniques result in firm contact between the fiber and its protective buffering material. Other techniques result in a loose fit, permitting the fiber to slip in the buffer tube. Added protection may be obtained by using several buffer layers.

fiber bundle. See optical fiber bundle.

fiber cable component. See optical fiber cable component (OFCC).

fiber cladding. A transparent material that surrounds the core of an optical fiber and that has a lower refractive index than the core material.

fiber coating. See optical fiber coating.

fiber/coating offset ratio. At a cross section of an optical fiber, the minimum coating thickness divided by the maximum coating thickness.

fiber concentricity error. See optical fiber concentricity error.

fiber connector set. See optical fiber connector set.

fiber core. The central portion of an optical fiber. The core has a higher refractive index than the cladding that surrounds it. The bulk of lightwave energy of an electromagnetic wave propagating in the fiber is confined to and propagates in the core. Fibers can be made to operate in single mode. Their core diameters range from 2 to 11 μ (micron), depending on the numerical aperture, core radius, and wavelength of the incident light.

fiber crosstalk. In an optical fiber, the exchange of lightwave energy between the core and the cladding, between the cladding and external surroundings, or between layers with different refractive indices. Fiber crosstalk is usually undesirable because differences in optical path length and propagation time can result in dispersion and consequent distortion, thus limiting the data signaling rate (DSR) for a given bit error ratio (BER). Attenuation may be deliberately introduced into the cladding to suppress the crosstalk by making it a lossy medium and thereby reducing dispersion.

fiber cutoff wavelength. For a short uncabled single-mode optical fiber with a specified large radius of curvature, that is, macrobend, the wavelength at which the presence of a second order mode introduces a significant attenuation increase when compared to a fiber whose differential mode attenuation is not changing at that wavelength. Because the cutoff wavelength of a fiber is dependent upon length, bend, and cabling, the cabled fiber cutoff wavelength may be a more useful value for cutoff wavelength from a systems point of view. In general, the cable cutoff wavelength is less than the fiber cutoff wavelength. Also see cable cutoff wavelength.

fiber-cutting tool. A special cutting tool designed to prepare the ends of optical fibers for splicing or connecting. When using the tool, the fiber is bent, a small groove is made with the tool at the spot under tension. This causes the fiber to fracture, producing a smooth cleaved end-surface along a molecular lattice.

fiber delay line. See optical fiber delay line.

fiber diameter. The nominal diameter of a round optical fiber, normally including the core, the cladding, and any coating not normally removed when making a connection, such as hermetic seals and special buffers.

fiber dispersion. The lengthening of the duration, that is, the width, of an electromagnetic pulse as it propagates along an optical fiber, caused by material dispersion which is caused by the wavelength-dependence of the refractive index; modal dispersion which is caused by different group velocities of the different modes; and waveguide dispersion which is caused by frequency-dependence of the propagation constant for a given mode.

fiber distributed data interface (FDDI) standard. A fiber optic communication network standard, developed by the American National Standards Institute (ANSI), in which a single bit stream format is used rather than a set of optical data signaling rates (DSRs) and formats using a byte format. Also see synchronous optical network (Sonet) standard.

fiber drawing. The fabrication of an optical fiber from the controlled pulling of the fiber, in a melted or softened state, through an aperture, causing it to elongate and reduce its diameter as it cools, adding buffers and other coatings, and winding the fiber on a spool, in an inside-payout or outside-payout ball or cone-shaped winding called a bundpack.

fiber end-to-end separation sensor. A fiber optic sensor in which the amount of light coupled from a source fiber, mounted on one platform, to a photodetector fiber mounted on another platform, is a function of the distance of separation of the end faces of the two fibers, that is, as the separation distance increases, the amount of coupled light decreases from a maximum to zero. Operation is dependent upon exit and acceptance cone angles, that is, numerical aperture, core diameters, and wavelength. If the end-to-end separation distance oscillates, the photodetector output signal will oscillate.

fiber faceplate. A plate made by cutting a transverse slice from a boule, that is, from a bundle of fused optical fibers.

fiber global attenuation-rate characteristic. A plot of the attenuation rate as a function of transmitter wavelength for an optical fiber. The plot should show the peaks and valleys caused by different absorption, scattering, and reflection levels at different wavelengths. The plot should also show (1) the useful wavelength regions for the fiber and (2) typical values rather than worst-case values so that the plot can be used to determine how the fiber will respond to new applications and to changes made in existing systems. Designers ensure that fibers operate at a wavelength at which the attenuation rate is the lowest, such as 1.31 μ (micron) for silica glass fibers. Another trough occurs at 1.55 μ. Global values are typical values because the only worst-case end-of-life values are those specified at time of purchase. Attenuation rates in dB/km are usually plotted at 23°C for wavelengths about 20 percent on either side of the transmitter nominal central wavelength. When designing an optical station/regenerator section, allowance must be made for increases in typical attenuation rates because of transmitter spectral width and the effect of temperature at the worst-case temperature conditions. Synonymous with fiber global loss characteristic. Also see loss budget constraint; optical cable facility loss.

fiber global dispersion characteristic. A plot that shows the dispersion coefficient (psec/nm-km) for an optical fiber as a function of wavelength. If the refractive index profile is properly shaped the fiber dispersion coefficient can be reduced to zero at a given wavelength. This wavelength should also coincide with the wavelength at which the attenuation rate is a minimum on the fiber global attenuation characteristic. The plot should show (1) the useful wavelength regions for the fiber and (2) typical values rather than worst-case values so that the plot can be used to determine how the fiber will respond to new applications and to changes made in existing systems.

fiber global loss characteristic. See fiber global attenuation-rate characteristic.

fiber hazard. See optical fiber hazard.

fiber identifier. A device that indicates the operational status of an optical fiber, such as whether there is data traffic or whether a tone is being transmitted. The identifier is used to help ensure that service is not interrupted when repairs or connections are made to fiber optic cables. It can be pocketed, hand held, and taken anywhere.

fiber jacket. See optical fiber jacket.

fiber junction. See optical fiber junction.

fiber laser. An optically-pumped solid state laser in which an optical fiber is the active laser medium. The core of the fiber is doped, usually with one of the standard rare earth ions, such as neodymium (Nd) or erbium (Er) used for bulk crystalline or glass lasers. The fiber laser is similar to a bulk laser, such as a Nd:YAG laser, except that an optical fiber is used as the gain medium instead of a rod or a slab. The high degree of confinement of the optical (electromagnetic) fields within the core and the long interaction distance in the fiber combine to provide excellent operational characteristics, including low lasing thresholds and high quantum efficiencies, that is, relatively high electrical to optical power conversion ratios. One fiber laser, developed by GTE Laboratories, is a neodymium-doped fluorozirconate heavy metal fluoride glass fiber laser emitting at a wavelength between 1.33 and 1.40 μ (micron). Fiber lasers exhibit a spectral (line) width of only a few MHz compared to 10 MHz or more for the distributed feedback laser. Only the external cavity semiconductor laser has a narrower spectral (line) width. The laser may be used in local (subscriber) loops, local area networks (LANs), metropolitan area networks (MANs), and longhaul communication networks. Synonymous with self-lasing fiber.

fiber longitudinal compression sensor. A fiber optic sensor in which a force applied to a length of optical fiber causes the fiber to shorten. By using interferometric techniques, the variation in monochromatic light irradiance at a photodetector can be made a function of the applied compressive force.

fiber loop multiplexer. A fiber optic multiplexer for providing multichannel (multiplexed) capability for local loops to user end-instruments in offices and homes.

fiber mandrel. See optical fiber mandrel.

fiber merit figure. See optical fiber merit figure.

fiber net. A communication network in which optical fibers are used in the cables rather than copper wires and coaxial cables. An all-fiber net has fiber in trunk lines between switching centers and central offices as well as in local loops and local area networks (LANs).

fiber optic. 1. Pertaining to optical fibers and the systems in which they are used. 2. Pertaining to the branch of science and technology devoted to combining the features and use of optical fibers and other dielectric waveguides, with other components, such as electronic components, to fabricate communication, sensing, telemetry, endoscopic, illumination, display and other types of devices, components, and systems.

fiber optic attenuator. A device that operates upon its input optical signal power level in such a way that its output signal power level is less than the input level, the reduction caused by such means as absorption, reflection, diffusion, scattering, deflection, diffraction, and dispersion, and usually not a result of geometric spreading, for example, a length of high-loss optical fiber. Also see optical attenuator.

fiber optic borescope. An optical device in which optical fibers are used to view and take pictures of the internal parts of a system, such as the interior of machines or interior organs of the human body. Also see flexible borescope; rigid borescope.

fiber optic branching device. An optical waveguide that combines light from two or more inputs or distributes light to one or more outputs, such as a splitter, combiner, or star coupler.

fiber optic bundle. See optical fiber bundle.

fiber optic cable. 1. A cable in which one or more optical fibers are used as the propagation medium. The optical fibers are usually surrounded by buffers, strength members, and jackets for protection, stiffness, and strength. Synonymous with optical cable; optical fiber cable. See Tempest-proofed fiber optic cable.

fiber optic cable assembly. 1. A fiber optic cable that is terminated with fiber optic connectors, that is, with one part of a two-part connector on each end. 2. A fiber optic cable that is terminated and ready for installation. Synonymous with optical cable assembly; optical fiber cable assembly.

fiber optic cable core. The portion of a fiber optic cable that serves as the waveguide proper, such as an optical fiber, a bundle of optical fibers, or a ribbon holding a group of optical fibers. Usually the cable core is protected from environmental effects by various other components, such as additional buffers, strength members, gels, tubes, jackets, over-all sheaths, or overarmor.

fiber optic cable facility. See optical cable facility.

fiber optic cable facility loss. See optical cable facility loss.

fiber optic cable feed-through. A mechanism that provides strain relief to a fiber optic cable entering an interconnection box and that may also be used to seal around the cable.

fiber optic communication system. See integrated fiber optic communication system.

fiber optic connector. A device that simply and easily permits coupling, decoupling, and recoupling of optical signals or power from each optical fiber in a cable to corresponding fibers in another cable, usually without the use of any tool. The connector usually consists of two mateable and demateable parts, one attached to each end of a cable, or to a piece of equipment, for the purpose of providing connection and disconnection of fiber optic cables.

fiber optic coupler. A device that transfers optical signals from one propagation medium to another, usually without using a fiber optic splice or connector. For example, in fiber optic transmission systems, a device that transfers optical signals from one optical fiber to one or more other fibers, such as by placing their cores in proximity. Thus, the coupler transfers optical power to a number of ports in a predetermined manner. The ports may connected to fiber optic components, such as fiber optic light sources, waveguides, and photodetectors. Synonymous with optical coupler; optical fiber coupler.

fiber optic cross-connection. Connection of two optical fibers by means of a third optical fiber, that is, a jumper, which serves as a link between the two fibers. Although two connections have to be made rather than the one required for a direct connection between the two fibers, the jumpers can be mounted on a panel so connections can be made conveniently at one place. Also see fiber optic interconnection.

fiber optic data link. A link, usually consisting of an electronically- modulated light source, a fiber optic cable, a photodetector, and associated fiber optic connectors, capable of transmitting data in the form of optical signals from one location to another. Other components commonly include amplifiers, time-division multiplexers (TDM), time-division demultiplexers (TDDM), and clock and data recovery circuits.

fiber optic data transfer network. A data transfer network (DTN) in which fiber optic modules and components are used to sense, transmit, display, or otherwise process data.

fiber optic demultiplexer (active). An electronically-operated optical device, with input and output optical fibers, that accepts information in the form of modulated lightwaves that have resulted from combining two or more optical signal streams in a multiplexer, and places each of the original streams on a separate output channel, for example, a device that uses the electrooptic effect to disperse a single-channel input polychromatic lightwave into its separate constituent colors each of which may have been separately modulated. The active optical demultiplexer may have two or more output fibers, each operating at a different wavelength, and one input fiber bearing all the wavelengths. Electrical energy, or other form of energy other than optical energy, is required to operate the active optical demultiplexer. Synonymous with optical fiber demultiplexer (active). Also see fiber optic multiplexer (active); optical demultiplexer (active); optical multiplexer (active).

fiber optic demultiplexer (passive). A purely passive optical device that accepts information in the form of modulated lightwaves that have resulted from combining two or more optical signal streams in a multiplexer, and places each of the original streams on a separate output channel, for example, a prism that disperses a single-channel input polychromatic lightwave into separate constituent colors each of which may have been separately modulated. For example, a passive optical demultiplexer may consist two or more output optical fibers, each operating at a different wavelength, and one input fiber bearing all the wavelengths. No energy is required to operate the passive optical demultiplexer other than that contained in the input lightwave. Synonymous with optical fiber demultiplexer (passive). Also see fiber optic multiplexer (passive); optical demultiplexer (passive); optical multiplexer (passive).

fiber optic display device. A device used to display pictorial, alphanumeric, or graphical data, usually consisting of a fiber faceplate made of the end faces of optical fibers in an aligned bundle, the aligned bundle of fibers being used to transfer an image to the display surface, and perhaps a lens to enlarge or project the image.

fiber optic distribution frame. A structure with optical waveguide terminations for interconnecting permanently-installed fiber optic cable in such a way that interconnection by cross connections may be made. The frame may hold connectors, splice trays, or both. The fiber optic distribution frame is usually located at a central office, switching center, or node in a communication network and considered part of the inside plant. Synonymous with fiber optic interconnection frame. Also see fiber optic interconnection box.

fiber optic dosimeter. An instrument for measuring cumulative exposure to high-energy radiation or bombardment, such as x-rays, gamma radiation, cosmic rays, and high-energy neutrons, by measuring the induced attenuation in an optical fiber from exposure to the radiation. Also see induced attenuation.

fiber optic drop. A fiber optic transmission line that carries multiplexed signals from a central office inside plant to a distribution point where lines lead to taps with user end instruments, such as telephones, data terminals, perhaps in individual offices and homes. Current trends are to run optical fiber all the way to the taps for video, telephone, and data channels. Satellite dishes, coaxial cable, and fiber optic cables are competing signal transport media for television, telephone, and data systems into home and office.

fiber optic endoscope. An optical device used to view and to take pictures of the internal parts of a system, such as the internal cavities and organs of the human body or the interior of machines. In medicine, fiber optic endoscopes, such as bronchoscopes, gastroscopes, colonoscopes, cholodochoscopes, cystoscopes, laparoscopes, and arthroscopes are used for in vivo examination of internal body cavities, performing biopsies, and performing polypectomies. Industrial counterparts of the endoscope are used for remote nondestructive inspection of internal parts and cavities of machine systems while they are operating. Also see fiberscope.

fiber optic filter. A device that operates on the various frequencies in an input optical signal in such a way that certain frequencies are allowed to pass while others are blocked, for example, a piece of blue glass that will transmit only the blue wavelengths contained in incident white light and block all the other wavelengths, or a device that screens out all the wavelengths above, or below, a given value.

fiber optic flood illumination. Illumination of a relatively large area with a wide light beam emanating from the end of an optical fiber or bundle of fibers.

fiber optic gyroscope (FOG). A gyroscope in which optical fibers, such as single-mode or polarization-preserving fibers, and monochromatic light, such as that produced by lasers, are used to measure changes in rotational displacement, velocity, and acceleration, and hence changes in orientation and direction of the platform holding the sensor. Interferometric techniques, such as are used in the Sagnac fiber optic sensor, are used to detect the changes in phase or polarization of the lightwaves.

fiber optic illumination detection. The use of an optical fiber, or bundle of fibers, to determine whether light is emanating from a given source.

fiber optic illuminator. A device in which an optical fiber, or bundle of fibers, is used to convey light to and illuminate an area remote from the source of light. Illumination devices may be used to shed light on specific and often inaccessible surfaces, such as surgical fields, instrument panels, and auxiliary equipment, particularly in atmospheres where electrical illumination might be hazardous.

fiber optic interconnection. Connection of two optical fibers by means of a direct connection from one to the other, thus requiring no fiber optic jumpers. Also see fiber optic cross-connection.

fiber optic interconnection box. A housing for holding fiber optic splices, connectors, and couplers used to distribute signals on incoming cables to outgoing cables by means of connections. The connections may be made by interconnection or cross-connection. It is usually a local box or housing at a user premises for holding connections to fiber optic cables from distribution frames and fiber optic splices, or splice trays that hold splices, to loops going to optical transceivers or other user end-instruments. Synonymous with fiber optic distribution box; optical fiber interconnection box. Also see fiber optic distribution frame.

fiber optic isolator. An optical link inserted into a communication system to provide electrical isolation between two or more parts of the system. The fiber optic isolator is often used to provide nonmetallic entry and exit from secure areas. The fiber optic isolator serves as an optical transmission link, consisting of an optical transmitter, an optical waveguide, and a photodetector, to provide electrical isolation between two communication systems or components. The optical waveguide serves as an electrical insulator as well as an optical transmission line. The fiber optic isolator also performs impedance transformation. Also see optical isolator.

fiber optic jumper. A jacketed short optical fiber with a fiber optic connector on both ends used for effecting a fiber optic cross-connection. Jumpers are mounted on panels for easy access.

fiber optic light source. A device that emits lightwaves, that is, radiation in or near the visible region of the electromagnetic spectrum, for example, light-emitting diodes (LEDs), lasers, and lamps, for providing optical power to optical systems. Some fiber optic light sources are capable of being modulated by an electronic input signal and have an integral optical fiber as a pigtail, in which case they can serve as a component in fiber optic transmitters for command, communication, control, and telemetry systems. Others simply supply light that can be modulated by means other than by operating on the source, such as by a sensing mechanism. Fiber optic light sources usually have an optical fiber as an output lead and one or more wires for input electrical power and modulation signals.

fiber optic link. A communication link that transmits signals by means of modulated light propagated in an optical fiber. The link usually consists of a fiber optic light source as a transmitter, a fiber optic cable, and a photodetector as a receiver. Other components commonly include amplifiers, time-division multiplexers (TDM), time-division demultiplexers (TDDM), and clock and data recovery circuits. Light from the fiber optic transmitter is usually modulated by an intelligence-bearing signal. The intelligence-bearing signal may be in the form of an electrical signal imposed on the light source, thus varying the radiance, that is, the light intensity, emanating from the source, or in the form of a modulator that modulates the light after it emanates from a constant optical power source, such as by a sensing device. The receiver demodulates the signal to obtain the original modulating signal containing the original intelligence. Synonymous with optical link.

fiber optic mixer. A device that accepts wavelength-division multiplexed signals from two or more input optical fibers, mixes the signals, and transmits the mixed signal containing all the input wavelengths, that is, transmits the resulting dichromatic or polychromatic light. For example, a fiber optic mixer can be a rod of transparent material with optical fiber input ports and internal mirrors for multiple reflection everywhere except at the output ports, at which optical fibers are attached.

fiber optic mode stripper. Material applied to the cladding of an optical fiber, slab dielectric waveguide, or integrated optical circuit (IOC), that allows optical energy propagating in the cladding to leave the cladding, supports only certain propagating modes, usually does not support the modes propagating in the cladding, and does not disturb the modes propagating in the core. Optical power removed from a waveguide by a stripper usually is not used.

fiber optic modulator. A device capable of accepting a nonintelligence-bearing input signal, that is, a carrier, and an intelligence-bearing input signal, and mixing them in such a manner that the output signal consists of a parameter of the carrier varied in accordance with the intelligence-bearing input signal. At least one of the input or output leads is an optical fiber.

fiber optic multimode dispersion. See multimode dispersion.

fiber optic multiplexer (active). An optoelectronic device that accepts information in the form of modulated lightwaves in optical fibers, that is, optical signal streams, on two or more channels, and places all of the input information on a single output channel in such a way that the information on the input channels can be recovered at the end of the single output channel. For example, an active fiber optic multiplexer may consist of two or more input optical fibers, each operating at a different wavelength, and one output fiber containing all the wavelengths. The multiplexing component may or may not be constructed with optical fibers. Electrical energy, or other forms of energy, other than that contained in the input lightwaves, are required to operate active fiber optic multiplexers and optical multiplexers. Synonymous with optical fiber multiplexer (active). Also see fiber optic demultiplexer (active); optical demultiplexer (active); optical multiplexer (active).

fiber optic multiplexer (passive). A purely passive optical device that accepts information in the form of modulated lightwaves in optical fibers, such as streams of optical pulses, on two or more channels, and places all of the input information on a single output channel in such a way that the information on the input channels can be recovered at the end of the single output channel. For example, the passive fiber optic multiplexer may consist of two or more input optical fibers, each operating at a different wavelength, and one output fiber containing all the wavelengths. The multiplexing component may or may not be constructed with optical fibers. For example, they may be optical fiber couplers. They may be constructed of optical mixing rods or boxes, or other mixing devices. No energy is required to operate the passive fiber optic multiplexer or the optical multiplexer (passive) other than that contained in the input lightwaves. Synonymous with optical fiber multiplexer (passive). Also see optical demultiplexer (passive); optical multiplexer (passive).

fiber optic multiport coupler. A passive optical device with two or more output or input ports that can be used to couple various sources to various receivers. Optical fibers are attached to the coupler at the ports. If there is only one input and one output it is a fiber optic connector or splice. Most fiber optic multiport couplers consist of a piece of transparent material. Operation depends on reflection, transmission, scattering, and diffusion.

fiber optic patch panel. A panel on which fiber optic connectors and couplers are mounted in an organized array for easy access. Usually both sides are accessible with sufficient spacing between components to facilitate handling individual components. Individual connectors should be easily identifiable. An individual connectorization and organization plan should accompany each panel and the interconnection box in which it is installed.

fiber optic penetrator. A device that allows an optical fiber or fiber optic cable to pass from one compartment to another, such as through a wall, partition, bulkhead, hull, fuselage, or cabinet.

fiber optic phase modulator. See optical phase modulator.

fiber optic photodetector. A device that converts input optical signals into equivalent electronic output signals, usually consisting of an optical fiber signal-input pigtail; a light-sensitive element, such as a photodiode; an electrical signal output wire; and an electrical power input wire.

fiber optic polarizer. See optical fiber polarizer.

fiber optic preform. See optical fiber preform.

fiber optic receiver. An optoelectronic device that accepts optical signals from a transmitter or from a propagation medium, detects them by converting them into electronic signals, amplifies, and further processes them.

fiber optic ribbon. Optical fibers arrayed side by side and held in place by tapes, adhesives, or plastic strips, for example, a cable consisting of optical fibers laminated within a flat plastic strip. Synonymous with fiber ribbon; optical fiber ribbon.

fiber optic rotary joint. A passive optical device made of optical fibers and connectors that allows signals from one or more fixed platforms to be coupled to one or more platforms that are rotating relative to the fixed platforms.

fiber optics. 1. The branch of science and technology devoted to the transmission of radiation, that is, radiant power, through optical fibers made of transparent materials, such as glass, fused silica, and plastic. Optical fibers in fiber optic cables may be used for data transmission, and for sensing, illumination, endoscopic, control, and display purposes, depending on their use in various geometric configurations, modes of excitation, and environmental conditions. The fibers usually may be wound and bound in various shapes and distributions singly or in bundles, which may be aligned bundles or unaligned bundles. The aligned bundles are used to transmit and display images as well as to scramble images. 2. In 1956, Kapany first defined fiber optics as the art of active and passive guidance of light as rays and waveguide modes in the ultraviolet, visible, and infrared spectra in transparent fibers along predetermined paths. See woven fiber optics; ultraviolet fiber optics.

fiber optic scrambler. Similar to a fiberscope, except that the center section of the aligned bundle has its optical fibers randomly distributed. When the randomized fibers are potted and sawed, each half is capable of coding a picture that can only be readily decoded only by the other half.

fiber optic sensor. A device that responds to a physical, chemical, or radiant field input stimulus, such as heat, light, sound, pressure, temperature, strain, magnetic field, and electric field, and transmits on an optical fiber a pulse, signal, or other representation indicating one or more characteristics of the stimulus, for example, a thermometer, tachometer, hydrophone, microphone, or barometer whose output lead is an optical fiber. See Fabry-Perot fiber optic sensor; Mach-Zehnder fiber optic sensor; Michelson fiber optic sensor; Sagnac fiber optic sensor. Also see optical fiber sensor.

fiber optic splice. An inseparable, that is, permanent, joint between one dielectric waveguide, such as an optical fiber, and another, with minimal power loss at the junction. The purpose of the splice is to couple optical power between the two waveguides. Synonymous with optical splice. Also see optical fiber splice.

fiber optic splice tray. A flat, usually-rectangular, pan-shaped device for holding and protecting the individual optical fibers from two fiber optic cables that have been spliced. The tray holds the fibers even though they may not be sheathed, jacketed, or otherwise covered as a group, although the fiber optic splices may be individually covered.

fiber optic splitter. A device that extracts a portion of the optical signal power propagating in a dielectric waveguide, such as an optical tap or a partial mirror, and diverts that power to a destination different from that of the remaining portion.

fiber optic spot illumination. Illumination of a relatively small area with a narrow beam of light emanating from the end of an optical fiber or bundle of fibers.

fiber optic station cable. See optical station cable.

fiber optic station facility. See optical station facility.

fiber optic station/regenerator section. See optical station/regenerator section.

fiber optic supporting structures. Structures that are used to fasten, guide, and hold fiber optic components in place in operational systems, for example, bend limiters, raceways, harnesses, hangars, ducts, and housings, without which a fiber optic system cannot be installed, held in place, and operated.

fiber optic switch. A device that can selectively transfer optical signals from one optical fiber to another depending upon the application of external stimuli, such as a force or an applied electric, magnetic, electromagnetic, acoustic, gravitational, or other force field. The switch may be latching or nonlatching.

fiber optic telemetry system. A telemetry system in which fiber optic components, such as fiber optic sensors, data links, light sources, photodetectors, and related components, are used to gather and distribute data originating from a sensor.

fiber optic terminus. 1. A device used to terminate an electrical conductor or dielectric waveguide, such as an optical fiber, that provides a means of locating and holding the conductor or waveguide within a connector. 2. The part of a fiber optic connector into which the optical fiber is inserted and attached mechanically or by adhesive.

fiber optic test method (FOTM). A general description of the overall approach to the testing of fiber optic systems and components, identifying the system or component to be tested, the type and nature of the test, the parameters to be measured, and the environmental conditions under which the test is to be conducted. The FOTM does not explicitly describe in every detail the exact steps to be taken during the conduct of the test. Engineering analysis is required and one or more fiber optic test procedures (FOTPs) must be prepared before an FOTM can be executed. Also see fiber optic test procedure (FOTP).

fiber optic test procedure (FOTP). A detailed, highly-explicit, unambiguous, stand-alone, step-by-step sequence of actions, or the document describing them, for testing fiber optic systems and components, each step precisely described, with all dimensions, instrument settings, apparatus, structures, parameters to be measured, environmental conditions, exact action to be taken at each step, and data to be taken, clearly described for each part or run of the test. An FOTP can be executed without additional engineering analysis. FOTPs are usually prepared from or based on previously prepared fiber optic test methods (FOTMs). Also see fiber optic test method (FOTM).

fiber optic transmitter. An optoelectronic device capable of accepting electrical signals, converting them into optical signals, and launching the optical signals into one or more optical waveguides.

fiber optic waveguide. See optical waveguide.

fiberoptronics. 1. An abbreviation of fiber optics, optoelectronics, and electrooptics. 2. The branch of science and technology devoted to exploiting the advantages obtained by combining optical fibers, other active and passive optical devices, and electronic circuits into useful systems, for example electronically modulating a light source in order to impress information on its output light beam, guiding the beam through a fiber optic cable to a photodetector, and recovering the impressed information in electronic form.

fiber organizer. See fiber-and-splice organizer.

fiber parameter. See global fiber parameter.

fiber pattern. In the fiber faceplate of a fiberscope, the arrangement of the ends of the individual optical fibers that comprise the faceplate. Inspection of an image on the end surface might reveal that the fiber pattern makes the image appear as a mosaic of individual picture elements.

fiber pigtail. See optical fiber pigtail.

fiber polarizer. See optical fiber polarizer.

fiber preform. See optical fiber preform.

fiber-pulling machine. A device capable of drawing an optical fiber from a preform heated to fusion temperature. The increased temperature provides for ductility and fusion of dopants to control the refractive-index profile. The cross section decreases and the length increases as the fiber is pulled from the preform. Steps in the drawing process include application of buffers or other coatings, and packaging, such as winding on spools in readiness for the cabling process.

fiber pulse compression. See optical fiber pulse compression.

fiber radiation damage. See optical fiber radiation damage.

fiber retention. A measure of the ability of a fiber optic component with an optical fiber for access, such as a fiber splice or a fiber optic coupler with an optical fiber pigtail, to retain or hold the fiber when an attempt is made to pull the fiber from the component with a known or measured tensile force.

fiber ribbon. See fiber optic ribbon.

fiber ringer. See optical fiber ringer.

fiber scattering. See configuration scattering.

fiberscope. A device consisting of an aligned bundle of optical fibers with terminating fiber faceplates, an objective lens on one end for focusing the image of an object, and an eyepiece for viewing the transmitted image in full color on the fiber faceplate at the opposite end. The fiberscope is used for viewing objects that are otherwise inaccessible for direct viewing, such as the interior of machines and the internal organs of the human body. See hypodermic fiberscope. Also see fiber optic endoscope.

fiberscopic recording. A recording method in which light emerging from the fiber faceplate of an aligned bundle of optical fibers, that is, a fiberscope, is used to expose film.

fiber sensor. See coated-fiber sensor.

fiber source. See optical fiber source.

fiber splice. See optical fiber splice.

fiber splice housing. A housing, such as tapes, jackets, coatings, and other components necessary for attaching, supporting, and aligning fibers, applied over a fiber optic splice and proximate fiber for their protection against the environment, for some mechanical strength, and for preservation of the integrity of the fiber coating, buffer, cladding, and core. The housing includes a means for mounting the aligned assembly in an interconnection box or cable splice closure.

fiber strain-induced sensor. A fiber optic sensor in which optical time-domain reflectometry (OTDR), interferometry, birefringence, polarization and polarization-plane rotation, wave coherency, special coatings, microbending, and other types of schemes are used together with the application of a transverse, longitudinal, or torsional stress that produces a strain on an optical fiber, causing a change in irradiance, that is, light intensity, at a photodetector.

fiber tensile strength. See optical fiber tensile strength.

fiber tension sensor. A fiber optic sensor in which an increase in tension applied to an optical fiber results in an elongation. By using a reference fiber not subject to the increase in tension and applying interferometric techniques, the force producing the tension can be measured. If the force is applied directly, it can be measured directly. If the fiber is wound on a bobbin and pressure is applied to the inside of the bobbin to cause it to expand, the fiber will be subjected to tension and thereby elongated.

fiber transfer function. See optical fiber transfer function.

fiber transverse compression sensor. A fiber optic sensor in which the optical attenuation is a function of the longitudinally-applied pressure, that is, the pressure is uniformly applied radially against the outside of an optical fiber. A length of cabled fiber, a light source, not necessarily coherent or monochromatic, and a photodetector are usually required.

fiber trap. See optical fiber trap.

field. See borescope view field; electric field; electromagnetic field; evanescent field; reference surface tolerance field.

field component. See magnetic field component.

field coupling. See evanescent-field coupling.

field diameter. See mode field diameter.

field diffraction pattern. See near-field diffraction pattern.

field intensity. See field strength.

field radiation pattern. See near-field radiation pattern.

field scanning technique. See near-field scanning technique.

field splicing. The joining of the ends of two fiber optic cables in a field environment, such as on open terrain, aboard ships, and under water, without the use of detachable connectors and in such a manner that continuity through the splice is preserved in all elements of the cable, such as optical continuity of optical fibers, electrical continuity, and continuity of jacketing, sheathing, buffers, stuffing, insulation, strength members, and waterproofing.

field strength. The intensity, that is, the amplitude or magnitude, of an electric, magnetic, electromagnetic, gravitational, or other force field at a given point. The term is normally used to refer to the rms value of the electric field, expressed in volts per meter, or of the magnetic field, expressed in amperes per meter. Field strength is usually given as a gradient, and therefore is a vector quantity, since it has both magnitude and direction. For example, the units of electric field strength may be volts per meter, kilograms per coulomb, or lines per square meter divided by the electric permittivity of the medium at the point it is measured; magnetic field strength might be given as amperes per meter, oersteds, or lines per square meter divided by the magnetic permeability of the medium at the point it is measured; and gravitational field strength as newtons per kilogram. Synonymous with field intensity. See electric field strength; magnetic field strength.

field template. See four-concentric-circle near-field template.

field vector. See electric field vector; magnetic field vector.

figure. See optical fiber merit figure.

filled cable. A cable that has a nonhygroscopic material, usually a gel, inside the sheath or jacket. The gel is used to prevent moisture from entering minor leaks.

filled fiber. See fully-filled fiber.

film. See optical thin film; photoconductive film.

film optical modulator. See thin-film optical modulator.

film optical multiplexer. See thin-film optical multiplexer.

film optical switch. See thin-film optical switch.

film optical waveguide. See thin-film optical waveguide.

film waveguide. See periodically-distributed thin-film waveguide.

filter. In optics, a device used to modify the spectral composition of light, such as absorb certain wavelengths or transmit certain wavelengths. See core mode filter; dichroic filter; fiber optic filter; high-pass filter; interference filter; low-pass filter; mode filter; optical filter.

finish. See end finish.

fixed attenuator. An attenuator in which the amount of attenuation it produces cannot be varied. The attenuation is expressed in dB. The operating wavelength for optical attenuators and fiber optic attenuators should be specified for the rated attenuation, because optical attenuation of a material varies with wavelength.

fixed connector. In fiber optics, a connector that has one of its mating halves mounted on board, panel, casing, bulkhead, or other rigid object or surface. Also see free connector.

fixed optics. The development and use of optical components whose characteristics cannot be changed or controlled during their operational use, except perhaps for minor adjustments in position, such as in focusing telescopes, binoculars, and microscopes, to accommodate the human eye. Also see active optics.

flat-coil fiber sensor. A distributed-fiber sensor in which the optical fiber is distributed in a plane in rows and columns, or in a flat spiral, so that the distance, usually measured by optical time domain reflectrometry (OTDR), to a stimulated point on the plane, such as a pressure point or a hot point, can be used to calculate the cartesian or polar coordinates of the point.

flattened fiber. See dispersion-flattened fiber.

flexible borescope. A portable fiber optic borescope that has an aligned-bundle (coherent bundle) in a fiber optic cable with sufficient flexibility to reach an inspection area via a multiturn path and sufficient rigidity to cross unsupported gaps in the path. There is usually an eyepiece or a fiber faceplate for viewing the image and a controllable articulating tip on the objective end to enable inspection at various angles, such as up to 90 degrees from the cable optical axis. The borescope is hand held and energized via a fiber optic cable from a light source. The flexible borescope usually consists of a basic borescope unit and ancillary equipment required for operation. Also see rigid borescope.

flood illumination. See fiber optic flood illumination.

fluorescence. The emission of electromagnetic radiation by a material during absorption of electromagnetic radiation from another source. Also see luminescence; phosphorescence.

flux. See radiant power.

focusing optical fiber. See self-focusing optical fiber.

FOG. Fiber optic gyroscope.

foot-candle. A unit of illuminance equal to 1 lumen (of light flux) incident per square foot. It is the illuminance of a curved surface, all points of which are placed 1 foot from a light source having a luminous intensity (candlepower) of 1 candle, that is, a candela. Thus, 4π lumens emanate from 1 candela. However, this is not an SI (Systemè International) unit. The SI unit is the lux, equal to 1 lumen per square meter.

format. See signal format.

forward scatter. 1. The deflection by reflection or refraction of an electro-magnetic wave or signal in such a manner that at least a component of the wave is deflected in the direction of propagation of the incident wave or signal. 2. The component of an electromagnetic wave or signal that is deflected by reflection or refraction in the direction of propagation of the incident wave or signal. 3. To deflect, by reflection or refraction, an electromagnetic wave or signal in such a manner that a component of the wave or signal is deflected in the direction of propagation of the incident wave or signal. The term scatter can be applied to reflection or refraction by relatively uniform media, but it is usually taken to mean propagation in which the wavefront and direction are modified in a relatively disorderly fashion. In some instances, particularly in radio transmission, the term "forward" refers to the resolution of field components when resolved along a line drawn from the source of radiation to the point of scatter. Also see backscatter.

FOTM. Fiber optic test method.

FOTP. Fiber optic test procedure.

four-concentric-circle near-field template. A template comprising four concentric circles applied to a near-field radiation pattern radiating from the exit face of a round optical fiber. The template is used as an overall check of various geometrical properties of the fiber all at once.

four-concentric-circle refractive-index template. A template comprising four concentric circles applied to a complete refractive-index profile of a round optical fiber. The template is used as an overall check of various geometrical properties of the fiber all at once.

fraction. See packing fraction.

fraction loss. See packing fraction loss.

frame. See fiber optic distribution frame.

Fraunhofer diffraction pattern. See far-field diffraction pattern.

free connector. In fiber optics, a connector that is not attached or associated with any other object or surface, that is, neither of its mating halves is mounted on board, panel, casing, bulkhead, or other rigid object or surface. Also see fixed connector.

free space. A theoretical concept of space devoid of all matter. In electromagnetic wave propagation, the term implies remoteness from material objects that could influence the propagation of electromagnetic waves, freedom from the influence of extraneous fields other than the fields of interest, and thus usually free of electric charges, except when the charge itself is of interest. Thus, the interior of an optical fiber is not considered free space, but there might be some free space between fibers, fibers and light sources, and fibers and photodetectors.

free-space coupling. Energy transfer via electromagnetic fields that are not in a conductor, that is, the fields are in free space.

free-space loss. The signal attenuation that would result if all obstructing, scattering, or reflecting influences were sufficiently removed so as to have no effect on propagation. Free-space loss is primarily caused by beam divergence, that is, geometric spreading of signal energy over larger areas at increased distances from the source.

frequency. For a periodic function, the number of cycles or events per unit of time. When the unit of time is 1 second, the measurement unit is the hertz (Hz). For example, in an electromagnetic wave, the frequency is the number of times per second the electric field vector reaches its peak value in a given direction. See cutoff frequency; normalized frequency; pump frequency; spectrum designation of frequency; threshold frequency.

frequency band. A continuous and contiguous group of electromagnetic wave frequencies, usually defined by a lower and an upper limit of frequency.

frequency cutoff. See low-frequency cutoff.

frequency-division multiplexing (FDM). A multiplexing scheme in which the available transmission frequency range is divided into narrow frequency bands, each used as a separate channel. Because an optical fiber can transmit more than one wavelength of light at the same time, each wavelength can be separately modulated and used as a separate transmission channel as long as a combination of dispersive components, such as prisms, and photodetectors on the receiving end are wavelength-sensitive for demultiplexing. In fiber optics, FDM is usually called wavelength-division multiplexing (WDM) because lightwaves and optical components are best and more often described in terms of wavelength. To be consistent, modulation of the instantaneous wavelength is called wavelength modulation (WM) and it avoids confusion with FDM that also may be in use in the same system. FDM signals can be modulated onto optical carriers by means of WM or intensity modulation (IM).

frequency response function. See transfer function.

Fresnel diffraction pattern. See near-field diffraction pattern.

Fresnel equations. The equations that define the reflection and transmission coefficient at an optical interface when an electromagnetic wave is incident upon the interface surface. The coefficients are functions of the refractive indices of the transmission media on both sides of the interface, the incidence angle, and the direction of polarization with respect to the interface surface.

Fresnel reflection. The reflection of a portion of incident light at an interface between two homogeneous transmission media having different refractive indices. Fresnel reflection occurs at the air-glass interfaces at the entrance and exit ends of an optical waveguide. Resultant transmission losses, on the order of 4 percent per interface, can be eliminated by use of antireflection coatings or index-matching materials. For incident electromagnetic waves with the magnetic field vector parallel to the interface, there is no Fresnel reflection at the Brewster angle. The reflection coefficient is zero and the transmission coefficient is unity. Fresnel reflection depends on the refractive index difference across an interface surface and on the incidence angle. In optical elements, a thin transparent film may be used to cause an additional Fresnel reflection that cancels the original one by interference. This is called an antireflection coating.

Fresnel reflection method. The method for determining the refractive-index profile of an optical waveguide by measuring the reflectance as a function of position on an end-face.

Fresnel reflective loss. Loss caused by refractive index differences at a terminus interface. The loss is the optical power in the Fresnel reflection.

front-emitting LED. See surface-emitting LED.

front velocity. See phase-front velocity.

frustrated total (internal) reflection sensor. A fiber optic sensor consisting of two optical fibers with an end of each separated by an air gap produced by cutting a fiber and polishing the cut ends at a precise angle to produce total (internal) reflection in the source fiber when the fibers are widely separated. When the distance between the ends, that is, the air gap, is sufficiently small, a large portion of the light in the source fiber is coupled to the fiber connected to a photodetector. As the gap is widened, say by moving the fiber axes laterally away from one another, by moving the fiber end-faces longitudinally away from one another, or by increasing the angular misalignment of the fibers, the light coupled across the gap decreases. The irradiance that is, the light intensity, at the photodetector will be a function of the lateral offset, longitudinal offset, or angular misalignment of the fibers.

full-duration half-maximum (FDHM). Pertaining to the time interval during which a characteristic or property of a variable, such as the amplitude of a pulse, has a value greater than 50 percent of its maximum value.

full-wave half-power point. In fiber optics, a measure of the information-carrying capacity of an optical fiber of given length in which the power or amplitude of an optical pulse of a full wave, that is, a 50 percent duty cycle, is reduced to half of the steady state level. Dispersion and attenuation contribute to the reduction in pulse amplitude or power level.

full-width half-maximum (FWHM). Pertaining to the range over which a property of a variable has a value greater than 50 percent of its maximum value. FWHM describes characteristics such as radiation patterns, optical pulse widths, spectral linewidths, beam diameters, and beam divergences; and to variables, such as wavelength, voltage, power, and current.

fully-connected mesh network. In network topology, a network configuration in which every node is directly connected to every other node. Thus, each node is connected to n-1 branches. The number of branches, N_b, in a fully-connected mesh network is given by the relation

$$N_b = n(n-1)/2$$

where n is the number of nodes in the network.

fully-filled fiber. An optical fiber in which an electromagnetic wave is propagating in such a manner that the optical power is distributed among all the modes supported by the fiber in the equilibrium modal power distribution condition. Leaky, that is, high-order modes are lost in long fibers. These modes are filtered by being stripped. Some sources, such as lensed light-emitting diodes (LEDs) and edge-emitting LEDs, couple most of their optical power into the low-order modes. Fiber optic connectors mix modes by adding power back into the high-order modes.

function. See impulse response function; optical fiber transfer function (OFTF); transfer function; work function.

fundamental mode. 1. In a multimode fiber, the lowest order mode a waveguide with a given numerical aperture and set of launch conditions is capable of supporting. It corresponds to the cut-off frequency, that is, the longest wavelength the guide is capable of supporting. 2. In a single-mode fiber, the one mode is the fundamental mode. If the frequency of the source is increased, and consequently the wavelength decreased, so that the same optical fiber can support additional modes, the fundamental mode still remains the same mode, even though the same fiber is supporting more modes with wavelengths shorter than that of the fundamental mode.

fused quartz. Glass that is made by melting crystals of natural quartz, resulting in a glass that is not as pure as the fused (vitreous) silica glass.

fused silica. Glass that consists of pure silicon dioxide (SiO_2). Synonymous with vitreous silica.

fusion splice. A fiber optic splice made by applying sufficient heat to melt, fuse, and thus join an end from each of two lengths of optical fiber in order to form a single optical fiber with near-zero attenuation at the splice.

fusion splicing. In optical transmission systems using solid dielectric propagation media, the joining together of two media by butting them, forming an interface between them, and then removing the common surfaces by a melting process so that there is no interface between them. Thus, a lightwave will be propagated from one propagation medium, such as an optical fiber, to another without reflection at the joint and therefore without an insertion loss. However, the joint is never perfect, and therefore some small loss will occur at the fiber optic splice.

FWHM. Full-width half-maximum.

G

g. In fiber optics, the symbol used for the refractive-index profile parameter. Also see power-law refractive index profile.

gain. See statistical terminal/regenerator system gain; terminal/regenerator system gain.

gamma photon. A fundamental particle or quantum of gamma radiation, with an energy equal to hf, where h is Planck's constant and f is the frequency of the radiation, that is, of the photon. Gamma radiation frequency is higher than that of x-rays and optical spectra, which includes visible, infrared, and ultraviolet spectra. Gamma radiation occupies the 10^{10} to 10^{12} GHz band.

gamma radiation. Electromagnetic waves that have a frequency higher than that of lightwaves and x-rays, that can only be stopped or absorbed by dense materials such as lead and depleted uranium. They cannot be confined to or guided in optical fibers and are usually produced by nuclear reaction and high-powered lasers when transitions occur from very high to very low electron energy levels in molecules. Frequencies of gamma rays lie in the 10^{10} to 10^{12} GHz band. At these frequencies even single photons can be destructive to human tissues.

gap energy. See band-gap energy.

gap loss. In fiber optics, the radiant power loss caused by a space between optical fiber end-faces at a joint, such as in a connector, even though the fiber axes are angularly aligned. The loss increases as the spacing departs from optimum. The loss is extrinsic to the fibers. For waveguide-to-waveguide coupling, it is called longitudinal offset loss.

gas laser. See mixed-gas laser.

Gaussian beam. A beam whose irradiance, that is, radiant power density or light intensity across its diameter is somewhat proportional to a Gaussian distribution curve, that is, the bell curve, in which the maximum electromagnetic field strength occurs at the center and diminishes toward the edges, the cross section normally being symmetrical in field strength about the center. When such a beam is circular in cross section, the electric field strength is given by the relation

$$E_r = E_o e^{-r/w}$$

where E_r is the electric field strength at the distance r from the center, E_o is the electric field strength at the beam center, r is the distance from the center for which E_r is determined, and w is the beam width, that is, the radius at which the field strength is 1/e of its value at the center.

Gaussian pulse. A pulse that has the waveform of a Gaussian distribution curve, that is, the bell curve. In the time domain, the waveform is given by the relation

$$f(t) = A_0 \exp\left[-(t/a)^2\right]$$

where A_0 is a constant, a scale factor, and the magnitude of the pulse at t=0, t is time, and a is the pulse half duration at the 1/e points.

geometric optics. 1. The optics of light rays that follow mathematically- defined paths when passing through optical elements, such as lenses, prisms, and other optical transmission media that refract, reflect, or transmit electromagnetic radiation. 2. The branch of science and technology that treats lightwave propagation in terms of rays considered as straight or curved lines in homogeneous, nonhomogeneous, isotropic, and anisotropic media, rather than as wavefronts as in physical optics. Light rays and wavefronts are always and everywhere orthogonal.

geometric spreading. In a wave propagating in a propagation medium in which there are no sources, the decrease in irradiance, that is, the power density, as a function of distance, in the direction of propagation, that is caused only by the divergence of rays rather than by absorption, scattering, diffusion, or transverse radiation. For example, a point source, or a source with a nonzero exit angle, will have its energy spread over larger and larger areas as the distance from the source increases. Geometric spreading is not considered to take place in a collimated beam, though some spreading will occur because collimation is never perfect and some light is scattered transverse to the beam by discontinuities in the transmission media, such as air molecules, smoke particles, or water vapor.

GI fiber. See graded-index (GI) fiber.

gigahertz. A unit of frequency equal to 1 billion (U.S.) hertz or 10^9 Hz, abbreviated GHz.

glass. See dry glass; halide glass.

glass fiber. See all-glass fiber; drawn glass fiber.

glass powder. Pulverized glass produced from raw materials by industrial processing. When in the molten state, the glass is purified and dried for making optical fiber preforms.

global attenuation-rate characteristic. See fiber global attenuation-rate characteristic.

global fiber parameter. An optical fiber parameter, such as fiber attenuation rate, dispersion, and splice insertion loss, that is likely to vary as a result of temperature, humidity, and aging and for which an allowance should be made when designing a terminal/regenerator section so as to permit unforseen conditions and events, such as upgrading of terminal equipment, rerouting of traffic, restoration of services, and prevention of traffic saturation. If a known upgrade is planned in the design of an optical station/regenerator section, the required (global) parameters should be specified at the outset.

global dispersion coefficient. In an optical station/regenerator section, a value of an optical fiber chromatic dispersion coefficient that lies between the upper and lower limiting fiber global dispersion characteristics. The upper limit of the global fiber dispersion coefficient (psec/(nm-km)) is given by the relation

$$D_1(\lambda) = S_{o\ max}(\lambda - \lambda_{o\ min}{}^4/\lambda^3)/4$$

and the lower limit is given by the relation

$$D_2(\lambda) = S_{o\ max}(\lambda - \lambda_{o\ max}{}^4/\lambda^3)/4$$

where λ is the operating wavelength, $S_{o\ max}$ is the maximum worst-case zero-dispersion slope (psec/(nm^2-km)), $\lambda_{o\ min}$ is the minimum value of the zero-dispersion wavelength and $\lambda_{o\ max}$ is the maximum value of the zero-dispersion wavelength, the variation in values being caused by manufacturing tolerances, temperature, humidity, and aging.

Goos-Haenchen shift. The phase shift that occurs in a lightwave when it is reflected, the magnitude of the shift being a function of the incidence angle and the refractive-index gradient at the reflecting interface surface. This shift occurs to some degree with every internal reflection that occurs in an optical fiber. When total (internal) reflection occurs, the amount of phase shift in the direction of propagation can be precisely determined. The ray trajectory is changed from that which would be predicted from simple ray theory because of the penetration of the ray into the lower-refractive-index material of the cladding a short distance before it is turned completely from the incidence angle to the reflection angle. The ray trajectory is shifted in the direction of the fiber optical axis. If the refractive indices at the core-cladding interface were a perfect step function, that is, a step change in refractive index over zero distance, there would be no Goos-Haenchen shift. There would simply be Fresnel spectral reflection. Also see reflected ray.

graded-index (GI) fiber. An optical fiber with a core refractive index that is a function of the radial distance from the fiber optical axis, the refractive index becoming progressively lower as distance from the axis increases. This characteristic causes the light rays tending to leave the core to be continuously refracted, that is, redirected back into the core, thus forcing them to remain in the core.

graded-index profile. 1. In an optical fiber, a refractive-index profile in which the refractive index varies with the radial distance from the optical axis of the core. The refractive index decreases as the distance from the center increases. 2. The condition of having the refractive index vary continuously and smoothly between two extremes. 3. Any refractive-index profile that varies with radial distance. It is distinguished from a step-index profile, in which there is no variation of refractive index from the optical axis to the core-cladding interface.

grating. See diffraction grating.

grating sensor. See moving grating sensor.

Green interferometer. See Twyman-Green interferometer.

GRIN^R lens. See GRIN^R rod.

GRIN^R rod. A cylindrically-shaped rod, such as a short length of optical fiber, with a graded refractive-index profile parameter that will cause all light rays entering within a given acceptance cone to be focused at one point for a given operating wavelength. Thus, the GRIN^R also has the capability to collimate and focus a light beam emanating from a point source. The GRIN^R rod was developed by Bell Laboratories. The profile parameter is approximately 2, making the refractive index profile close to that of parabola. Synonymous with GRIN^R lens. Also see SELFOC^R lens; self-focusing fiber.

grooved cable. A fiber optic cable in which the optical fibers are fitted into grooves in a cylindrical element. Fiber optic cables with a large number of fibers can be produced by stranding two or more cylindrical elements together and sheathing or jacketing the whole assembly.

group delay. In optics, the time required for optical power propagating in a given mode at the modal group velocity to travel a given distance. For measurement purposes, the unit of interest is the group delay per unit length which is the reciprocal of the group velocity of the particular mode. The measured group delay per unit length of an optical signal through an optical fiber exhibits a wavelength dependence caused by the various dispersion mechanisms in the fiber. See multimode group delay. Also see Sellmeier equation.

group delay time. The rate of change of the total phase shift with angular frequency, that is, angular velocity, through a device or transmission system. Group delay time is the time interval that is required for the crest of a group of waves to propagate through a device or transmission facility or system where the component wave trains have slightly different individual frequencies. Any other significant instant or point in the wave may be chosen instead of the crest. Thus, there is a rate of change of the total phase shift with angular velocity through the device, facility, system, or component. The group delay time is expressed by the relation

$$t_g = \Delta\theta/\Delta\omega \quad \text{or } d\theta/d\omega$$

where θ is the phase shift angle and ω is the angular frequency, that is, the angular velocity. The group delay time has the units of time because θ is normally expressed in radians and ω in radians/second. The angular velocity is given as $\omega = 2\pi f$, where f is the frequency. The changes occur over the length of the propagation medium in the direction of propagation. Thus, for a wave of a certain frequency in a group of waves with different frequencies, the group delay time is the first derivative with respect to frequency of the phase shift between two given points in the propagating wave. In a transmission system where phase shift is proportional to frequency, the group delay time is constant.

group index (N). In fiber optics, for a given mode in an electromagnetic wave propagating in a given propagation medium, the group index, N is given by the relation

$$N = c/v_g$$

where c is the velocity of light in vacuum and v_g is the group velocity of the mode in the medium. For a plane wave, the group index for a given mode is given by the relation

$$N = n - \lambda(dn/d\lambda)$$

where n is the refractive index of the medium in which the wave is propagating and λ is the wavelength.

group velocity. The velocity of propagation of an envelope produced when an electromagnetic wave is modulated by, or mixed with, other waves of different frequencies. Ideally, the group velocity would be the velocity of a signal represented by two superimposed sinusoidal waves of equal amplitude and slightly different frequencies approaching a common limiting value. It is the velocity of information propagation, and loosely, of energy propagation. The modulating signal is considered the information bearing signal and the modulated signal is considered the carrier. Thus, the group velocity is the velocity of transmission of energy associated with a progressing wave consisting of a group of sinusoidal components, that is, the velocity of a certain feature of the wave envelope, such as the crest. The group velocity differs from the phase velocity. Only the latter varies with frequency. In general, the group velocity, represented by the relation

$$v_g = d\omega/d\beta$$

is less than the phase velocity, represented by the relation

$$v_p = \omega/\beta$$

where ω is the carrier angular velocity, $d\omega$ is the signal angular velocity, and β is the phase constant at the carrier frequency. βL is the carrier phase delay for a line L meters long. The angular velocity, that is the angular frequency, ω is again $2\pi f$, where f is the frequency. The group velocity is also equal to the rate at which frequency changes with respect to the reciprocal of the wavelength. In nondispersive media, the group velocity and the phase velocity are equal if the phase constant is a linear function of the angular velocity. In a waveguide, each mode has its own group velocity. Also see phase velocity.

guided mode. See bound mode.

guided ray. In an optical waveguide, a ray that is confined to the core or is bound to a mode in the core. Specifically for an optical fiber, a ray at a given radial position having a direction that satisfies the relation

$$0 \leq \sin \theta_r = [n_r^2 - n_a^2]^{1/2}$$

where r is the radial distance of the ray from the optical axis, θ_r is the angle that the ray makes with the optical axis at the radial position r, n_r is the refractive index at the radial position r, and n_a is the refractive index at the core radius, that is, at the core-cladding interface. Synonymous with bound ray; trapped ray.

guided wave. A wave whose energy is confined between surfaces, or in the vicinity of surfaces, of materials because of specific properties of the materials. In guided electromagnetic waves, wave energy is concentrated near interfaces, that is, near boundaries or between substantially parallel boundaries separating materials of different properties and whose direction of propagation is effectively parallel to these boundaries. A guided electromagnetic wave may consist of several bound modes. Also see bound mode.

guiding fiber. See weakly guiding fiber.

gyroscope. See fiber optic gyroscope (FOG).

H

h. The symbol used to represent Planck's constant.

hard-clad silica (HCS) fiber. An optical fiber with a silica (glass) core and a hard polymer (plastic) cladding bonded to the core.

half-duration. See pulse half-duration.

half-maximum. See full-duration half-maximum (FDHM); full-width half-maximum (FWHM).

half-power point. See full-wave half-power point.

halide glass. A special glass, containing halogens, such as fluorine, in combination with heavy metals, such as zirconium, barium, or hafnium, that transmits light in the visible and infrared spectra of the electromagnetic spectrum, such as wavelengths up to 7 μ (micron). Applications include remote sensing systems, night-vision devices, and fiber optic systems. Halide glasses have a potential ultra-low loss fiber optical attenuation rate of 10^{-3} dB/km (decibels/kilometer), making them particularly attractive for long-distance repeaterless communication links.

hardness. See nuclear hardness; radiation hardness.

harmonic distortion. See total harmonic distortion.

harness. See optical harness.

harness assembly. See optical harness assembly.

hazard. See optical fiber hazard.

H-bend. A gradual change in the direction of the axis of a waveguide throughout which the axis remains in a plane parallel to the direction of the magnetic vector (H) transverse polarization. Synonymous with H-plane bend. Also see E-bend.

HCS fiber. See hard clad silica (HCS) fiber.

HDTV system. High-definition television system.

heavy-duty connector. In fiber optics, a connector that is designed and intended from use outside of an interconnection box (distribution box) or cabinet.

helical polarization. See left-hand helical polarization; right-hand helical polarization.

Helmholtz equations. The set of equations that describe uniform plane-polarized electromagnetic waves in an unbounded, lossless, that is, nonabsorptive, source-free propagation medium, such as an optical fiber, when (1) the wave equations are expressed in Cartesian, that is, rectangular, coordinates, (2) the components of the electric and magnetic fields in the direction of propagation are identically equal to zero, and (3) the transverse first derivatives $\partial/\partial x$ and $\partial/\partial y$ when the wave is propagating in the z-direction are also identically zero. The Helmholtz equations are given by the relations

$$d^2E_x/dz^2 - \Gamma^2 E_x = 0 \qquad d^2E_y/dz^2 - \Gamma^2 E_y = 0$$

$$d^2H_x/dz^2 - \Gamma^2 H_x = 0 \qquad d^2H_y/dz^2 - \Gamma^2 H_y = 0$$

where E is the scalar electric field strength component and H is the scalar magnetic field strength component in the direction indicated by the subscript for a wave propagating in the z-direction. Γ is given by the relation

$$\Gamma^2 = j\omega\mu(\sigma + j\omega\epsilon) = -\omega^2\mu\epsilon + j\omega\mu\sigma$$

where j is $-1^{1/2}$, ω is the angular velocity, μ is the magnetic permeability, ϵ is the electric permittivity, and σ is the electrical conductivity. Thus, Γ^2 is a complex function. For dielectric materials, such as the glass used in dielectric waveguides, $\mu = 1$ and $\sigma = 0$. These equations apply to propagation in optical elements under certain geometrical conditions. These equations are solutions of the vector Helmholtz equations given by the relations

$$\nabla^2 E - \Gamma^2 E = 0 \qquad \nabla^2 H - \Gamma^2 H = 0$$

where ∇ is the spatial derivative used in the vector algebra and Γ is as above.

Hertzian wave. An electromagnetic wave that has a frequency lower than 3,000 GHz (gigahertz), that is, 3×10^{12} Hz, and is propagated in free space, that is, without a waveguide, e.g., radio waves. Lightwave frequencies are about 3×10^{14} hertz. Hertzian waves and lightwaves are electromagnetic.

heterodyne. The process of combining two electromagnetic waves of different frequency in a nonlinear device in order to produce frequencies that are equal to the sum and difference of the combining frequencies. See self-heterodyne. Also see homodyne.

heterojunction. A semiconductor p-n junction in which the two regions differ in conductivity, because of their different dopant levels, and differ in their atomic compositions. In heterojunction transistors, diodes, and lasers, a sudden transition occurs in material composition across the junction boundary, such as a sudden change in refractive index or a transition from p-type, that is positively-doped, to n-type, that is, negatively-doped, material. See single heterojunction. Also see homojunction.

high-birefringence fiber. An optical fiber in which the polarization beat length is 1 mm (millimeter) or less. The beat length, L_B, is given by the relation

$$L_B = 2\pi/(\beta_x - \beta_y)$$

where β_x and β_y are the propagation constants of the two polarized waves caused by the birefringence of the fiber. Thus, the propagation constant difference is large. High-birefringence fiber is designed for applications in which a stable polarization state is important and must be maintained. Also see birefringence; low-birefringence fiber.

high-definition television (HDTV) system. A television system with more than two times the resolution of the existing National Television Standards Code (NTSC) published by the National Television Standards Committee (NTSC) for North America, with 1,125 horizontal scan lines and a wider screen. Fiber optic cables have the broader bandwidth required for over 100 HDTV station channels, with bandwidth to spare for an integrated services data network (ISDN) including optical fiber in the local loop. HDTV systems are not compatible with conventional systems and would render them obsolete. See advanced television system; enhanced-definition television (EDTV) system; improved-definition television (IDTV) system.

high-order mode. In an electromagnetic wave propagating in a waveguide, a mode corresponding to the larger eigenvalue solutions to the wave equations, regardless of whether it is a mode in a transverse electric (TE), transverse magnetic (TM), or transverse electromagnetic (TEM) waves. Thus, it is a mode in which more than just a few whole wavelengths of the wave fit transversely in the guide and therefore can be supported by the guide. A multimode fiber supports as many modes as the core diameter, numerical aperture, and wavelength permit. For the high-order modes, the v-parameter value must be above 4 in order that the number of modes be sufficiently high for there to be high-order modes. In a fiber supporting a single-mode, there are no high-order modes. Conceptually, however, if there are only two modes, one could be considered the low-order mode and the other the high-order mode. Also see low-order mode.

high-pass filter. A filter that passes frequencies above a given frequency and attenuates all others.

holding parameter. See polarization-holding parameter.

homodyne. Pertaining to the process of combining two waves, such as electromagnetic waves, of the same frequency. For example in fiber optics, pertaining to detection based on the use of only one frequency, such as monochromatic light, to achieve detection. The light is launched into a length of optical fiber. The baseband signal, that is, the parameter being detected, varies the length of the fiber thus shifting the phase of the output wave. The output wave is combined with the original wave with a beam splitter and sent to a photodetector. Shifting the phase of one wave relative to the other causes the combined-wave intensity at the photodetector to vary as the amount of cancellation and reinforcement of the two waves vary. Thus, the photocurrent amplitude will be a function of the phase shift, which in turn is a function of the baseband signal that is modulating the length of the fiber. If the relative phase shift varies through many cycles, the photodetector photocurrent frequency will be proportional to the rate of change of phase shift. Calibration enables measurement of any physical parameter that changes the length of the fiber, such as a sound wave, pressure, force, magnetostriction, or displacement. Another example of homodyning pertains to a system of suppressed carrier radio reception in which the receiver generates a voltage having the original carrier frequency and combines it with the incoming signal (zero-beat reception). Also see heterodyne; homodyne detection; self-heterodyne.

homodyne detection. Detection, that is, demodulation, using techniques that depend on the mixing two signals of the same frequency to obtain the baseband signal. Also see homodyne.

homogeneous cladding. Cladding in which the refractive index has the same value everywhere. An optical fiber may have several homogeneous claddings, each having a different refractive index.

homojunction. A semiconductor p-n junction in which the two regions differ in electrical conductivity because of their different dopant levels while their atomic compositions are the same. Also see heterojunction.

hopping. See mode hopping.

housing. See fiber splice housing.

h-parameter. See polarization-holding parameter.

H-plane bend. See H-bend.

h-value. See polarization-holding parameter.

hybrid. In electrical, electronic, fiber optic, or communications engineering, pertaining to a device, circuit, apparatus, or system made up of two or more components, each of which is normally used in a different application and not usually combined in a given requirement. Some examples of hybrid systems include a cable containing optical fibers and electrical wires, an electronic circuit having both vacuum tubes and transistors; a mixture of thin-film and discrete integrated circuits; a computer that has both analog and digital capabilities; and a transformer, or a combination of transformers and resistors, affording paths to three branches, that is, circuits A, B, and C, so arranged that A can send to C, B can receive from C, but A and B are effectively isolated.

hybrid cable. In fiber optics, a cable that contains optical fiber and electrical conductors.

hybrid connector. In fiber optics, a connector that contains optical fiber and electrical conductors.

hybrid mode. In an electromagnetic wave propagating in a waveguide, a mode that has components of both the electric and magnetic field in the direction of propagation. In fiber optics, hybrid modes correspond to skew, that is, nonmeridional, rays.

hydroxyl ion absorption. The absorption of electromagnetic waves, particularly lightwaves in optical glass, caused by the presence of trapped hydroxyl ions remaining from water as a contaminant. The hydroxyl ion can penetrate glass during and after product fabrication, such as while an optical fiber is being drawn, after it has been wound on a spool, after it has been cabled, during storage, and during operational use.

hypodermic fiberscope. A fiberscope consisting of a light source for illumination; one or more optical fibers, say of the order of a total of 4 to 8 μ (micron) in diameter for forward transmission of the illumination for the object field and backward transmission of the light reflected from the object; and a device for displaying the reflected image from subcutaneous tissue.

I

identification. See equipment identification.

IDTV system. Improved-definition television system.

ILD. Injection laser diode.

illumination. See fiber optic flood illumination; fiber optic spot illumination.

illuminator. See fiber optic illuminator.

IM. Intensity modulation.

imagery. The representation of objects reproduced electronically or by optical means on film, electronic display devices, fiber optic display devices, or other media.

imaging. The sensing of real objects, or representations of objects, followed by their representation by optical, electronic, or other means, on a film, screen, plotter, cathode ray tube, thin-film electroluminescent (TFEL) display panel, or other device. Aligned bundles of optical fibers may be used for imaging. Imaging photon-counting detector systems can produce images of objects by scanning and counting photons over a shorter time period than even the fastest photographic films, such as 20 photons/msec for 2 minutes compared to 14 hours of exposure on the ASA 400 photographic film to produce the same quality image of the same object illuminated at an extremely low irradiance level.

imaging system. A display system capable of forming images of objects. Examples of imaging systems include lens systems, optical fiber systems, computer-controlled CRT or fiberscope terminals, film systems, video tape systems, and *thin-film electroluminescent* (TFEL) systems.

impedance. See characteristic impedance; transimpedance; wave impedance.

***improved-definition television* (IDTV) *system*.** A television system in which improvements in conventional-system performance and picture definition are made that do not make existing receivers and other equipment obsolete. These improvements are considered as compatible improvements. See advanced television system; enhanced-definition television (EDTV) system; high-definition television (HDTV) system.

impulse response. The response of a device after a delta-function, such as a step voltage or step optical signal, is applied to its input. The impulse response is the inverse Laplace or Fourier transform of the transfer function, that is, the output function is determined by the transfer function operating upon the input function.

impulse response function. The function, h(t), that describes the response of an initially relaxed system after a Dirac-delta (step) function is applied at time t = 0. The root-mean-square (rms) duration of the impulse response may be used to characterize a component or system by means of a single parameter rather than a function. The rms value of the impulse response function, σ_{rms}, is given by the relation

$$\sigma_{rms} = [1/M_0 \int_{-\infty}^{+\infty} (T - t)^2 h(t)dt]^{1/2} \text{ where}$$

$$M_0 = \int_{-\infty}^{+\infty} h(t)dt \text{ and } T = 1/M_0 \int_{-\infty}^{+\infty} th(t)dt.$$

The impulse response may be obtained by deconvolving (deriving) the input waveform from the output waveform, or as the inverse Fourier transform of the transfer function. Also see root-mean-square (rms) pulse broadening; root-mean-square (rms) pulse duration; root-mean-square (rms) deviation; spectral width.

incandescence. The emission of light by thermal excitation, which brings about energy level transitions that produce sufficient quantities of photons with sufficient energies to render the source of radiation, or the radiation itself, visible.

incidence. See normal incidence.

incidence angle. The angle between a ray striking a surface, such as a reflecting or refracting surface, and the normal to the surface at the point where the ray strikes the surface.

inclusion. In optical glass, a particle of foreign or extraneous matter, such as an air bubble or speck of dust, including undesirable impurities, such as hydroxyl or iron ions; usually an impurity. Dopants used to achieve desired refractive index profiles are normally not considered as inclusions.

incoherent bundle. See unaligned bundle.

incoherent radiation. Radiation that has a low coherence degree.

index. See absorption index; group index (N); refractive index; relative refractive index.

index contrast. See refractive-index contrast.

index difference. See ESI refractive-index difference.

index dip. See refractive-index dip.

index-matching material. Transparent material, that is, light-transmitting material, with a refractive index such that when used in intimate contact with other transparent materials, radiant power loss is reduced at interfaces by reducing reflection, increasing transmission, avoiding scattering, and reducing dispersion. For example, a liquid or cement whose refractive index is nearly equal to that of the core of an optical fiber, used to reduce Fresnel reflections from the fiber end-face. Also see antireflection coating.

index of refraction. See refractive index.

index profile. See graded-index profile; linear refractive-index profile; parabolic refractive-index profile; power-law refractive-index profile; radial refractive-index profile; refractive-index profile; step-index profile.

index profile parameter. See refractive index-profile parameter.

index template. See four-concentric-circle refractive-index template.

indirect wave. A wave, such as a lightwave, radio wave, or sound wave, that arrives at a point in a propagation medium by reflection or scattering from surrounding objects or surfaces, such as a mountain for sound waves, a steel structure for radio waves, and a refractive-index interface surface for lightwaves.

induced attenuation. The increase in attenuation in a component or system, or the increase in attenuation rate, caused by external factors, such as environmental changes, mechanical treatment, and immersion in fluids over and above the attenuation, or attenuation rate, measured before the external factors were applied to the component or system. When fiber optic components, such as optical fibers and fiber optic connectors, splices, and couplers, are tested, the induced attenuation, or attenuation rate, is determined by measuring the attenuation, or attenuation rate, before and after the test. Synonymous with change in transmittance; transmittance change. Also see fiber optic dosimeter.

induced modulation. See mechanically-induced modulation.

information descriptor. See receiver information descriptor; transmitter information descriptor.

information payload capacity. See payload rate.

information rate. See system information rate.

infrared (IR). Pertaining to electromagnetic radiation in the range of frequencies that extends from the longest wavelength of the visible red region of the spectrum to the radio wave region, the frequency being lower and the wavelength longer than visible red. The band of IR lies between the longest wavelength of the visible spectrum, about 0.8 μ (micron) and the shortest radio waves, about 100 μ. The IR region of the spectrum is often divided into near IR, 0.8-3; middle IR, 3-30; and far IR, 30 to 100 μ. See far infrared; middle infrared; near infrared.

injection fiber. See launching fiber.

injection laser diode (ILD). See laser diode.

injection-locked laser. A laser whose peak spectral wavelength, that is, peak intensity emission wavelength, is controlled by the injection of a separate optical signal from a different source or from an optical signal reflected from an external mirror.

input. See maximum receiver input.

input power. See optical receiver maximum input power.

insert. In a fiber optic connector, the portion of the connector that contains the precision alignment components.

insertion loss. 1. In an optical system, the radiant power loss caused by absorption, scattering, diffusion, leaky waves, dispersion, microbends, macrobends, reflection, radiation, or other causes when an optical component is inserted into the system, such as when a fiber optic connector or splice is inserted in a fiber optic cable. 2. In a fiber optic transmitter for an optical link, the radiant power lost at the point where the light source output is coupled into the optical fiber, that is, coupled into the optical fiber pigtail. Also see launch loss; transmission loss.

inside vapor deposition (IVD). In the production of optical fiber preforms, the deposition of dopants on the inside of a rotating glass tube, called a bait tube, which is then sintered to produce a doped layer of higher refractive-index glass on the inside. A solid optical fiber is then pulled from the tube as part of the fiber drawing process.

inside vapor-phase oxidation (IVPO) process. A chemical vapor-phase oxidation (CVPO) process for production of optical fibers, in which dopants are burned with dry oxygen mixed with a fuel gas to form an oxide stream, that is, a soot stream. The stream is deposited on the inside of a rotating glass tube, called a bait tube, and then sintered to produce a doped layer of higher refractive-index glass on the inside for forming the core. A solid optical fiber is then pulled from the tube as part of the fiber-drawing process.

inspection lot. A group of units of a given product, taken at random from a given production run in which all units were produced under the same conditions, from which a sample, consisting of one or more units, is to be taken and inspected to determine conformance with acceptability criteria. The number of units in the inspection lot, and the number of units to be randomly selected from the inspection lot for testing, depends on the number of units being acquired or purchased.

instant. See significant instant.

integrated fiber optic communication system. A communication system or network consisting of fiber optic links connected to other types of links, such as wire and microwave links.

integrated optical circuit (IOC). A circuit, or group of interconnected circuits, either monolithic or hybrid, consisting of miniature solid-state active and passive optical, electrical, electrooptic, or optoelectronic components, such as light-emitting diodes (LED); optical filters; photodetectors; memories; differential amplifiers; logic gates, such as AND, OR, NAND, NOR, NEGATION gates; and thin-film optical waveguides, usually on semiconductor or dielectric substrates, used for signal processing.

integrated optics. The branch of science and technology devoted to the interconnection of miniature optical components via optical waveguides on transparent dielectric substrates, such as lithium niobate and titanium-doped lithium niobate, to make integrated optical circuits (IOCs). Integrated optics includes the design, development, and operation of circuits that apply the technology of integrated electronic circuits produced by planar masking, etching, evaporation, and crystal film growth techniques to microoptic circuits on a single planar dielectric substrate. Thus, a combination of electronic circuitry and optical waveguides are produced for performing various communication, switching, and logic functions, including amplification, gating, modulating, light generation, photodetecting, filtering, multiplexing, signal processing, coupling, and storing.

integrated receiver. See monolithic integrated receiver; PIN-FET integrated receiver.

integrated services digital (or data) network (ISDN). A communication network capable of providing video, voice, digital, and analog data transmission and interconnection services over a single transmission medium, such as a network in which optical fiber is used for local loops, local area networks (LANs), metropolitan area networks (MANs), and long-haul trunks between switching centers. For example, one single-mode optical fiber in the local loop to home or office could handle all forms of signals and many different user end-instruments because of the wideband capability of the fiber, such as 60 analog video channels, or, for 100-Mbps FSK digital data signaling with 200 MHz spacing, a carrier/noise ratio of 16 dB, a BER of 10^{-9}, and modulation of a laser source with a 4-GHz signal at frequencies between 2 and 6 GHz, integrated services on the single fiber can be all of (1) 50 analog broadcast-quality video channels: 2 GHz; (2) 4 HDTV channels, FM modulation: 800 MHz; (3) 4 switched-video channels, digital: 800 MHz;

(4) 25 digital audio channels: 200 MHz; and (5) voice, data, and other services channels: 200 MHz. The bandwidths needed for each service group sum to 4 GHz.

intensity. See radiant intensity.

intensity modulation (IM). Variation of the power level of an optical carrier in accordance with a modulating signal. IM can be achieved several ways, including direct modulation of a light source and modulation of the carrier after launching. Intensity modulation is similar to amplitude modulation of a radio frequency carrier.

interconnect feature. See optical cable interconnect feature.

interconnection. See fiber optic interconnection; Open Systems Interconnection (OSI).

interconnection box. See fiber optic interconnection box.

interface. 1. A concept involving the interconnection between two devices or systems. The definition of the interface includes the type, quantity, and function of the interconnecting circuits and the type and form of signals to be interchanged via those circuits. Mechanical details, such as details of plugs, sockets, and pin numbers, may be included in the interface definition. 2. A shared boundary, such as the boundary between two subsystems or two devices. 3. A boundary or point common to two or more similar or dissimilar command and control systems, subsystems, or other entities at, against, or through which information flow takes place. 4. A boundary or point common to two or more systems or other entities across which useful information flow requires the definition of the interconnection of the systems which enables them to interoperate. 5. The process of interrelating two or more dissimilar circuits or systems. 6. In telephone networks, the point of interconnection between terminal equipment and telephone company communication facilities.

interface device. See network interface device.

interface rate. The gross bit rate of an interface after all processing is completed, for example, the actual bit rate at the boundary between the physical layer and the physical medium.

interface standard. See fiber distributed data interface (FDDI) standard.

interference. 1. The phenomenon that occurs when two or more coherent waves are superimposed so that they form beats in time or patterns in space. 2. Noise induced in a system by another system. See intersymbol interference.

interference filter. An optical filter that consists of one or more thin layers of dielectric or metallic material and whose operation is based on interference effects. Synonymous with multilayer filter.

interferometer. An instrument in which the interference of lightwaves is used for making measurements. See Twyman-Green interferometer.

interferometric sensor. In fiber optics, a sensor in which a single coherent narrow-spectral-width beam is divided into two or more beams. The individual beams are subjected to the various environments or stimuli that are being sensed, then recombined with the original beam so that cancellation and enhancement vary as the phases of the waves are shifted relative to each other, resulting in a modulation of irradiance, that is, light intensity, incident upon a photodetector. Optical fibers are used to convey the light beams. Usually there is a sensing leg and a reference leg, the outputs of which are combined to develop the intensity variation. The sensing leg is exposed to the physical variable being sensed, while the reference leg is protected from the stimulating physical variable. The sensor will still perform properly if both legs are equally exposed to another physical variable not being sensed.

interferometry. The branch of science and technology devoted to measurements involving the interaction of waves, such as the interaction between electromagnetic waves, such as lightwaves. Lightwaves can be made to interact so as to produce various spatial, time-domain, and frequency-domain light energy distribution patterns. Modulation of these variations can be used in fiber optic sensors. See slab interferometry; transverse interferometry.

intermediate-field region. Relative to a source of electromagnetic radiation, the region between the near-field and the far-field regions.

intermodal distortion. See multimode distortion.

intermodal dispersion. See modal dispersion.

internal photoelectric effect. The changes in characteristics of a material that occur when incident photons are absorbed by the material and excite the electrons in the various energy bands in the molecules composing the material. Characteristic changes include changes in electrical conductivity, photosensitivity, and electric potential development. For example, electrons may move from a valence band to a conduction band when the material is exposed to radiation.

internal photoeffect detector. A photodetector in which incident photons raise electrons from a lower to a higher energy state, resulting in an altered state of the electrons, holes, or electron-hole pairs generated by the transition, which is then detected. The effect is used in photodetectors to detect signals at the end of an optical fiber.

internal reflection. In an optical element in which an electromagnetic wave is propagating, a reflection at an outside surface toward the inside such that a wave that is incident upon the surface is reflected wholly or partially back into the element itself. Optical fibers depend on total (internal) reflection at the core-cladding interface for successful transmission of lightwaves by confining enough of the transmitted energy to the core all the way to the end of the fiber.

internal reflection sensor. See frustrated total internal reflection sensor.

intersymbol interference. Extraneous energy from a signal in one or more keying intervals, that is, temporal or spatial separation between corresponding points on two consecutive pulses, that tends to interfere with the reception of the signal in another keying interval, or the disturbance that results therefrom. In fiber optics, intersymbol interference can occur when dispersion causes pulse broadening, that is, spreading in time and space along the fiber, as it propagates, resulting in pulse overlap that might be so large that a photodetector can no longer distinguish clear boundaries between pulses. When this occurs to a sufficient degree in digital data systems, the bit error ratio (BER) may become excessive. If the spread is too much, the data signaling rate (DSR) has to be reduced so as to provide more time, or space, between pulses.

interval. See Nyquist interval.

intramodal dispersion. See material dispersion.

intramodal distortion. Distortion caused by dispersion, such as material or profile dispersion, of a specific propagating mode, for example, distortion resulting from dispersion of group velocity of a propagating mode. Intramodal distortion is the only form of modal distortion that can occur in a single-mode fiber.

intrinsic coupling loss. In fiber optics, the coupling insertion loss caused by optical fiber parameter mismatches when two dissimilar fibers are joined. Synonymous with intrinsic joint loss. Also see extrinsic coupling loss.

intrinsic joint loss. See intrinsic coupling loss.

intrinsic quality factor (IQF). In fiber optics, a factor that indicates the quality of a multimode optical fiber referenced to the intrinsic splice loss. The IQF can be used as an alternative to specifying precise requirements of refractive index profile characteristics, such as core diameter, numerical aperture, concentricity errors, and core noncircularity by simply requiring that fibers meet an average intrinsic splice loss. This approach allows simultaneous parameter deviations to compensate for each other in terms of the measured intrinsic splice loss.

inversion. See population inversion.

IOC. Integrated optical circuit.

ion absorption. See hydroxyl ion absorption.

ion exchange process. In fiber optics, a graded-index optical fiber manufacturing process in which the fiber is fabricated by replacing undesirable ions with desirable ions in order to achieve the desired composition and structure of the material used to fabricate the fiber.

ion laser. A laser using ionized gases, such as argon, krypton, and xenon to produce lasing action.

IQF. See intrinsic quality factor (IQF).

IR. Infrared.

irradiance. 1. The optical energy per unit of time transmitted by a light beam through a unit area normal to the direction of propagation or the direction of maximum power gradient, expressed in watts per square meter or joules per second-(square meter), joules per cubic meter, or lumens per square meter, that is, it is the electromagnetic radiant power per unit area incident upon a surface. If the radiant power is incident upon a surface, the amount of radiant power distributed per unit area of the surface is the irradiance. Thus, the radiant power in a beam is the total power obtained by integrating the irradiance over the cross-sectional area of the beam. If the radiant power in a beam is distributed uniformly over the cross-sectional area of the beam, the irradiance is the radiant power divided by the cross-sectional area, which is also the average irradiance. For an electromagnetic wave propagating in a vacuum or a material medium, the radiant power per unit transverse area propagating in the direction of maximum power gradient is also the irradiance, that is, the power density, which is usually expressed in watts per square meter. Because the wave is propagating with a velocity given by the relation

$$v = c/n$$

where c is the speed of light in a vacuum and n is the refractive index of the material at the point at which the speed is being considered, the irradiance can also be expressed in terms of the energy per unit volume of vacuum or propagation medium, expressed as joules per cubic meter, hence giving rise to the term energy density. 2. Radiant power per unit area passing through free space or a material medium in a direction perpendicular to the unit area, that is, in the same direction as the unit area vector. In an electromagnetic wave, the power flow rate, a vector quantity, propagates in a specific direction at a particular point in a propagation medium. Therefore, for an electromagnetic wave, the irradiance may be expressed (1) as the energy per unit time, that is, the power, passing through a unit cross-sectional area that is perpendicular to the direction of propagation of the wave, (2) as the scalar energy per unit volume contained in an electromagnetic wave propagating in a propagation medium, and (3) as visible radiation, that is, as the lumens per square meter of area perpendicular to the direction of propagation. All three dimensional concepts give rise to the term "power density". Irradiance, or power density, usually diminishes with distance from the source, due to absorption, dispersion, diffusion, deflection, reflection, scattering, refraction, diffraction, and geometric spreading. Irradiance is a point function. It can be increased at a point by causing convergence of waves, such as might be accomplished by means of a convex lens or concave mirror or reflecting antenna, that is, a dish. A convex lens only a few centimeters in diameter and less than a centimeter thick can increase the irradiance of solar radiation, that is, sunlight, when focused at a point on the surface of a combustible material, to a level high enough to ignite the material, but the radiant power entering the lens and incident on the surface is the same. Synonymous (colloquial) with power density. See spectral irradiance. Also see radiance; radiant power.

irradiation. The product of irradiance and time, that is, the radiant energy received per unit area during a given time interval.

ISDN. Integrated services digital network.

isochrone. A line on a map or chart joining all points associated with a constant propagation time from the transmitter or source.

isolation. In a fiber optic coupler, the extent to which optical power from one signal path is prevented from reaching another signal path. For example, path A is considered to be isolated from path B if the amount of optical power from path B coupled into path A is zero or extremely small compared to the power levels involved.

isolator. See fiber optic isolator; optical isolator; waveguide isolator.

isotropic. Pertaining to material whose properties, such as electric permittivity, magnetic permeability, and electrical conductivity, are the same regardless of the direction in which they are measured, that is, their spatial derivatives are zero in all directions. Therefore, an electromagnetic wave propagating in the material will be affected in the same way no matter what the direction of propagation and direction, or type, of polarization of the wave. Also see anisotropic; birefringent medium.

isotropic propagation medium. Pertaining to a material medium in which properties and characteristics of the medium are everywhere the same in reference to a specific phenomenon, such as a medium whose electromagnetic properties, such as the refractive index, at each point are independent of the direction of propagation and polarization of a wave propagating in the medium.

isotropic source. A theoretical antenna, such as a light source or radio antenna, that radiates with equal irradiance, that is, with equal power density or equal field intensity, in all directions. It can only be approximated in actual practice. However, it is a convenient conceptual reference for comparing and expressing the directional properties of actual sources.

IVD. Inside vapor deposition.

J

jacket. See cable bundle jacket; optical fiber jacket.

jacket leak. A measure of the imperviousness of a fiber optic cable jacket, determined by such techniques as the water-submerge-and-vacuum method and the gas-detection-and-vacuum method.

jacketed cable. See tight-jacketed cable.

joint. See multifiber joint.

jitter. 1. The variation in time or space of a received signal compared to the instant or point of its transmission or to a fixed time frame or point at the receiver. Sources of jitter include signal-pattern-dependent laser turn-on delay, noise induced at a gating turn-on point, gating hysteresis, and variations in signal delay that accumulate on a data link caused by cable vibration. The signal variations are usually abrupt and spurious. They include time and spatial variations in length, amplitude, spacing, or phase of successive pulses. Because the jitter may occur in time, amplitude, frequency, phase or other signal parameter, there should be an indication of the measure of jitter, such as average, rms, peak-to-peak, or maximum jitter. 2. Rapid or jumpy undesired movement of display elements, display groups, or display images about their normal or mean positions on the display surface of a display device. For example, movement of a display image on the fiber faceplate of a fiberscope when the image source at the objective end of the aligned bundle of optical fibers is vibrated relative to the aligned bundle, or the movement of an image on the screen of a CRT when the bias voltage on the deflecting plates oscillates at say 5 to 10 Hz. If the jitter rate is above 15 Hz, or if the persistence of the screen is long, the jitter will cause the image to appear blurred because of the persistence of vision. See longitudinal jitter; phase jitter; pulse jitter; time jitter. Also see phase perturbation; swim.

Johnson noise. See thermal noise.

joint. See fiber optic rotary joint.

jumper. See fiber optic jumper.

junction. 1. An optical interface. 2. In a semiconducting material, such as that used in a transistor, diode, or laser, the contact interface between two regions of different semiconducting material, for example, the interface between n-type material, which is negatively doped and therefore donor material, and p-type material, which is positively doped and therefore acceptor material; or between n-type material and intrinsic material. At a junction, a voltage, that is, an electrical potential gradient or energy barrier, occurs because of the migration of electric charges (holes or electrons) to the junction and the accumulation of unlike charges on either side of the junction. See heterojunction; homojunction; optical fiber junction; optical junction; p-n junction; single heterojunction.

K

k. 1. The symbol used to represent Boltzmann's constant. 2. The symbol used to represent the wave number of an electromagnetic wave.

Kerr cell. A substance, usually a liquid, whose refractive index changes in direct proportion to the square of the applied electric field strength. The substance is configured so as to be part of another system, such as part of the optical path of another system. The cell thus provides a means of modulating the light in the optical path. The device is used to modulate light passing through a material. The modulation depends on the rotation of the polarization plane caused by the applied electric field. The amount of rotation determines how much of a beam can pass through a fixed polarizing filter. Also see Pockels cell.

Kerr effect. The creation of birefringence in a material that is not normally birefringent by subjecting the material to an electric field. The degree of birefringence, that is, the difference in refractive indices for light of orthogonal polarizations, is directly proportional to the square of the applied electric field strength. Thus, the effect is a polarization-plane rotation that can be used with polarizers to modulate light, such as to modulate the irradiance of light incident upon a photodetector. Also see Pockels effect.

Kerr-effect sensor. A fiber optic birefringent sensor in which the phase of the induced ordinary ray can be advanced or retarded relative to the phase of the extraordinary ray when an electric field is applied. The electric field causes double refraction, that is, an incident beam of light is divided into two beams that propagate at different phase velocities, resulting in a rotation of the polarization plane. The amount of phase shift is directly proportional to the square of the applied voltage, and the direction of shift depends on the polarity of the applied voltage.

knife-edge effect. The transmission of electromagnetic waves into the line-of-sight shadow region caused by the diffraction that occurs because of an obstacle in the path of the waves, such as a sharply-defined mountain top. The deflection of a light beam caused by a diffraction grating is an example of a multiplicity of knife-edge effects.

L

lambert. A unit of luminance equal to $10^4/\pi$ ca/m² (candela/square meter). The SI (Systemè International) unit of luminance is the lumen per square meter. 4π lumens of light flux emanate from 1 candela.

Lambertian radiator. A radiator or source of radiation in which the radiation is distributed angularly according to Lambert's cosine law. Synonymous with Lambertian source.

Lambertian reflector. A reflector of radiation in which the radiation is distributed angularly according to Lambert's cosine law.

Lambertian source. See Lambertian radiator.

Lambert's cosine law. The radiance of certain idealized surfaces is independent of the angle from which the surface is viewed. According to this law, the energy emitted in any direction by an electromagnetic radiator is proportional to the cosine of the angle that the selected direction makes with the normal to the emitting surface, given by the relation

$$N = N_o \cos A$$

where N is the radiance, N_o is the radiance normal to the emitting surface, and A is the angle between the viewing direction and the normal to the emitting surface. Emitters that radiate according to this law are certain highly-diffuse radiators or scatterers called Lambertian radiators or sources. Synonymous with cosine emission law; Lambert's emission law.

Lambert's emission law. See Lambert's cosine law.

Lambert's law. In the transmission of electromagnetic radiation, such as light, when propagating in a scattering or absorptive medium, the internal transmittance is given by the relationship

$$T_2 = T_1^{d2/d1}$$

where T_2 is the unknown internal transmittance of a given thickness d_2, and T_1 is the known transmittance of a given thickness d_1.

LAN. See local area network (LAN).

laser. A device that produces a high irradiance, that is, a high-intensity, narrow-spectral-width, coherent, highly-directional, that is, near-zero-divergence, beam of light by stimulating electronic, ionic, or molecular transitions to higher energy levels and allowing them to fall to back to lower energy levels, thus producing a stream of photons of various discrete energy levels. The lasing action is produced by population inversion. See atmosphere laser; atomic laser; fiber laser; injection-locked laser; ion laser; liquid laser; mixed-gas laser; molecular laser; multiline laser; multimode laser; tunable laser. Also see light amplification by stimulated emission of radiation (laser).

laser beam. A collimated, highly-directional beam of narrow-spectral-width light, that is monochromatic light, with near-zero divergence and exceptionally-high irradiance, that is, power density, emitted from materials that are undergoing lasing action.

laser chirp. A form of laser instability in which the nominal central wavelength of the spectral emission of the laser is shifted during a single light pulse.

laser diode. A laser in which stimulated emissions of coherent light occur at a p-n junction. The laser diode operates as a laser producing a monochromatic light modulated by insertion of carriers across a p-n junction of semiconductor materials. It has a narrower spatial and wavelength emission characteristic needed for the higher data-signaling-rate (DSR) systems than the light emitting diodes (LED). The LEDs are more useful for large-diameter, large-numerical-aperture optical fibers that operate at lower frequencies. Synonymous with diode laser; injection laser diode; semiconductor laser. See stripe laser diode.

laser medium. See active laser medium.

lasing. A phenomenon occurring when resonant frequency-controlled energy is coupled to a specially-prepared material, such as uniformly-doped semiconductor crystals that have free-moving or highly mobile loosely-coupled electrons. As a result of resonance and the imparting of energy by collision or close approach, electrons are excited to high energy levels. When the electrons move to lower levels, quanta of high-energy radiation is released as coherent lightwaves. The action takes place in a laser. In addition to certain semiconductors and crystals, gases, such as helium, neon, argon, krypton, and carbon dioxide; and liquids, such as organic and inorganic dyes, can also be made to undergo lasing action.

lasing condition. See prelasing condition.

lasing threshold. The lowest excitation input electrical power level at which the optical power output of a laser is primarily caused by stimulated emission rather than a form of spontaneous emission.

latching. A switch actuation method that requires a specific signal to place the switch in a position where it remains until another actuating force or signal is applied. Also see nonlatching.

latching switch. In fiber optics, a switch that will selectively transfer optical signals from one optical fiber to another when an actuating force or signal is applied and will continue to transfer signals after the actuating force or signal is removed until another actuating force or signal is applied. Also see nonlatching switch.

lateral offset loss. In fiber optics, an optical power loss caused by transverse or lateral deviation from optimum alignment of the optical axes, that is, the lateral off-set distance between the axes, of source to optical waveguide, waveguide to waveguide, or waveguide to photodetector. Synonymous with transverse offset loss.

launch angle. 1. In an optical fiber or fiber bundle, the angle between the input radiation vector, that is, the input chief ray, and the optical axis of the fiber or fiber bundle. If the end surface of the fiber is perpendicular to the axis of the fiber, the launch angle is equal to the incidence angle when the ray is external to the fiber and equal to the refraction angle when initially inside the fiber, because when inside the fiber, the ray might be considered as having been "launched" by the face of the fiber. 2. The beam divergence from any emitting surface, such as that of a light-emitting diode (LED), laser, lens, prism, or optical fiber end-face. 3. The angle at which a light ray emerges from a surface. Synonymous with departure angle. Also see exit angle.

launch condition. When light rays exit from the surface of a material, such as the surface of a light source or the exit end face of an optical fiber, a parameter that describes the geometric relationships between the ray and the surface, the optical characteristics of the interfaces and paths, the characteristics of the rays, and other related parameters, for example, exit angle, launch angle, wavelength, refractive-index contrast, launch numerical aperture, launch loss, and spectral width.

launching. See single-mode launching.

launching fiber. An optical fiber pigtail attached to an optical source used to enable splicing to another component, such as a coupler or optical fiber. The launching fiber may be used in conjunction with a light source to excite the modes of another fiber in a particular fashion. They are often used in test systems to improve the precision of measurements. Synonymous with injection fiber.

launch loss. The radiant power lost at the point where the radiant power output from a light source is coupled into an optical waveguide, such as an optical fiber pigtail attached to the light source. Launch loss can be caused by aperture mismatch, angular misalignment, longitudinal offset, lateral offset, and Fresnel reflection. Also see insertion loss.

launch numerical aperture (LNA). The numerical aperture of an optical system used to couple, that is, launch power into an optical waveguide. The LNA may differ from the stated NA of a final focusing element if, for example, that element is underfilled or the focus is other than that for which the element is specified. The LNA is one of the parameters that determine the initial distribution of power among the modes of an electromagnetic wave propagating in an optical waveguide.

launch spot. The spot of light produced by a light beam from an optical element, such as from a lens or the exit endface of an optical fiber, when the beam is incident upon a transverse surface, that is, a screen perpendicular to the optical axis of the element. The diameter of the spot is dependent upon the departure angle, that is, the launch angle, from the element and the distance between the transverse surface and the element. The launch spot size can be used to determine the numerical aperture of the optical element. The optical element is aligned to provide maximum irradiance on the screen. The numerical aperture is given by the relation

$$NA = D/(D + 4d^2)^{1/2}$$

where D is the spot diameter and d is the distance from the element, such as the fiber exit endface, to the screen. If D/2d is less than 0.25, the numerical aperture of the element is given by the approximate relation

$$NA \approx D/2d = r/d$$

where r is the spot radius and r/d is the tangent of the launch angle. Also see numerical aperture; XX/YY restricted launch.

law. See Bouger's law; Brewster's law; Lambert's cosine law; Lambert's law; Planck's law; radiance conservation law; reflection law; Snell's law.

layer. See application layer; barrier layer; data link layer; network layer; physical layer; presentation layer; session layer; transport layer.

leak. See jacket leak.

leaky mode. 1. In an optical waveguide, a mode that has an evanescent field which decays monotonically for a finite distance in the transverse direction outside the core but becomes oscillatory and conveys power in the transverse direction everywhere beyond that finite distance. Leaky modes in physical optics are equivalent to leaky rays in geometric optics. 2. An electromagnetic wave propagation mode in a waveguide that couples significant energy into leaky waves. Leaky modes are usually high-order modes. Specifically, a leaky mode is a mode that satisfies the relation

$$[(n_a k)^2 - (m/a)^2]^{1/2} \leq \beta \leq n_a k$$

where n_a is the refractive index at the core-cladding interface surface, that is, at the distance a from the optical axis where a is the core radius, k is the free-space wave number, given by the relation $k = 2\pi/\lambda$, where λ is the wavelength, m is the azimuthal index of the mode, and β is the imaginary part (phase term) of the axial propagation constant. Leaky modes experience attenuation even if the waveguide is perfect in every respect. Synonymous with tunneling mode. Also see bound mode; cladding mode; leaky ray; unbound mode.

leaky ray. 1. In an optical waveguide, a ray that escapes from the guide even though the theory of geometric optics predicts total (internal) reflection should be taking place at the core-cladding boundary, perhaps caused by microbends and curvatures in the boundary. Leaky rays in geometric optics are equivalent to leaky modes in physical optics. 2. In an optical waveguide, a ray for which calculations in geometric optics would predict total (internal) reflection at the core-cladding interface, but for which there is a loss because the core-cladding interface surface is curved. Specifically, a ray at radial distance r from the optical axis that satisfies the relation

$$n_r^2 - n_a^2 \leq \sin^2\theta_r$$

and the relation

$$\sin^2\theta_r \leq [n_r^2 - n_a^2]/[1 - (r/a)^2\cos^2\Phi_r]$$

where θ_r is the angle the ray makes with the optical axis of the waveguide, n_r is the refractive index at the radial distance r from the optical axis, a is the core radius, and Φ_r is the azimuthal angle of the projection of the ray on the transverse plane. Leaky rays correspond to leaky modes in the terminology of mode descriptors. Synonymous with tunneling ray. Also see bound mode; cladding mode; leaky mode; unbound mode.

leaky wave. In a waveguide, an electromagnetic wave that is coupled or transferred to a propagation medium outside the waveguide, such as inside and outside the cladding of optical fibers. Certain leaky modes are no longer guided because they are no longer coupled to modes inside the waveguide. Leaky waves normally stem from incident waves that have a large skew component at entry into the fiber. They become detached and radiate from the guide after a short distance od propagation within the guide. The "short distance" may be only a few wavelengths. These modes will have escaped by the time the equilibrium length, that is, equilibrium modal power distribution length, is reached. Leaky waves are usually high-order modes and are in the cut-off frequency region. In optical fiber waveguides, low order-modes are usually bound to the core and therefore are not leaky modes. Unless coupling to other guides is desired, efforts are usually made to reduce leaky waves to a minimum in order that optical power is not lost, especially in long-haul communication links.

LED. Light-emitting diode. See edge-emitting LED (ELED); front-emitting LED; superluminescent LED (SRD); surface-emitting LED.

left-hand circular polarization. Circular polarization of an electromagnetic wave in which the electric field vector rotates in a counterclockwise direction, as seen by an observer looking in the direction of propagation of the wave. Also see right-hand circular polarization.

left-hand helical polarization. Helical polarization of an electromagnetic wave in which the electric field vector rotates in a counterclockwise direction as it advances in the direction of propagation, as seen by an observer looking in the direction of propagation. The tip of the electric field vector advances like a point on the thread of a left-hand screw, the normal screw being a right-hand screw, when entering a fixed nut or tapped hole.

left-hand polarized electromagnetic wave. An elliptically or circularly polarized electromagnetic wave in which the direction of rotation of the electric field vector is counterclockwise as seen by an observer looking in the direction of propagation of the wave. Also see right-hand polarized electromagnetic wave.

length. See borescope overall length; borescope tip length; borescope working length; coherence length; dispersion-limited length; electrical length; equilibrium length; nonequilibrium modal power distribution length; optical path length; polarization beat length; wavelength.

lens. See SELFOC^{R} lens.

lensed connector. See expanded-beam connector.

level. See optical power level.

lever. See optical lever.

light. 1. The region of the electromagnetic spectrum that can be perceived by human vision, designated the visible spectrum, and nominally including the wavelength range of 0.4 to 0.8 μ (micron), including all the colors, from red to violet, to which the normal human retina responds. In the laser and optical communication fields, custom has extended usage of the term to include a somewhat broader portion of the electromagnetic spectrum that can be handled by the basic optical techniques and components used for the visible spectrum. This region has not been clearly defined, but, as employed by most workers in the field, light may be considered to extend from the near-ultraviolet region of approximately 0.3 μ, through the visible region, and into the mid-infrared region to 3 μ, designated by what has been called the near-visible spectrum. The near-visible spectrum extends part way into the ultraviolet and infrared regions of the optical spectrum. For example, the 1.31-μ wavelength used in fiber optic systems is considered to be within the realm of lightwaves, though it is not within the visible spectrum and hence cannot be detected by the human eye but can cause damage to the retina. The optical spectrum is considered to extend even further, that is, from the beginning of vacuum ultraviolet at 0.001 μ to the end of far infrared at 100 μ. See coherent light; convergent light; divergent light; monochromatic light; time-coherent light; ultraviolet light; white light. Also see optical spectrum.

light amplification by stimulated emission of radiation (laser). The generation of coherent light by having molecules of certain substances absorb incident electrical or electromagnetic energy at specific frequencies, store the energy for short periods in higher electron energy-band levels, and then release the energy upon return to the lower levels in the form of light, that is, photons or lightwaves, at particular frequencies in extremely narrow bands. The release of radiated energy can be controlled in time and direction so as to generate an intense highly-directional narrow beam of coherent electromagnetic energy, that is, the electromagnetic fields at every point in the beam are uniquely and specifically definable and predictable. Also see laser.

light attenuation. The conversion of lightwave energy into other forms of energy or directions when propagating a given distance in a propagation medium, thus reducing the transmitted lightwave energy, that is, by reducing the transmittance. When lightwaves propagate in the medium for a given distance, they undergo transmission, reflection, absorption, scattering, and radiation. The law of conservation of energy is obeyed, as given by the relationship

$$T + R + A + S + D = 1$$

where T, R, A, S, and D are the coefficients of energy transmittance, reflectance, absorption, scattering, and radiation, respectively. All the coefficients are normalized to the input energy. All the coefficients, except transmittance, contribute to the attenuation.

light current. See photocurrent.

light-duty connector. In fiber optics, a connector that is designed and intended from use inside of an interconnection box (distribution box) or cabinet.

light-emitting diode (LED). A p-n junction semiconductor device that produces incoherent radiation by spontaneous emission under suitable operational conditions. The LED operates in a manner similar to a laser diode, that is, by injecting electrons and holes across the junction. It has about the same total optical output power, limited data signaling rate (DSR), and operational electric current densities as the laser diode, but is simpler and cheaper, has a lower tolerance requirement, and is more rugged. However, its spectral width is about 10 times that of a laser and its launch angle is greater.

light pipe. 1. A passive optical device that transmits light from one location to another, such as an optical fiber or slab-dielectric waveguide. 2. A hollow tube with a reflecting inner wall that guides lightwaves in its hollow center. Aligned and unaligned bundles of optical fibers may be used as light pipes.

light ray. In geometric optics, the path described by a succession of tangents at each point in the direction of propagation of light energy. The ray is perpendicular to the wavefront of a lightwave propagating in an isotropic propagation medium. It represents the lightwave itself. For plane-polarized light, the ray is in the same direction as the Poynting vector. Also see ray.

light source. See borescope light source; fiber optic light source.

light susceptibility. See ambient light susceptibility.

lightwave. An electromagnetic wave with a wavelength within the optical spectrum, namely a wavelength within or near the visible spectrum, usually including the ultraviolet and near infrared. Its wavelength ranges from about 0.3 to 3 μ (micron), that is, about 300 to 3,000 nm (nanometer).

lightwave spectrum analyzer. A device capable of determining the existence and measuring the energy levels at various wavelengths in a light beam. The device is essentially a tunable filter that can examine each portion of the optical spectrum in the beam. For example, one type of analyzer has a slit for admitting the incident beam and excluding stray ambient light, some lenses, a diffraction grating that is tuned by a stepper motor, more lenses, and another slit. A Fabry-Perot interferometer at the output of the diffraction grating will improve the resolution. Further improvements can be made using a lightwave synthesizer, that is, a tunable local oscillator with a sufficiently narrow bandwidth.

limited. See diffraction-limited.

limited operation. See attenuation-limited operation; quantum-limited operation; quantum-noise-limited operation.

limiter. See bend limiter.

line. See optical fiber delay line; spectral line.

linear device. A device whose output is a linear function of its input. If the output is represented by y and the input by x, then the output is related to the input by the relation

$$y = mx + b$$

where m and b are constants. For example, a device in which the output electric field, voltage, or current is linearly proportional to the input electric field, voltage, or current and no new wavelengths or modulation frequencies are generated by the device. The behavior of a linear device can be described by a transfer function or an impulse response function. Also see nonlinear device.

linearly polarized (LP) mode. A mode of a linearly-polarized electromagnetic wave propagating in a weakly-guiding propagation medium, such as an optical fiber, whose electric and magnetic field components in the direction of propagation are small compared to the transverse components.

linear polarization. Electromagnetic wave polarization in which the electric field vector maintains a fixed spatial direction and varying magnitude.

linear refractive-index profile. A refractive-index profile of the core of a dielectric waveguide, such as an optical fiber, in which the refractive index varies uniformly with distance, from a given value at the center to a given value at the core-cladding interface surface. Thus, the linear refractive-index profile is produced when the refractive-index profile parameter is unity, that is, equal to exactly 1. Synonymous with uniform refractive-index profile. Also see parabolic refractive-index profile; power-law refractive-index profile; profile parameter; radial refractive-index profile.

linear scattering. See nonlinear scattering.

line code. A sequence of symbols that represent binary data for transmission purposes, e.g., Manchester, return-to-zero, and block codes. Line codes are used to recover precise timing and may be used to detect errors.

line rate. See optical line rate.

line source. 1. An optical source that emits one or more spectral lines of narrow spectral linewidth, that is, one or more monochromatic beams, as compared to a more or less continuous spectrum with many wavelengths. 2. An optical source that emits a spatially very narrow beam, spatially narrow in one dimension, usually emitted by an optical source whose active area, that is emitting area, forms a spatially narrow line of light. Also see coherent; spectral width.

line spectrum. The various wavelengths of radiation emitted by a source. It consists of one or more spectral lines rather than a continuous spectrum.

linewidth. See spectral linewidth.

link. 1. In a communication network, the facilities between adjacent nodes. 2. A portion of a circuit connected in tandem. See control link; data link; dedicated data link; fiber optic link; fiber optic data link; optical link; repeatered optical link; repeaterless optical link; satellite optical link.

link layer. See data link layer.

liquid laser. A laser whose active medium is in liquid form, such as organic dyes and inorganic solutions. Dye lasers are commercially available and are often called "organic dye" or "tunable dye" lasers.

LNA. Launch numerical aperture.

local area network (LAN). A nonpublic telecommunication system, within a specified geographical area, designed to allow a number of user end-instruments and independent devices, such as telephones, data terminals, television sets, and computers, to communicate with each other over a common transmission system at fairly high data signaling rates (DSRs). LANs are usually restricted to relatively small geographical areas, such as rooms, buildings, or clusters of buildings. A LAN is not subject to public telecommunications regulations. LANs are usually connected to a switching center or central office for outside communication via telephone and other networks.

local loop. A communication channel from a switching center or an individual message or packet distribution point, to a user terminal or user end-instrument. For example, in a telephone system, the local loop may consist of a pair of wires or a fiber optic cable to a user's telephone. In a fiber optic local loop, a fiber optic cable connects user end-instruments, such as telephones, data terminals, computers, and television sets, to a communication network, usually via multiplexing equipment to a network central office or switching center. Synonymous with subscriber loop.

locked laser. See injection-locked laser.

long-haul communication network. A communication network designed for handling communication traffic over long distances, such as nationwide or worldwide traffic. Long-haul systems are characterized by long-distance trunks between towns and cities, large-size switching centers and central offices, high-quality equipment for high-fidelity and high-definition analog (voice) and digital data transmission, integrated services digital (data) networks (ISDN), high transmission capacity, and automatic switching for handling calls and messages without operator assistance. It is anticipated that by the year 2000 over 600 billion voice circuit-kilometers will be on fiber optic long-and short-haul networks and only 16 billion on microwave, 160 billion on satellite, and 3 billion on coaxial cable. Also see short-haul communication network.

longitudinal compression sensor. See fiber longitudinal compression sensor.

longitudinal jitter. In facsimile transmission, the effect caused by irregular scanning speed. The speed irregularity may occur from many causes, such as the irregular rotation of the drum or helix that causes slight waviness or breaks in the lines of the reproduced image, lines that were straight on the original object (document).

longitudinal offset loss. See gap loss.

long wavelength. In fiber optics, pertaining to optical radiation that has a wavelength greater than a nominal 1 μm (micron).

loop. See local loop.

loop multiplexer. See fiber loop multiplexer.

loose cable structure. See loose-tube cable.

loose-tube cable. A fiber optic cable in which one or more optical fibers are fitted loosely in a tube. One or more such tubes may be used to form a single cable. The tubes may be filled with a seal or gel to protect the fiber. Within certain limits, stresses applied to the cable are not transferred to the fiber. Synonymous with loose cable structure. Also see tight-jacketed cable.

loose-tube splicer. A tube with a square hole used to splice two optical fibers. The curved fibers are made to seek the same corner of the square hole, thus holding then in alignment until an index-matching epoxy already in the tube cures, thus forming a low-loss butted joint.

Lorentzian fiber. An optical fiber that has a refractive index profile defined by the relation

$$n_r^2 = n_1^2/[1 + 2\Delta(n_1^2/n_2^2)(r/a)^2] \qquad \text{for } r \leq a$$

where Δ is given by the relation

$$\Delta = (n_1^2 - n_2^2)/2n_1^2$$

where n_1 is the maximum refractive index of the core, which is at the optical axis, that is, at $r = 0$; n_2 is the refractive index of the homogeneous cladding, that is, the refractive index of the cladding is given by the relation

$$n_r = n_2 \qquad \text{for } r \geq a$$

where r is the radial distance from the optical axis of the fiber and a is the radius of the core. Skew rays entering the fiber at angles less than the acceptance angle, thus satisfying the critical angle criterion for total internal reflection, will travel a helical path within the fiber. A skew ray is a ray that is not a meridional ray nor an axial ray. If the value of is appropriately selected, all the helical rays will arrive at the end of the fiber at the same time. However, this profile will then not permit the meridional rays and the axial rays to arrive at the end at the same time as the helical rays.

loss. 1. The amount of electrical, optical, sound, or other form of power or energy consumed in a circuit or component. 2. The energy dissipated without accomplishing useful work, usually expressed in dB (decibels). In directed signal and power transmission, the difference between power or energy that is dispatched and that which is received. For example, in a fiber optic data link, signal power that is absorbed, reflected, scattered, or radiated from a fiber optic cable between the optical transmitter and receiver is considered a loss. Thus, the loss is the transmitted power minus the received power. See absorption loss; angular misalignment loss; bending loss; coupler loss; coupler excess loss; coupling loss; curvature loss; extrinsic coupling loss; free-space loss; gap loss; insertion loss; intrinsic coupling loss; lateral offset loss; microbend loss; modal loss; optical cable facility loss; packing fraction loss; reflection loss; return loss; scattering loss; splice loss; statistical optical cable facility loss; transmission loss.

loss budget. In a link, such as a fiber optic link, the distribution of the total loss among the components of a system that can be tolerated in order that the received signal is above the threshold of sensitivity of the receiver, including allowance for a power margin. The loss is distributed among the components of the system, such as cables, couplers, and splices, in an optimum fashion so as to design for minimum cost at tolerable bit error ratios for digital data systems. Required transmitted power, receiver sensitivity, intervening losses, and safety margins are all considered in the distribution, that is, in the budgeting, of the losses.

loss budget constraint. In the design of an optical station/regenerator section, the terminal/regenerator system gain must be equal to or larger than the sum of all of the optical power losses in the optical fiber path between terminal/regenerator spliced interfaces. The constraint is given by the relation

$$G > L$$

where G is the terminal/regenerator system gain given by the relation

$$G = P_T - P_R - P_D - R_P - M - U_{wdm} - \ell_{sm}U_{sm} - N_{con}U_{con}$$

where P_T is the transmitter power, P_R is the receiver sensitivity (power), P_D is the dispersion power penalty, R_P is the reflection power penalty, M is the overall safety power margin, U_{wdm} is the worst-case value of all losses associated with wavelength-division multiplexing equipment at both ends, ℓ_{sm} is the fiber length in the stations, U_{sm} is the worst-case end-of-life loss (dB/km) of the single-mode cable at both stations, N_{con} is the number of fiber optic connectors within the stations (inside plants), and U_{con} is the loss (dB) per connector. G is used to overcome all the losses, L, in the optical cable facility (outside plant) of the station/regenerator section, given by the relation

$$L = \ell_t(U_c + U_{cT} + U_\lambda) + N_s(U_S + U_{ST})$$

where ℓ_t is the total sheath, that is, jacket, length of spliced-fiber cable (km), U_c is the worst-case end-of-life cable attenuation rate (dB/km) at the transmitter nominal central wavelength, U_λ is the largest increase in cable attenuation rate that occurs over the transmitter central wavelength range, U_{cT} is the effect of temperature on the end-of-life cable attenuation rate at the worst-case temperature conditions over the cable operating temperature range, N_s is the number of splices in the length of the cable in the optical cable facility, including the splice at the optical station facility on each end and allowances for cable repair splices, U_S is the loss (dB/splice)) for each splice, and U_{ST} is the maximum additional loss (dB/splice) caused by temperature variation. L must be equal to or less than the fiber optic terminal/regenerator system gain, G, for the optical station/regenerator section to operate satisfactorily. Also see statistical loss budget constraint; fiber global attenuation-rate characteristic.

loss characteristic. See fiber global loss characteristic.

loss test set (OLTS). See optical loss test set (OLTS).

lossy medium. A propagation medium in which significant amounts of energy in a wave propagating in the medium is absorbed per unit distance traveled by the wave. For example, in optical fiber cladding, a lossy medium may be used to attenuate waves by absorbing the energy in those that have leaked outside the core.

lot. See inspection lot.

low-birefringence fiber. An optical fiber in which the polarization beat length is 50 m (meter) or greater. The beat length is given by the relation

$$L_B = 2\pi/(\beta_x - \beta_y)$$

where β_x and β_y are the propagation constants of the two polarized waves caused by the birefringence of the fiber. Thus, the propagation constant difference is small. The low-birefringence optical fiber has a negligible intrinsic birefringence so that birefringence effects induced in the fiber by external forces can be calculated directly from the polarization state of the output light. Low-birefringence applications include Faraday-effect electric current sensors, magnetic field sensors, and optical fiber isolators. Two approaches have been used to obtain very low-birefringence fibers, namely (1) by preserving the geometrical circular symmetry of the fiber cross section to a very high degree and using carefully selected dopant materials to reduce the transverse stress in the fiber, and (2) by rapidly spinning the preform while pulling the fiber. The spin pitch must be much less than the fiber beat length that would be obtained if the preform were not spun. Also see birefringence; high-birefringence fiber.

lowest-order transverse mode. The lowest-frequency in an electromagnetic wave that can propagate in a given waveguide that can support more than one transverse electric (TE) mode or more than one transverse magnetic (TM) mode, the limitation in the number of modes being determined by the boundary conditions and the geometrical shape of the waveguide as well as the frequency (or wavelength). Solution of Maxwell's equations with the boundary conditions for a rectangular waveguide operating in the TM mode yields the relationship

$$\omega^2\mu\epsilon > [(m\pi/a)^2 + (n\pi/b)^2]$$

where ω is the angular velocity ($\omega = 2\pi f$ where f is the frequency), μ is the magnetic permeability of the material in the waveguide, σ is the electric permittivity of the material in the waveguide, a and b are the cross-section dimensions, and m and n are the whole numbers (eigenvalues) that satisfy and provide solutions to Maxwell's equations. The solutions to Maxwell's equations for transverse magnetic (TM) and transverse electric (TE) modes of propagation yield modes identified as TM_{mn} and TE_{mn}, except that for TM modes neither m nor n can be zero, since these conditions result in a zero electric and magnetic field. Therefore, the lowest-order mode for TE is TE_{10} and the lowest-order mode for TM is TM_{11}. The TE_{10} mode, called the dominant mode, is obtained by designing a waveguide with a width-to-depth ratio of about 2, using an operating frequency above the cutoff frequency, given by the relation

$$f_c = v/2a$$

where v is the velocity of light in the medium of the guide, but below the next higher cutoff frequency. In optical fiber waveguides, the dimensional parameters relate to those of the fiber. For example, in a circular cross-section optical fiber, the core diameter corresponds to the a and b for the rectangular waveguide. The variables for a rectangular electromagnetic metal waveguide relate one-for-one to the variables in the waveguide parameter (V-value) equation for optical fibers, namely that the number of modes is a function of the number, that is, the V-value, determined by the relation

$$V = (2\pi a/\lambda_o)(n_1^2 - n_2^2)^{1/2}$$

where a is the fiber core diameter, λ_o is the free-space wavelength, and n_1 and n_2 are core and cladding refractive indices. When both equations are solved for wavelength, it can be shown that the modes in both waveguides are functions of the dimensions of the guides, their refractive indices, the velocity of light, and the launch conditions. For the circular cross-section optical fiber, the governing dimension is the diameter, or the radius, of the core. Thus, there is no fundamental difference between the equations for determining supportable modes in electromagnetic rectangular filled or hollow metal waveguides operating at radio, microwave, and video frequencies and the equations governing the number of supportable modes in optical fibers

operating at lightwave frequencies. Also see low-order mode.
low-frequency cutoff. Because of dimensional and boundary conditions, the lowest electromagnetic frequency a waveguide with given dimensions and constructed of given materials is capable of supporting. The lowest frequency corresponds to the longest wavelength the guide can support. In fiber optics, the low-frequency cutoff is the frequency of the longest wavelength an optical fiber is capable of supporting. In essence, the core diameter has to be at least the order of magnitude of the wavelength of the mode propagating in the core or else the core can't transmit, that is, can't support, the mode.

low-loss fiber. See ultralow-loss fiber.

low-order mode. In an electromagnetic wave propagating in a waveguide, a mode corresponding to the lesser, that is, the first few, eigenvalue solutions to the wave equations, regardless of whether it is a mode in a transverse electric (TE), transverse magnetic (TM), or transverse electromagnetic (TEM) wave. Thus, it is a mode in which only a few whole wavelengths of the wave fit transversely in the guide and therefore can be supported by the guide. A multimode fiber supports as many modes as the core diameter, numerical aperture, and wavelength permit. For the waveguide to support only low-order modes, the normalized frequency, that is, the V-parameter or V-value, must be less than 4 in order that the number of modes be sufficiently small so there will be no high-order modes. In a single-mode fiber there are no high-order modes. Conceptually, however, if there are only two modes, one could be considered the low-order mode and the other the high-order mode. In addition, an optical fiber operating in single mode operating at 1.31 μ (micron) may operate in multimode if the wavelength is reduced to 0.85 μ. Also see low-order mode; lowest-order transverse mode.

low-pass filter. A device that passes all frequencies below a specified frequency with little or no loss, but discriminates strongly against higher frequencies by removing, blocking, rejecting, absorbing, or otherwise heavily attenuating frequencies above the specified value.

LP. Linearly polarized.

LP mode. See linearly polarized (LP) mode.

luminescence. The process by which certain materials, such as radium, emit electromagnetic radiation, which for certain wavelengths or restricted regions of the spectrum, is in excess of that attributable to the thermal state of the material and the emissivity of its surface. The radiation is characteristic of the particular luminescent material and occurs without outside stimulation. See electroluminescence. Also see fluorescence; phosphorescence.

luminance threshold. See absolute luminance threshold.

luminosity curve. See absolute luminosity curve.

lux. The SI (Systemè International) unit of illuminance, equal to 1 lumen per square meter.

M

m. The abbreviation for meter.

MAA. Maximum acceptance angle.

machine. See fiber-pulling machine.

Mach-Zehnder fiber optic sensor. An interferometric sensor in which an electromagnetic wave, such as a lightwave, is split, each half propagating around half a loop in opposite directions, one half via a beam splitter and a fixed mirror, the other via a movable mirror and a beam splitter, both halves recombining in an optical fiber or on the sensitive surface of a photodetector where their relative phases can enhance or cancel each other. The movable mirror can be used to modulate the resultant irradiance, that is, the field intensity, at the photodetector. Displacements as short as 10^{-13} m (meter) can be measured. Optical fibers may be used for the light paths.

macrobend attenuation. Optical power radiated at a macrobend in an optical waveguide. Evanescent waves, cladding modes, and high-order leaky modes in the core become decoupled from core propagating modes because of phase shifts and velocity differences at the bend. For macrobend radii less than the critical radius most of the propagating optical power is radiated laterally from the waveguide.

macrobending. In an optical waveguide, all macroscopic deviations of the optical axis from a straight line. Macrobending is distinguished from microbending. In optical fibers, macrobend radii must be greater than both the minimum bend radius, that is, the radius less than which the fiber will break; and the critical radius, that is, the radius less than which substantial radiation will occur.

macrobend loss. See curvature loss.

magnetic. See transverse magnetic (TM).

magnetic field component. In an electromagnetic wave, the part of the wave that consists of a time-varying magnetic field, whose interaction with an electric field gives rise to the propagation of a field of force or energy in a direction perpendicular to both fields. Reflection, refraction, and transmission that occur at an interface between two different media depend on the direction of the magnetic field component and the electric field component relative to the interface surface, and on the permittivities, permeabilities, and conductivities of the propagation media on both sides of the interface.

magnetic field strength. The intensity, that is, the amplitude or magnitude, of a magnetic field at a given point. The term is normally used to refer to the rms value of the magnetic field, expressed in amperes per meter. Instantaneous magnetic field strength is usually given as a gradient, and therefore is a vector quantity, since it has both magnitude and direction. For example, the units of magnetic field strength might be given as amperes per meter, oersteds, or lines per square meter divided by the magnetic permeability of the medium at the spatial position that the magnetic field strength is to be determined. Also see electric field strength.

magnetic field vector. In an electromagnetic wave, such as a lightwave, the vector that represents the instantaneous magnetic field strength at any point in a medium in which the wave is propagating.

magnetic permeability. A material medium parameter that defines the magnetic characteristic of the medium and serves as the constant of proportionality in the constitutive relation between the applied magnetic field strength and the resulting magnetic flux density, specifically, by the relation

$$\mathbf{B} = \mu \mathbf{H}$$

where μ is the magnetic permeability, **B** is the magnetic flux density, and **H** is the magnetic field strength. If B is in gauss and H in oersteds, μ will be in SI (Systemè International) units. The permeability is also the constant of proportionality in the equation expressing the force of attraction of unlike magnetic poles a given distance apart. Except for ferrous metals, which have a high magnetic permeability, and a few metals, which have a much lower permeability, but nevertheless greater than unity, the magnetic permeability of most materials, such as dielectric materials like glass and plastic, is unity. Thus, magnetic fields are practically unaffected by the glass and other dielectric materials from which optical fibers are made. Therefore, the magnetic permeability of glass does not contribute to the refractive index of glass. For electrically nonconducting media, that is, propagation media in which the electrical conductivity is zero, the relative velocities of electromagnetic waves, such as lightwaves, propagating within them, are given by the relation

$$v_1/v_2 = [(\mu_2\epsilon_2)/(\mu_1\epsilon_1)]^{1/2}$$

where v is the velocity and μ and ϵ are the magnetic permeability and electric permittivity, respectively, of media 1 and 2. If medium 1 is free space, the above equation becomes the relation

$$c/v = [(\mu\epsilon)/(\mu_0\epsilon_0)]^{1/2}$$

where c is the velocity of light in a vacuum, v is the velocity in a material medium, the non-subscripted values of the constitutive relations are for the material propagation medium and the subscripted values for free space. However, c/v is the definition of the refractive index of a medium relative to free space. From this is obtained the relation

$$n = (\mu_r\epsilon_r)$$

where n is now a dimensionless number and relative to free space. The magnetic permeability and electric permittivity are also usually given relative to free space, or air. As stated above, for dielectric materials, μ_r is approximately 1, being very much greater than 1 only for ferrous substances and slightly greater than 1 for a few metals, such as nickel and cobalt. Hence, for the glass and plastics used to make optical fibers and other dielectric waveguides, the refractive index, relative to a vacuum, or air, is given by the relation

$$n \approx \epsilon_r^{1/2}$$

where ϵ_r is the electric permittivity of the propagation medium. Refractive indices are usually given relative to a vacuum, or relative to 1.0003 for air near the earth's surface and less as the air gets thinner in the upper atmosphere and outer space. In absolute units for free space, the electric permittivity is $\epsilon = 8.854 \times 10^{-12}$ F/m (farads per meter) while the magnetic permeability is $4\pi \times 10^{-7}$ H/m (henries per meter). The reciprocal of the square root of the product of these values yields approximately 2.998 x 10^8 m/s (meters per second), the velocity of light in a vacuum. Because the refractive index for a propagation medium is defined as the ratio between the velocity of light in a vacuum and the velocity of light in the medium, the ratio becomes unity when the propagation medium is a vacuum. See refractive index; relative magnetic permeability.

magnetooptic. Pertaining to a change in a material's refractive index under the influence of a magnetic field. Magnetooptic materials generally are used to rotate the polarization plane of an electromagnetic wave.

magnetooptic effect. The rotation of the polarization plane of a plane-polarized electromagnetic wave, such as a lightwave, caused by subjecting the propagation medium to a magnetic field, that is, Faraday rotation. The effect can be used to modulate a light beam in a material because many coefficients, such as the reflection and transmission coefficients at interfaces, acceptance angles, critical angles, refraction angles, reflection angles, transmission modes, propagation velocities, and other properties are dependent upon the direction of propagation of the lightwave relative to the interface. The applied magnetic field adds to the magnetic field component of the electromagnetic wave. The amount of angular rotation, that is, the angular displacement, A, is given by the relation

$$A = VHL$$

where V is a constant of proportionality, H is the applied magnetic field strength, and L is the distance the lightwave is in the magnetic field. The applied magnetic field is in the direction of propagation of the lightwave for polarization plane rotation. In any case, the applied magnetic field affects the magnetic field of the electromagnetic wave, the resultant depending on their direction. Synonymous with Faraday effect. Also see electrooptic effect.

magnetooptics. The branch of science and technology devoted to the study and application of the interaction between magnetic fields and electromagnetic waves in the optical region of the electromagnetic spectrum. Also see acoustooptics; electrooptics; optooptics; photonics.

magnetostriction. The phenomenon exhibited by some materials, such as ferromagnetic materials including iron, cobalt, and nickel, in which dimensional changes occur when the material is subjected to a magnetic field, usually becoming longer in the direction of the applied field. The effect can be used to launch a shock or sound wave each time the field is applied or changed, possibly giving rise to phonons that could influence energy levels in the atoms of certain materials, such as semiconductors and lasers, and thereby serve as a modulation method. Along with photon or electric field excitation, the phonon energy could provide threshold energy to cause electron energy level transitions, causing photon absorption or emission. If an optical fiber is coated with a bonded magnetostrictive material, the length of the fiber can be modulated by varying the applied magnetic field. Hence, a coherent lightwave exiting from the end, can be made to shift phase. An interferometer can be used to detect the phase shift. Thus, the output of a photodetector can be modulated by the applied magnetic field that is causing the magnetostriction. The magnetostrictive effect can also be used to apply pressure to an optical fiber, causing changes in the refractive index, which, in turn, can be used as a modulation method.

magnification. See borescope magnification.

magnitude. See pulse magnitude.

maintainability. A characteristic of design and installation of an item, expressed as the probability that the item will be retained in or restored to a specific condition within a given time, when the maintenance is performed in accordance with prescribed procedures and resources.

MAN. Metropolitan area network.

mandrel. See optical fiber mandrel.

margin. See power margin.

maser. See optical maser.

matched cladding. In a dielectric waveguide, cladding composed of a single homogeneous layer of dielectric material.

material. See index-matching material; nonlinear optical (NLO) material; optically active material; polymeric nonlinear optical material; third-order nonlinear material.

material absorption. See absorption.

material dispersion. In fiber optics, the spreading, that is, the lengthening of the time and spatial width of a light pulse as it propagates in a dielectric waveguide. The spreading is caused by the different velocities of the different wavelengths in the pulse, that is, in the spectral width of the light. This should not be called spectral or intramodal dispersion because all dispersion is spectral and material dispersion affects all modes. Material dispersion is that part of the total dispersion of an electromagnetic pulse in a waveguide, such as an optical fiber, due to the dependence on wavelength of the refractive index of the material used to make the waveguide. As the wavelength is increased, and frequency is decreased, material dispersion decreases. At high frequencies, the rapid interaction of the electromagnetic field with the waveguide renders the refractive index even more dependent upon frequency. Since each frequency experiences a different refractive index, some frequencies will propagate faster than others, so that they arrive at the end of the fiber at different times, making the pulse at the end of a path broader in space and time than at the beginning.

material dispersion coefficient. See material dispersion parameter.

material dispersion parameter. A parameter that characterizes material dispersion, given by the relation

$$M(\lambda) = -(1/c)(dN/d\lambda) = (\lambda/c)(d^2n/d\lambda^2)$$

where n is the refractive index, N is the group index, λ is the free-space wavelength, and c is the velocity of light in a vacuum. M = 0 at a particular wavelength, λ_o, usually about 1.3 μ (micron) for many fiber optic propagation media, such as the silica glass used to make optical fibers. The minus sign is chosen so that M is positive for wavelengths less than λ_o and negative for wavelengths greater than λ_o. The amount of pulse broadening, that is spreading or widening, per unit length of optical fiber is given by M times the spectral width, that is, the spectral linewidth, except at a wavelength near λ_o, where the square of the spectral width is more significant. Also see dispersion coefficient.

material scattering. Scattering caused by the properties of the materials used in fabricating electromagnetic wave propagation media. For example, it is the part of the total scattering attributable to the properties of the materials used in fabricating an optical fiber.

matrix. See transmittance matrix.

maximum acceptance angle (MAA). In an optical fiber, the maximum angle between the longitudinal axis of the fiber and an incident light ray at the fiber end-face in order that that ray be totally (internally) reflected at the core-cladding interface inside the fiber. For an optical fiber, the sine of the maximum acceptance angle (MAA) is the numerical aperture, given by the relation

$$MAA = \sin^{-1} NA, \quad \text{and } NA = (n_1^2 - n_2^2)^{1/2}$$

where NA is the numerical aperture, n_1 is the fiber core refractive index at the point on the fiber end-face at which the NA is being determined, and n_2 is the cladding refractive index. For a graded-index fiber, because the NA depends on the refractive index, and the refractive index varies with distance from the center of the fiber, the NA varies with the distance from the center of the fiber and therefore the true MAA also depends on the maximum refractive index found on the fiber end-face, which is at the center.

maximum cable cutoff wavelength. The maximum wavelength at which a cabled waveguide, such as a cabled optical fiber, will support a mode. For longer wavelengths, the fiber will not support any wavelength. The operating wavelength range, as determined by the transmitter nominal central wavelength and the transmitter spectral width, must be less than the maximum cutoff wavelength and greater than the minimum cutoff wavelength to ensure the cable operates entirely in the fiber single-mode region. Usually, the highest value of cabled fiber cutoff wavelength occurs in the shortest cable length. A criterion that will ensure a system is free from high cutoff wavelength problems is given by the relation

$$\lambda_{cc\ max} > \lambda_{t\ min}$$

where $\lambda_{cc\ max}$ is the maximum cutoff wavelength and $\lambda_{t\ min}$ is the minimum value of the transmitter central wavelength range, which is also caused by the worst-case variations introduced by manufacturing, temperature, aging, and any other significant factors determined when the cable is operated under standard or extended operating conditions. Also see fiber cutoff wavelength.

maximum input power. See optical receiver maximum input power.

maximum optical reflection. In an optical transmitter, the percent of total output optical power reflected back into the transmitter that it can accommodate and still maintain its stated performance.

maximum pulse rate. In optical waveguides and electrical conductors in which pulse dispersion limits the pulse repetition rate (PRR), that is, the data signaling rate (DSR), the PRR that is just sufficient to create a specified bit error ratio (BER), given by the relation

$$PRR = AL^b$$

where A is determined by the line characteristics that also fix the value of b and L is the length of the line. Normally, b = 0.5 for single-mode optical fibers. For multimode fibers, b is between 0.5 and 1.0. For wires, b = 2.

maximum receiver input. In an optical receiver terminal/regenerator facility of an optical station/regenerator section, the maximum value of the input optical power (dBm) to the receiver at the line side of the receiver module fiber optic connector or splice when operated under standard or extended operating conditions that the receiver will accept and still not exceed a specified bit error ratio (BER). If the receiver input power should exceed this maximum, the section is overdesigned or an optical attenuator must be inserted.

maximum theoretical numerical aperture. See numerical aperture.

maximum transceiver dispersion. The worst-case dispersion (psec/nm) caused by optical fiber length between transmitter and receiver pair that can be accommodated by the pair to meet the bit rate (data signaling rate) and bit error ratio (BER) specified by the manufacturer, when operated under standard or extended operating conditions.

Maxwell's equations. A group of basic equations, in either integral or differential form, that (1) describe the relationships between the properties of electric and magnetic fields, their sources, and the behavior of these fields in free space and material propagation media and at interfaces between these media; (2) express the relations among electric and magnetic fields that vary in space and time in material media and free space; and (3) are fundamental to the propagation of electromagnetic waves in material media and free space. The equations are the basis for deriving the wave equations that express the electric and magnetic field vectors in a propagating electromagnetic wave in a propagation medium, such as a lightwave in an optical fiber or an electromagnetic wave in a hollow or filled metallic waveguide. Solutions to the equations are dependent upon boundary conditions. Maxwell's equations in differential form are given by the relations

$$\nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \partial \mathbf{D}/\partial t$$

$$\nabla \bullet \mathbf{B} = 0$$

$$\nabla \bullet \mathbf{D} = \rho$$

where **E**, **H**, **B**, and **D** are the vectors of the electric field strength, that is, electric field intensity (volts per meter), the magnetic field strength, that is, magnetic field intensity (amperes per meter, oersteds), the magnetic flux density (webers per square meter or gauss), and the electric flux density or displacement (coulombs per square meter), respectively; **J** is the electric current density (amperes per square meter); and ρ is the electric charge density (coulombs per cubic meter). The ∇ is the "del" space derivative operator, expressing differentiation with respect to all distance coordinates, the × being the curl or cross-product operator resulting in a vector, and the • being the divergence or dot-product operator resulting in a scalar. The partial derivatives are with respect to time. These equations are used in conjunction with the constitutive relations to obtain useful practical results when actual sources of charge and current in free space and material media are known. The equations are valid only when the field and current vectors are single-valued, bounded, continuous functions of position and time, and have continuous derivatives. Wave equations are the solutions of Maxwell's equations, given the boundary conditions. For optical fibers, the medium is considered charge free and electrically nonconducting. Thus, $\rho = 0$ and $\mathbf{J} = 0$, which results in simplified solutions to Maxwell's equations.

MCVD. Modified chemical vapor deposition.

MCVD process. See modified chemical vapor deposition (MCVD) process.

mean-square pulse duration. See root-mean-square (rms) pulse duration.

mean time between failures (MTBF). For a particular measurement interval, the total functional life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, kilometers, events, or other measure-of-life units. It is the sum of all the operational times of all the items in the population, divided by the total number of failures within the population during the measurement time interval. For example, if kilometers are used, the result would be expressed as mean distance between failures.

mean time between outages (MTBO). The mean time between equipment failures that result in loss of system continuity or unacceptable degradation of performance. The MTBO may be expressed by the relation

$$MTBO = MTBF/(1-FFAS)$$

where MTBF is the nonredundant mean time between failures and FFAS is the fraction of failures for which the failed equipment is bypassed automatically.

mean time to failure (MTTF). In a population of similar items, the mean time an item functions successfully from the initial instant it is placed in operation to the instant of first failure, that is, the infant mortality period averaged over the population of items.

mean time to repair (MTTR). The total corrective maintenance time, that is, the total time devoted to maintenance, divided by the total number of maintenance actions, during a given time period, such as a month, a year, or to date since placed in service.

mean time to service restoral (MTTSR). The mean time to restore service, that is, restore acceptable operational capability, following system failures that result in a service outage or unacceptable operational capability. The time to restore service is all the time from the occurrence of the failure until the restoral of service, including fault detection, fault location, and fault correction time, that is, the actual time to repair.

measurement range. In an optical time domain reflectometer (ODTR), the length of optical waveguide, such as an optical fiber, that lies between the minimum length and the maximum length that the ODTR can make an attenuation measurement, such as measure the distance to, and the insertion loss caused by, a fiber optic connector. Measurement ranges are typically from several centimeters to over a hundred kilometers operating at typical wavelength of 0.85, 1.3, and 1.55 μ (micron). Also see distance resolution; dynamic range.

mechanically-induced modulation. 1. In fiber optics, modulation of a lightwave propagating in an optical fiber in accordance with physical distortion of the fiber. The distortion may be caused by a force field deliberately applied to the fiber, such as by vibrating, bending, compressing, or stretching it, in order to measure or sense the force field. The modulation may appear as amplitude, phase shift, wavelength, polarization rotation, or other form of modulation. 2. The introduction of undesirable modulation (noise) of a lightwave in an optical fiber caused by physical distortion of the fiber.

mechanical splice. A fiber optic splice made by mechanical fixtures or materials, such as optical cements, rather than by thermal fusion.

medium. See active laser medium; anisotropic propagation medium; birefringent medium; dispersive medium; isotropic propagation medium; lossy medium; nondispersive medium; propagation medium.

medium-loss fiber. An optical fiber having a medium-level optical signal power loss per unit length of fiber, usually measured in dB (decibels/kilometer) at a specified wavelength and due to all intrinsic causes. In medium-loss fiber, attenuation in amplitude of a propagating wave is caused primarily by scattering caused by metal ions, absorption caused by water in the form of the hydroxyl ion, and Rayleigh scattering. This does not include extrinsic losses, such as high-order mode loss caused by launch conditions or fiber optic connector losses at fiber-to-fiber interfaces.

megahertz (MHz). A unit of frequency denoting 1 million, that is, 10^6, Hz.

meridional ray. In fiber optics, any ray that passes through the axis of an optical fiber. Therefore, a meridional ray must lie in a plane that contains the fiber axis.

merit figure. See optical fiber merit figure.

mesh network. In network topology, a network configuration in which there is more than one path between any two nodes and thus there are no end-point nodes, that is, no nodes connected to only one branch of the network. See fully-connected mesh network.

meter (m). The SI (Systemè International) unit of length. The meter was originally established by Napoleonic scientists as one ten millionth of the distance between an earth's pole and the equator, that is, 10^{-7} of that distance along the surface of the earth. Later, the standard international meter was the distance between two fine lines engraved on a platinum bar held at the International Bureau of Weights and Measures near Paris, France. Now the meter is defined as 1,650,763.73 times the wavelength of the spectral line of orange light emitted when a gas consisting of the pure krypton isotope of mass number 86 is excited by an electrical discharge.

method. See fiber optic test method (FOTM); Fresnel reflection method; reference test method (RTM); refracted-ray method; transverse scattering method.

metric system. A decimal system of weights and measures based on the meter, the kilogram, and the second. The modern version of this system employs SI (Systemè International) units. See table I.

TABLE I. Metric system.

Quantity*	Base unit	Abbreviation
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
Supplementary units		
plane angle	radian	rad
solid angle	steradian	sr

*Certain derived terms have also been standardized, such as the hertz (2π radians or 360 degrees per second), equivalent to the obsolete cycle per second.

TABLE I. Metric system (continued).

Prefixes used with metric units		
Unit	Abbreviation	Value
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
Examples:		
Term	Abbreviation	Meaning
megahertz	MHz	10^{6} hertz
picofarad	pF	10^{-12} farads
nanosecond	ns	10^{-9} seconds
micrometer (micron)	μ or mμ	10^{-6} meters

metropolitan area network (MAN). A communication network that covers a geographical area larger than a local-area network. The MAN typically interconnects two or more local-area networks, operates at higher data signaling rates (DSRs), crosses administrative boundaries, and uses multiple-access methods. For example, the Washington, DC MAN includes parts of the 301 and 703 area codes and all of the 202 area code.

MFD. Mode field diameter.

MHz. Megahertz.

Michelson fiber optic sensor. A high-resolution interferometric sensor in which an electromagnetic wave, such as monochromatic light, is split, one half reflected from a fixed mirror and back through the splitter to a photodetector, the other half passed directly through the splitter to a movable mirror that reflects it back to the splitter where it is reflected to the same photodetector. The two waves can enhance or cancel each other thereby modulating the irradiance, that is, the light intensity, at the photodetector in accordance with an input signal in the form of a displacetemperature variation. If an optical fiber is used, the ends of the fiber form the reflecting surfaces. Moving one end relative to the other produces the same effect as moving the mirror. Displacements less than 10^{-13} m (meter) can be measured when narrow spectral-width, that is, monochromatic, laser sources are used.

microbend. In optical fibers, a small deviation or dent in the core-cladding interface surface of a fiber. Undulated core-cladding interface surfaces with large numbers of microbends per unit length are often created during the cabling process when manufacturing fiber optic cables, when winding cables on spools and reels, and when passing cables around capstans. Microbends can be created in fiber optic cables under hydrostatic pressure, particularly when buffering is inadequate or strength members are improperly positioned. Simply bending a cable can introduce microbends because of stress differentials imposed on the fiber at the inside and outside radii of the bend. The size of icrobends may be from a fraction of a micron to several microns in the direction of the optical axis or transverse distortion of the core-cladding interface. A waviness of the optical axis, up to several millimeters in wavelength, are also considered as microbends. Lightwaves striking a microbend may escape from the core because the critical angle at the microbend can become less than that required for total (internal) reflection.

microbending. In an optical waveguide, the introduction of minute curves with small radii in the optical axis of the guide or the core-cladding interface surface, at which incidence angles of light rays propagating in the guide are, or tend to become, less than the critical angle so that some of the radiant power in the ray escapes from the fiber core into the cladding. Microbends may result from manufacturing processes, such as application of coatings, making cables, and spooling; packaging; shipment; storage; installation, and use. Microbends can cause radiation loss and mode coupling. The size of microbends may be from a fraction of a micron to several microns in the direction of the optical axis or transverse distortion of the core-cladding interface. A waviness of the optical axis, up to several millimeters in wavelength, are also considered as microbends. When microbends are large enough, they may be considered macrobends, such as will occur when the cable containing the fiber is bent around a curve in a raceway, duct, or trench. Care must be taken in installation that the macrobend radius be greater than both the minimum bend radius and the critical radius.

microbend loss. In an optical fiber, the loss caused by microbends.

microbend sensor. A fiber optic sensor in which an optical fiber is passed between toothed, or serrated, plates. When a force or pressure is applied to the plates, the fiber is squeezed between them, causing microbends in the fiber. An electromagnetic wave, such as a lightwave, propagating in the fiber will escape at the bends, ejecting light into the cladding at each point at which the incidence angle at the core-cladding interface is greater than the critical angle for total (internal) reflection. The increase in attenuation of the main beam in the fiber, caused by the loss of light into the cladding as pressure is applied to the plates, is detected by a photodetector whose output decreases as the pressure increases. Thus, the output signal of the sensor is a function of the applied force or pressure.

microcrack. In optical fibers, a minute crack or partial break, usually along the outer surface of the cladding, but possibly deep enough to enter the core. Microcracks may become enlarged by exposure to adverse environmental conditions, such as moisture, bending, twisting, tensile stress, thermal gradients, vibration, shock, and corrosive atmospheres. Light striking a microcrack will be reflected, refracted, and scattered, generally causing light to escape from the fiber. Proofing of fibers under tension enlarges microcracks. If the cracks become sufficiently large, the fiber ruptures under the applied tension and must be spliced. However, proofing is done to reduce the possibility of a fiber rupturing when it is not under tension.

micrometer (μm). See micron (μ).

micron (μ). A micrometer, that is, one millionth of a meter, or 10^{-6} m (meters). The SI (Systemè International) unit is the micrometer. The micron, instead of the nanometer which is widely used in the optics scientific community, is widely used by the fiber optic technology community to express the wavelengths of light and the geometry of optical fibers, such as the core, cladding, and mode field radii and diameters. This tends to simplify wavelength and geometric comparisons. The wavelengths of light used in fiber optics is of the order of 1 μ, which also makes the micron a convenient unit. Synonymous with micrometer (μm).

middle infrared. Pertaining to the region of the electromagnetic spectrum that lies between the longer-wavelength end of the near-infrared region and the shorter-wavelength end of the far-infrared region, that is, from about 3 to 30 μ (micron). Thus, the near-infrared region is included in the near-visible spectrum, but the middle-infrared and far-infrared regions are not included in the near-visible region. The far infrared extends to the shorter-wavelength end of the radio wave region, which is also the longer-wavelength end of the optical spectrum, that is, to about 100 μ. None of the infrared, that is, the near, middle, or far, are included in the visible spectrum.

minimum cable cutoff wavelength. The minimum wavelength at which a cabled waveguide, such as a cabled optical fiber, will support a single mode. For shorter wavelengths, the fiber will support more than one mode. The operating wavelength range, as determined by the transmitter nominal central wavelength and the transmitter spectral width, must be less than the maximum cutoff wavelength and greater than the minimum cutoff wavelength to ensure that the cable operates entirely in the fiber single-mode region. Usually, the highest value of cabled fiber cutoff wavelength occurs in the shortest cable length. Worst-case variations that are introduced by manufacturing, temperature, aging, and any other significant factors determined when the cable is operated under standard or extended operating conditions. Also see fiber cutoff wavelength.

mirror. See dichroic mirror; partial mirror.

mirror sensor. See optical cavity mirror sensor.

misalignment loss. See angular misalignment loss.

mixed-gas laser. An ion laser in which a mixture of gases, such as argon and krypton, is used as the active laser medium.

mixer. See fiber optic mixer.

mixing. See optical mixing.

mixing box. See optical mixing box.

mixing rod. See optical mixing rod.

modal dispersion. In fiber optics, the spreading of a light pulse in an optical waveguide caused by the different paths taken by the various modes in the lightwaves. Synonymous with inter-modal dispersion; mode dispersion.

modal distortion. See multimode distortion.

modal distribution. 1. In an optical waveguide, such as an optical fiber, operating at a single frequency, or narrow spectral width, the number and types of modes supported by the guide and their propagation time differences. 2. In an optical waveguide operating at multiple frequencies simultaneously, the separation in frequency among the modes being supported by the guide.

modal loss. In an open waveguide, such as an optical fiber, a loss of power in one or more modes in an electromagnetic wave propagating in the guide. Modal loss is caused by anomalies inside and outside the guide, such as obstacles outside the waveguide, changes in dimensions of the guide, and sharp bends in the guide. A loss of power from a mode in an electromagnetic wave propagating in a waveguide also occurs when radiant power is transferred to high-order modes and leaky modes that enter the cladding where they may be absorbed, scattered, or radiated away from the waveguide.

modal noise. Noise generated in an optical system by the combination of mode-dependent optical losses, fluctuations in the distribution of radiant power among the modes or in the relative phases of the modes, and the effects of differential mode attenuation. Synonymous with mode-partition noise; speckle noise.

modal power distribution. See nonequilibrium modal power distribution.

modal power distribution length. See nonequilibrium modal power distribution length.

mode. One of the various possible patterns of standing or propagating electromagnetic fields in a cavity or waveguide. Modes are characterized by their wavelength; the spatial distribution and direction of their electric and magnetic field components relative to the boundaries of the waveguide; and the field strengths of these components. Any electromagnetic field distribution that satisfies Maxwell's equations and the boundary conditions, that is, is a solution to these equations, is a mode. The field pattern of a mode depends on the wavelength, refractive index, and cavity or waveguide geometry. In guided electromagnetic waves, each mode is a particular condition or arrangement of the waves in the waveguide. Each different orientation, that is, polarization, of the electric and magnetic fields of an electromagnetic wave in the guide corresponds to a different mode. Different propagating wavelengths correspond to different propagating modes. Different paths correspond to different modes. Optical fibers can support many modes, the number being given by the relation

$$N = 2\pi^2 a^2 (n_1 - n_2^2)/\lambda^2$$

where a is one-half the core diameter, n_1 and n_2 are the refractive indices of the core and cladding, and λ is the free-space wavelength of the lightwave launched into the fiber, not the wavelength inside the fiber. Single-mode fiber diameters range from 2 to 11 μ (micron), but the number of modes that a given fiber can support depends on the core radius, the wavelength, and the numerical aperture, which depends on core and cladding refractive indices. Thus, an optical fiber operating in single-mode can be made to operate in multimode if the wavelength is reduced. See bound mode; cladding mode; coupled mode; cutoff mode; fundamental mode; high-order mode; hybrid mode; leaky mode; linearly polarized (LP) mode; lowest-order transverse mode; low-order mode; propagation mode; radiation mode; transverse magnetic (TM) mode; transverse electromagnetic (TEM) mode; transverse electric (TE) mode; unbound mode.
mode attenuation. See differential mode attenuation (DMA).

mode conversion. In a guided electromagnetic wave, such as a lightwave, the transfer of some or all of the electromagnetic power in one mode to another mode. Mode conversion can be intentional, such as inducing high-order cladding modes for transferring energy to another fiber or for microbend sensing; or can be unintentional, such as when energy is transferred to high-order modes that escape from the guide and are radiated away causing signal attenuation.

mode coupling. In an optical waveguide, the exchange of power among modes. The exchange of power may reach statistical equilibrium after propagation over a finite distance in a waveguide, such as an optical fiber. This finite distance is designated as the equilibrium modal power distribution length, or simply the equilibrium length.

mode dispersion. See modal dispersion.

mode distortion. See multimode distortion.

mode field diameter. For Gaussian statistical distributions of power and energy among the modes of an electromagnetic wave propagating in a single-mode optical fiber, the diameter at which the electric and magnetic field strengths are reduced to 1/e of their maximum values. This is equivalent to the diameter at which the radiant power is reduced to $1/e^2$ of the maximum power, because the power is proportional to the square of the electric or magnetic field strength.

mode filter. An optical device that can accept, pass, reject, or attenuate, that is, reduce the power level of, a certain mode or modes in an electromagnetic wave. See core mode filter.

mode hopping. The transfer of radiant power from one mode to another. Mode hopping occurs in lasers. Synonymous with mode jumping.

mode jumping. See mode hopping.

mode mixer. See mode scrambler.

mode-partition noise. See modal noise.

mode simulator. See equilibrium mode simulator.

mode scrambler. A device that induces mode coupling in a waveguide, such as an optical fiber. The fiber optic mode scrambler usually consisting of one or more optical fibers, in which a desired distribution of radiant power among modes propagating in an optical fiber is accomplished by transferring power among the modes by means of induced mode coupling. The mode scrambler is frequently used to provide a modal distribution that is independent of source characteristics or that meets other specifications. Synonymous with mode mixer.

mode stripper. See cladding mode stripper; fiber optic mode stripper.

mode volume. The number of bound modes that an optical waveguide is capable of supporting. The mode volume is approximately given by the relation

$$M_{si} = V^2/2$$

for step-index waveguides, and by the relation

$$M_{gi} = (V^2/2)(g/(g+2))$$

for graded-index power-law profile waveguides, where g is the refractive-index profile parameter and V is the normalized frequency, that is, the V-parameter or V-value, when V is greater than 5. See effective mode volume.

modified chemical vapor deposition (MCVD) process. A modified inside vapor phase oxidation (IVPO) process for production of optical fibers in which the burner travels along the glass tube optical fiber preform. Soot particles are created inside the tubing rather than in the burner flame as in the outside vapor phase oxidation (OVPO) process. The chemical reactants, such as oxygen, dopants, and silicon tetrachloride, are caused to flow through the rotating glass tube at a pressure of about 1 atmosphere, gauge. The high temperature causes the formation of oxides, in the form of a soot, and a glassy deposit on the inside surface of the tube. This deposit determines the the refractive index profile of the glass and forms the core when the tube is drawn into a solid optical fiber.

modulate. To vary a characteristic or parameter of an entity in accordance with a characteristic or parameter of another entity, for example, to vary the irradiance, that is, the intensity, of a beam from a light source, such as a laser, in accordance with an intelligence-bearing electronic signal applied to the source, or to vary the radiant power at a point in a waveguide, such as an optical fiber, in accordance with a physical variable being sensed or measured, such as in a microbend or Sagnac sensor. Also see demodulate.

modulation. The controlled variation of a parameter, such as amplitude, phase, frequency, or pulse position or width, of a wave usually for the purpose of transferring information. Modulation can be accomplished by superimposing another wave or by varying a physical parameter to which the wave is sensitive, such as by varying attenuation in an optical fiber or controlling the output of a laser by varying the driving voltage. Uncontrolled or random modulation is considered to be noise or interference. See mechanically-induced modulation; polarization modulation; pulse modulation; pulse-amplitude modulation (PAM); wavelength modulation (WM).

modulator. See fiber optic modulator; optical phase modulator; thin-film optical modulator.

molecular laser. A type of gas laser whose active laser medium is a molecular substance, that is, a compound, such as carbon dioxide, hydrogen cyanide, or water vapor. Also see atomic laser.

molecular stuffing process. A process of making graded-index (GI) optical fibers in perhaps five broad steps--glass melting, phase separation, leaching, dopant introduction, and consolidation.

monitor. In communications, to place emissions, such as radio, radar, video, optical, microwave, or sonar transmissions, under continuous surveillance, by detecting, measuring, recording, and interpreting them.

monochromatic. Pertaining to a single wavelength or pure color. In practice, a "single" wavelength source is at best a narrow band of wavelengths. Also see coherent; line source; spectral width.

monochromatic light. Electromagnetic radiation, in the visible or near-visible spectrum, that has only one frequency or wavelength. Production of high radiance, that is, high intensity, high-energy light at a single wavelength, that is, with a zero spectral linewidth, is not practical at present. Light with narrow spectral widths, such as that produced by lasers, is considered monochromatic light, that is, it consists of one color.

monochromator. An instrument for selecting narrow portions, that is, selecting specific spectral lines, from an optical spectrum.

monolithic integrated receiver. An optical receiver in which a PIN photodiode is combined with a monolithic transimpedance amplifier in a single housing. The packaging is performed in such a way that the performance of the combination is better than that of the individual components packaged separately. Also see PIN-FET integrated receiver.

monomode optical fiber. See single-mode fiber.

moving grating sensor. A fiber optic sensor in which two optical fibers are separated by a small gap in which a pair of gratings is placed in such a way that one is fixed and the other is movable. Both gratings consist of alternate opaque and transparent parallel elements of equal width. When the transparent elements of both gratings line up, light is transmitted from the light source fiber to the photodetector fiber. When the opaque elements of one grating line up with the transparent elements of the other, the light transmission from fiber to fiber is zero. Starting from a line up of opaque elements covering transparent elements, and consequently zero transmission, as the movable grating starts to uncover the transparent elements, light begins to pass through the gratings, causing the transmitted amount of light to increase to the maximum when the transparent elements line up. As the movable grating continues to be moved in the same direction, the amount of light decreases to zero, rising again as the grating continues to move in the same direction, until the end of its movement. The number of times peak transmission is reached is proportional to the distance moved. The frequency of the output signal is proportional to the speed of movement. The acceleration of the movable grating is proportional to the time rate of change of output signal frequency. For example, a sound wave impinging on the movable grating will be reproduced as an electronic output signal of the photodetector.

MTBF. Mean time between failures.

MTBO. Mean time between outages.

MTTF. Mean time to failure.

MTTR. Mean time to repair.

MTTSR. Mean time to service restoral.

multifiber cable. A fiber optic cable that contains two or more optical fibers. Each fiber provides a separate transmission channel.

multifiber joint. An optical fiber splice or connector designed to mate two multifiber cables. The joint provides simultaneous optical alignment of all the individual fibers. Optical coupling between the aligned waveguides may be achieved by various techniques, such as proximity butting, the use of lenses, and the use of index matching materials.

multilayer filter. See interference filter.

multiline laser. A laser that emits radiation at two or more wavelengths.

multimode dispersion. See optical multimode dispersion.

multimode distortion. In an optical waveguide, distortion resulting from multimode group delay and differential mode attenuation. In an optical fiber in which more than one mode is propagating, multimode distortion is caused by the different modes having different propagation properties, such as different propagation constants. The term "multimode dispersion" is often used as a synonym. However, such usage is discouraged because the mechanism is not one of dispersion. Synonymous with intermodal distortion; modal distortion; mode distortion.

multimode fiber. An optical fiber that will allow more than one mode to propagate at a given wavelength. The number of modes will depend on the core diameter, the numerical aperture, and the wavelength. Also see mode volume.

multimode group-delay. In an electromagnetic wave propagating in a waveguide, the variation in group delay time, caused by differences in group velocity, among bound propagating modes even at a single frequency. The differences in arrival times of the leading and trailing edges of a pulse at the end of the waveguide, as compared to the sending end, is caused by the different propagation delays of the different modes. The modes can be considered as different optical paths of different optical path lengths. For example, in an optical fiber, it is possible for photons or waves that propagate along the optical axis of the fiber core to arrive at the end sooner than those that follow a helical path through the core, thus causing the pulse duration at the end of the fiber to be increased. If the pulse duration is too great, intersymbol interference, that is, an overlapping of consecutive pulses, will occur. The received pulse width can be reduced if the refractive-index profile of the core is arranged so that light rays taking a helical path along the outer edges of the core propagate through a lower-refractive-index material, hence travel faster in the longer path than axial rays propagating along the optical axis, or in a helical path closer to the axis of the core, in the higher-refractive-index material, so that they arrive at the end of the fiber at the same time. Actual propagation delay is of little consequence, as long as all rays of a given pulse arrive at the end of the fiber at the same time. So-called zero-dispersion fibers are being made. Synonymous with differential mode delay.

multimode laser. A laser that emits radiation containing two or more modes.

multimode waveguide. A waveguide that can support more than one mode. Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture and the core diameter, a given "multimode" waveguide might support only one mode and therefore could be called a single-mode waveguide if the operating wavelength is long enough, and conversely, a given "single-mode waveguide" might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough.

multipath. Pertaining to electromagnetic wave propagation that results in the waves reaching a receiver by two or more paths. For lightwaves in dielectric waveguides, multipath may be due to many causes, such as refractive-index variations in optical fibers. For radio, video, and microwave transmissions, atmospheric ducting, ionospheric reflection, and reflection from terrestrial objects such as mountains and buildings produce multipath effects. Multipath affects signals because the waves combine in a variety of ways, such as by constructive reinforcement, destructive cancellation, and phase shifting at the receiver.

multiplexer. See fiber loop multiplexer; fiber optic demultiplexer (active); fiber optic demultiplexer (passive); fiber optic multiplexer (active); fiber optic multiplexer (passive); optical demultiplexer (active); optical demultiplexer (passive); optical multiplexer (active); optical multiplexer (passive); thin-film optical multiplexer.

multiplexing. See frequency-division multiplexing (FDM); space-division multiplexing; time-division multiplexing; wavelength-division multiplexing (WDM).

multiplication. See avalanche multiplication.
multiply-connected star network. See star-mesh network.

multiport coupler. See fiber optic multiport coupler.

multirefracting crystal. A transparent crystalline substance that is anisotropic with respect to the velocity of light propagating within it in different directions, that is, the refractive index is different in different directions.

N

n. In optics, the symbol for refractive index, usually implying the refractive index of a material relative to that of a vacuum.

nanometer (nm). One billionth (U.S.) of a meter, that is, 10^{-9} m (meter) or 10 Å. Though a large part of the scientific community still use nanometers to express the wavelength of light, the trend in the fiber optics engineering and industrial community is toward the use of the micron, 1 millionth of a meter or 1,000 nm (nanometer), perhaps because of the convenience of the numbers and to indicate spatial relationships in optical fibers. The optical wavelengths used in fiber optics is of the order of 1 μ (micron). Optical fiber core and cladding diameters; cladding, core, and reference tolerance areas and fields; longitudinal offset, that is, fiber end-face-to-end-face distances in a fiber optic connector; optical thin-film thicknesses; and many other dimensional aspects of optical waveguides, are also expressed in microns, which simplifies comparisons between optical wavelengths and optical waveguide geometry, such as comparing mode field diameters and fiber core diameters and comparing fiber mode volumes using formulas that contain both geometric values and wavelengths. Many of the equations and formulas contain wavelengths and geometric values in numerators and denominators. Calculations and estimates are simplified when geometric values and wavelength values are expressed in the same units.

narrow-band. Pertaining to a group or range of frequencies that are within a relatively restricted part of the spectrum or whose limiting frequencies are relatively close together, the concept of "closeness" being dependent upon the position in the electromagnetic frequency spectrum. Thus, at a median frequency of 100 kHz, a band of frequencies 5 kHz wide would be considered wide. The same 5 kHz band at 100 MHz would be considered narrow. A rule of thumb is that if the band is less than 0.1 percent of the median or operating frequency, the band is narrow.

near-field diffraction pattern. A diffraction pattern for an electromagnetic wave observed in the near-field region. Synonymous with Fresnel diffraction pattern.

near-field pattern. See near-field radiation pattern.

near-field region. The region close to an aperture or source of electromagnetic radiation where the radiation pattern and irradiance, that is the incident power per unit area, is highly dependent upon the distance from the source, such as where the electric field strength varies inversely as the cube of the distance and the propagation times to points within the region are negligible compared to propagation times to points in the far-field region.

near-field radiation pattern. The radiation pattern of a source of electromagnetic radiation in the near-field region, for example, the radiation pattern for an optical fiber that describes the distribution of radiant emittance as a function of position in the plane of the exit face of the fiber. Synonymous with near-field pattern.

near-field scanning technique. The method for determining the refractive-index profile of an optical waveguide by illuminating the entrance face with a light source and measuring the point-by-point radiant emittance as a function of position on the exit face.

near-field template. See four-concentric-circle near-field template.

near infrared. Pertaining to the region of the electromagnetic spectrum that lies between the longer-wavelength end of the visible spectrum and the shorter-wavelength end of the middle-infrared region, that is, from about 0.8 to 3.0 μ (micron). Thus, the near infrared is included in the near-visible region but the middle-infrared and far-infrared regions are not included in the near-visible region. The far infrared extends to the shorter-wavelength end of the radio wave region, which is also the longer-wavelength end of the optical spectrum, that is, to about 100 μ. None of the infrared regions, near middle, or far, are included in the visible spectrum.

NEP. Noise equivalent power.

network. 1. An organization of stations capable of intercommunication but not necessarily on the same channel. 2. Two or more interrelated circuits. 3. A combination of switches, terminals, and circuits in which transmission facili-ties interconnect the user end-instruments directly, that is, there are no switching, control, or processing centers involved. 4. A combination of circuits and terminals serviced by a single processing center or switching center. 5. In network topology, a group of nodes interconnected by branches. See data transfer network (DTN); fiber optic data transfer network; fully-connected mesh network; integrated services digital (or data) network (ISDN); local area network (LAN); long-haul communication network; short-haul communication network; mesh network; metropolitan area network (MAN); ring network; single-node network; star network; star-mesh network; tree network.

network control center. A point in a command, control, and communication network whose main function is to control the network, but it may also serve as a switching center, a processing center, or both, for local users as well as the network. A network control center is usually located at one or more nodes in the network.

network interface device. A device used to access a bus or a network, for example, a modem.

network layer. In open systems architecture, the layer that provides the functions, procedures, and protocol that are needed to control the transfer of data in a specific transmission facility or system. The network layer masks the routing and switching characteristics of the data link and physical layers below from the layers above. In a fiber optic network, the data link and physical layers consist of fiber optic and electronic components and systems. Also see Open Systems Interconnection (OSI) Reference Model (RM).

network standard. See synchronous optical network (Sonet) standard.

node. In network topology, a terminal, that is, the end of any branch of a network, or a terminal common to two or more branches of a network. See end-point node.

noise. See Johnson noise; modal noise; polarization noise; quantum noise; shot noise; thermal noise.

noise current. The electrical current caused by noise voltage.

noise equivalent power (NEP). In an optical detector, the value of the input radiant power that produces an output signal-to-noise ratio equal to one for a given wavelength, modulation frequency, and noise equivalent bandwidth. Some manufacturers and authors have defined NEP as the minimum detectable power per square root unit bandwidth. In this case, NEP has the units watts/(hertz)$^{1/2}$ and therefore NEP is a misnomer because NEP should have the units of power, such as watts. Others have defined NEP as the radiant power that produces a signal-to-dark-current noise ratio of unity. However, this can be misleading when dark-current noise does not dominate the noise spectrum, as is often true in fiber optic systems.

noise-limited operation. See quantum-noise-limited operation.

noise voltage. In fiber optic systems, a voltage that is not coherent with the signal radiant power, such as an rms component of the photodetector electrical output voltage. The noise voltage is usually measured with the signal power removed.

nominal central wavelength. In an optical transmitter, the nominal value of transmitter wavelength for a given application. The central wavelength is the wavelength at which the effective optical power may be considered to be concentrated as defined by a peak mode or power weighted measurement method. The central wavelength range is defined by the minimum and maximum wavelength limits of the total range of transmitter wavelengths caused by the combined worst-case variations due to manufacturing, temperature, aging, and any other significant factors when operated under standard or extended operating conditions.

noncircularity. See cladding noncircularity; core noncircularity; reference surface noncircularity.

nondispersive medium. In the propagation of electromagnetic waves in material media, a medium in which the phase velocity does not vary with frequency. Thus, if an optical pulse consisting of more than a single wavelength is passed through a dispersive medium, all the different wavelengths will arrive at the end at the same time. Thus, the phase velocity and the group velocity are one and the same thing. All materials are dispersive to some extent. Also see dispersive medium.

nonequilibrium length. See nonequilibrium modal power distribution length.

nonequilibrium modal power distribution. In an electromagnetic wave propagating in a multimode waveguide, such as an optical fiber, the distribution of radiant power among modes such that the fractional power in each mode changes as the wave propagates along the waveguide. The power distribution among the modes will continue to change until the equilibrium length is reached, after which the fraction of total power in each mode will remain fairly constant.

nonequilibrium modal power distribution length. The distance in a waveguide, such as an optical fiber, between the entrance end face and the beginning of equilibrium modal power distribution, that is, the point at which the modal radiant power fractional distribution no longer changes with distance along the guide. Thus, the nonequilibrium length and the equilibrium length are the same, because the end of nonequilibrium and the beginning of equilibrium occur at the same point. Synonymous with nonequilibrium length.

nonlatching. A switch actuation method that requires continuous application of an activating force or signal to cause the switch to remain in the position that it is in. Also see latching.

nonlatching switch. In fiber optics, a switch that will selectively transfer optical signals from one optical fiber to another when an actuating force or signal is applied and will continue to transfer signals only as long as the actuating force or signal is continuously applied. When the actuating force or signal is removed, the switch will revert to its original position. Also see latching switch.

nonlinear device. A device whose output is not a linear function of its input. If the output is represented by y and the input by x, then the output is related to the input by a nonlinear function, such as by the relation

$$y = ax^2 + bx + c,$$

where a, b, and c are constants. For example, a device in which the output electric field, voltage, or current is not linearly proportional to the input electric field, voltage, or current. Such a device might have a resistance (varistor) that is a function of the current within it such that for the relation

$$e = ir$$

where e is the instantaneous output voltage, i is the instantaneous current, and r is a function of i, such as $r = ai + b$, giving rise to the relation

$$e = ai^2 + bi$$

New wavelengths or modulation frequencies would be generated by the device. The behavior of a nonlinear device can be described by a transfer function or an impulse response function. Also see linear device.

nonlinear material. See third-order nonlinear material.

nonlinear optical (NLO) material. In fiber optics, a transparent material, such as special glasses, polymers, and organic materials, that display nonlinear properties, such as generate higher harmonic frequencies when energized with optical signals. The generation of second and higher harmonic frequencies means switching speeds of fewer than 100 femtoseconds. The process is also lossless and thus can be repeated many times. An exit wave can be frequency mixed and output beams can be considerably different from input beams. For example, at the exit point of an integrated optical circuit waveguide, different signals can be switched to different ports. Synonymous with NLO material. See polymeric nonlinear optical material.

nonlinear scattering. 1. Scattering of electromagnetic radiation in which wavelengths other than the original wavelength are generated, such as occurs in Raman scattering and Brillouin scattering. 2. Direct conversion of a photon from one wavelength to one or more other wavelengths. In an optical waveguide, nonlinear scattering is usually not significant below the threshold of irradiance for stimulated nonlinear scattering.

nonuniformly distributive coupler. A fiber optic coupler in which optical power input to each input port is not distributed equally among the output ports, and the optical power input to each output port is not distributed equally among the input ports. Also see uniformly distributive coupler.

normal incidence. A direction that makes an angle of 90 degrees with a surface. A light ray that strikes a surface at an angle of 90 degrees is a normal ray.

normalized detectivity. See specific detectivity.

normalized frequency. In fiber optics, a dimensionless quantity, usually denoted by V, given by the relation

$$V = (2\pi a/\lambda_o)(n_1^2 - n_2^2)^{1/2}$$

where a is the waveguide core radius, λ_o is the free-space wavelength, that is, in vacuum, and n_1 and n_2 are the maximum refractive indices in the core and homogeneous cladding, respectively, of an optical fiber. In a fiber having a power-law refractive-index profile, the approximate number of bound modes is given by the relation

$$M_p \approx (V^2/2)(g/(g+2))$$

where g is the refractive-index profile parameter. For a large number of modes, that is, V > 5, the number of modes, or mode volume, is given by the relation

$$M_t \approx V^2/2$$

where V is the normalized frequency. Synonymous with V-number; V-value.

NTSC. National Television Standards Code; National Television Standards Committee.

n-type semiconductor. A semiconducting material, such as silicon or germanium, that has been doped with minute amounts of donor-type material, that is, with material having a valence that allows extra relatively free electrons to wander about the lattice structure of the semiconducting crystal, all other atomic bonds being complete. The free electrons will move readily from atom to atom under the influence of an applied electric field, albeit a relatively weak field, thus constituting an electric current. The dopant, that is, the doping material "donates" electrons to this current, constituting a stream of negatively-charged particles, hence the name n-type semiconducting material. Also see p-type semiconductor.

nuclear hardness. The physical attributes of a system or component that will allow survival in an environment that includes nuclear radiation and electro-magnetic pulses (EMP). Hardness may be measured in terms of susceptibility or vulnerability. Hardness is usually measured in terms of the effects of nuclear environmental conditions, such as overpressure, peak velocities, energy absorbed, and electrical stress, on the characteristics of the system or component, such as its electrical conductivity, molecular structure, or tensile strength. Hardness is achieved through design specifications and is verified by test and analysis techniques. In general, fiber optic systems and components have demonstrated higher survivability levels than other systems and components intended to perform a similar function.

number. See wave number.

numerical aperture (NA). 1. The sine of one half of the vertex angle of the largest cone of meridional rays that can enter or leave an optical system or element, multiplied by the refractive index of the propagation medium in which the cone is located. It is generally measured with respect to an image point and will vary as that point is moved. For an optical fiber in which the refractive index decreases monotonically from n_1 on the optical axis to n_2 in the cladding, the maximum theoretical numerical aperture is given by the relation

$$NA = (n_1^2 - n_2^2)^{1/2}$$

where n_1 is usually taken as the maximum refractive index of the core and n_2 is the refractive index of the innermost homogeneous cladding. However, for a graded-index fiber, because the NA depends on the refractive index, and the refractive index varies with distance from the center of the fiber, the NA varies with the distance from the center of the fiber and therefore the true NA also depends on the maximum refractive index found on the fiber end-face, which is at the center, and of course is progressively less as the distance from the center increases. 2. Colloquially, the sine of the radiation or acceptance angle of an optical fiber, multiplied by the refractive index of the material in contact with the exit or entrance face. This usage is approximate and imprecise, but is often encountered. For optical fibers, the NA is a measure of the light-accepting property of a fiber in as much as only the light that propagates an appreciable distance, such as propagates beyond the equilibrium length, inside the core can be considered to have been accepted by the fiber. Thus, the aperture of an unaided fiber is limited to an acceptance cone, namely the cone within which all rays will undergo total (internal) reflection when inside the core. Typical numerical apertures for optical fibers range from 0.25 to 0.45. Loose terms, such as openness, light-gathering ability, angular acceptance, and acceptance cone have been used to describe the numerical aperture. One way to measure the numerical aperture of an optical fiber is by measuring the launch spot size produced by an illuminated fiber. The spot of light produced by a light beam from the exit endface of an optical fiber is adjusted for maximum irradiance on a transverse screen, that is, a surface perpendicular to the fiber axis, by aligning the fiber. The diameter of the spot is dependent upon the departure angle, that is, the launch angle, from the fiber endface and the distance from the fiber endface to the screen. The numerical aperture is given by the relation

$$NA = D/(D + 4d^2)^{1/2}$$

where D is the spot diameter and d is the distance from the fiber exit endface to the screen. If D/2d is less than 0.25, the numerical aperture of the element is given by the approximate relation

$$NA \approx D/2d$$

The NA is defined as the sine of the acceptance angle. However, the ratio of the spot diameter and twice the distance from the fiber endface to the screen, which is the same as the ratio between the radius of the spot and the distance to the screen, is the tangent of the acceptance angle. However, for the smaller angles the sine and tangent are nearly the same. See launch numerical aperture (LNA). Also see launch spot.

Nyquist bandwidth. The minimum bandwidth in the frequency domain needed to reproduce faithfully a sampled waveform in the time domain. If T is the time interval between adjacent equally spaced samples, then the Nyquist bandwidth is O.5(1/T). If the time interval is in seconds, the Nyquist bandwidth will be in hertz. Thus, in order to reproduce an analog signal with a sufficiently high degree of fidelity, the sampling rate must be at least twice the highest significant frequency present in the signal being sampled. Also see sampling theorem.

Nyquist criterion. In order to faithfully reproduce a signal with high fidelity using sampling techniques wherein a signal is sampled, transmitted in discrete pulses, and reconstituted at the receiving end, the sampling rate must be at least twice the highest significant frequency present in the signal being sampled.

Nyquist interval. The maximum time interval between regularly spaced samples of a signal that will permit the signal waveform to be completely determined. It is equal to the reciprocal of twice the bandwidth of the sampled signal. If the bandwidth, that is, the highest significant frequency in the signal being sampled, is in hertz, the Nyquist interval will be in seconds; if in megahertz, it will be in microseconds. Thus for 5 MHz, the interval will be 0.1 μs, that is, a sample must be taken every 0.1 μs for the Nyquist criterion to be satisfied.

Nyquist rate. The sampling rate required to satisfy the Nyquist criterion, that is, the reciprocal of the Nyquist interval. The Nyquist rate is equal to twice the highest significant frequency in a signal. It is usually expressed in samples per second. Also see sampling theorem.

O

OFCC. See optical fiber cable component (OFCC).

objective. In an optical system, the optical component that receives light directly from the object and forms the first or primary image. In simple cameras without added lenses, such as zoom or telescopic lenses, the image formed by the objective is the final image. In telescopes, microscopes, range finders, binoculars, and other special instruments, the image formed by the objective is further processed by other optical components, such as magnification by an eyepiece.

offline. 1. In communication systems, pertaining to the operation and use of devices and components that are not directly connected to a system and therefore are not available for immediate use on demand by the system without human intervention. Offline devices may be operated independently of the system relative to which they are considered to be offline and they may be operated independently of each other. 2. Pertaining to a condition wherein a device or subsystem is not connected to, is not a part of, and is not subject to, the same controls as the components that are online to a system. Also see online.

offset loss. See lateral offset loss.

offset ratio. See fiber/coating offset ratio.

OFTF. Optical fiber transfer function.

OLTS. Optical loss test set.

old telephone service. See plain old telephone service (POTS).

online. 1. In communication systems, pertaining to the direct connection, operation, and control of devices and components for immediate use on demand by a system, normally without human intervention. 2. Pertaining to a condition wherein devices or subsystems are connected to, are a part of, or are subject to the same controls as the other components of the system to which they are connected. Also see offline.

open systems architecture. The structure, configuration, or model of a distributed data processing system or network that enables system design, development, and operation to be described as a hierarchical structure, that is, as a layering of functions. In the concept, each layer provides a set of accessible functions that can be controlled and used by the layer above it. Thus, each layer can be implemented without affecting the implementation of other layers. The concept is useful because it permits the alteration of system performance at any layer without disturbing the huge investment in existing equipment, procedures, or protocols at that or other higher or lower levels. For example, converting from electrical wire to optical fibers at the physical layer need not affect the data link layer or network layer except to provide more traffic capacity; the network need never be shut down for alterations; and service to the user is not interrupted during system modification or improvement.

Open Systems Interconnection (OSI) Reference Model (RM). An abstract description of digital communication among application processes running in distinct systems. This standard model is a hierarchical structure of seven layers, namely, the (1) physical (lowest), (2) data link, (3) network, (4) transport, (5) session, (6) presentation, and (7) application (highest) layers. Each layer performs value-added service at the request of the adjacent higher layer and, in turn, requests more basic services from the adjacent lower layer. See also (from lowest to highest) physical layer; data link layer; network layer; transport layer; session layer; presentation layer; application layer.

open waveguide. A waveguide without electrically-conducting walls in which electromagnetic waves are guided only by a refractive-index profile so that the waves are confined to the guide by refraction and reflection at the outer surface of the guide or dielectric interface surfaces within the guide. Usually the open waveguide is constructed in such a manner that most of the radiant power in the electromagnetic waves propagate, with negligible radiative loss, inside an inner higher-refractive-index material and along the interface between the two media. An optical fiber is an open waveguide of a transparent material, such as silica glass or plastic. Also see closed waveguide.

operating condition. See extended operating condition; standard operating condition.

operating bounce time. See switch operating bounce time.

operating time. See switch operating time.

operation. See attenuation-limited operation; bit-rate-length-product-limited operation; distortion-limited operation; quantum-limited operation; quantum-noise-limited operation.

optic. See electrooptic; fiber optic; magnetooptic.

optical. 1. Pertaining to the field of optics. 2. Pertaining to eyesight. 3. Pertaining to systems, devices, or components that generate, process, and detect lightwaves or light energy, such as lasers; lens systems; optical fibers, bundles, and cables; and photodetectors. 4. Pertaining to the lightwave region of the electromagnetic spectrum, that is, the region in which the techniques and components used in the visible spectrum also apply to the region extending somewhat beyond the visible region into the ultraviolet and infrared regions, corresponding to wavelengths between 0.3 and 3 μ (micron). 5. Pertaining to the range of wavelengths of optical radiation, which is the electromagnetic spectrum within the wavelength region extending from the vacuum ultraviolet at 0.001 μ to the far infrared at 100 μ, that is, from about 1 nm (nanometer) to 0.1 mm (millimeter), which lies between the region of transition from radio waves and the transition to x-rays. Also see optical spectrum.

optical attenuator. A device used to reduce the radiant power, that is, the intensity, of lightwaves without otherwise altering them. Optical attenuators may be fixed, step-wise variable, and continuously variable. See continuously-variable optical attenuator; stepwise-variable optical attenuator. Also see fiber optic attenuator.

optical axis. 1. In an optical fiber, the longitudinal geometric axis of symmetry. For example, the optical axis of an optical fiber of circular cross section is the locus of all points at the centers of cross-sectional circles, that is, the central longitudinal axis of the core. 2. In a lens, the straight line that passes through the centers of curvature of the lens surfaces. 3. In an optical system, the line formed by the coinciding principal axes of the series of optical elements. Also see optic axis.

optical blank. A piece of optical material having a particular shape, such as a casting molded into the desired geometry, for grinding, polishing, or reshaping into desired geometry with desired optical and mechanical properties. In fiber optics, the blank may be drawn or reshaped, after adding dopants, to make a preform for drawing into a fiber. Also see optical fiber blank; preform.

optical branching device. A device that has three or more ports and shares input light among its ports in a given fashion without changing the input signal other than distributing its energy among the ports. Types of branching devices include unidirectional, bidirectional, symmetric, and asymmetric.

optical cable. See aerial optical cable; bidirectional optical cable; central-strength-member optical cable; fiber optic cable; peripheral-strength-member optical cable.

optical cable assembly. See fiber optic cable assembly.

optical cable facility. The part of an optical station/regenerator section that consists of the fiber optic cable, including splices, that connects the cable splice at the optical cable interconnect feature at one optical station facility to the splice at the optical cable interconnect feature at another optical station facility, i.e., the outside plant between stations. When designing an optical station/regenerator section, the optical losses in the optical cable facility must be equal to or less than the terminal/regenerator system gain. Synonymous with fiber optic cable facility.

optical cable facility loss. In an optical station/regenerator section, the loss (dB) in the optical cable facility, i.e., in the outside plant, given by the relation

$$L = \ell_t(U_c + U_{cT} + U_\lambda) + N_s(U_S + U_{ST})$$

where ℓ_t is the total sheath (cable) length of spliced-fiber cable (km), U_c is the worst-case end-of-life cable attenuation rate (dB/km) at the transmitter nominal central wavelength, U_λ is the largest increase in cable attenuation rate that occurs over the transmitter central wavelength range, U_{cT} is the effect of temperature on the end-of-life cable attenuation rate at the worst- case temperature conditions over the cable operating temperature range, N_S is the number of splices in the length of the cable in the optical cable facility, including the splice at the optical station facility on each end and allowances for cable repair splices, U_S is the loss (dB/splice)) for each splice, and U_{ST} is the maximum additional loss (dB/splice) caused by temperature variation. L must be equal to or less than the fiber optic terminal/regenerator system gain, G, for the optical station/regenerator section to operate satisfactorily. See statistical optical cable facility loss. Synonymous with fiber optic cable facility loss. Also see fiber global attenuation-rate characteristic; terminal/regenerator system gain.

optical cable interconnect feature. In a station facility of an optical station/regenerator section, the device used to connect optical station cables (inside plant) to an optical cable facility (outside plant) via connectors and splices. Synonymous with fiber optic cable interconnect feature.

optical cable pigtail. A short length of fiber optic cable permanently fixed to a component and used to couple optical power between it and another optical cable pigtail or fiber optic cable, such as a transmission cable.

optical cavity. A geometric space in vacuum or material media, bounded by two or more mirrors, in which lightwaves can reflect back and forth, thus producing standing waves of high irradiance, that is, intensity, at certain wavelengths. Such standing waves might be obtained in a ruby crystal laser with two plane or spherical mirrors, forming a resonant cavity. The cavity is the portion of the crystal that lies between the mirrors. The molecules in the cavity can be excited by an inert-gas lamp which causes the cavity to generate and emit a narrow beam of monochromatic light of high irradiance, that is high electric field strength or high radiant power, in the direction of the crystal axis.

optical cavity mirror sensor. A fiber optic sensor in which operation is based on changes in the optical reflection coefficient caused by changes in pressure, temperature, strain, or other imposed stimuli. An arrangement of mirrors causes light to be reflected back to a photodetector via a partial mirror through which the incident beam has passed from the light source. The mirrors are positioned in such a way that one of the reflecting surfaces is at the critical angle of the incident light in the fiber core. The slightest variation in mirror position, caused by the applied stimulus to be sensed, causes the reflected light to pass into or out of total (internal) reflection, which changes the amount of light sent back to the photodetector.

optical cement. A permanent and transparent adhesive capable of withstanding extremes of temperature, such as Canada balsam. However, it is being replaced by modern synthetic adhesives, such as methacrylates, caprinates, and epoxies.

optical chopper. A device for periodically interrupting a light beam, for example, a rotating disk with radial slots through which a collimated beam must pass on to a photodetector will produce a signal with a pulse repetition rate proportional to the angular rotation rate of the disk. Optical fibers can be used to bring the light to and from the disk, or any other rotating element.

optical circuit. See integrated optical circuit (IOC).

optical combiner. 1. In fiber optics, a passive optical device in which radiant power from two or more input optical fibers is distributed among one or more output fibers. The input fibers may each insert light with a different wavelength into the combiner. The output fiber, or fibers, will contain all the input wavelengths. 2. A passive optical device in which radiant power from two or more input ports is distributed among a smaller number of output ports.

optical computer. A computer in which internal operations, such as storage, arithmetic and logic, and control functions, are performed using optical paths, optical switches, integrated optical circuits (IOCs), and optical images. For example, a computer with an optical modulator tube that memorizes optical information as charge patterns while performing arithmetic functions, makes images in memory consisting of picture elements in the form of on-off state of light sources.

optical conduction. The propagation or transmission of lightwaves through a material medium, usually in which they are guided or confined. For example, in an optical data link, the waves are guided from a light source via a fiber optic cable to a photodetector with minimal loss of light energy by absorption, dispersion, deflection, reflection, scattering, or diffusion, such that intelligence carried by the lightwaves at the source can be recovered at the end of the cable. Care must be taken when using the term conductor in fiber optics because the terms conductor, conduction, and conducting are applied to materials that conduct electric currents, such as semiconducting materials and metals, whereas optical materials are dielectric materials which are referred to as "nonconductors". Thus, optical fibers are poor "conductors" of electric currents but good "conductors" of lightwaves. In fiber optics, the words guided, transmitted, and propagated are preferred over the word conducted, thus avoiding ambiguous statements, such as, "Optical fibers are good conductors". Also see optical conductor.

optical conductor. 1. A transparent material that offers a low optical attenuation rate to the transmission of lightwaves, such as certain glasses, plastics, and crystals. 2. An optical waveguide. (The term is obsolete and deprecated. "Conductor" should be reserved for electrical and sonic systems rather than optical systems. Also see optical conduction.

optical connector. See receiver optical connector; transmitter optical connector.

optical connector variation. The maximum value of the difference in insertion loss between mating fiber optic connectors of the same type and model and from the same manufacturer.

optical contact. See terminus.

optical coupler. See fiber optic coupler.

optical data bus. A data bus, that is, a single optical fiber or cable to which all stations and terminals are directly connected so that they can communicate with each other via the single bus. Messages intended for specific addressees must be addressed depending on network protocol. However, all messages placed on the bus can be made available to any or all of the stations and terminals connected to the bus without having to pass through any specific station or terminal.

optical data processing. 1. The performance of digital data processing operations, such as execution of Boolean functions, using a combination of optical and electronic elements. 2. The performance of analog data-processing operations that model or emulate actual systems represented by mathematical functions and relationships governing the behavior of light passing through optical elements, such as by making use of diffraction, interference, and reflection patterns produced by variously-shaped optical elements.

optical demultiplexer (active). An active optical device that uses optical components and other components, such as electrical and acoustic components, to accept signal streams or messages that have been previously multiplexed into a single channel and that separates the streams or messages and places them in individual independent channels so the messages can be used immediately or be separately routed to their ultimate destination. An active optical demultiplexer might consist of an electrically-operated switching device that separates individual wavelengths so as to cause each color in the polychromatic light to be incident upon a different photodetector in order that the intelligence-bearing signal that modulated each color in the optical transmitter can be recovered by the optical receiver. Also see fiber optic demultiplexer (active); fiber optic multiplexer (active); optical multiplexer (active).

optical demultiplexer (passive). A passive optical device that uses only optical components to accept signal streams or messages that have been previously multiplexed into a single channel and that separates the streams or messages and places them in individual independent channels so the messages can be used immediately or be separately routed to their ultimate destination. An optical demultiplexer might consist of a prism that can accept polychromatic light resulting from the multiplexing action of a mixer and separate the individual wavelengths so as to cause each color in the polychromatic light to be incident upon a different photodetector in order that the intelligence-bearing signal that modulated each color in the optical transmitter can be recovered by the optical receiver. Also see fiber optic demultiplexer (passive); fiber optic multiplexer (passive); optical multiplexer (passive).

optical density. An inverse logarithmic measure of transmittance. Transmittance is the ratio of the transmitted radiant power to the incident radiant power at an interface of an optical element. The optical density, O_D, is expressed by the relation

$$O_D = \log_{10}(1/T)$$

where T is the transmittance. The reflectance density, R_D, is given by the relation

$$R_D = \log_{10}(1/R)$$

where R is the reflectance. The reflectance is the ratio of the reflected power to the incident power at an interface of an optical element. The higher the optical density, the lower the transmittance. The optical density times 10 is equal to the transmission loss expressed in decibels. For example, an optical density of 0.3 corresponds to a transmission loss of 3 dB (decibels). The sum of the reflectance and the transmittance is unity, because at an interface, the reflected radiant power plus the transmitted radiant power equals the incident radiant power. Synonymous with transmittance density.

optical detector. A transducer that generates an output signal when irradiated with optical power, for example, a device that converts the optical power or energy of a signal to other forms of power or energy that represent the original optical signal, such as a device that converts optical signals to electrical, sound, other optical, chemical-reaction, or mechanical signals. Also see photodetector. See video optical detector.

optical detector type. Characterization of an optical detector, i.e., a photodetector, by identifying the type of detector (PIN photodiode, APD), compositional material (Ge, Si), and possibly other features.

optical device. See active optical device; passive optical device.

optical disk. A flat circular disk coated with a photosensitive medium on which binary digits in the form of light and dark spots may be stored by modulation of light from a source such as a laser. Disks of the order of 30 cm in diameter can store up to 10^{13} bits, that is, up to 10 Tb (terabits), at recording rates of 10 Mbps (megabits per second) with BERs (bit error ratios) less than 10^{-7}.

optical dispersion attenuation. The attenuation of a signal in an optical waveguide in which each frequency component of a launched pulse is attenuated in such a manner that the shorter wavelengths in the spectral width of the pulse, that is, the higher frequencies, are attenuated more than the lower frequencies, giving rise to a form of distortion. The dispersion attenuation factor is given by the relation

$$DAF = e^{-df}$$

where d is an empirically-determined material constant, including substance and geometry, and f is a significant frequency component of the attenuated signal.

optical distortion. An aberration of spherical-surface optical systems due to the variation in magnification with distance from the optical axis.

optical emitter. A source of optical radiant power, for example, a source of electromagnetic radiation in the visible and near-visible region of the frequency spectrum.

optical energy density. In a light beam propagating through a unit area normal to the direction of maximum power gradient, the amount of optical energy contained in a unit volume of space within the beam, usually expressed in joules per cubic meter, which corresponds to an irradiance level in watts per square meter because the electromagnetic waves in the beam are propagating with the speed of light. Thus, the time rate of energy flow across a unit area is the optical energy density multiplied by the speed, that is joules/meter^3 x meters/second, which is joules/meter^2-second. But joules/second is watts. Therefore, watts/meter^2 remain as the equivalent to joules/meter^3, which implies that the optical energy density and the irradiance, that is, the optical power density, are the same for a propagating electromagnetic wave.

optical fiber. A filament-shaped waveguide, made of dielectric material such as glass or plastic, that guides light. It usually consists of a single discrete optically-transparent transmission element consisting at least of a cylindrical core with cladding on the outside. Though most optical fiber cross sections are round, there are other cross sections, such as elliptical, rectangular, planar, and slotted, for special purposes. The refractive index of the core has to be higher than that of the cladding for lightwaves (or photons) to remain within and propagate in the fiber. If the incidence angle of light rays at the core-cladding interface exceeds a certain angle called the critical angle, rays headed out of the core will be reflected back into the core. The lightwaves can be modulated with an information-bearing signal. Synonymous with optical fiber waveguide. See active optical fiber; compensated optical fiber; overcompensated optical fiber; self-focusing optical fiber; triangular-cored optical fiber; undercompensated optical fiber.

optical fiber acoustic sensor. A highly-sensitive device capable of sensing sound waves by allowing them to impinge upon a length of optical fiber, the waves causing variations in the refractive indices of the materials in the fiber. The variation of refractive indices is used to modulate lightwaves, usually from a laser, that are propagating in the fiber on their way to a photodetector. The spatial distribution of the fiber determines the directional capability of the sensor. For example, if the fiber is wound in the shape of a sphere, the sensor will be omnidirectional; if distributed in a plane, it will be unidirectional; if shaped in the form of a rod, it will be cylindrically directional.

optical fiber active connector. An optical connector with a built-in active device, such as an LED (light-emitting diode) or laser (transmitter), or a photodetector (receiver), or both. The device is usually built into one of the mating elements of the connector, usually in the form of a semiconductor chip with an optical fiber pigtail for connection to a fiber. The connector is built to enable improved fiber-to-fiber or fiber-to-pigtail coupling. The combination provides an improved overall coupling efficiency. For example, one such connector provides 50 times normal coupling efficiency at 30 Mbps (megabits per second) over a 1-km (kilometer) length. Apertures of the semiconductor element are about 0.20 mm (millimeter) for a 0.20-mm-diameter core with a numerical aperture of 0.48, adaptable for bulkhead or printed-circuit-board mounting and EMI and RFI shielding. The connector also serves as a repeater.

optical fiber axis. The locus of the core centers of an optical fiber.

optical fiber blank. A cylindrically shaped piece of glass of high purity, such as glass with a transition metal composition of 10 to 50 ppb (parts per billion, that is, 10^{-9}), used to make a preform from which optical fibers are pulled. In the doped-deposited silica (DDS) process for making optical fibers, the glass and dopants are deposited on a mandrel mounted on a lathe using an inside vapor-phase oxidation (IVPO) process or an outside vapor-phase oxidation (OVPO) process to control the refractive-index profile of the fiber. After sufficient glass has been deposited on the mandrel to form the optical fiber blank, it is removed from the lathe. The mandrel is then removed and the blank is consolidated into a dense glass preform. The fiber is subsequently pulled from the preform. Also see optical blank; optical fiber mandrel; optical fiber preform.

optical fiber bundle. 1. An assembly of unbuffered optical fibers. Usually an optical fiber bundle is used as a single transmission channel, as opposed to multifiber cables in which each fiber provides a separate channel. Bundles used only to transmit light, as in optical communications and illumination systems, are flexible and are typically unaligned. Aligned bundles, that is, coherent bundles, are used to transmit and display images. 2. Two or more optical fibers in a single protective sheath or jacket. The number of fibers might range from a few to several hundred, depending on the application and the characteristics of the fibers. Synonymous with fiber optic bundle.

optical fiber cable. See fiber optic cable.

optical fiber cable component (OFCC). 1. A component or part of a fiber optic cable. 2. The waveguide portion of a fiber optic cable, such as a 12-fiber ribbon complete with fibers, a buffered fiber complete with strength members and jacket suitable for cabling with other similar components. 3. A buffered fiber augmented with a concentric layer of strength members and an overall jacket.

optical fiber coating. 1. A protective material, often called a buffer, bonded to an optical fiber over the cladding for various purposes, such as preserving fiber strength, inhibiting cabling losses, protecting against mechanical damage (microbending), protecting against moisture and other debilitating environments, providing compatibility with fiber and cable manufacturing processes, and providing compatibility with the jacketing process. Coating application methods include dipcoating, extrusion, spray coating, and electrostatic coating. Coating materials include fluoropolymers, Teflon, Kynar, polyurethane, and many others. 2. Special materials bonded to optical fibers to make them sensitive to a specific physical variable that is to be sensed, such as magnetostrictive materials to measure magnetic fields, metals to measure electric currents, and thermally sensitive materials for measuring temperature.

optical fiber communications. The use of physical paths, such as lines, circuits, and links, that are made of optical fibers between terminals, from terminals to user end-instruments, between exchanges and switching centers, or between other components of a communication system.

optical fiber concentrator. A communication system component that multiplexes a number of separate incoming optical fiber communication channels. For example, a distribution frame that accepts 3000 voice optical fiber channels from home optical transceivers and time-division multiplexes them using ten 10-to-1 multiplexers. The output of each goes into 30 more 10-to-1 multiplexers, the final output modulating a lightwave carrier in an optical fiber. Another example is a unit that multiplexes 32 full-duplex digital data channels on a single multiplexed fiber optic data link or cable by means of an interconnection box.

optical fiber concentricity error. In an optical fiber, the distance between the center of the two concentric circles that specify the cladding diameter and the center of the two concentric circles that specify the core diameter. The measurement is used in conjunction with tolerance fields to specify optical fiber core and cladding geometry. Synonymous with core eccentricity.

optical fiber connector set. The total of the fiber optic connector parts required to provide demountable coupling between two or more fiber optic cables.

optical fiber coupler. See fiber optic coupler.

optical fiber delay line. An optical fiber of precise length used to introduce a delay in a lightwave pulse equal to the time required for the pulse to propagate from beginning to end. The delay line may be used for such operations as phase adjustment, pulse positioning, pulse interval coding, or data storage.

optical fiber demultiplexer (active). See fiber optic demultiplexer (active).

optical fiber demultiplexer (passive). See fiber optic demultiplexer (passive).

optical fiber interconnection box. See fiber optic interconnection box.

optical fiber hazard. A feature of a fiber optic system that has the potential of causing injury. Examples of optical fiber hazards include fiber optic cables that have been treated with a special flame-retardant material that is also caustic and can cause skin lesions, the output of high-radiation lasers that can cause eye injury, fragments of fibers that can cause eye damage, and grinding and polishing residues suspended in air that can cause lung damage if inhaled. Precautions include the use of gloves, goggles, masks, ventilators, filters, and frequent washing with warm water and soap during handling and processing operations. Particular precaution must be taken in regard to viewing radiation from the end of an energized fiber because the radiation may not be in the visible spectrum of the electromagnetic spectrum thus giving the impression the fiber is not energized or the appearance that the radiation is at a lower irradiance level than it actually is.

optical fiber jacket. The material that is placed over or wrapped around the buffered or unbuffered optical fiber, strength members, added buffers, fillers, and any other elements used in the construction of a fiber optic cable. Except perhaps for over-armor, the jacket forms the outside of the cable. Markings are placed on it. Synonymous with sheath.

optical fiber junction. An interface formed by butting the end-faces of two optical fibers to allow direct fiber-to-fiber optical transmission.

optical fiber link. See optical link.

optical fiber mandrel. A cylindrically shaped piece of glass of high purity, such as glass with a transition metal composition of 10 to 50 ppb (parts per billion, that is, 10^{-9}), used to make an optical fiber blank which is used to make an optical fiber preform. In the doped-deposited silica (DDS) process for making optical fibers, the glass and dopants are deposited on the mandrel mounted on a lathe using an inside vapor-phase oxidation (IVPO) process or an outside vapor-phase oxidation (OVPO) process to control the refractive-index profile of the fiber. After sufficient glass has been deposited, the blank is removed from the lathe. The mandrel is then removed and the blank is consolidated into a dense glass preform. The fiber is subsequently pulled from the preform under tight melt, tension, flow and diameter control conditions. Also see optical fiber blank; optical fiber preform.

optical fiber merit figure. A figure that indicates the ability of an optical fiber to handle high-frequency signals over given distances with specified distortion limits and bit error ratios (BERs). For example, the pulse repetition rate times the fiber length when pulse dispersion is the specified limiting factor in signal distortion rather than attenuation. Another such figure of merit, FM, for multimode fibers is given by the relation

$$FM = PL^s$$

where s varies between 0.5 and 1, L is the length of the fiber, and P is the pulse repetition rate.

optical fiber multiplexer (active). See fiber optic multiplexer (active).

optical fiber multiplexer (passive). See fiber optic multiplexer (passive).

optical fiber organizer. See fiber-and-splice organizer.

optical fiber pigtail. A short length of optical fiber extending from and permanently attached to a component, such as a fiber optic coupler, connector, repeater, tap, or mixer, to which an optical fiber can be spliced. The pigtail is used to facilitate connecting the component to another optical fiber or component, such as for coupling optical power or signals between the component and a transmission line. It performs a function similar to that of an electrical pigtail, which is a length of wire extending from an electrical circuit element, such as a resistor, transistor, capacitor, diode, or inductor, used for connecting the element to another circuit element or terminal. An optical fiber pigtail on a light source is also called a launching fiber.

optical fiber polarizer. An optical fiber, usually with a specially shaped cross section, that produces a single well-defined polarized mode by selecting one of the two polarized modes from a lightwave propagating in a single-mode fiber. The unwanted polarization is extinguished while the other is transmitted. When the optical fiber polarizer is spliced into a conventional single-mode system the need for collimation is eliminated and the sensitivity to vibration and other disturbances is reduced. Synonymous with fiber optic polarizer.

optical fiber preform. A specially-shaped piece of optical material from which optical fibers may be pulled or rolled. For example, a solid rod made with a higher-refractive-index glass than the tube into which it is slipped, to be heated and pulled or rolled into a cladded optical fiber; or four lower-refractive-index rods surrounding a higher-refractive-index rod heated and drawn into a cladded fiber. The drawing process results in fiber many times longer than the preforms. For round solid preforms, the length of the drawn fiber is equal to the square of the ratio of the preform and fiber radii times the length of the preform, resulting in a fiber tens of kilometers long from a single preform. In the doped-deposited silica (DDS) process for drawing optical fiber, a cylindrically shaped piece of glass of high purity, such as glass with a transition metal composition of 10 to 50 ppb (parts per billion or 10^{-9}), used to make a fiber optic blank which is used to make the preform. The glass and dopants are deposited on a mandrel mounted on a lathe. The inside vapor-phase oxidation (IVPO) process or an outside vapor-phase oxidation (OVPO) process is used to control the refractive-index profile of the fiber. After sufficient glass has been deposited, the blank is removed from the lathe. The mandrel is then removed and the blank is consolidated into a dense glass preform. The fiber is subsequently pulled from the preform. Synonymous with fiber optic preform. Also see optical fiber blank; optical fiber preform.

optical fiber pulse compression. In the transmission of pulses in optical fibers, the compression or shortening of certain frequency-modulated pulses arriving at the end of the fiber when longer wavelengths emitted later catch up with shorter wavelengths emitted earlier.

optical fiber radiation damage. The increased attenuation of lightwaves propagating in an optical fiber caused by increased losses from absorption, diffusion, scattering, or deflection at specific sites created by exposure to high-energy bombardment, such as by gamma rays, cosmic rays, or high-energy neutrons. Degradation can be catastrophic or graceful. Effects of radiation on optical fibers are cumulative, and for the most part irreversible, though there have been indications of considerable recovery after exposure to short bursts of high-energy radiation.

optical fiber ribbon. A cable consisting of optical fibers laminated within a flat plastic strip.

optical fiber ringer. A signaling system for soliciting attention in which a photodetector and transmitter convert enough lightwave energy from information-bearing modulated-carrier signals in optical fibers into an audio tone for sound signaling, that is, for ringing. The ringer power may also be used for other applications, such as providing power for electronic circuits.

optical fiber source. An electronically-powered light source, such as an LED or laser, that can insert radiant power into an optical fiber, usually via a pigtail for splicing or coupling to the fiber. Light emitted by some sources can be directly modulated by electronic signals before the light enters the fiber. In other cases, the radiant power from a constant-output source can be modulated after the light is coupled into the fiber. Typical power output of such sources is of the order of several milliwatts at optical wavelengths.

optical fiber splice. A connection between two optical fibers made by joining an end of one fiber to an end of another fiber. It consists of the optical fiber joint and a fiber splice housing. It is usually contained within an interconnection box or a cable splice closure. Types of splices include fusion, ultraviolet cured or bonded, mechanical, rotary mechanical, and ribbon. Also see fiber optic splice.

optical fiber tensile strength. The maximum load that a short piece of optical fiber can sustain without breaking, normally calculated by the relation

$$T_s = Er/r_{min}$$

where T_s is the safe tension stress; E is Young's modulus, that is, the modulus of elasticity, which normally for glass is about 10^7 lbs/in^2 (7 x 10^9 kg/m^2 (kilograms per square meter) or 70 x 10^9 N/m^2 (newtons per square meter)); r is the radius of the fiber; and r_{min} is the minimum bend radius before breaking. The T_s thus calculated is approximate and must be adjusted for probabilistic increases in occurrences of fractures and microcracks in longer fibers.

optical fiber transfer function (OFTF). The transformation that an optical fiber performs on an electromagnetic wave that enters it, such that if the input signal composition is known, and the transfer function is known for the fiber, the output signal can be determined, for example by the relation

$$OFTF = e^{-af}$$

where a is a constant for the fiber and f is a frequency component of the input signal, that is, the input electromagnetic wave.

optical fiber trap. An optical fiber that breaks easily when stressed; can be placed on approaches to areas to be secured, such as fences and fields; can signal the location of a break and so cannot be cut without detection; and thus can be used to detect the presence of trespassers. Also, the fiber itself is almost invisible, particularly in dimly lit areas.

optical fiber waveguide. See optical fiber.

optical filter. An optical element capable of altering the spectral composition of lightwaves that are incident upon it. The transmitted light emanating from the filter might have the radiant power of certain wavelengths in the incident light reduced or wholly removed. The transmitted light will not contain wavelengths that are not in the incident wave and the radiant power input will always be greater than the optical power output.

optical harness. A number of multifiber cables or jacketed bundles placed together in an array that contains branches. A harness is usually installed within other equipment and mechanically secured to that equipment.

optical harness assembly. An optical harness that is terminated and ready for installation.

optical impedance discontinuity. An abrupt spatial variation in the refractive index, absorption coefficient, scattering coefficient, geometric configuration, or other parameters of an optical waveguide, such as an optical fiber or slab dielectric waveguide. The electric permittivity, magnetic permeability, and electrical conductivity can also contribute to optical impedance discontinuities. Optical impedance discontinuities are not only a function of the intrinsic physical properties of the material from which the guide is constructed, but they are also a function of other extrinsic parameters, such as the frequency or wavelength of an electromagnetic wave propagating in the waveguide, the temperature, and the applied pressure.

optical isolator. 1. A device that prevents light energy from propagating in a given direction at a point in a transmission path. For example, it prevents reflections from proceeding toward the source of the incident light. 2. A two-port optical device that attenuates optical radiation more in one direction than in the opposite direction. Synonymous with optoisolator. Also see fiber optic isolator.

optical junction. Any optical interface, that is, a physical interface, in a fiber optic system. Source to optical fiber, fiber to fiber, fiber to detector, beam in air to prism or lens, fiber to lens, and lens to fiber are examples of optical junctions.

optical length. See optical path length.

optical lever. A means of detecting and measuring small angular displacements of an object by reflecting a beam of light from the object, such as from a smooth reflecting surface of the object or from a mirror or prism attached to the object. The reflected beam is allowed to form a spot of light on a scale to measure the angular displacement.

optical line rate. The data signaling rate (DSR), in bits/second at a given wavelength, that appears at the interface, that is, boundary, between an optical fiber and transmission equipment.

optical link. An optical transmission channel designed to connect two end terminals or to connect other channels in series, that is, in tandem. The link usually consists of a transmitter, that is, a light-emitting unit, a fiber optic cable, a receiver, that is, a photodetector, and necessary connecting elements, such as fiber optic connectors, penetrators, and repeaters. Sometimes terminal hardware, such as transmitter/receiver modules, modulators, and modems are also considered as parts of the optical link to which they are connected. Other components commonly include amplifiers, time-division multiplexers (TDM), time-division demultiplexers (TDDM), and clock and data recovery circuits. Synonymous with fiber optic link; optical fiber link. See repeatered optical link; repeaterless optical link; satellite optical link.

optical loss test set (OLTS). A device consisting of a stabilized light source, such as a laser or an incoherent light-emitting diode (LED), and a calibrated optical power meter. The set measures the optical power loss between two points by launching a known amount of power at one of the points and comparing it with the amount of power received at the other point. The set can also be used to measure insertion loss and attenuation rate. Also see optical time domain reflectometry (OTDR).

optically active material. A material that can rotate the polarization of a lightwave that propagates within it. For example, an optically active material exhibits different refractive indices for left-hand and right-hand circular polarizations, that is, circular birefringence.

optical maser. A source of monochromatic and coherent electromagnetic radiation produced by the synchronous and cooperative emission of optically-pumped ions introduced into a crystal host lattice, a gas, or a liquid whose atoms are excited in a discharge tube. The radiation is a lightwave with a sharply-defined wavelength, that is, with a narrow spectral width, that propagates in a high-power highly-directional beam.

optical material. See nonlinear optical (NLO) material; polymeric nonlinear optical material.

optical mixing. The production of a lightwave that contains all the wavelengths that are in all the input lightwaves, for example, the production of dichromatic or polychromatic radiation from two or more monochromatic lightwaves through the use of an optical mixing box, mixing rod, or other means; or the production of a pulsating electrical current proportional to the difference in wavelength between two interfering monochromatic lightwaves incident upon the same photodetector.

optical mixing box. A fiber optic coupler consisting of a piece of transparent material that receives several optical wavelengths, or frequencies, and that mixes them to produce dichromatic or polychromatic lightwaves for dispatch via one or more outputs for transmission elsewhere and perhaps subsequent separation into the constituent wavelengths to produce the original intelligence introduced by the modulation of each of the constituent wavelengths. The optical mixing box usually has reflective inner surfaces, except at the ports. The lightwaves entering the box are usually a group of monochromatic waves each of a different wavelength and each having been modulated separately.

optical mixing rod. An optical mixing box that has the general shape of a right circular cylinder, usually with pigtails for entrance and exit ports.

optical modulator. See thin-film optical modulator.

optical multimode dispersion. Dispersion of the various frequencies comprising the pulses in an optical waveguide caused by mode scrambling that occurs when two or more transmission modes are supported by the same guide. Optical multimode dispersion is greatly reduced in graded-index (GI) fibers and somewhat reduced by using a monochromatic light source, such as a laser.

optical multiplexer (active). A device that uses optical components and other types of components, such as electrical and acoustic components, to create data links, circuits, or channels to increase the transmission capacity of a system, such as by using space-division, wavelength-division (optical), frequency-division (baseband), and time-division multiplexing schemes, singly or in combination. Examples of active optical multiplexers include optoelectronic multiplexers and electrooptic multiplexers. Additional energy is required to operate the active optical multiplexer over and above that contained in the lightwaves being multiplexed. See thin-film optical multiplexer. Also see fiber optic demultiplexer (active); fiber optic multiplexer (active); optical demultiplexer (active); optical multiplexer (passive).

optical multiplexer (passive). A device that uses only optical components to create data links or channels to increase the transmission capacity of a system, such as by using space-division or wavelength-division multiplexing schemes, for example, an optical mixer. No energy is required to operate the passive optical multiplexer other than that contained in the lightwaves being multiplexed. See thin-film optical multiplexer. Also see fiber optic demultiplexer (passive); optical demultiplexer (passive); fiber optic multiplexer (active); fiber optic multiplexer (passive); optical multiplexer (active).

optical network standard. See synchronous optical network (Sonet) standard.

optical path component. A component whose only function is to convey an optical signal through a point or from one point to another, that is, simply to provide a path for the signal. Examples of optical path components are a dielectric waveguide, optical fiber, fiber optic cable, splice, connector, terminus, penetrator, rotary joint, distribution frame, splice tray, or raceway. The ideal optical path component does not introduce propagation delay, distortion, attenuation, noise, or in any way change or operate upon the optical signals that are passing through them. Multiplexers, demultiplexers, filters, and attenuators are examples of components that are not path components because they operate upon the signals. Also see passive optical device.

optical path length. In a propagation medium of constant refractive index, n, the geometrical distance times the refractive index. If n varies with position the optical path length is the line integral of nds, where ds is an element of length along the path, that is, the optical path length is given by the relation

$$L = \int n\,ds$$

where n, the refractive index, is a function of position and ds is the elemental path length in the integration path. Optical path length is proportional to the phase shift of a lightwave propagating along the path. Synonymous with optical length.

optical phase modulator. An optical device that can control or vary the phase of a lightwave relative to a fixed reference or relative to another lightwave, such as a phase modulator that uses the same Sagnac interferometric principle to make fiber optic gyroscopes. Signals are kept amplified, coherent, and in phase prior to entering the Sagnac fiber loop. Synonymous with fiber optic phase modulator.

optical power. In fiber optics, the radiant power. See transmitter optical power.

optical power budget. In an optical transmission system, the distribution of the available radiant power required for transmission within specified distortion limits or bit error ratios (BER). The distribution is usually made in decibels of attenuation for each component of the system from source to sink. Usually an allowance is made for a power margin. In an optical link, the power level change from source radiant power output to photodetector input power threshold of sensitivity is typically about 30 dB. The power is distributed among the intervening components, such as fiber optic cables, connectors, splices, couplers, multiplexers, demultiplexers, attenuators, and mixers.

optical power density. See irradiance.

optical power efficiency. The ratio of electromagnetic output power from an optical source to the electrical input power to the source.

optical power output. The power in the optical portion of the electromagnetic spectrum emitted by a device. It may be expressed in total watts, total lumens per second, or watts per unit solid angle per unit of projected area of the source in a given direction, that is, the radiance.

optical protective coating. Films that are applied to a coated or uncoated optical surface primarily for protecting the surface from mechanical abrasion, chemical corrosion, or both. An important class of protective coatings consists of evaporated thin films of titanium dioxide, silicon monoxide, or magnesium fluoride. A thin layer of silicon monoxide may be added to protect an aluminized surface to prevent corrosion.

optical pulse broadening. See optical pulse stretching.

optical pulse distortion. An unintentional change in a property that characterizes an optical pulse, such as its shape, amplitude, phase, wavelength, position, or duration.

optical pulse lengthening. See optical pulse stretching.

optical pulse stretching. Increasing the duration (width or length), or the increase itself, of an optical pulse by transmission through one or more optical elements, such as optical fibers. The stretching is given by the empirical relationship

$$T_2 = T_1(L_2/L_1)^k$$

where T_2 is the pulse duration at the end of a fiber of length L_2, T_1 is the pulse duration at the end of fiber length L_1, L_2 is the overall system fiber length including L_1, and k is a factor that is dependent upon the system length, L_2, and the refractive index profile. Typically k varies between 0.5 and 0.9, but more usually varies between 0.7 and 0.9. Pulse stretching is caused primarily by dispersion.

optical pulse suppressor. A device that attenuates an optical pulse, such as 1 km (kilometer) of optical fiber. Optical pulse suppressors were originally conceived to compensate for the dead zones of optical time domain reflectometers (OTDRs) so that measurements could be made beginning at the entrance face of an optical fiber, a connector, or a pigtail.

optical pulse widening. See optical pulse stretching.

optical radiation. Electromagnetic radiation at wavelengths between the transition to x-rays and the transition to radio waves, that is, the electromagnetic spectrum between about 1 nm (nanometer) and about 0.1 mm (millimeter), that is, between 0.001 μ (micron) and 100 μ.

optical ray. A representation of the direction of propagation of electromagnetic radiation as defined by directional parameters. A ray is perpendicular to a wavefront and in the direction of the Poynting vector at each point in a propagation medium.

optical receiver. A device that accepts optical signals from a transmitter or from a propagation medium, detects them by converting them into electronic signals, amplifies, and further processes them.

optical receiver maximum input power. The maximum input optical power (dBm) coupled to an optical receiver, as measured using specified standard procedures, from the line side of the receiver fiber optic connector when operated under standard or extended operating conditions, that the receiver will accept and still (1) not exceed the manufacturer-specified bit error ratio (BER) for digital systems, or (2) operate in a linear nonsaturated mode for analog systems.

optical reflection. See maximum optical reflection.

optical regenerative repeater. See optical repeater.

optical repeater. In an optical transmission system, an optoelectronic device or module that receives optical signals, amplifies them, or in the case of a regenerative optical repeater for digital signals, recovers, reshapes, retimes, or otherwise reconstructs the signals, and transmits the result as an optical signal representing the same information as the input signals. The repeater is inserted at a point in a propagation medium, such as a long fiber optic cable, to overcome the effects of attenuation and dispersion.

optical repeater power. In optical systems, the power required to operate an optical repeater. The power may be delivered to the repeater by such means as (1) an electrical conductor in the cable that also contains the optical waveguides, (2) a separate electrical wire or cable, (3) a solar cell, (4) a local battery, primary or secondary, such as a seawater battery, (5) an electrical power system local power outlet, (6) an optical power cable separate from the optical signal cable or a fiber bundle in the same cable with the signal waveguides, or (7) by tapping the signal power contained in the optical signal fibers without disturbing the information content of the signals.

optical rotation. 1. The angular displacement of the polarization plane of an electromagnetic wave, such as a lightwave propagating through a propagation medium. 2. The azimuthal displacement of the field of view achieved through the use of a rotating prism.

optical rotor. A fiber optic device that permits optical signals propagating in one optical element to pass across the axial interface into another element while they are axially rotating at different speeds, such as between an optical fiber rotating about its optical axis and a stationary fiber, which might occur when a fiber optic system fixed to a platform that is rotating with respect to the ground or frame is connected to a system that is fixed to the ground or frame. Also see fiber optic joint.

optical sensitivity. See receiver optical sensitivity.

optical serrodyne. A modulator in which the phase of a coherent lightwave is modulated by controlling the transit time.

optical signal. See two-level optical signal.

optical source. A device that generates and emits radiant power, that is, electromagnetic energy in the optical region of the electromagnetic spectrum. See standard optical source; video optical source.

optical source type. Characterization of a light source by identifying the type of source (laser, LED, SLED), compositional material (InGaAs), generic device structure (edge-emitting, DFB), and possibly other features.

optical spectrum. The range of wavelengths of optical radiation. Generally, it is the electromagnetic spectrum within the wavelength region extending from the vacuum ultraviolet at 0.001 μ (micron) to the far infrared at 100 μ, that is, from about 1 nm (nanometer) to 0.1 mm (millimeter). This region lies between the region of transition from radio waves and the transition to x-rays. Thus, the lightwave region lies within the optical spectrum and the visible spectrum lies within the lightwave region. The lightwave region has meaning in the sense that techniques for handling lightwaves and components designed for the human visible region also apply to regions somewhat beyond the human visible region, that is, the lightwave region is "visible" to the components though not in its entirety to humans. The optical spectrum lies between the lower wavelength limit of radio waves, that is, 100 μ (micron) or 0.1 mm (millimeter), and the upper wavelength limit of x-rays, that is, 0.001 μ, 1 nm (nanometer), or 10 Å (angstrom). Thus, the optical spectrum is divided into several regions. See table II. Also see electromagnetic spectrum; light; optical.

TABLE II Optical spectrum.

Electromagnetic spectrum region for optical devices*	Wavelength limits (microns)	
	Lower	Upper
Radio*	100	-
Optical	0.001	100
Ultraviolet	0.001	0.4
Lightwave	0.3	3

TABLE II Optical spectrum-continued.

Electromagnetic spectrum region for optical devices*	Wavelength limits (microns)	
	Lower	Upper
Visible	0.4	0.8
Infrared	0.8	100
Near infrared	0.8	3
Middle infrared	3	30
Far infrared	30	100
X-ray	-	0.001

optical speed. In lens systems, the reciprocal of the square of the f-number, which is inversely proportional to twice the numerical aperture. Thus, the optical speed of an optical fiber is directly proportional to the numerical aperture squared, which is equal to the difference of the squares of the refractive indices of the core and cladding.

optical splice. See fiber optic splice.

optical station cable. In an optical station/regenerator section, the fiber optic cable from the optical transmitter or receiver fiber optic pigtail to the splice on the optical cable facility side (line or outside-plant side) of the optical station facility. It includes the cable to and within the cable interconnect feature. The cable is used within a building environment to connect the outside plant fiber optic cable to the fiber optic system terminal equipment. The station fiber optic cable may provide the optical path in the form of optical patch panels that allow rearrangement of paths to the outside plant fibers. Synonymous with fiber optic station cable; station optical cable.

optical station/regenerator section. A fiber optic transmission system consisting of (1) an optical station facility (fiber optic transmitter, connectors, station cables, and an optical cable interconnect feature, (2) a cable facility (cable sections joined by splices between station facilities, and (3) another station facility (fiber optic cable interconnect feature, station cables, connectors, and receiver). Synonymous with fiber optic station/regenerator section.

optical station facility. The part of an optical station/regenerator section that lies within a station, that is the inside plant, including the transmitter, station cable, connectors, and cable interconnect features. Synonymous with fiber optic station facility.

optical surface. In an optical system, a reflecting or refracting surface of an optical element, or any other identifiable geometric surface in the system. Normally, optical surfaces occur at boundaries of discontinuity, that is, at abrupt changes of refractive indices, absorptive qualities, transmittance, vitrification, or other optical quality or characteristic of material.

optical switch. A circuit that enables signals in optical fibers, integrated optical circuits (IOC), or other optical waveguides, to be selectively switched from one circuit or path to another or to perform logic operations with these signals by using electrooptic effects, magnetooptic effects, or other effects or methods that operate on transmission modes, such as transverse-electric versus transverse-magnetic modes, type and direction of polarization, or other characteristics of electromagnetic waves. For example, a multimode achromatic electrooptic waveguide switch or an optical polarization switch. Synonymous with photonic switch. See thin-film optical switch.

optical system. A group of interrelated parts and equipment designed to accept, process, and utilize lightwaves transmitted or guided for the most part in material media, such as lenses, prisms, optical fibers, filters, multiplexers, couplers, connectors, mixers, and various waveguides, to accomplish such functions as communication, illumination, inspection (endoscopy), sensing, and display. Examples of optical systems include optical fiber communication links, telemetry systems, optical gyrocompasses, telescopes, microscopes, and aligned bundles of fibers.

optical taper. An optical fiber with a diameter that is a linear function of its length, thus having a conical shape with either increasing or decreasing diameter in a longitudinal direction. The taper can be used in aligned bundles to increase or decrease the size of an image or as a transition fiber for splicing fibers with different diameters.

optical tapping. The removal or extraction of some of the radiant power, that is, optical power, from electromagnetic waves, such as lightwaves, that are propagating in an optical waveguide, such as an optical fiber, bundle, cable, slab dielectric waveguide, or a waveguide in an integrated optical circuit (IOC). Optical tapping is usually accomplished by using connectors, couplers, taps, and branches. Synonymous with optical tapoff.

optical tapoff. See optical tapping.

optical thickness. 1. The physical thickness times the refractive index of an optical element consisting of an isotropic propagation medium. 2. The total optical path length through an optical element or a series of elements.

optical thin film. A thin layer of an optical propagation medium, usually deposited or formed on a substrate, with a geometric shape and refractive quality so as to enable control, transmission, and guidance of lightwaves for specific purposes, usually to accomplish logical functions by forming optical switches and gates. For example, a thin layer of transparent material in an integrated optical circuit (IOC).

optical time domain reflectometer (OTDR). A device used to characterize an optical waveguide, such as an optical fiber, by means of reflectometry.

optical time domain reflectometry (OTDR). A method for characterizing an optical fiber wherein an optical pulse is coupled into the fiber and the light that is backscattered or reflected back to the input is measured as a function of time. The method is useful in estimating the attenuation rate of the fiber, that is, the optical attenuation coefficient, as a function of distance; identifying the nature and location of defects; determining other localized losses, such as insertion losses caused by fiber optic connectors, couplers, and splices; and measuring other parameters of optical fibers and other components. The distance to a reflection interface surface or other discontinuity is determined by measuring the time it takes for a lightwave pulse to travel to the discontinuity and back. Reflection surfaces include the ends of fiber optic cables, breaks in fibers, splices, connector interfaces, cracks, fractures, or other anisotropic features and discontinuities of the propagation medium. The measurement equipment is called an optical time domain reflectometer. It displays the reflected waves on a time axis for precise reading by showing, for example, the leading edge of a transmitted optical pulse and the various reflections that occur, usually before the next pulse is launched.

optical transimpedance. In an optical transmission system, the ratio of the output voltage at the

photodetector to the input current at the light source.
optical transmitter. A source of light capable of being modulated and coupled to a propagation medium, such as an optical fiber or an integrated optical circuit (IOC).

optical video disk (OVD). A disk on the surface of which digital data may be recorded at high packing densities in concentric circles, or in a spiral, using a laser beam to record spots that are read by means of a reflected laser beam of lower irradiance, that is, intensity, than the recording intensity. Up to 10^{13} bits are being recorded on a single disk at rates of 1 Mbps, making optical video disks suitable for hours of television programming playback.

optical waveguide. Any structure having the ability to guide the flow of optical energy along a path parallel to its axis and, at the same time, to contain the energy within, or adjacent to, its surface(s). See diffused optical waveguide; step-index optical waveguide; thin-film optical waveguide.

optical waveguide connector. A device whose purpose is to transfer optical power between two optical waveguides or optical fiber bundles, and that is designed to be connected and disconnected repeatedly.

optical waveguide coupler. 1. A device whose purpose is to distribute optical power among two or more ports. 2. A device whose purpose is to couple optical power between a waveguide and either a light source or a photodetector.

optical waveguide splice. A permanent joint whose purpose is to couple optical power between two waveguides.

optical waveguide termination. The point in an optical waveguide at which optical power propagating along the waveguide leaves the waveguide and continues in a nonwaveguide mode of propagation. For most applications, care should be taken to prevent leakage, losses, and reflection.

optic attenuator. See fiber optic attenuator.

optic axis. In an anisotropic medium, a direction of lightwave propagation in which orthogonal polarizations have the same phase velocity. Also see optical axis.

optic borescope. See fiber optic borescope.

optic branching device. See fiber optic branching device.

optic bundle. See optical fiber bundle.

optic cable. See fiber optic cable; Tempest-proofed fiber optic cable.

optic cable assembly. See fiber optic cable assembly.

optic cable core. See fiber optic cable core.

optic cable feed-through. See fiber optic cable feed-through.

optic connector. See fiber optic connector.

optic coupler. See fiber optic coupler.

optic cross-connection. See fiber optic cross-connection.

optic data link. See fiber optic data link.

optic data transfer network. See fiber optic data transfer network.

optic demultiplexer (active). See fiber optic demultiplexer (active).

optic demultiplexer (passive). See fiber optic demultiplexer (passive).

optic display device. See fiber optic display device.

optic distribution frame. See fiber optic distribution frame.

optic dosimeter. See fiber optic dosimeter.

optic drop. See fiber optic drop.

optic endoscope. See fiber optic endoscope.

optic filter. See fiber optic filter.

optic flood illumination. See fiber optic flood illumination.

optic gyroscope. See fiber optic gyroscope (FOG).

optic illumination detection. See fiber optic illumination detection.

optic illuminator. See fiber optic illuminator.

optic interconnection. See fiber optic interconnection.

optic interconnection box. See fiber optic interconnection box.

optic isolator. See fiber optic isolator.

optic jumper. See fiber optic jumper.

optic light source. See fiber optic light source.

optic link. See fiber optic link.

optic mixer. See fiber optic mixer.

optic mode stripper. See fiber optic mode stripper.

optic modulator. See fiber optic modulator.

optic multiplexer (active). See fiber optic multiplexer (active).

optic multiplexer (passive). See fiber optic multiplexer (passive).

optic multiport coupler. See fiber optic multiport coupler.
optic patch panel. See fiber optic patch panel.

optic penetrator. See fiber optic penetrator.

optic photodetector. See fiber optic photodetector.

optic receiver. See fiber optic receiver.

optic ribbon. See fiber optic ribbon.

optic rotary joint. See fiber optic rotary joint.

optics. The branch of science and technology devoted to the study of (1) the nature and properties of electromagnetic radiation in the optical spectrum, with most of the emphasis placed on the visible and near-visible spectra, (2) the application of the radiation in useful systems, and (3) the phenomena of vision. See acoustooptics; active optics; coated optics; electrooptics; fiber optics; fixed optics; geometric optics; integrated optics; physical optics; ultraviolet fiber optics; woven fiber optics.

optic scrambler. See fiber optic scrambler.

optic sensor. See fiber optic sensor.

optic splice. See fiber optic splice.

optic splice tray. See fiber optic splice tray.

optic splitter. See fiber optic splitter.

optic spot illumination. See fiber optic spot illumination.

optic supporting structures. See fiber optic supporting structures.

optic switch. See fiber optic switch.

optic telemetry system. See fiber optic telemetry system.

optic terminus. See fiber optic terminus.

optic test procedure. See fiber optic test procedure (FOTP).

optic test method. See fiber optic test method (FOTM).

optic transmitter. See fiber optic transmitter.

optoacoustic transducer. A device that converts an audio-frequency modulated lightwave into a sound tone by causing a crystal to vibrate at the audio modulation frequency of the lightwave.

optoelectrical cable. A cable that contains optical waveguides, such as optical fibers, and electrical conductors.

optoelectronic. Pertaining to devices containing both optical and electronic components, usually involving the conversion of optical power or energy into electrical power or energy, such as the conversion of an optical signal into an electrical signal, or vice versa, representing the same information. Optoelectronic devices must have at least one electrical port. They respond to, emit, or modify optical radiation, or use optical radiation for internal operation. An optoelectronic device may function as an electrical-to-optical or optical-to-electrical transducer. Photodiodes, light-emitting diodes (LEDs), injection lasers, repeaters, and integrated optical circuits (IOCs) are optoelectronic devices commonly used in fiber optic systems. Not synonymous with electrooptic. Also see electrooptic; electrooptic effect.

optoelectronic detector. 1. A device that detects radiation by utilizing the influence of light in forming an electrical signal. 2. A device in which a modulated optical signal is converted into an electrical signal having the original modulation information content.

optoelectronic directional coupler. A directional coupler in which the coupling function is electronically controllable, usually with a photodetector that permits an electronic circuit to be driven by the coupler by tapping some of the passing optical power.

optoelectronic receiver. A receiver that accepts an optical signal from a fiber optic cable and converts it to an electrical signal for further processing or use.

optoelectronics. The combination of pure and applied electronics, optics, and electromagnetics. Synonymous with optronics.

optoelectronic transmitter. A transmitter that accepts an electrical signal and converts it to an optical signal that represents the same information as the electrical signal.

optoisolator. See optical isolator.

optooptics. The branch of science and technology devoted to the use of optical power to control the generation, transmission, reception, and processing of optical signals and power. Optooptics is being applied in integrated optical circuits (IOCs) using nonlinear optical materials to perform modulation, multiplexing, and switching functions. Also see acoustooptics; electrooptics; magnetooptics; photonics.

optronics. See optoelectronics.

ordinary ray. A light ray that has an isotropic velocity in a doubly-refracting crystal. An ordinary ray obeys Snell's law of refraction at the crystal surface. Also see extraordinary ray.

organizer. See fiber-and-splice organizer.

OSI. Open Systems Interconnection.

OSIRM. Open Systems Interconnection Reference Model.

OTDR. 1. Optical time domain reflectometry. 2. Optical time domain reflectometer.

outages. See mean time between outages (MTBO).

output. See optical power output.

output angle. See radiation angle.

output aperture. The aperture at the point of exit of an optical system, usually equal to the aperture of the final optical component, such as an eyepiece lens or the end of an optical fiber, from which the image or exit beam is projected for viewing or for input to another device. The output aperture of an optical fiber can be measured by projecting the exiting beam on a screen and taking the ratio of half the beam diameter at the screen and the distance to the screen.

outside vapor deposition (OVD). Pertaining to a process for the production of optical fibers in which materials are deposited in vapor or soot form on the outside of optical fiber blanks which are then sintered to make optical fiber preforms. Fibers with desired refractive-index profiles are then pulled from the preforms, buffered, and wound on spools or reels for subsequent cabling.

outside vapor phase oxidation (OVPO) process. A chemical vapor-phase oxidation (CVPO) process for the production of optical fibers, in which the soot stream and heating flame are deposited on the outside surface of a rotating glass rod.

OVD. 1. Optical video disk. 2. Outside vapor deposition.

overarmor. An additional cover, jacket, or sheath wrapped around a cable to provide more strength and added protection against harsh environments and for uses in addition to transmission of signals, such as use as a tether cable from ship to a buoy or ship to ship, as a shore-to-ocean interface, or as a ground cable where an abrasive environment is expected. The overarmor is usually braided and made of metal or high-strength polymers. Smooth metal tubing that serves as the jacket over optical fibers is not considered as overarmor.

overall length. See borescope overall length.

overcompensated optical fiber. An optical fiber whose refractive-index profile is adjusted so that the high-order propagating modes arrive ahead of the low-order modes. Higher-order modes have higher eigenvalues in the solution of the wave equations, higher frequencies, and shorter wavelengths than lower-order modes. Also see compensated optical fiber; undercompensated optical fiber.

overfill. When coupling lightwaves from a light source to an optical fiber, the situation that occurs when the core diameter is smaller than the diameter of the cone of light emanating from the source at the end face of the fiber, that is, the launch spot is larger than the core diameter, and the launch angle of the source exceeds the acceptance angle of the fiber.

overhead rate. In a transmission system, the bit rate at an interface corresponding to the bits required to operate the system, usually consisting of bits for error detection and correction, synchronization, buffer stuffing, control, and other system purposes. The interface may be between a user end-instrument and the system or between functional units within the system. Overhead bits representing information generated by the user are not considered as system overhead bits, whereas overhead bits generated within the system and not delivered to the user are considered as system overhead bits. Thus, user throughput is reduced by both overheads while system throughput is only reduced by system overhead. The interface rate is the payload rate plus the system overhead rate. Also see interface rate; payload rate.

OVPO. Outside vapor-phase oxidation.

OVPO process. See outside vapor-phase oxidation process.

oxidation process. See axial vapor-phase oxidation (AVPO) process; chemical vapor-phase oxidation (CVPO) process; inside vapor-phase oxidation (IVPO) process; outside vapor-phase oxidation (OVPO) process.

P

packing density. In an optical fiber bundle, the end cross-sectional total core area per unit of total cross-sectional area, usually within the ferrule, including jacket, strength-member, buffer, core, cladding, and interstitial areas, of the assembly or bundle of all the fibers whose cross-sectional areas are being counted, that is, per unit of the total area within the perimeter of the bundle, such as within the jacket. Packing density varies with the size of fiber, core areas relative to total fiber area, pressure applied to the bundle, and other factors.

packing fraction. In an optical fiber bundle, the ratio of the aggregate cross-sectional core area to the total cross-sectional area of the bundle of fibers. It may be necessary to specify the conditions under which the packing fraction is to be measured. For example, the end area of an optical fiber bundle or fiber optic cable might be the inside area of a coupler, connector, or termination. A packing fraction might be given by the relation

$$PF = N(a/d)^2$$

where N is the number of optical fibers, a is the diameter of the core in each fiber, and d is the diameter of the whole assembly or bundle.

packing fraction loss. The irradiation, that is, the optical power, lost because the packing fraction is always less than unity, except, of course, when there is only one optical fiber in the bundle. The loss is usually expressed in decibels.

PACVD. Plasma-activated chemical vapor deposition.

PACVD process. See plasma-activated chemical vapor deposition (PACVD) process.

pad. See attenuate; attenuator.

PAM. Pulse-amplitude modulation.

panel. See fiber optic patch panel.

parabolic refractive-index profile. In an optical fiber, a power-law refractive index profile in which the profile parameter, g, is equal to 2. Synonymous with quadratic refractive index profile. See linear refractive-index profile; power-law refractive-index profile; radial refractive-index profile.

parameter. See application parameter; global fiber parameter; polarization-holding parameter; material dispersion parameter; profile dispersion parameter; refractive-index profile parameter; signal parameter; wave parameter.

paraxial ray. In optical systems, a ray that is close to and nearly parallel with the optical axis. For computation, the angle θ, between the paraxial ray and the optical axis is small enough for $\sin\theta$ to be practically equal to $\tan\theta$ and either or both can be replaced by θ in radians.

Parseval's theorem. An extension of the superposition theorem applied to nonperiodic wave shapes for spectral irradiance, that is, spectral power density. In the periodic case, the various signals are considered orthogonal over the period, but in the nonperiodic case, the interval of orthogonality extends over the entire time axis from minus to plus infinity.

partial coherence. In an electromagnetic wave, or waves, coherence such that the electromagnetic fields at two points in space or two instants of time have a low statistical level of correlation.

partial mirror. A surface that simultaneously transmits and reflects a significant portion of incident electromagnetic radiation, such as a beam of lightwaves. Usually the surface consists of a substrate, such as glass, with a layer of reflective coating, such as a metal, so thin that it reflects approximately half of the incident radiation and transmits approximately half, with negligible absorption. If two persons, A and B, are on opposite sides of such a mirror, A might see B but B can't see A. If the mirror is constructed with precise dimensions, such as a half or quarter wavelength thick, with a thin reflective and transmitting coating on both sides of glass, it can be used as a beam splitter, combiner, or interferometer to mix two coherent lightwaves from different directions that are incident on opposite sides of the mirror. Depending on the nature of the reflective and transmitting coatings on both sides of the transparent substrate, the output of the mirror would then consist of either (1) two coherently mixed beams, each component of the mixture down 3 dB from its original power level, or (2) one coherently mixed beam. Also see beam splitter.

passive optical device. A device that operates with, or performs specific operations on, electromagnetic waves having wavelengths that are in the optical spectrum, that is, in the optical region of the electromagnetic spectrum, usually within the visible and near-visible spectra. The operations are performed by the propagation media through which the waves pass without the use of input energy other than that contained in the waves themselves. Optical couplers, splitters, mixers, filters, attenuators, gratings, lenses, prisms, and all-optical multiplexers and demultiplexers are passive optical devices. Fiber optic cables, splices, and connectors are also passive optical devices. However, these three perform no specific operation on lightwaves except transport them between and through points. Also see optical path component.

patch panel. See fiber optic patch panel.

path. 1. In network topology, a route between any two nodes of a network. The route may consist of several branches and several nodes that lie enroute between the two nodes connected by the path. The path has a start point and an end point. 2. In communication systems, a route between any two points in a network. The points may be two telephones, a control panel and a motor controller of a ship propulsion system, a remote data input terminal and a computer, or two switching centers.

path attenuation. In communications, the power losses that occur in a wave or signal propagating between a transmitter and a receiver. Usually measured in decibels, it is caused by many effects, such as free-space loss, refraction, reflection, aperture-propagation-medium coupling loss, and absorption.

path component. See optical path component.

path length. See optical path length.

pattern. See equilibrium radiation pattern; eye pattern; far-field diffraction pattern; far-field radiation pattern; fiber pattern; Fraunhofer diffraction pattern; Fresnel diffraction pattern; near-field diffraction pattern; near-field radiation pattern; radiation pattern; speckle pattern.

payload rate. In a transmission system, the interface rate minus the overhead rate. Synonymous with information payload capacity. Also see interface rate; overhead rate.

PCS. Plastic-clad silica.

PCS fiber. See plastic-clad silica (PCS) fiber.

PD. Photodetector.

peak emission wavelength. In fiber optics, the wavelength at which a light source emits its maximum value of optical power.

peak spectral power. The maximum radiance, that is, optical power, emitted by a light source, usually occurring at a specific wavelength or within a specific range of wavelengths. For example, a gallium arsenide light-emitting diode (LED) emits its peak spectral power at a wavelength of 0.910 μ (micron).

peak spectral wavelength. The wavelength at which a light source emits its maximum total optical power. For example, a gallium arsenide light-emitting diode (LED) emits its peak spectral wavelength of 0.910 μ (micron) when operating at a peak diode current of 50 mA (milliampere) at 1 mW (milliwatt) of total optical power output with about 0.30 mW of the optical power output coupled to an optical fiber pigtail.

peak radiance wavelength. The wavelength at which the radiance of a light source in a given direction is a maximum. Synonymous with peak wavelength. Also see radiance.

peak wavelength. See peak radiance wavelength.

penalty. See dispersion power penalty; reflection power penalty.

penetration. In fiber optic systems, the passage through a partition, wall, hull, tank, bulkhead, or other obstacle, usually by means of a fiber optic penetrator or continuous optical cable.

penetrator. See fiber optic penetrator.

periodically-distributed thin-film waveguide. A slab dielectric waveguide that is formed by evaporating, growing, etching, cementing, depositing, masking, or otherwise placing thin films of transparent dielectric material on substrates. For example, an integrated optical circuit (IOC) chip having a deposited wave-guide with a periodically-varying width, in order that only selected modes are propagated while other modes are eliminated because of the geometric shape.

peripheral-strength-member optical cable. An optical cable containing optical waveguides, such as optical fibers, that are surrounded by a group of high-tensile-strength materials, such as stranded or solid contrahelical or longitudinal steel wires, Nylon or Kevlar strands, steel or copper tubes, or other material, with a crush-resistant jacket, sheath, or overarmor on the outside of the cable. Also see central-strength-member optical cable.

permeability. See magnetic permeability; relative magnetic permeability.

permittivity. See electric permittivity; relative electric permittivity.

Perot fiber optic sensor. See Fabry-Perot fiber optic sensor.

perturbation. See phase perturbation.

petahertz (PHz). A unit of frequency equal to 1 thousand trillion hertz, or 10^{15} Hz.

phase. In a periodic function or phenomenon, such as the electric field vector in an electromagnetic wave, the instant, event, or position at which a specified significant parameter of the function occurs relative to a given time reference or relative to a significant instant, event, or position in another function or phenomenon. An example of a phase relationship is the angular displacement between the peak values of two sinusoidal waves of the same frequency. Thus, when lightwaves propagate in an optical fiber, waves of different wavelength are shifted in phase over given lengths of the fiber by different amounts due to their different propagation velocities, giving rise to distortion of signals because they invariably consist of more than one optical frequency, that is, more than one wavelength.

phase constant. See phase term.

phase departure. In a wave propagating in a transmission line or waveguide, an unintentional deviation from the nominal phase value of a point in the wave, that is, an unintentional phase deviation not caused by modulation.

phase detector. A circuit or device that detects the difference in phase between corresponding points on two synchronous signals.

phase-front velocity. In an electromagnetic wave, such as a lightwave, the velocity of a wavefront, the wavefront being a surface described by the locus of all points at which the same significant instant occurs in the wave, such as the surface that describes the locus of all points at which the peak value of the electric field vector is a constant.

phase jitter. A rapid or repeated phase perturbation.

phase modulator. See optical phase modulator.

phase perturbation. The cause of a rapid shifting of the relative phase of a signal, or the momentary phase shift itself. The phase shift may be random, cyclic, or a single shift. Other signal parameter perturbations may also occur along with phase perturbations, caused by superimposed noise, spikes, propagation media anomalies and changes, and interference. The amount of phase perturbation may be expressed in electrical degrees or radians. A cyclic (recurring) perturbation of any sort may be expressed in hertz. Phase perturbation may be negligible in a given transmission system. Also see jitter.

phase term. In transmission lines and waveguides, the imaginary part of the axial propagation constant for a particular mode, usually expressed in radians per unit length. Synonymous with phase constant.

phase velocity. The velocity of propagation of a uniform plane-polarized electromagnetic wave, given by the light-source wavelength times the frequency divided by the refractive index of the propagation medium in which the wave is propagating. In SI (Systemè International) units, the refractive index of free space may be considered to be unity because the refractive indices of materials are normalized with respect to that of a vacuum. Strictly speaking, this concept can only be applied to a single-frequency wave, such as an unmodulated carrier wave from a single-frequency or monochromatic source. The phase velocity is the velocity an observer would have to move to make the wave characteristic appear to remain constant in phase in a given propagation medium. For a given frequency of an electromagnetic wave, which remains constant at interfaces, the wavelength and speed are less in material media than in free space. In nondispersive media, that is, media that do not cause dispersion, the phase velocity and the group velocity are equal.

phonon. An acoustic energy packet similar in concept to a photon, because its energy is a function of the frequency of vibration of the sound source that produced it. Phonon streams form a sound wave, depending on whether one speaks in terms of the quantum theory or the wave theory of sound, just as is the case for light. The energy of a phonon is usually less than 0.1 eV. It is an order of magnitude less than the energy of a photon. However, when dealing with band-gap energies in semiconductors, the energy of a phonon is not negligible and with appropriate coupling, can contribute appreciably to the movement of electrons into higher energy levels on a statistical basis. When these excited electrons move to lower energy levels, photon emission occurs. Thus, the existence of phonons can affect the spectral composition of radiation emitted by a light source.

phosphorescence. The emission of electromagnetic radiation by a material after stimulation from an outside source of energy ceases. However, phosphorescence may also occur during such stimulation. Also see fluorescence; luminescence.

photocell. A device that produces an output electric current, voltage, or power proportional to incident irradiance, that is, optical power, integrated over the illuminated area of the surface that is sensitive because of photovoltaic, photoconductive, or photoemissive effects.

photoconductive effect. The phenomenon in which some nonmetallic materials exhibit a marked increase in electrical conductivity upon absorption of photon energy. Photoconductive materials include (1) gasses that have been ionized by the energy in photons and (2) certain crystals. They are used in conjunction with semiconductor materials that are ordinarily poor electrical conductors but become distinctly conducting when subjected to photon absorption. The incident photons excite electrons into the conduction band where they move more freely, resulting in good electrical conductivity. The increase in conductivity is due to the additional free carriers generated when photon energies are absorbed in energy transitions. The rate at which free carriers are generated and the length of time they remain in conducting states, that is, their lifetime, determines the amount of change in conductivity produced by the incident stream of photons. Synonymous with photoconductivity; internal photoelectric effect.

photoconductive film. A film of material whose electrical current-carrying capacity is enhanced when illuminated by electromagnetic radiation, particularly in the visible and near-visible spectra, that is, the lightwave region, of the electromagnetic frequency spectrum.

photoconductivity. The photoelectric effect in which electrons are emitted from the surface of a material irradiated by optical electromagnetic radiation.

photocurrent. The electrical current, in a material medium, resulting from the absorption of electromagnetic radiation, such as light energy, by the material. In a strict sense, photocurrents result from the photovoltaic or photoemissive effects rather than from an increase in conductivity because then the actual source of current is a power source external to the photodetector. However, because the electric current is a function of incident electromagnetic power, the term may be applied in any case. Photocurrents occur in photodiodes and other photodetectors. Photocurrents may be calculated from the relation

$$I_{ph} = \Gamma eP/hf$$

where Γ is the carrier collection quantum efficiency, e is the electron charge, P is the incident optical power, h is Planck's constant, and f is the frequency of the incident radiation. Synonymous with light current.

photodarlington. A combination of a photodetector and a Darlington-pair transistor circuit. The photodarlington is capable of detecting an optical signal and producing an amplified electrical version of the signal.

photodetector (PD). A transducer capable of accepting an optical signal and producing an electrical signal containing the same information as in the optical signal. See avalanche photodetector; fiber optic photodetector; photoelectromagnetic photodetector; photoemissive photodetector; photovoltaic photodetector. Also see optical detector.

photodetector responsivity. The ratio of the RMS value of the output current or voltage of a photodetector to the RMS value of the incident optical power. In most cases, photodetectors are linear in that their responsivity is independent of the irradiance, that is, the power density or intensity, of the incident radiation. Thus, the photodetector output in amperes or volts is proportional to the incident optical power in watts. Differential responsivity applies to small variations in input optical power. Photodetectors are square-law detectors in that they respond to the irradiance of the incident electromagnetic wave, that is, to the square of the electric field strength associated with the incident wave, which is proportional to the optical power.

photodetector signal-to-noise ratio. The signal-to-noise ratio for a photodetector is given by the relation

$$SNR = (N_p/B)(1 - e^{-hf/kT})$$

where N_p/B is the number of incident photons per unit of bandwidth, h is Planck's constant, f is the frequency of the incident photons, k is Boltzmann's constant, and T is the absolute temperature.

photodiode. A photodetector consisting of a p-n junction, that is, an interface between two semiconductors of different composition, or between a semiconductor and a metal, that either (1) absorbs radiation in the area of the junction, producing a photocurrent or (2) increases its conductivity with increased power level in incident electromagnetic radiation, that is, in irradiance, in which case a source of voltage is required because photoemissive or photovoltaic effects are not being used. See avalanche photodiode (APD); PIN photodiode. Synonymous with diode photodetector.

photoeffect detector. See internal photoeffect detector.

photoelastic effect. That property of a material in which Young's modulus, that is, the modulus of elasticity, mechanical elasticity, or the coefficient of elasticity (stress/strain), at a point in the material is a function of the instantaneous electromagnetic irradiance at the point; and conversely, the effect that changes in elasticity have on electromagnetic waves propagating in a material medium. When an electromagnetic wave is propagating in a material or free space, the irradiance of the wave is (1) the instantaneous electromagnetic power passing through a cross-sectional area, that is, power density in watts per square meter, or (2) the electromagnetic energy contained in a unit volume of the radiation, that is, power density in joules per cubic meter, at the point in the material. These are identical units of irradiance.

photoelastic sensor. A fiber optic sensor in which the photoelastic effect is used for sensing based on the change in refractive index or the double refraction that is produced when stress is applied to a transparent material, especially transparent plastics. When the several lightwaves caused by the changes in refractive indices reinforce or cancel one another, light patterns indicate points of stress. A photodetector can be used to produce a signal indicating the resultant modulation of light from specific points being subjected to stress in a mechanical system.

photoelectric effect. 1. The changes in the electrical characteristics of a material caused by photon energy absorption. 2. The phenomenon of (1) the liberation of electrons and other electrical charge carriers in a material, (2) their increased flow as a result of increased conductivity, (3) their aggregation at material interfaces to produce a voltage, or any combination of these, as a result of photon energy absorption exciting the material. The energy of the incident individual photon is given by the relation

$$E_p = hf$$

where h is Planck's constant and f is the frequency of the photon, that is, the frequency of the incident radiation. If the incident radiation consists of a mixture of frequencies within a given range, the energy level of each photon will be determined by one of the frequencies in the range. The electrons may be released into a vacuum or into another material. The excited material may be a solid, liquid, or gas. Thus, photoconductive, photoelectromagnetic, photoemissive, and photovoltaic effects are all photoelectric effects. See internal photoelectric effect.

photoelectric equation. The equation that relates photon energy, the work function of a material, such as certain metals and oxides, and the emitted-electron energy, that is, the kinetic energy with which an electron will be emitted by the material when the photon strikes it, given by the relation

$$hf = W + (1/2)mv^2$$

where h is Planck's constant, f is the frequency associated with the incident photon, W is the work function of the material the photon strikes, m is the mass of the electron, and v is the velocity with which the electron is ejected. If the emitted-electron energy is zero, that is, the electron has negligible velocity, the photon has just sufficient energy to overcome the work function. The frequency corresponding to this condition is the threshold frequency. If the energy of every photon in a stream of incident photons is less than that of the work function, the photons cannot cause an electron to be emitted no matter how many photons strike the material during a given time period or at what rate they strike the material. Also see work function.

photoelectromagnetic effect. The production of an electric potential difference as a result of the interaction of a magnetic field with a photoconductive material when subjected to incident lightwaves. The incident radiation creates hole-electron pairs that diffuse into the material. The magnetic field causes the paired components to separate as they move in the same direction, but they constitute oppositely-directed electric currents, resulting in the production of an electric potential difference across the material. In most applications, the light is made to fall on a flat surface of an intermetallic semiconductor located in a magnetic field that is parallel to the surface. Excess hole-electron pairs are created by the magnetic field to produce a current flow through the semiconductor that is at right angles to both the light rays and the magnetic field. This is caused by transverse forces acting on electrons and holes that are diffusing into the semiconductor from the surface. Synonymous with photomagnetoelectric effect.

photoelectromagnetic photodetector. A photodetector that makes use of the photoelectromagnetic effect, that is, a photodetector that needs an applied magnetic field, accepts incident optical electromagnetic radiation, and produces an electric current proportional to the electric field strength of the incident radiation.

photoemissive effect. The ejection of electrons, usually into a vacuum, from a material surface irradiated by optical radiation. The emission is a result of photon absorption. Synonymous with external photoelectric effect.

photoemissive photodetector. A photodetector that makes use of the photoemissive effect. An applied electric field is necessary to attract or collect the emitted electrons, thus producing an electric current. Were it not for the applied field, the density of emitted electrons would build up and create an electric field, or space-charge cloud, that would inhibit further emission.

photomagnetoelectric effect. See photoelectromagnetic effect.

photon. A quantum of electromagnetic energy. The energy of a photon is given by the relation

$$E_p = hf$$

where h is Planck's constant and f is frequency. The energy of a photon with a wavelength of 1 μ (micron) is approximately 1.2 eV (electron-volts). A value for the energy of a typical phonon is approximately 0.1 of that of the typical photon. The photon has some particle-like characteristics, for example, they can be counted and their individual energy measured. See gamma photon.

photon detector. A device that responds to incident photons, that is, it signals, with some reasonable probability of being correct, the absorption of a photon, that is, a quantum of electromagnetic energy. The photon detector contains a sensitive material that exhibits a change in property when it absorbs a photon, that is, the material becomes photoemissive, photoconductive, photovoltaic, or photoelectromagnetic.

photonics. The branch of science and technology devoted to the study, control, and use of photons, or lightwaves, including the generation, transmission, reception, and processing of optical signals and power. The control of lightwaves may be effected by electrical, optical, acoustic, or other means. Also see acoustooptics; electrooptics; magnetooptics; optooptics.

photonic switch. See optical switch.

photon noise. See quantum noise.

phototransistor. A transistor that produces electrical output signals corresponding to input incident optical signals. Phototransistors may be used as photodetectors and in other circuits, such as in photodarlington circuits.

photovoltaic. Pertaining to the capability of generating a voltage as a result of exposure to electromagnetic radiation in the optical spectrum.

photovoltaic effect. The production of an electromotive force, that is, a voltage, usually across a semiconductor p-n junction because of the absorption of photon energy. The electrical potential is caused by the diffusion of hole-electron pairs across the junction potential barrier, which the incident photons cause to shift or increase, leading to direct conversion of a part of the absorbed energy into usable electromotive force (voltage). The effect is used to produce voltages in nonhomogeneous semiconductors, such as silicon, or to produce voltages at a junction between two different types of material.

photovoltaic photodetector. A photodetector that makes use of the photovoltaic effect. A source of voltage is not needed for the photovoltaic photodetector because it is a source of voltage.

physical layer. In open systems architecture, the layer that provides the functions that are used or needed to establish, maintain, and release physical connections, and to conduct signals between data terminal equipment, data circuit-terminating equipment, and switching equipment, that is, between user end-instruments and end-point nodes, between switching nodes and end-point nodes, or between switching nodes and control nodes. For example, fiber optic and electronic components can be used to implement the physical layer. Also see Open Systems Interconnection (OSI) Reference Model (RM).

physical optics. The branch of optics in which light is considered as a form of wave motion in which energy is propagated by electromagnetic radiation in the form of waves described by wavefronts, that is, as surfaces, rather than as rays as in geometric optics. The wavefront is perpendicular to the direction of propagation at every point, that is, it is perpendicular to the Poynting vector. The plane of the wavefront contains, and is defined by, the electric and magnetic field vectors at any given point. Synonymous with wave optics.

PHz. Petahertz.

picosecond One millionth of 1 millionth of a second, that is, 10^{-12} s.

picowatt. One millionth of 1 millionth of a watt, that is, 10^{-12} W.

pigtail. See optical fiber pigtail.

PIN. Positive-intrinsic-negative.

PIN diode. A junction diode whose junction consists of three semiconducting materials joined in sequence in the forward-current conducting direction; the first of the three materials being p-type semiconductor, thereby creating holes; that is, acceptor sites; the second being undoped, that is, it is made of intrinsic material; and the third being n-type material, thereby creating free electrons, that is, donor sites. PIN diodes are used extensively as photodetectors in fiber optic systems and integrated optical circuits (IOCs).

PIN-FET integrated receiver. An optical receiver formed by combining a PIN photodiode and a field effect transistor (FET) in a single housing. The packaging is performed in such a way that the performance of the combination is better than that of the individual components employed as discrete components. Also see monolithic integrated receiver.

PIN photodiode. A PIN diode that changes its electrical conductivity in accordance with the irradiance, that is, the optical power density or intensity, and with the wavelength of incident light. The PIN photodiode has an intrinsic region between p-type and n-type semiconductor regions. Photons absorbed in this region create electron-hole pairs that are separated by an electric field, thus generating an electric current, that is, a photocurrent.

pipe. See light pipe.

plain old telephone service (POTS). Telephone service that provides voice and low-speed digital data services only. Wire pairs are used in local loops. Therefore, video, high-speed digital, and broadband analog signals cannot be carried. If POTS wires to homes and offices are replaced with fiber optic cables, all services could be provided with one optical fiber.

planar diffused waveguide. A thin-film slab dielectric waveguide, usually 1 to 10 μ (micron) thick and usually with a graded-refractive-index profile that is made by controlling the diffusion of dopants during its construction.

Planck's constant. A physical constant equal to 6.626 x 10^{-34} joule-seconds. It is usually designated by h. The energy of a photon is given by the relation

$$E_p = hf$$

where f is the frequency of the radiation associated with the photon. The energy of a photon of 1 μ (micron) wavelength is about 1.2 ev (electron-volts). Electrons can only exist in certain energy levels. Therefore, only certain transitions between these levels can occur, giving rise to absorption and emission of only certain quanta of energy, as expressed by hf, where h is Planck's constant and f is the frequency of the absorbed or emitted photon. Therefore, only certain discrete wavelengths of optical radiation exist in a given spectral line. For example, photon energy is given by the relations

$$PE = hf = hkc$$

where h is Planck's constant, k is the wave number, and c is the velocity of light. The wave number turns out to be the number of wavelengths per unit distance in the direction of propagation. The work function of a material is defined according to the relation

$$W = hf_o$$

where h is Planck's constant and f_o is the threshold frequency required to release an electron from the material. Photocurrents may be calculated from the relation

$$I_{ph} = \Gamma eP/hf$$

where Γ is the carrier collection quantum efficiency, e is the electron charge, P is the incident optical power, h is Planck's constant, and f is the frequency of the incident radiation. The signal-to-noise ratio for a photodetector is given by the relation

$$SNR = (N_p/B)(1 - e^{-hf/kT})$$

where N_p/B is the number of incident photons per unit of bandwidth, h is Planck's constant, f is the frequency of the incident photons, k is Boltzmann's constant, and T is the absolute temperature. The equation that relates photon energy, the work function of a material, such as certain metals and oxides, and the emitted electron energy, that is, the kinetic energy with which an electron will be emitted by the material when the photon strikes it, given by the relation

$$hf = W + (1/2)mv^2$$

where h is Planck's constant, f is the frequency associated with the incident photon, W is the work function of the material the photon strikes, m is the mass of the electron, and v is the velocity with which the electron is ejected from the surface of the material into free space assuming there is no surface charge to cause attraction back into the material. In a photoemissive detector, the remaining energy of an electron that escapes from the emissive material due to the energy imparted to it by an incident photon, given by the relation

$$E_e = hf-qw$$

where E_e is the remaining energy of the electron, h is Planck's constant, f is the photon frequency, q is the charge of an electron, and w is the work function of the emissive material. In quantum mechanics, the total energy, E, in a stream of photons of many frequencies during the time the flow occurs, is expressed by the relation

$$E = h\sum_{i=1}^{m} f_i n_i t_i$$

where f_i is the ith frequency; n_i is the number of photons of the ith frequency; t_i is the time duration of the ith frequency summed over all the frequencies, photons, and time durations of each in a given light beam or beam pulse; and h is Planck's constant.

Planck's law. The quantum of energy associated with an electromagnetic field is given by the relation

$$E_p = hf$$

where E_p is the energy of each photon, h is Planck's constant, and f is the frequency of the radiation associated with the photon. The product of the energy and the time is sometimes referred to as the action. Hence, h is sometimes referred to as the elementary quantum of action. Planck's law is the fundamental law of quantum theory. It has direct application in optical fiber communication systems. It describes the concept of the particle, granular, or corpuscular theory of electromagnetic radiation, particularly of light.
plane. See polarization plane.

plane polarization. 1. In an electromagnetic wave, such as a lightwave or radio wave, polarization of the electric and magnetic field vectors in such a manner that they describe a plane that remains perpendicular to a constant direction of propagation. At a given instant, if successive planes were to be identified they would be parallel. Thus, the orientation of the plane is constant with respect to distance coordinates in the direction of propagation. The orientation of the plane at a point in space or in a propagation medium does not change with time except perhaps slowly with respect to frequency. A slowly rotating source may be considered to be capable of producing plane-polarized electromagnetic waves at each instant of time. 2. The polarization of a plane-polarized electromagnetic wave.

plane-polarized electromagnetic wave. An electromagnetic wave whose electric field vector is contained in a plane that is perpendicular to a fixed direction of propagation so that successive planes in space remain parallel. Thus, plane-polarized wavefronts are planar rather than spherical. See uniform plane-polarized electromagnetic wave.

plane (electromagnetic) wave. An electromagnetic wave that predominates in the far-field region of an antenna, that has a wavefront that is essentially in a flat plane, and in which all of the wavefront planes are parallel. Thus, a wave whose surfaces of constant phase are infinite parallel planes normal to the direction of propagation. A uniform plane-polarized electromagnetic wave, that is, a plane wave, propagating in free space or in dielectric media has a characteristic impedance, that is, the ratio between the electric and magnetic field strengths, given by the relation

$$Z = E/H$$

in which E and H are orthogonal and are in a direction perpendicular to the direction of propagation, namely perpendicular to the Poynting vector, which is the vector obtained from the cross (vector) product of the electric and magnetic field vectors, with the direction of a right-hand screw obtained when rotating the electric vector into the magnetic vector over the smaller angle. In free space, the characteristic impedance of a plane wave is 377 ohms. From Maxwell's equations, the characteristic impedance of a plane wave in a linear, homogeneous, isotropic, dielectric, and electric-charge-free propagation medium is given by the relation

$$Z = (\mu/\epsilon)^{1/2}$$

where μ is the magnetic permeability and ϵ is the electric permittivity, where $\mu = 4\pi \times 10^{-7}$ H/m and $\epsilon = (1/36\pi) \times 10^{-9}$ F/m, from which 120π, or 377, ohms is obtained for free space. For dielectric media, the electric permittivity is the dielectric constant, which for glass, ranges from about 2 to 7. However, the refractive index is the square root of the dielectric constant. Thus, the characteristic impedance of dielectric materials is 377/n, where n is the refractive index.

plasma-activated chemical vapor deposition (PACVD) process. A chemical vapor deposition (CVD) process for making graded-index (GI) optical fibers by depositing a series of thin layers of materials of different refractive indices on the inner wall of a glass tube as chemical vapors flow through the tube. A microwave resonant cavity is used to stimulate the formation of oxides by means of a nonisothermal plasma generated by the microwave cavity.

plastic-clad silica (PCS) fiber. An optical fiber consisting of a pure silica glass core with a plastic cladding, thus being a stepped-refractive-index fiber. Optical power loss and dispersion are generally higher in plastic-clad silica fibers than in all-glass fibers. Usually the plastic is a soft silicone material.

plastic fiber. See all-plastic fiber.

p-n junction. In a semiconductor device, such as a transistor or diode, the interface between p-type and n-type semiconductor material, thus creating holes, that is, acceptor sites, on one side of the interface, and relatively free-electrons, that is, donor sites, on the other side of the interface. The junction is usually assumed to be abruptly or linearly graded in its transition region across the interface from the p-type to the n-type material, that is, from the positively doped to the negatively doped region. The holes are less mobile than the electrons. Both contribute to the total electric current.

Pockels cell. A material, usually a crystal, whose refractive index changes linearly with an applied electric field, the material being configured so as to be part of an optical system. Thus, the cell provides a means of modulating the light in the optical path in which it is placed. The modulation depends on the rotation of the polarization plane of the light in a beam, the rotation being caused by an applied electric field. The beam is passed through a polarizer that transmits only certain parts of the beam. The parts of the beam that are transmitted depends on the orientation of the polarization plane of the part. Lithium niobate can be used to make a Pockels cell.

Pockels effect. In birefringent media, an increase in their normal or natural birefringence caused by an applied electric field. The change is linearly proportional to the applied electric field strength, which causes a rotation of the polarization plane of a plane-polarized electromagnetic wave. When combined with polarizers, the effect can be used in modulators and other active optical devices, such as optical switches. Also see Kerr effect.

Pockels-effect sensor. A fiber optic birefringent sensor in which an applied electric field (1) produces birefringence in a material that is not ordinarily birefringent medium without the applied field or (2) enhances birefringence in a material that is inherently birefringent. The voltage applied across the material causes plane-polarized light propagating within it to be resolved into two orthogonal vectors. The change in phase retardation between the two vectors (ellipticity), is directly proportional to the applied electric field strength. An optical fiber polarizer analyzes the output beam, causing irradiance, that is, intensity, modulation of light at a photodetector. The effect is found in particular crystals that are capable of advancing or retarding the phase of the induced ordinary ray, relative to the phase of the extraordinary ray, when the electric field is applied. Thus, the applied electric field strength controls the output of the photodetector.

polarimetric sensor. See polarization sensor.

polariscope. A combination of a polarizer and an analyzer used to detect birefringence in materials placed between them or to detect polarization plane rotation caused by materials placed between them.

polarization. The property of an electromagnetic wave describing the time- varying direction and amplitude of the electric field vector; specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space. In general, the figure is elliptical and is traced in a clockwise or counter-clockwise sense. The commonly referenced circular and linear polarizations are obtained when the ellipse becomes a circle or a straight line, respectively. When observed along the direction of propagation, clockwise rotation of the electric vector is designated right-hand polarization, and couterclockwise rotation is designated left-hand polarization. See circular polarization; elliptical polarization; left-hand circular polarization; left-hand helical polarization; plane polarization; right-hand circular polarization; right-hand helical polarization; rotating polarization.

polarization beat length. For a plane-polarized lightwave propagating in an optical fiber, the distance over which the polarization goes through one complete cycle of change due to modal birefringence, such as from linear polarization in one transverse direction, through elliptical polarization to circular polarization, then through linear polarization in the opposite direction from before, through elliptical to circular and back to linear in the original direction. Thus, the polarization plane rotates through an angle of 360 degrees during one beat length. The beat length for a single-mode optical fiber is given by the relation

$$L_B = 2\pi/(\beta_x - \beta_y)$$

where β_x and β_y are the propagation constants of the two polarized waves caused by the birefringence of the fiber. Beat lengths of single-mode fibers are typically a few centimeters.

polarization diversity. 1. Pertaining to the ability to change the polarization of an electromagnetic wave, usually at the source of radiation, by changing the direction of the polarization plane or by changing the linear, circular, elliptical, or helical polarization of the wave. 2. Pertaining to two or more types of polarization mixed in the same light beam or in the same transmission. 3. Pertaining to any method of transmission and reception of electromagnetic waves in which the same information signal is transmitted and received simultaneously using orthogonally polarized waves with independent propagation characteristics. 4. Pertaining to the ability to change the direction of polarization of an electromagnetic wave, usually at the source, by changing the horizontal or vertical polarization of the transmitted wave.

polarization-holding parameter. A parameter of a polarization-preserving (PP) fiber that indicates the ability of a high-birefringence optical fiber to maintain the polarization of a lightwave launched into the fiber. The parameter describes the average rate at which optical power is transferred from one excited mode to the other orthogonally polarized mode. The relative cross-coupled power increases with the length of the fiber according to the relation

$$P_x/(P_x + P_y) = (1 - e^{-2hL})/2$$

where P_x and P_y are the optical powers in the two orthogonal modes of the high-birefringence fiber, h is the polarization-holding parameter, and L is the fiber length. A polarization-holding parameter value, or h-parameter value, of $1 \times 10^{-5}\ m^{-1}$ corresponds to 1 percent average cross-coupled power after 1 km of fiber. Synonymous with h-parameter; h-value.

polarization modulation. The modulation of an electromagnetic wave in such a manner that the polarization of the electromagnetic wave, such as the direction of polarization of the electric and magnetic field vectors, or their relative phasing, to produce changes in polarization angle in linear, circular, or elliptical polarization, is varied according to a characteristic of an intelligence-bearing signal, such as a pulse-or-no-pulse digital signal. Polarization modulation can be accomplished in waves propagating in waveguides. For example, in dielectric waveguides, such as optical fibers, polarization shifts that are made in accordance with an input signal are a practical means of modulation.

polarization plane. In a typical transverse electromagnetic (TEM) wave, the plane defined by the electric and magnetic field vectors of the wave, that is, both field vectors at a point in space or in a material medium. They lie in, and therefore define, the polarization plane at any instant and any position. The direction of propagation, or electromagnetic power flow, of the wave is perpendicular to both the electric and magnetic field vectors at a point and therefore is perpendicular to the surface of the instantaneous polarization plane. In geometric optics, the unit vector that would represent the direction of the polarization plane is always and everywhere in the same direction as the Poynting vector, that is, in the direction of the ray. In physical optics, the wavefront at a point lies in the polarization plane.

polarization-maintaining (PM) fiber. See polarization-preserving (PP) fiber.

polarization noise. Fluctuations of the direction of the polarization plane of an electromagnetic wave emanating from the end of an optical fiber. The fluctuations are caused by variations in the direction of polarization of the input lightwave and from added fluctuation caused by longitudinal and transverse variations in the refractive index profile along the fiber. Polarization noise above certain threshold levels will interfere with the operation of polarization-preserving optical fibers. Synonymous with birefringence noise. Also see birefringence.

polarization-preserving (PP) fiber. An optical fiber with a flattened, elliptical, or rectangular core such that the direction of the polarization plane of a plane-polarized lightwave entering the fiber remains fixed with respect to the direction of the optical axis of the fiber as the lightwave propagates along the fiber. Launch conditions at the entrance of the fiber must be consistent with the direction of the transverse axis of the fiber cross section. Synonymous with polarization-maintaining (PM) fiber.

polarization sensitivity. In an optical device, the change in a performance parameter, such as the transmittance of an attenuator or the power splitting ratio of a coupler, per unit change in the angle of the polarization plane.

polarization sensor. In fiber optics, a sensor in which the polarization plane of an electromagnetic wave, such as a lightwave in an optical fiber, is rotated by a longitudinal magnetic field applied by a coil wrapped around the fiber. The total number of times the polarization plane is rotated when the fiber passes through the magnetic field is a function of the magnetic field strength and the distance that the fiber is in the field. A change in the number of polarization plane rotations produced by a change in the electric current level in the coil can be detected by a photodetector placed after a polarization analyzer, the output of which is a maximum when the analyzer grating is parallel to the polarization plane and is zero when perpendicular. A finite number of output signal peaks occurs for a finite change of current in the coil. The instantaneous pulse repetition rate or the frequency of the output pulses is proportional to the rate of change of the current in the coil. Thus, the time derivative of an amplitude-modulated input electrical signal to the coil results in a frequency modulated output signal from the photodetector. Synonymous with polarimetric sensor.

polarized electromagnetic wave. See left-hand polarized electromagnetic wave; plane-polarized electromagnetic wave; right-hand polarized electromagnetic wave; uniform plane-polarized electromagnetic wave.

polarized mode. See linearly polarized (LP) mode.

polarized wave. See clockwise polarized wave; counterclockwise polarized wave.

polarizer. An optical device capable of transforming unpolarized light, that is, diffused or scattered light, into polarized light, or capable of altering the type of polarization of polarized light. See optical fiber polarizer.

polychromatic radiation. Electromagnetic radiation consisting of two or more frequencies or wavelengths.

polymeric nonlinear optical material. A transparent polymer, such as a polymer that functions as a third-order nonlinear material, that displays nonlinear optical properties when energized by lightwaves, e.g., a polymer that produces second and higher-order harmonic frequencies when energized with single-frequency lightwave signals. The generation of higher harmonic frequencies means switching speeds of fewer than 100 femtoseconds and less. The process is also lossless and thus can be repeated many times. An exit wave can be frequency mixed and output beams can be considerably different from input beams. For example, at the exit point of an integrated optical circuit waveguide made of polymeric nonlinear optical material, different signals can be switched to different ports. Polymeric materials are being used to manufacture optical modulators, multiplexers, and switches.

population inversion. A redistribution of electron energy levels in a population of atoms in chemical elements and molecules in chemical compounds such that instead of having more atoms with lower-energy-level electrons, there are fewer atoms with higher-energy-level electrons. Thus, an increase in the total number of electrons in the higher excited states occurs at the expense of the energy in the electrons in the lower and ground states and at the expense of the resonant energy source, that is, the pump. Population inversion is not an equilibrium condition. Population inversion is brought about by, and must be maintained by, the pumping action of an energy source. When population inversion occurs, the probability of downward energy transitions, giving rise to radiation, is greater than the probability of upward energy transitions, giving rise to photon absorption. This results in a net output radiation level, thus obtaining stimulated emission, that is, the laser action that occurs in a laser. Also see pump frequency.

port. 1. In a communication network, a point at which signals can enter or leave the network enroute to or from another network. For example, the point in a shipboard data transfer network (DTN) at which a ship-to-shore communication link can be connected is considered as a port in the DTN. 2. In an optical fiber, cable, or bundle, a point at which signals can enter or leave. 3. A place of access to a device or network where energy may be supplied or withdrawn or where the device or network variables may be observed or measured.

positive-intrinsic-negative (PIN) diode. See PIN diode.

positive-intrinsic-negative (PIN) photodiode. See PIN photodiode.

POTS. Plain old telephone service.

powder. See glass powder.

power. See chromatic resolving power; noise equivalent power (NEP); optical receiver maximum input power; optical repeater power; peak spectral power; radiant power; resolving power; source-to-fiber coupled power; theoretical resolving power; transmitted power; transmitter optical power.

power budget. In a system, the allocation of available power, such as optical or electrical power, among the various functions that need to be performed and the various losses that have to be sustained. See optical power budget.

power density. See irradiance.

power distribution. See core-cladding power distribution; nonequilibrium modal power distribution.

power distribution length. See nonequilibrium modal power distribution length.

power efficiency. See optical power efficiency; source power efficiency.

power-law refractive-index profile. For a round optical fiber, the variation of refractive index of the core as an exponential function of the distance from the optical axis, that is, the variation is such that the refractive index within the core at any distance from the axis, r, is given by the relation

$$n_r = n_1(1 - br^g)^{1/2}$$

where n_1 is the refractive index at r = 0, that is, at the axis; r is the radial distance from the axis, g is the refractive-index profile parameter that determines the shape of the refractive-index profile, and b is a constant given by the relation

$$b = 2\Delta/a^g$$

where a is the value of r for which the refractive index becomes uniform, that is, the radius of the core; and Δ is given by the relation

$$\Delta = (n_1^2 - n_2^2)2n_1^2$$

where n_1 again is the refractive index at r = 0, that is, at the axis; and n_2 is the refractive index at the outer edge, that is, at r = a. For most optical fibers, the indices are nearly equal. Therefore Δ is also given by the relation

$$\Delta = 1 - (n_2/n_1)$$

where the parameters are as defined above. Because $n_r = n_2$ at r = a, this relation is also given by the equivalent relation

$$n_r = n_1[1 - 2\Delta(r/a)^g]^{1/2}.$$

Another form of the equation, approximately the same as those above, is given by the relation

$$n_r^2 = n_1^2[1 - 2\Delta(r/a)^g]$$

where the parameters are as defined above. The profile parameter, g, defines the shape of the profile. The Δ is the refractive index contrast when the refractive index of the cladding is constant. Nevertheless, in all these expressions, if the g is about 2.25, intermodal dispersion will be minimized or nearly eliminated for most fibers. If g = 2, a parabolic index profile results. If g = 1, a straight line, that is, a triangular variation of refractive index as a function of radial distance from the axis occurs. If g is infinite, the core refractive index is constant and equal to n_1, which is the case for the step-index fiber. Also see g; linear refractive-index profile; parabolic refractive-index profile; radial refractive-index profile.

power level. At any point in a transmission system, the ratio of the power at that point to some arbitrary amount of power chosen as a reference. This ratio is usually expressed either in decibels referred to 1 milliwatt, dBmW, or in decibels referred to 1 watt, dBW.

power margin. When designing optical links, a power loss (dB) value used to allow for unexpected losses and ensure performance criteria are met, such as the bit rate (data signaling rate) and bit error ratio (BER). The power margin should not include expected losses and degradations, e.g., laser aging, cable aging, reflections, and repairs. These effects should be included in the appropriate parameters of specific devices. Synonymous with power safety margin; safety power margin.

power output. See optical power output.

power penalty. See dispersion power penalty; reflection power penalty.

power safety margin. See power margin.

Poynting vector. In an electromagnetic wave, the resulting vector obtained from the cross-product, that is, the vector product, when the electric field vector is rotated into the magnetic field vector through the smaller angle, the resulting vector propagating in the direction of the end face of a right-hand screw. The Poynting vector, with propagation media parameters and physical constants, defines the irradiance, that is, the power density, and the direction of propagation of the wave.

PP fiber. Polarization-preserving fiber.

precision-sleeve splicer. A round tube that has a round hole with a diameter equal to the outer diameter of two optical fibers to be spliced, that contains an index-matching material, such as an epoxy, into which the two fibers may be inserted from opposite ends. If necessary, the ends of the sleeve may be crimped to hold the fibers tightly, at least until the material cures. The index-matching material may be an optical cement.

preform. See optical fiber preform.

prelasing condition. The operating condition of a laser in which its radiation is primarily spontaneous and not coherent.

presentation layer. In open systems architecture, the layer that provides the functions, procedures, services, and protocol that are selected by the application layer. For example, the functions may include data definition and control of data entry, data exchange, and data display. It is directly below the application layer in the Open Systems Interconnection (OSI) Reference Model (RM).

primary coating. A coating applied to the cladding of an optical fiber to preserve and protect the integrity of its outer surface. In the manufacturing of optical fibers, the coating is placed in contact with and usually bonded to the fiber cladding.

principle. See Fermat's principle.

procedure. See fiber optic test procedure (FOTP).

process. See axial vapor-phase oxidation (AVPO) process; cabling process; chemical vapor deposition (CVD) process; chemical vapor-phase oxidation (CVPO) process; doped-deposited silica (DDS) process; double-crucible (DC) process; inside vapor phase oxidation (IVPO) process; ion exchange process; modified chemical vapor deposition (MCVD) process; molecular stuffing process; plasma-activated chemical vapor deposition (PACVD) process; vapor-phase axial deposition (VAD) process.

processing. See optical data processing.

processing center. In a switched communication network, a point at which signal and data processing is accomplished for the network or for users of the network. A processing center is usually located at a node in the network.

product. See bit-rate-length product.

profile. See equivalent step-index (ESI) profile; graded-index profile; linear refractive-index profile; parabolic refractive-index profile; power-law refractive index profile; radial refractive-index profile; refractive-index profile; step-index profile; uniform refractive-index profile.

profile dispersion. In a waveguide, the dispersion caused by variation of the refractive-index profile with wavelength of the waves propagating in the guide. In an optical fiber, the profile variation also can be caused by variation in the refractive-index contrast and variation in the profile parameter.

profile dispersion parameter. In an optical fiber, the parameter that characterizes the part of the refractive-index profile dispersion caused by a variation of the refractive-index contrast with wavelength, given by the relation

$$P(\lambda) = (n_1/N_1)(\lambda/\Delta)(d\Delta/d\lambda)$$

where P is the profile dispersion parameter, n_1 is the maximum refractive index of the fiber core, N_1 is the group index corresponding to n_1, where N_1 is given by the relation

$$N_1 = n_1 - \lambda(dn_1/d\lambda)$$

where Δ is the refractive-index contrast, given by the relations

$$\Delta = (n_1^2 - n_2^2)/2n_1^2 \text{ or } (n_1 - n_2)/n_1$$

for optical fibers in which the refractive indices are not different from each other by more than 1 percent, and λ is the free-space wavelength of the source.

profile parameter. See refractive-index profile parameter.

proofed fiber optic cable. See Tempest-proofed fiber optic cable.

propagation. The motion or passage of waves within or through a propagation medium.

propagation constant. In an electromagnetic wave propagating in a waveguide, such as an optical fiber or a metal pipe, the factor in the expression for the exponentially varying characteristics of the wave given by the relation

$$e^{-pz} = e^{-ihz-az}$$

in which the term p = ih + a includes both the phase term, h, and the attenuation term, a, governing the propagation characteristics of the wave in the guide. Dispersion occurs because the propagation constant is a function of frequency as well as a function of the materials of construction of the guide. Synonymous with axial propagation constant. See transverse propagation constant.

propagation delay. 1. In an optical device, such as a fiber optic transmitter, receiver, cable, or coupler, the delay between the leading edge of an input signal, such as an optical pulse, and the leading edge of the corresponding output signal. 2. The time required for a signal to travel from one point to another, e.g., in an optical receiver, the time interval between the leading edge of an optical input pulse and the leading edge of the corresponding electrical output pulse.

propagation medium. Any material substance that can be used for the propagation of signals, usually in the form of modulated radio, light, or acoustic waves, from one point to another, such as metals for electrical current signals, glass and other dielectric materials for lightwave signals, and air for sound wave signals, with the possible exception that vacuum is considered as a propagation medium for electromagnetic wave signals, such as light, radio, video, and microwave signals. Except for electromagnetic transmission in vacuum, the propagation medium is usually shaped, or available in specific forms in order to guide the energy in a signal from a point of dispatch to a point of reception. Shaped media include optical fibers, cables, or bundles; wires, including coaxial cables; slab dielectric waveguides; and the sea-atmosphere interface. Synonymous with transmission medium. See anisotropic propagation medium; isotropic propagation medium.

propagation mode. 1. One of the possible electric and magnetic field configurations in which electromagnetic energy propagates in a waveguide or along a transmission line. The mode is an allowable electromagnetic field condition, distribution, or configuration that can exist in a waveguide relative to the direction of propagation of the wave in the guide. Each mode has a factor, that is, an eigenvalue, that defines the propagation constant but not the attenuation term in the wave equation for the discrete mode. The entire field can be described in terms of these modes. Bends and discontinuities may lead to mode conversion, that is, the transfer of energy from mode to mode, but not necessarily to energy that would radiate away from the waveguide. The number of modes a waveguide can support is dependent upon the dimensions of the guide, the wavelength, and the refractive indices of the propagation medium. With proper choice of waveguide size, refractive index, and operating wavelength, single-mode transmission can be achieved. In an open waveguide, that is, a dielectric waveguide such as an optical fiber, evanescent fields are established in a transverse plane. These modes are guided by the gradient of the refractive index. 2. In radio transmission, the manner in which radio signals propagate from a transmitting antenna to a receiving antenna, such as by ground wave, sky wave, direct wave, ground reflection, or scatter.

protective coating. See optical protective coating.

protective covering. In fiber optics, a covering placed over a component, such as a fiber optic cable, splice, or connector, usually in the form of a wrapped tape or bonded coating designed to protect the device, against the environment, such as humidity, abrasion, and bending. Caps, dust covers, and similar devices are also considered as protective covering.

proximity coupling. In fiber optics, the transfer of radiant energy, that is, optical power, from one optical fiber to another by stripping their cladding for a short distance and placing their cores close together, that is, adjacent to each other for the stripped length. The amount of power that is transferred can be controlled by the stripped length and the proximity of the fibers.

p-type semiconductor. A semiconductor material, such as silicon or germanium, that has been doped with minute amounts of acceptor-type material, that is, material with a chemical valence that creates molecular centers lacking an electron to complete their energy shells. These centers will attract an electron from their neighbors leaving a hole among the neighbors. These holes migrate when electrons moving under the influence of an electric field, albeit a relatively weak field, fill the holes, thus constituting an electric current that is oppositely directed to the flow of electrons, that is, the flow constitutes a positive electric current. Thus, the dopant creates holes, or positive centers, that trap electrons, hence the material is called p-type material. The positive current constituted by the migrating holes must be added to the oppositely-directed negative current of electrons when calculating the total electric current. Also see n-type semiconductor.

pulling machine. See fiber-pulling machine.

pulse. A temporal or spatial variation, usually characterized as a rise and decay from a baseline or reference, of the magnitude, such as amplitude, phase, frequency, or other parameter of a physical quantity, such as the electric field strength of an electromagnetic wave, the variation being short relative to the time or space schedule of interest. In fiber optics, the physical quantity might be a lightwave propagating in an optical fiber and the pulse is a sudden increase in irradiance, that is, optical power density or electric and magnetic field strength, a sudden shift in phase, a sudden change in frequency, or a change in polarization, and a return to the original state that existed before the change occurred. The pulse magnitude is the extent to which a parameter deviates from a reference. Thus, a pulse may have a spatial width measured in microns; a temporal width measured in nanoseconds; a bandwidth measured in hertz; or a phase shift measured in radians. Workers in the field tend to use pulse length or width for spatial dimensions and pulse duration, length, or width for temporal dimensions. Pulse modulation is the creation of pulse patterns or sequences to represent digital data or discrete samples of analog signals. Pulses are usually coded or modulated and transmitted in streams at high data signaling rates (DSRs) or pulse repetition rates to represent and transport information. See Gaussian pulse.

pulse amplitude. A measure of the extent to which a physical quantity, such as optical power, electric current, or voltage used to represent a pulse changes from a zero or other baseline value for the pulse duration. For example, the momentary change in optical power output of a laser to represent a single pulse or the amount of the change in photocurrent of a photodetector from the dark current value to the light current value. Often it is necessary to use modifiers, such as average, instantaneous, peak, and root-mean-square, to indicate the significance of the units of measure used to define the pulse amplitude. Synonymous with pulse height. Also see pulse magnitude.

pulse-amplitude modulation (PAM). A form of modulation in which the amplitude of the individual pulses of a constant-pulse-repetition-rate carrier, such as the amplitude of the individual pulses in a stream of light pulses, is varied in accordance with some characteristic of the modulating signal.

pulse broadening. Increasing the pulse width (spatial) or pulse duration (time) of a pulse as a result of dispersion. The distortion is caused by the spreading in time and space of an electromagnetic pulse, such as an optical pulse, propagating along a propagation medium or path, such as an electrical transmission line or optical fiber. The dispersion is caused by the variation of the propagation constant for each wavelength in the signal pulse, that is, the different wavelengths propagate at different speeds. This phenomenon limits the useful transmission bandwidth of the path, or for a given bandwidth, limits the data signaling rate (DSR), that is, limits the pulse repetition rate that may be transmitted because of the intersymbol interference that occurs when the pulse duration at the receiving end increases to a point where they begin to overlap each other upon arrival. For an optical fiber, the amount of spreading depends on the spectral width of the light, the refractive-index profile of the fiber, the length of the fiber, and the duration of the launched pulse. Because of the dependence on length, a significant measure of optical fiber performance is the bandwidth-length product. Pulse broadening may be specified by the impulse response or by the full-duration-half-maximum pulse broadening. Synonymous with pulse dispersion; pulse spreading.

pulse compression. See optical fiber pulse compression.

pulse decay time. See fall time.

pulse dispersion. See pulse broadening.

pulse distortion. See optical pulse distortion.

pulse duration. The time interval that a pulse lasts to represent a binary digit. For example in amplitude modulation, the time interval between the points on the leading and trailing edges of a pulse at which the instantaneous value bears a specified relation to the peak pulse amplitude, such as the time interval between the full-wave-half-power points in rise and fall or between the 10 percent values in rise and fall; or in frequency or phase-shift modulation, the time period during which the frequency or the phase remains changed to represent a binary digit. Because pulses have a duration at a point, that is, they have a temporal width, and they are propagating at a specific speed, they also have a spatial width, that is, they occupy a space in the propagation medium. Synonymous with pulse length; pulse width. See root-mean-square (rms) pulse duration.

pulse half-duration. In a pulse, half of the full duration of the pulse, the full duration being defined as the time interval between specified points on the pulse waveform, such as between the 90 percent, half, or 1/e of maximum value points. Synonymous with pulse half-width.

pulse half-width. See pulse half-duration.

pulse height. See pulse amplitude.

pulse jitter. The jitter of a pulse parameter, such as the jitter of the pulse duration, pulse time or space position, or pulse amplitude.

pulse length. See pulse duration.

pulse magnitude. A measure of the extent to which the physical parameter, quantity, or phenomenon used to represent a pulse changes from a baseline or reference for a short time, such as the amount of change in optical power output of a laser, the extent of the phase shift of a monochromatic wave, or the extent of a frequency change in a frequency-modulated system. Often it is necessary to use modifiers, such as average, instantaneous, peak, and root-mean-square, to indicate the significance of the units or measure used to define the magnitude of the pulse. Also see pulse amplitude.

pulse modulation. The temporal changing of one or more characteristics or parameters, such as pulse duration, pulse position, or pulse amplitude of a carrier wave in accordance with an intelligence-bearing signal. For example, in fiber optics, lightwave carrier pulse modulation can be accomplished by an intelligence-bearing electrical modulating signal sent to the light source, or by modulating the constant lightwave carrier output of the source after emission when the lightwave is in an optical fiber and the fiber is subjected to a continuously-varying or pulsating physical variable, such as pressure, sound, temperature, or interferometric variations.

pulse rate. See maximum pulse rate.

pulse-repetition rate. The number of pulses that occur per unit of time at a particular point in a propagation medium, usually expressed as pulses per second. In fiber optic systems, desired bit error ratios, dispersion, attenuation, available power, detector sensitivity, noise levels, and other factors limit the pulse-repetition rate that a given transmission system can handle.

pulse rise time. See rise time.

pulse spreading. See pulse broadening.

pulse stretching. See optical pulse stretching.

pulse suppressor. See optical pulse suppressor.

pulse width. See pulse duration.

pulse-width distortion. 1. In an optical fiber, the difference between the pulse width of an optical input pulse and the width of the corresponding optical output pulse at the distal end of the fiber. 2. In a fiber optic transmitter, the difference between the width of an optical input pulse and the width of the corresponding electrical output pulse. 3. In an optical receiver, the difference between the pulse width of an optical input pulse and the width of the corresponding optical output pulse. 4. In an optical link, the difference between an electrical input pulse at the transmitter and the electrical output pulse at the receiver.

pump frequency. The frequency of an oscillator used to provide the sustaining power to certain specially designed devices, such as parametric amplifiers or lasers. Pumps usually are designed to provide resonant frequencies to raise power levels in the devices they pump energy into. Also see population inversion.

Q

quadratic refractive-index profile. See parabolic refractive-index profile.

quadruply clad fiber. An optical fiber construction that has four claddings surrounding the fiber core. The core has a relatively very high refractive index compared to the four fiber claddings, which are of very low, high, low, and medium refractive-index materials, respectively, from the core radially outward. The quadruply clad fiber is usually designed so as to achieve single-mode operation.

qualification testing. Formal testing designed to demonstrate that the software and hardware of a system meet specified requirements. Qualification testing may be accomplished at any time during the life of a system, such as during prototype development, manufacturing, shipment, storage, installation, and operation. Most often the qualification testing is conducted to determine the extent to which a system passes a specified set of performance criteria.

quality factor. See intrinsic quality factor (IQF).

quantization. A process in which the continuous range of values of a signal is divided into nonoverlapping, but not necessarily equal, subranges; and, to each subrange, a discrete value of the output is uniquely assigned. Whenever the signal value falls within a given subrange, the output has the corresponding discrete value.

quantum. A unit of electromagnetic energy equal in magnitude to hf, where h is Planck's constant and f is the frequency of the radiation. A quantum of electromagnetic energy is released when an electron in an excited or radioactive chemical element moves from a higher to a lower energy level. A photon is a quantum of electromagnetic energy in the optical spectrum. The lowest energy photon would have the lowest frequency, that is, the longest wavelength, at the extreme end of the far-infrared region of what is considered to be the optical spectrum, 100 μ (micron), corresponding to a frequency of 3 THz (terahertz), or 3 x 10^{12} Hz (hertz). The highest energy photon wavelength is 0.001 μ, which corresponds to 0.3 EHz (exahertz) or 0.3 x 10^{18} Hz. The energy of a 1-μ photon is about 1.2 eV (electron-volts).

quantum efficiency. In a quantum device, the ratio of the countable elementary events at the output to the countable elementary events at the input. The ratio defines the device transfer function for the countable events. For example, in an optical semiconductor source, such as a photodiode, it is the ratio of the number of photons emitted to the number of electrons applied by an input electrical pulse; in a photodetector, it is the ratio of the number of electrons generated in the photocurrent to the number of photons applied by an input optical pulse. See differential quantum efficiency; response quantum efficiency.

quantum-limited operation. In the operation of a photodetector, the inability of the detector to measure incident radiation levels below a threshold level because of fluctuations in the output current that are not due to the incident photons, such as dark currents and noise.

quantum noise. Noise attributed to the discrete or particle nature of light, that is, light in the form of streams of photons. The absorption of each photon produces a discrete contribution to the total noise. Synonymous with photon noise.

quantum-noise-limited operation. The condition that prevails in a device or system when quantum noise at a point in the device or system limits its performance or the performance of the device or system to which it is connected. For example, the condition that prevails in an optical link when quantum noise is the predominant mechanism that limits link performance.

quartz. See fused quartz.

R

rad. The basic unit of radiation absorbed dose (rad) that produces ionization of the material upon which it is incident. A dose of 1 rad is equivalent to the absorption of 100 ergs of radiant energy per gram of absorbing material. An erg is a dyne-centimeter. A dyne is 1/980th of a gram of force, or about 10^{-5} newtons. A joule is 10^7 ergs. Also see radiation hardness.

radial refractive-index profile. In an optical fiber with a circular cross section, the refractive index described as a function of the radial distance from the center and the index at the center, that is, a function whose general form may be described by the relation

$$n_r = n_o f(r)$$

where n_r is the refractive index at a radial distance r from the center, n_o is the refractive index at the center, and f(r) is the function of r that expresses the index at the distance r from the center. Zero-point symmetry, that is, axial symmetry, of the refractive-index profile is assumed. Also see linear refractive-index profile; parabolic refractive-index profile; power-law refractive-index profile.

radiance. Radiant power, in a given direction, per unit solid angle per unit of projected area of the source, as viewed from the given direction. Specifically, radiance at a given point is (1) the radiant power in a given direction at the given point on a real or imaginary surface transmitted by an elementary beam passing through the given point and propagating in the solid angle containing the given direction; divided by (2) the product of the value of this solid angle, the cross-sectional area of that beam containing the given point, and the cosine of the angle between the normal to that section and the beam. The surface is any surface that emits, intersects, or receives a light beam. Radiance is usually expressed in watts per steradian per square meter. Synonymous with brightness. See spectral radiance. Also see irradiance; peak radiance wavelength.

radiance conservation law. A passive optical device or optical system cannot increase the quantity given by the relation

$$Q = L/n^2$$

where L is the radiance of a beam and n is the local refractive index. Q would be constant if losses, such as losses caused by absorption and scattering, were zero. Synonymous with brightness conservation; brightness theorem.

radiant efficiency. In an optical system, the ratio of (1) the forward useful radiant power from a source, that is, the radiance integrated over the total forward solid angle from a source to (2) the total power input to the source. Thus, the radiant efficiency is a measure of the percentage of the input power that is converted into useful optical power output. Also see radiation efficiency.

radiant emittance. 1. The radiant power emitted into a full sphere, that is 4π steradians, per unit area of a source, expressed in watts per square meter. 2. The radiant power emitted per unit area of a source. For example, radiant emittance at a point is (1) the radiant power leaving an element of the surface containing the point divided by (2) the cross-sectional area of that element. Synonymous with radiant exitance.

radiant energy. The energy emitted, transferred, or received in the form of electromagnetic waves, that is, the time integral of radiant power, usually expressed in joules. Radiant energy is not considered to involve the motion or action of material matter to achieve its propagation, in contrast to elastic, kinetic, and some forms of potential energy.

radiant exitance. See radiant emittance.

radiant flux. Deprecated term. See irradiance; radiance; radiant power.

radiant intensity. Deprecated term. See radiant emittance.

radiant power. The time rate of flow of radiant energy, usually expressed in watts. If the radiant power is incident upon a surface, the amount of radiant power distributed per unit area of the surface is the irradiance, that is, the power density. Thus, the radiant power in a beam is the total power obtained by integrating the irradiance over the cross-sectional area of the beam. If the radiant power in a beam is distributed uniformly over the cross-sectional area of the beam, the irradiance is the radiant power divided by the cross-sectional area, which is also the average irradiance. For an electromagnetic wave propagating in a vacuum or a propagation medium, the radiant power propagating per unit area in the direction of maximum power gradient is also the irradiance, which is usually expressed in watts per square meter. Because the wave is propagating with a velocity given by the relation

$$v = c/n$$

where c is the speed of light in a vacuum and n is the refractive index of the material at the point at which the speed is being considered, the irradiance can also be expressed in terms of the energy per unit volume of vacuum or propagation medium, expressed as joules per cubic meter, hence giving rise to the term electromagnetic energy density. A convex lens a few centimeters in diameter and a centimeter thick can increase the irradiance of solar radiation, that is, sunlight, when focused on the surface of a combustible material, to a level high enough for combustion, but the total radiant power, that is, the radiance, at the lens and at the material is the same. Synonymous with flux (deprecated). Also see irradiance.

radiation. Energy in the form of electromagnetic waves or photons. See coherent radiation; electromagnetic radiation (EMR); gamma radiation; incoherent radiation; light amplification by stimulated emission of radiation (laser); optical radiation; polychromatic radiation; secondary radiation; visible radiation.

radiation angle. In fiber optics, half the vertex angle of the cone of light emitted at the exit face of an optical fiber. The cone is usually defined by the angle at which the far-field irradiance has decreased to a specified fraction of its maximum value or as the cone within which can be found a specified fraction of the total radiant power at any point in the far field. Synonymous with output angle.

radiation damage. See optical fiber radiation damage.

radiation efficiency. The ratio of the radiant emittance, that is, the total radiant power emitted by a source or radiator, to the total power supplied to the radiator. The radiation efficiency of a source or radiator is usually quoted at a given frequency or wavelength. Also see radiant efficiency.

radiation hardness. A measure of the ability of a system, such as a fiber optic system for communications; an optical fiber sensor; or a computer, control, or data processing system, to function satisfactorily after exposure to a given irradiance level, that is, radiant power distributed over a given area of the system, for a specified time or after absorbing a given number of rads, that is, radiation dose. Also see rad.

radiation mode. In an optical waveguide, a mode that transfers radiant power in a direction transverse to the direction in which power is intended to be transferred or guided, whose electric and magnetic fields are transversely oscillatory everywhere external to the waveguide, and whose fields exist even at the limit of zero wavelength. Radiation modes correspond to refracted rays. A radiation mode satisfies the relation

$$\beta \leq [n_a^2 k^2 - (\mathring{a}/r)^2]^{1/2}$$

where β is the imaginary part (phase term) of the axial propagation constant, n_a is the refractive index at r = a, where a is the core radius, å (an integer) is the azimuthal index of the mode, and k is the free space wave parameter, equal to $2\pi/\lambda$, where λ is the free-space wavelength. The k is also used to designate the wavenumber, which is equal to $1/\lambda$.

radiation pattern. 1. In fiber optics, the relative radiant power distribution, as a function of position or angle, emitted from a surface, such as a light source or the exit face of an optical fiber. The near-field radiation pattern describes the radiant emittance as a function of position in the plane of the exit face of a source. The far-field radiation pattern describes the irradiance as a function of angle in the far-field region of the exit face of an optical fiber. The radiation pattern is a function of the length of the waveguide, the manner in which it is excited, and the wavelength. 2. The radiant emittance of a source as a function of direction. The pattern is represented graphically for the far-field conditions in either horizontal or vertical planes. See equilibrium radiation pattern; far-field diffraction pattern; near-field radiation pattern.

radiation scattering. The diversion of radiant power, such as radiation from thermal, electromagnetic, or nuclear sources, from its original path as a result of interactions or collisions with atoms, molecules, or large particles in the atmosphere, waveguides, or other propagation media between the source of radiation, such as a light-emitting diode (LED), laser, or nuclear explosion and a point some distance away. As a result of scattering, radiation, that is, radiant power, especially neutron and gamma radiation, will be received at such a point from many directions instead of only from the direction of the source. In an optical fiber, scattering contributes to signal attenuation and pulse broadening, that is, pulse spreading.

radiator. See Lambertian radiator.

radiometry. The branch of science and technology devoted to the measurement of electromagnetic radiation. See table III.

TABLE III. Radiometric terms.

Term	Symbol	Quantity	Unit
Radiant energy	Q	Energy	joule (J)
Radiant power (Optical power)	ϕ	Power	watt (W)

TABLE III. Radiometric terms-continued.

Term	Symbol	Quantity	Unit
Irradiance	E	Power incident per unit area irrespective of angle	$W \cdot m^{-2}$
Spectral irradiance	E_λ	Irradiance per unit wavelength interval at a given wavelength	$W \cdot m^{-2} \cdot nm^{-1}$
Radiant emittance (Radiant exitance)	W	Power emitted (into a full sphere) per unit area	$W \cdot m^{-2}$
Radiant intensity	I	Power per unit solid angle	$W \cdot sr^{-1}$
Radiance	L	Power per unit solid angle per unit projected area	$W \cdot sr^{-1} \cdot m^{-2}$
Spectral radiance	L_λ	Radiance per unit wavelength interval at a given wavelength	$W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$

radius. See critical radius.

Raman scattering. The generation of many different wavelengths of light from a single-wavelength source by means of laser action and interaction with molecules thereby creating many different excited molecular energy levels that will produce photons of various energies, which corresponds to various wavelengths when transitions to lower excited states occur. In addition, when two frequencies beat together, they induce dipole moments in molecules at the difference frequency. This causes modulation of laser-molecule interaction which produces light at sideband frequencies, that is, additional wavelengths.

range. See dynamic range; measurement range; transmitter central wavelength range.

range designation of data signaling rates (DSRs). A method of referring to a range, or band, of data signaling rates. The designator is a two- or three-letter abbreviation for the name. Each range is a decade wide. The range limits for each decade have coefficients of 3. Thus, the logarithmic mid-range value of each range (decade) is close to 1 times a power of ten. Each range is designated by a number that is the power of ten of the mid-range value. For example, the logarithmic mid-range value of the 30-300 Gbps EHR (Extremely High Data Signaling Rate) is 10^{11}. Therefore the numerical designator for this range is 11. The data signaling rate (DSR) describes the rate at which data passes through a point, for example, in bits, characters, words, or other data units per unit time. It is not the speed at which lightwaves propagate in an optical fiber, such as in meters per second. See table IV. Also see data signaling rate (DSR); spectrum designation of frequency.

TABLE IV. Data signaling rate ranges and their designators.

Data signaling rate range*	Letter group and word designator	Numerical designator
Below 300 bps	ELR (Extremely Low Data Signaling Rate)	2
300-3000 bps	ULR (Ultra Low Data Signaling Rate)	3
3-30 kbps	VLR (Very Low Data Signaling Rate)	4
30-300 kbps	LR (Low Data Signaling Rate)	5
300-3000 kbps	MR (Medium Data Signaling Rate)	6
3-30 Mbps	HR (High Data Signaling Rate)	7
30-300 Mbps	HR (Very High Data Signaling Rate)	8
300-3000 Mbps	UHR (Ultra High Data Signaling Rate)	9
3-30 Gbps	SHR (Super High Data Signaling Rate)	10
30-300 Gbps	EHR (Extremely High Data Signaling Rate)	11
300-3000 Gbps	THR (Tremendously High Data Signaling Rate)	12
3-30 Tbps	AHR (Awesomely High Data Signaling Rate)	13
30-300 Tbps	PHR (Phenomenally High Data Signaling Rate)	14
300-3000 Tbps	-	15
3-30 Pbps	-	16
30-300 Pbps	-	17
300-3000 Pbps	-	18
3-30 Ebps	-	19
30-300 Ebps	-	20

*Lower limit exclusive, upper limit inclusive. The prefixes are:
k = kilo = 10^3 M = mega = 10^6 G = giga = 10^9
T = tera = 10^{12} P = peta = 10^{15} E = exa = 10^{18}
The theoretical upper limit for the numerical designator is about 30.

rate. See data signaling rate (DSR); interface rate; maximum pulse rate; Nyquist rate; optical line rate; payload rate; pulse-repetition rate; system information rate.

rate characteristic. See wavelength-dependent attenuation rate characteristic.

rate-length product. See bit-rate-length product.

rates. See range designation of data signaling rates (DSRs).

ratio. See axial ratio; bit error ratio (BER); fiber/coating offset ratio; photodetector signal-to-noise ratio.

ray. An infinitesimally narrow beam of electromagnetic radiation, such as a lightwave, that is represented by a straight line drawn in the direction of propagation at a point in a propagation medium or free space. The line representing the ray is drawn tangent to and in the direction of the line representing the path taken by the wave. Rays are used for analyses of lightwave behavior in the terminology of geometric optics. Rays are in the direction of the Poynting vector and therefore perpendicular to wavefronts in the terminology of physical optics. See axial ray; direct ray; extraordinary ray; guided ray; leaky ray; light ray; meridional ray; optical ray; ordinary ray; paraxial ray; reflected ray; refracted ray; skew ray; x-ray. Also see light ray.

ray bundle. 1. A group of ordinary rays in which the ordinary rays differ from one another in some specific respect, such as wavelength (color) or intensity, yet have one or more aspects in common, such as direction or velocity. For example, the rays of a given bundle may be separated from each other by dispersion caused by a prism, in which case a multiwavelength bundle of rays incident on the prism are spatially separated into distinct ordinary rays of different color; in an optical fiber, dispersion will cause different wavelengths to arrive at the end at different times thus temporally separating the rays of an incident bundle. 2. A group of light rays considered as a unit for some purpose or discussion. Synonymous with bundle of rays.

ray method. See refracted-ray method.

Rayleigh distribution. A mathematical statement of the frequency distribution of random variables, for the case where two orthogonal variables are independent and normally distributed with the same variance. The Rayleigh distribution occurs because of the intrinsic molecular structural pattern of the propagation media, such as glass. Also see Rayleigh scattering.

Rayleigh fading. Phase interference fading that is approximated by the Rayleigh distribution and is caused by recombination after multipath.

Rayleigh scattering. Scattering caused by refractive-index fluctuations that are small, with respect to wavelength. The refractive-index variations are caused by inhomogeneities in material optical density, composition, and molecular structure. The scattered radiant power is inversely proportional to the fourth power of the wavelength. Also see Rayleigh distribution.

ray optics. See geometric optics.

ray trajectory. The path or course taken by a light ray in a propagation medium or a vacuum. The trajectory is perpendicular to the wavefront.

real time. 1. The absence of delay, except for the time required for the transmission of electromagnetic energy, between the occurrence of an event or the transmission of data and the knowledge of the event or reception of the data at some other location. 2. The actual time during which a physical process occurs. 3. Pertaining to the performance of a computation during the actual time that the related physical process occurs, in order that results of the computation can be used in guiding the physical process.

receiver. See fiber optic receiver; monolithic integrated receiver; optical receiver; optoelectronic receiver; PIN-FET integrated receiver.

receiver information descriptor. A unique descriptor from which information about a receiver can be determined, such as the manufacturer, terminal equipment association, system design application (single-mode, multimode), performance specifications, detector type (APD, PIN photodiode), temperature controller, and manufacturer product change designation (issue, revision).

receiver input. See maximum receiver input.

receiver maximum input power. See optical receiver maximum input power.

receiver optical connector. The optical connector provided at the input of an optical receiver that is attached to the receiver pigtail. The receiver optical connecter description should include the manufacturer, type (biconic, FC, etc.) model number, classification (multimode, single-mode), and mating connector model number.

receiver optical sensitivity. The worst-case value of input optical power (dBm) coupled into a receiver, as measured on the line side of the receiver connector under specified standard or extended operating conditions, that is necessary to achieve the manufacturer-specified bit error ratio (BER) as measured under standard procedures. The worst-case value combines manufacturing, temperature, aging, extinction ratio, and rise-fall time variations in a worst-case fashion. The receiver sensitivity should not include power penalties associated with dispersion or reflection.

recording. See *fiberscopic recording*.

REED. Restricted edge-emitting diode.

reference model. See Open Systems Interconnection (OSI) Reference Model (RM).

reference surface. In a round optical fiber, the cylindrical surface used for reference purposes when joining optical fibers. The reference surface usually is the outer surface of the outer-most cladding. The core-cladding interface surface, that is, the inner surface of the inner-most cladding, has also been used as the reference surface because this surface identifies the core.

reference surface center. 1. In the cross section of an optical fiber, the center of the circle that best fits the outer limit of the reference surface. The reference surface center may not be the same as the core and cladding centers. The method of best fit must be specified. 2. The center of the smallest circle into which the reference surface can be fitted.

reference-surface concentricity. See core reference-surface concentricity.

reference surface noncircularity. The difference between the diameters of the two circles used to define the reference surface tolerance field divided by the reference surface diameter.

reference surface tolerance field. In the cross section of an optical fiber, the region between the smallest circle concentric with the center of the reference surface circumscribed about the core area and the largest circle, concentric with the first one, that fits inside the reference surface.

reference test method (RTM). In fiber optics, a test method in which a given characteristic of a specified class of fiber optic devices, such as optical fibers, fiber optic cables, connectors, photodetectors, and light sources, is measured strictly according to the definition of this characteristic and that gives accurate and reproducible results relatable to practical use. Also see *alternative test method*.

reflectance. In optics, the ratio of the reflected to the incident irradiance, that is, optical power, at an interface point. The conditions under which the reflectance occurs should be stated, such as the spectral composition and polarization of the incident wave, the geometrical shape of the reflecting surface, and the composition of the propagation media on both sides of the interface. In optics, the reflectance is often expressed as a percent or as reflectance density, that is, as the logarithm to the base 10 of the reciprocal of the reflectance. In communications, it is usually expressed in decibels.

reflectance density. The logarithm to the base 10 of the reciprocal of the reflectance. Also see optical density.

reflected ray. When an electromagnetic wave is incident upon an interface surface between two different propagation media, such as a boundary between dielectric materials with different refractive indices, the ray that is turned back into the medium containing the incident ray. If the refractive indices at the interface vary as a step function across the interface, spectral reflection takes place. The angle that the reflected ray makes with the normal to the interface surface, namely the reflection angle, has the same value as the incident ray has with the normal, that is, the incidence angle is equal to the reflection angle. The power of the reflected ray is equal to the power in the incident ray times the reflection coefficient, as determined by the refractive indices and the incidence angle, assuming no power is absorbed at the interface, that is, at the reflection surface. For example, in an optical fiber, the reflected ray is the portion of a ray that is in the core and incident to the core-cladding interface that is returned to the core. For core-cladding interface incidence angles greater than the critical angle, all the optical power in the incident ray is contained in the reflected ray. For incidence angles equal to the critical angle, a refracted ray will propagate along the core-cladding interface surface. If there is a smooth transition of refractive index at the core-cladding interface of an optical fiber, such as in a graded-index fiber, there will be some penetration of an incident ray a short distance into the cladding and the incident ray will be returned to the core by successive or continuous reflection. Also see Goos-Haenchen shift; refracted ray.

reflecting loss. See reflection loss.

reflection. The changing of direction of an incident wave at an interface between two dissimilar propagation media so that it is directed partially or totally back into the medium from which it originated. See diffuse reflection; Fresnel reflection; internal reflection; maximum optical reflection; specular reflection; total reflection.

reflection coefficient. 1. The ratio between the amplitude of the reflected wave and the amplitude of the incident wave. For large smooth surfaces, the reflection coefficient may be near unity. At near grazing incidence, even rough surfaces may reflect relatively well. 2. At any specified point in a transmission line between a source of power and a sink, that is, an absorber of power, the complex ratio of the electric field strength associated with the reflected wave to that associated with the incident wave. The reflection coefficient magnitude is given by the relation

$$RC = |(Z_2-Z_1)/(Z_2+Z_1)| = (SWR-1)/(SWR+1)$$

where Z_1 is the impedance toward the source, Z_2 is the impedance toward the load, the vertical bars designate absolute magnitude, and SWR is the standing wave ratio. 3. The ratio of the reflected electric field strength to the incident electric field strength when an electromagnetic wave is incident upon an interface surface between dielectric propagation media of different refractive indices. For example, if, at oblique incidence, the electric field vector of the incident plane-polarized electromagnetic wave is parallel to the interface, the reflection coefficient is given by the relation

$$R = (m_2\cos A - m_1\cos B)/(m_2\cos A + m_1\cos B)$$

where m_1 and m_2 are the reciprocals of the refractive indices of the incident and transmitted media, respectively, and A and B are the incidence and refraction angles, respectively. This is one of the Fresnel equations. The sum of the reflection coefficient and the transmission coefficient is not necessarily unity. Also see transmission coefficient.

reflection density. See optical density.

reflection law. When a ray of electromagnetic radiation is reflected in whole or in part, the reflection angle is equal to the incidence angle; the incident ray, reflected ray, and normal to the surface all being in the same plane.

reflection loss. The ratio, usually expressed in decibels, between incident and the reflected wave radiant powers at any discontinuity or impedance mismatch. When the two waves have opposite phases and appropriate magnitudes, a reflection gain may be obtained. The reflection loss for a given frequency at the junction of a source of power and a load is given by the relation

$$\text{Reflection loss} = -20\log_{10} \left| (Z_1 + Z_2)/(4Z_1Z_2)^{1/2} \right|$$

where the reflection loss is in decibels, the vertical bars designate absolute magnitude, and Z_1 and Z_2 are the impedances of the source of power and the load. Synonymous with reflecting loss.

reflection method. See Fresnel reflection method.

reflection power penalty. In an optical receiver, the additional power (dB) required by a receiver, when the manufacturer-specified value of maximum optical reflection is introduced at the line side of the associated transmitter connector to achieve the same bit error ratio (BER) that is obtained without the introduced reflection using standard measurement procedures.

reflection sensor. See frustrated total (internal) reflection sensor.

reflective star coupler. An optical fiber coupler in which signals in one or more fibers are transmitted to one or more other fibers by entering the signals into one end of an optical fiber, cylinder, or other piece of transparent material with a reflecting back surface in order to reflect the diffused signals into output ports for further transmission in one or more fibers.

reflectivity. The reflectance of an opaque object, that is, an object of such thickness that further increases in thickness do not alter the reflectance. See spectral reflectivity. The term is no longer in common use.

reflectometer. See optical time-domain reflectometer (OTDR).

reflectometry. See optical time-domain reflectometry (OTDR).

reflector. 1. In optics, a surface with a high reflection coefficient at all incidence angles, such as a mirror. 2. In radio, one or more electrical conductors or conducting surfaces for reflecting radiant energy, such as a parabolic dish receiving antenna. See Lambertian reflector.

refracted near-field scanning method. See refracted ray method.

refracted ray. When a ray of an electromagnetic wave is incident upon an interface surface between two different propagation media, such as a boundary between dielectric materials with different refractive indices, the ray that emerges on the side of the boundary opposite the side of incidence. When the incident ray is in a higher refractive-index material, such as in the core of an optical fiber, the refracted ray is bent away from the normal and toward the interface surface; if in a lower refractive-index material the refracted ray is bent toward the normal. For example, in an optical fiber, the portion of a ray incident to the core-cladding interface that enters the cladding and does not return to the core at the point of incidence is a refracted ray. For incidence angles greater than the critical angle, there is no refracted ray. For incidence angles equal to the critical angle, the refracted ray will propagate along the core-cladding interface surface. The amplitude of the refracted ray relative to the incident ray is given by the refraction coefficient. In an optical fiber, a ray at radial position r is refracted into the cladding from the core when it has such a direction that it satisfies the relation

$$[n_r^2 - n_a^2]/[1 - (r/a)^2 \cos^2\theta_p] \leq \sin^2\theta_r$$

where n_r^2 is the refractive index at the radial distance r from the optical axis, that is, the core center, n_a^2 is the refractive index at radial distance a from the optical axis, but a is the core radius, therefore it is the refractive index on the core side of the core-cladding interface, a is the radius of the core, θ_p is the azimuthal projection angle of the ray on the transverse plane of the fiber, that is, a plane normal to the optical axis, and θ_r is the angle the ray makes with the optical axis of the fiber. A refracted ray corresponds to a radiation mode in the terminology used for mode description. Also see reflected ray.

refracted-ray method. In fiber optics, a method for measuring the refractive-index profile of an optical fiber by scanning the entrance face of the fiber with the vertex of light from a high-numerical-aperture cone and measuring the change in power of the refracted rays. The refracted rays leave the core and therefore are unguided. Synonymous with refracted near-field scanning method.

refracting crystal. See multirefracting crystal.

refraction. The bending of a sound wave, radio wave, or lightwave as it passes obliquely across the interface from one propagation medium to another with a different refractive index or the bending that occurs in a propagation medium in which the refractive index is a continuous function of spatial position, for example, in a medium with a graded-index profile. See double refraction.

refraction angle. When an electromagnetic wave strikes a surface of another propagation medium and is wholly or partially transmitted into the new medium, the acute angle between the normal to the surface and the refracted ray.

refraction coefficient. See transmission coefficient.

refractive index. At a point in a propagation medium and in a given direction, the ratio of the velocity of light in vacuum to the magnitude of the phase velocity of a sinusoidal electromagnetic plane wave propagating in that direction. It is also the ratio of the sines of the incidence and refraction angles as a light ray passes across an interface from one medium to the another. If one of the media is a vacuum, the measured refractive index will be the refractive index for that medium relative to a vacuum. The refractive index of a vacuum is defined as 1.000000, of air it is 1.000292, of water it is about 1.333, and of ordinary crown glass it is 1.156. The refractive index of a dielectric substance, that is, whose electrical conductivity is zero, is also given by the relation

$$n = (\mu\epsilon/\mu_0\epsilon_0)^{1/2}$$

where μ is the magnetic permeability and ϵ is the electric permittivity of the substance, and the other variables are the corresponding values for a vacuum, which are nearly the same as for air, namely unity. In absolute units for free space, the electric permittivity is $\epsilon = 8.854 \times 10^{-12}$ F/m (farads per meter) and the magnetic permeability is $\mu = 4\pi \times 10^{-7}$ H/m (henries per meter). The reciprocal of the square root of the product of these values yields approximately 2.998×10^8 m/s (meters per second), the velocity of light in a vacuum. Because the refractive index for a propagation medium is defined as the ratio between the velocity of light in a vacuum and the velocity of light in the medium, the ratio becomes unity when the propagation medium is a vacuum. Thus, the relative refractive index is given by the relation

$$n_r = (\mu\epsilon)^{1/2}$$

where the n_r is the refractive index relative to vacuum (or air). The refractive indices for the materials used in optical fibers are always given as relative to a vacuum and are therefore dimensionless. Also, except for ferrous materials, cobalt, and nickel, and some diamagnetic materials, the relative magnetic permeability of materials, especially dielectric materials, is approximately 1. For a vacuum it is 1. See relative refractive index. Also see electric permittivity; magnetic permeability; relative electric permittivity; relative magnetic permeability; wave impedance.

refractive-index contrast. A measure of the relative difference in refractive index across the interface surface between propagation media with two different refractive indices. For an optical fiber, the refractive index contrast, Δ, is given by the relation

$$\Delta = (n_1^2 - n_2^2)/2n_1^2$$

or, for interfaces where the indices are not different by more than 1 percent of each other, by the relation

$$\Delta = (n_1 - n_2)/n_1$$

where n_1 is the maximum refractive index in the core and n_2 is the refractive index of the homogeneous cladding.

refractive-index difference. See ESI refractive-index difference.

refractive-index dip. In an optical fiber, a reduced refractive index at the central region of the core. The dip is an imperfection that occurs only when certain fiber fabrication and drawing techniques are used.

refractive-index profile. In a dielectric waveguide, the variation of refractive index in the direction transverse to the direction of wave propagation, that is, in a cross section of the guide. In a round optical fiber, the refractive index profile is a description of the value of the refractive index as a function of distance from the optical axis along any fiber diameter. The refractive index variation is symmetrical about the central axis of the fiber, that is, there is zero-axis symmetry. See linear refractive-index profile; parabolic refractive-index profile; power-law refractive-index profile; radial refractive-index profile.

refractive index profile parameter. The exponent, g, in the several relations for the power-law refractive-index profile. Also see power-law refractive- index profile.

refractive-index template. See four-concentric-circle refractive-index template.

regenerator section. See optical station/regenerator section.

regenerator system gain. See statistical terminal/regenerator system gain; terminal/regenerator system gain.

region. See far-field region; intermediate-field region; near-field region.

relations. See constitutive relations.

relative electric permittivity. The incremental or absolute electric permittivity of a material, ϵ_r, normally represented as ϵ and implied to be relative to free space, that is, compared with that of a vacuum, ϵ_o. The actual electric permittivity of free space in SI (Systemè International) units absolute or incremental, is 8.854 x 10^{-12} (coulombs per square meter)/(volts per meter), which is the same as farads per meter. The refractive index for the silica glass of optical fibers is given approximately by the relation

$$n \approx \epsilon^{1/2}$$

where ϵ is the electric permittivity of the glass. Because it is relative to free space, a vacuum, or air, it is dimensionless for specific materials, about 2 or 3 for glass and up to 10 or 12 for the special dielectric materials used in capacitors to increase their capacity and provide for electrical separation of electrodes. Also see electric permittivity; refractive index.

relative magnetic permeability. The incremental or absolute magnetic permeability of a material, μ_r, normally represented as μ and implied to be relative to free space, that is, compared with that of a vacuum, μ_o. The magnetic permeability of free space in SI (Systemè International) units, absolute or incremental, is 4π x 10^{-7} (webers per square meter) per (ampere per meter), or webers per ampere-meter, which is the same as henrys per meter. For an optical fiber, the magnetic permeability is very nearly equal to that of free space. Thus, μ_r for an optical fiber is very close to unity and since it is relative to free space, a vacuum, or air, it is dimensionless for specific materials. Also see magnetic permeability; refractive index.

relative refractive index. The refractive index of a substance relative to another substance. Thus, if two glasses have refractive indices, that is, refractive indices relative to a vacuum, of $n_1 = 2.100$ and $n_2 = 1.781$ then the refractive index of substance 1 relative to substance 2 is n_1/n_2, or 1.179.

release time. See switch release time.

remanence. The magnetization, that is, the magnetic polarization, that remains in a magnetized material after the applied magnetic field that magnetized the material is removed.

repair. The restoration of an item to serviceable condition by correction of a specific failure or unserviceable condition. See mean time to repair (MTTR).

repeater. A device that amplifies an input signal or, in the case of pulses, recovers, amplifies, reshapes, retimes, or performs a combination of any of these functions on an input signal, and transmits the signal. It may be either a one-way or a two-way repeater. See optical repeater.

repeatered optical link. An optical link that has optical repeaters along its cable to recover, amplify, and perhaps reshape and time, optical signals.

repeaterless optical link. A fiber optic link, usually in a longhaul communication link, in which repeaters are not used because of the short length, the high bandwidth-distance factor of the fiber, or the low attenuation rate of the fiber. Repeaterless optical links thousands of kilometers long are expected to be in place before the year 2000. Optical links for short distances, such as for intercity or local area network use in which repeaters were never needed or anticipated, are simply called optical links rather than repeaterless optical links, even though they have no repeaters.

repetition rate. See pulse-repetition rate.

resolution. See borescope target resolution; distance resolution.

resolving power. A measure of the ability of a lens or optical system to form separate and distinct images of two objects with small angular separation. Because of diffraction at the aperture, no optical system can form a perfect image of a point, but produces instead a small disk of light, called an airy disk, surrounded by alternately dark and bright concentric rings. See chromatic resolving power; theoretical resolving power.

resonant cavity. A geometric space that may be empty or contain a fluid or solid material, that is bounded by two or more reflectors, and in which electromagnetic waves can reflect back and forth, thus producing standing waves of high intensity at certain wavelengths. For example, standing waves might be produced in a ruby crystal laser with two plane or spherical mirrors, forming a resonant cavity, with the crystal itself between the mirrors, the molecules of which can be excited by an inert-gas lamp, thus generating and emitting a narrow beam of monochromatic light of high power and high irradiance, that is, high optical power density or intensity, in the direction of the crystal axis.

response. See impulse response; spectral response.

response function. See impulse response function.

response quantum efficiency. The ratio of the number of countable output events to the number of incident photons that occur when energy in the form of electromagnetic waves, such as lightwaves, gamma radiation, x-rays, and cosmic rays, are incident upon a material, often measured as electrons emitted per incident quantum, that is, for lightwaves, per incident photon. Optical response quantum efficiency indicates the efficiency of conversion or utilization of optical energy. It is an indication of the number of events produced for each quantum incident on the sensitive surface of a photodetector. It is a function of the wavelength, incidence angle, polarization, and other factors.

responsivity. 1. In a photodetector, such as an avalanche photodiode (APD), the ratio of the electrical current or voltage output to the optical power input. It is expressed in amperes of electrical current output per watt of optical power input, or in volts per watt. The value will change with the wavelength of the incident radiation. 2. In a light source, such as a light-emitting diode (LED) or laser, the ratio of its optical power output to the driving current input, for example, 3 mW/μA at 0.810 μ (micron). The term is often used improperly as a synonym for sensitivity. See photodetector responsivity; spectral responsivity. Also see sensitivity.

restoral. See mean time to service restoral (MTTSR).

restricted edge-emitting diode (REED). An edge-emitting LED (ELED), that is, a light-emitting diode (LED) in which light is emitted over a small portion of an edge, permitting improved coupling with dielectric waveguides, such as optical fibers and integrated optical circuits (IOCs).

retention. See fiber retention.

return loss. In a fiber optic system, optical power that is reflected back toward the source of optical power by a component, such as a fiber optic splice, connector, coupler, attenuator, or rotary joint. Return loss may be expressed in absolute power units, such as microwatts, or in dB with reference to the incident optical power input to the component. Thus, return loss is the optical power reflected, rather than power that is transmitted, absorbed, scattered, or radiated, however, backscatter is included in the return loss measurement and should be considered when the actual return loss is calculated.

ribbon. See fiber optic ribbon.

ribbon cable. A fiber optic cable in which the optical fibers are held in grooves and laminated within a flat semirigid strip of plastic or other material that holds them and protects them. Fiber optic cables with large numbers of fibers can be produced by stacking two or more ribbons together, adding buffers, strength members, fillers, and perhaps gels to inhibit water penetration, and jacketing or sheathing the whole assembly. A ribbon cable may be either a tight-jacketed or a loose-tube type of fiber optic cable, depending on how tightly, or loosely, the fibers are held by the grooves in the ribbons. Thus, the fibers are laminated within the ribbon.

right-hand circular polarization. Circular polarization of an electromagnetic wave in which the electric field vector rotates in a clockwise direction as the wave advances in the direction of propagation and as seen by an observer looking in the direction of propagation. Thus, in a waveguide, the electric field vector of a circularly polarized wave always remains perpendicular to the direction of propagation as well as perpendicular to the magnetic field vector. Also see right-hand helical polarization.

right-hand helical polarization. Polarization of an electromagnetic wave in which the electric field vector rotates in a clockwise direction as it advances in the direction of propagation and as seen by an observer looking in the direction of propagation. The tip of the electric field vector advances like a point on the thread of a right-hand screw when entering a fixed nut or tapped hole, thus describing a helix in the shape of the thread itself. Thus, in a waveguide, the electric field vector of a helically-polarized wave always remains skewed to the direction of propagation. Also see right-hand circular polarization.

right-hand polarized electromagnetic wave. An elliptically or circularly polarized electromagnetic wave in which the direction of rotation of the electric field vector is clockwise as seen by an observer looking in the direction of propagation of the wave. Also see left-hand polarized electromagnetic wave.

rigid borescope. A portable fiber optic borescope that has an aligned bundle (coherent bundle) in a stiff fiber optic cable, or a train of lenses mounted in a rod, with sufficient rigidity to cross unsupported gaps in a path to an objective. There is usually an eyepiece for viewing the image and it may have a controllable articulating tip on the objective end to enable inspection at various angles, such as up to 90 degrees from the cable optical axis. The borescope is hand held and energized via a fiber optic cable from a light source. The rigid borescope usually consists of a basic borescope unit and ancillary equipment required for operation. Also see flexible borescope.

ringer. See optical fiber ringer.

ring network. 1. A type of network configuration consisting of a closed loop medium. 2. In network topology, a network configuration in which each node is directly connected to two and only two adjacent nodes, that is, to two nodes by means of a single branch to each. Thus, one and only one path connects all nodes and there are no end-point nodes nor are there any connections or ports to other networks.

rise time. 1. The time it takes for the amplitude of a pulse to increase from a specified value, usually near the lowest or zero value, to a specified value near the peak value. Values of rise time are often specified as the time interval between the 10-percent and 90-percent values of the peak value of a pulse. When other than 10 to 90 percent values are used, they should be specified. 2. The time it takes for the magnitude of a pulse, such as the amplitude, the phase shift, the frequency shift, or other parameter used to represent a pulse, to increase from one value to another to represent binary digits. Synonymous with pulse rise time. Also see fall time.

rms pulse broadening. See root-mean-square (rms) pulse broadening.

rms pulse duration. See root-mean-square (rms) pulse duration.

rod. See GRIN[R] rod; optical mixing rod.

rod-in-tube technique. A process in which a rod placed in a tube is used as an optical fiber preform in the manufacture and drawing of optical fibers.

root-mean-square (rms) deviation. A quantity that characterizes a function, f(x), by the relation

$$\sigma_{rms} = [1/M_0 \int_{-\infty}^{+\infty} (x - M_1)^2 f(x)dx]^{1/2} \text{ where}$$

$$M_0 = \int_{-\infty}^{+\infty} f(x)dx, \quad M_1 = 1/M_0 \int_{-\infty}^{+\infty} xf(x)dx, \text{ and}$$

M_0 is the normalization, which, in probability and statistics, is unity. Also see impulse response function; root-mean-square (rms) pulse broadening; root-mean-square (rms) pulse duration; spectral width.

root-mean-square (rms) pulse broadening. The temporal rms deviation of the impulse response function of a component or system. Also see impulse response function; root-mean-square (rms) pulse duration; root-mean-square (rms) deviation; spectral width.

root-mean-square (rms) pulse duration. A special case of root-mean-square deviation in which the independent variable is time and f(t) is the pulse waveform. Also see impulse response function; root-mean-square (rms) pulse broadening; root-mean-square (rms) deviation; spectral width.

rotary joint. See fiber optic rotary joint.

rotating polarization. Polarization of an electromagnetic wave such that the polarization plane rotates with an angular displacement that is a function of the distance along the ray or propagation path.

rotation. See optical rotation.

rotor. See optical rotor.

RTM. Reference test method.

runner-cut. On the surfaces of glass and other ground or polished materials, a curved scratch, such as might be caused by a grinding or polishing wheel.

S

safety power margin. See power margin.

Sagnac fiber optic sensor. An interferometric sensor in which a lightwave is split and passed in opposite directions around the same rigid rotating optical fiber loop by means of mirrors to a single photodetector. Phase cancellation and enhancement, and hence irradiance, that is, light intensity, changes when the angular velocity is varied, thereby obtaining an output frequency that is proportional to the angular acceleration. The output signal from the photodetector can be integrated once for obtaining angular velocity and twice for angular displacement.

sampling theorem. In order for a waveform to be sampled and then effectively or satisfactorily reconstituted from the sampled data, it is necessary that the sampling rate be equal to or greater than twice the highest significant frequency component of the wave being sampled, that is, the sampling rate must satisfy the Nyquist interval or Nyquist criterion. See also Nyquist bandwidth; Nyquist rate.

satellite. See direct broadcast satellite (DBS).

satellite optical link. A beamed optical transmission channel, usually consisting of a laser source shining a lightwave in the form of a narrow beam on an avalanche photodetector, operating between a ground station and a satellite station. The source is modulated in accordance with an intelligence-bearing signal.

scanning technique. See near-field scanning technique.

scatter. The process whereby the direction, frequency, or polarization of electromagnetic waves, such as lightwaves, is changed when the waves encounter particles or discontinuities, such as microcracks, abrupt changes in refractive index, and impurities in the propagation medium in which the waves are propagating, particularly when the particles and discontinuities have sizes on the order of 1 wavelength of the propagating waves. If the particles and discontinuities are larger, the diffusion phenomenon is one of spectral reflection and refraction rather than scattering. The term is frequently used to imply a disordered change in the properties of the incident waves, such as the distribution of energy or the direction of propagation of electromagnetic power. See backscatter; forward scatter. Also see scattering.

scattering. The change in direction of electromagnetic waves, such as lightwaves or photons, after striking a small particle, particles, or discontinuity in the material in which the rays, or photons, are propagating. Scattering may also be caused by the nonhomogeneity of the propagation medium. See backscattering; Brillouin scattering; configuration scattering; material scattering; nonlinear scattering; radiation scattering; Raman scattering; Rayleigh scattering; waveguide scattering. Also see scatter.

scattering center. A site in the structure, particularly the microstructure, of a propagation medium at which electromagnetic waves, such as lightwaves, are scattered. Examples of scattering centers include vacancy defects, such as missing atoms or molecules in the somewhat orderly though amorphous structure of the propagation medium; interstitial defects, such as misalignment of atoms or molecules; inclusion defects, such as trapped impurity atoms, molecules, and ions, including gas molecules, hydroxide ions, iron ions, and water molecules; microcracks; abrupt changes in refractive index, perhaps caused by pressure points; and microbends.

scattering coefficient. In the propagation of electromagnetic waves in material media, the part of the attenuation term, that is, attenuation constant, contributed by scattering in the exponent of the expression that describes Bouger's law. Absorption also contributes to the attenuation term. Both parts of the attenuation term, that is the scattering part and the absorption part, depend on impurities and the irregularity of the molecular structure of the intrinsic material.

scattering loss. In the propagation of electromagnetic waves in a material medium, such as lightwaves in an optical fiber, that part of the optical power loss that is due to scattering within the propagation medium and the power loss caused by irregularity or roughness of reflecting surfaces in the propagation medium.

scattering method. See transverse scattering method.

Schottky effect. See shot noise.

Schottky noise. See shot noise.

scrambler. See fiber optic scrambler; mode scrambler.

secondary coating. A coating applied to the primary coating of an optical fiber for added protection during handling, cabling, installation, and use.

secondary radiation. Particles or photons produced by the action of primary radiation on matter, such as Compton recoil electrons, delta rays, secondary cosmic rays, and secondary electrons.

section. Optical station/regenerator section.

selective absorption. The process by which a substance absorbs only certain frequencies, that is, certain wavelengths or colors, in a beam of incident electromagnetic radiation and reflects or transmits all others. Some substances are transparent to certain wavelengths, allowing them to be transmitted while absorbing others. Some substances reflect certain wavelengths and absorb or transmit all others. The color of a transparent object is usually the color it transmits while the color of an opaque object is usually the color it reflects. Some materials reflect and transmit the same color, absorbing all others.

self-adjusting. In fiber optic communication networks, pertaining to communication networks in which an adequate number of redundant fiber optic links are installed to accommodate lightwave data streams in both directions and to provide for automatic alternate routing if a link fails, thereby eliminating the necessity of repairing fiber optic cables before service can be restored. A digital access and fiber optic cross-connect system is used to reroute lightwave signals. Synonymous with self-healing.

self-focusing optical fiber. An optical fiber that is capable of focusing its lightwave propagation and output at one or more points by precision control of geometry, refractive index profile, and other parameters at a given operating wavelength. Thus, the fiber is wavelength selective. Self-focusing optical fibers, rods, and lenses are used in integrated optical circuits (IOCs) and other fiber optic and optoelectronic components, such as fiber optic connectors, attenuators, switches, multiplexers, and sensors. Also see GRIN® rod; SELFOC® lens.

self-healing. See self-adjusting.

self-heterodyne. In fiber optics, pertaining to a fiber optic communication network in which the reference oscillator for coherent communication is derived from the same light source as used for generating the signal that is detected. Also see homodyne.

SEL^R fiber. An optical fiber produced by Standard Electric Lorenz.

self-lasing fiber. See fiber laser.

SELFOC^R lens. A cylindrically-shaped lens, such as a short length of optical fiber, with a graded refractive-index profile parameter that will cause all light rays entering within a given acceptance cone to be focused at one point for a given operating wavelength. The SELFOC^R lens has the capability to collimate and focus a light beam emanating from a point source. The SELFOC^R lens was jointly developed by Nippon Sheet Glass Company and Nippon Electric Company, Ltd. The profile parameter is approximately 2, making the refractive index profile close to that of parabola. Also see GRIN^R rod; self-focusing fiber.

Sellmeier equation. An equation that expresses the group delay per unit length for an optical fiber, given by the relation

$$\tau(\lambda) = A + B\lambda^2 + C\lambda^{-2}$$

where A, B, and C are empirical fit parameters, or by the relation

$$\tau(\lambda) = \tau_o + (S_o/8)(\lambda - \lambda_o^2/\lambda)^2$$

where τ is the group delay per unit length of fiber, λ is the free-space wavelength, τ_o is the relative group delay minimum at λ_o, λ_o is the zero-dispersion wavelength, and S_o is the zero-dispersion slope. These functional forms may be assumed when measured group delay data near the zero-dispersion wavelength of a dispersion-unshifted fiber is numerically fitted for the purposes of calculating the chromatic dispersion coefficient, given by the relation

$$D(\lambda) = d\tau(\lambda)/d\lambda = S_o\lambda(1 - \lambda_o^4/\lambda^4)/4$$

where all the variables are as defined above. Also see chromatic dispersion coefficient; group delay.

semiconductor. See n-type semiconductor; p-type semiconductor.

semiconductor diode laser. Typical characteristics of semiconductor diode lasers for fiber optic communication applications are (1) for a GaAlAs type, 0.80 μ (micron), 1-40 mW (milliwatt, optical), 10-500 mA (milliampere), 2 V (volt), 1-20 percent efficiency, 1 gm (gram), 10^4 - 10^7 hours, 10 x 35 degrees divergence, and modulated directly by the drive current; and (2) for an InGaAsP type, 1.1-1.6 μ, 1-10 mW (optical), 20-200 mA, 1.5 V, 1-20 percent efficiency, 1 gm, up to 10^6 hours, 10 x 30 degrees to 20 x 40 degrees divergence, and modulated directly by the drive current. The efficiency is the electromagnetic (optical) power output divided by the electrical power input.

semiconductor laser. See laser diode.

sensitivity. In a device that develops an output signal as a result of an input signal, such as a transducer or optical fiber communication system receiver, the minimum input signal strength required to achieve a specified quality of performance, such as to produce a specified output signal having a specified signal-to-noise ratio or maintain a specified bit error ratio (BER). For example, the input signal may be expressed as power in dBm or as electric field strength in microvolts per meter, with input impedance stipulated. The output signal may be expressed in a power or other unit, such as current, voltage, or lumens. Sometimes the term is improperly used as a synonym for responsivity. See polarization sensitivity; receiver optical sensitivity. Also see responsivity.

separation sensor. See fiber end-to-end separation sensor.

sensor. A device or means for extending the natural senses, such as a device that measures and indicates temperature, pressure, speed, humidity, force, chemical composition or other physical variable or phenomenon. Examples of sensors include thermometers, gyroscopes, barometers, tachometers, and speedometers. Optical fibers are being used as the sensing element in various types of sensors. See birefringence sensor; bobbin-wound sensor; coated fiber sensor; critical-angle sensor; critical-radius sensor; distributed-fiber sensor; Fabry-Perot fiber optic sensor; fiber end-to-end separation sensor; fiber longitudinal compression sensor; fiber optic sensor; fiber strain-induced sensor; fiber tension sensor; fiber transverse compression sensor; fiber axial alignment sensor; fiber axial displacement sensor; frustrated total (internal) reflection sensor; interferometric sensor; Kerr-effect sensor; Mach-Zehnder fiber optic sensor; Michelson fiber optic sensor; microbend sensor; moving grating sensor; optical cavity mirror sensor; optical fiber acoustic sensor; photoelastic sensor; Pockels-effect sensor; polarization sensor; Sagnac fiber optic sensor.

serrodyne. See optical serrodyne.

service. See plain old telephone service (POTS).

service restoral. See mean time to service restoral (MTTSR).

services digital (or data) network. See integrated services digital (or data) network (ISDN).

session. A period of time, a temporary grouping of equipment, or a set of interactions among humans, among machines, or among humans and machines. Examples of sessions include the time interval between logging-on and logging-off a computer remote terminal, a connection between two terminals that allows them to communicate for a period of time, a temporary connection between a control panel and a ship or aircraft propulsion system controller to enable real-time online control of the system or one of its subsystems, and a conference telephone call. Also see session layer.

session layer. In open systems architecture, the layer that provides the functions and services that may be used to establish and maintain connections among elements of a session, to maintain a dialogue of requests and responses between the elements of a session, and to terminate the session. Also see session; Open Systems Interconnection (OSI) Reference Model (RM).

set. See optical fiber connector set; optical loss test set (OLTS).

sheath. See optical fiber jacket.

shell. In a fiber optic connector, the primary connector housing. See backshell.

shift. To change the frequency or phase of a signal, or the change itself. See Goos-Haenchen shift.

shifted fiber. See dispersion-shifted fiber; dispersion-unshifted fiber.

short-haul communication network. A communication network designed for handling communication traffic usually over distances less than 20 km (kilometer) and within the area covered by a telephone switching center or central office, such as metropolitan areas, large cities, or an entire county. Short-haul systems are characterized by not having long-distance trunks between towns and cities nor more than one switching center or central office. Like long-haul communication networks, short-haul networks may have high-quality equipment for high-fidelity and high-definition analog (voice) and digital transmission, integrated services digital (data) networks (ISDN), high transmission capacity, and automatic switching for handling calls and messages without operator assistance. It is anticipated that by the year 2000 over 600 billion voice circuit-kilometers will be on fiber optic long-and short-haul networks and only 16 billion on microwave, 160 billion on satellite, and 3 billion on coaxial cable. Also see long-haul communication network.

short wavelength. In fiber optics, pertaining to optical radiation that has a wavelength less than a nominal 1 μm (micron).

shot effect. See shot noise.

shot noise. Noise, that is, random surges of voltage, current, electrical power, or optical power caused in electronic and optoelectronic devices by random variations in the number and velocity of electrons emitted by heated cathodes, photosensitive surfaces subjected to incident radiation, and p-n junctions in semiconductors. The random noise occurs because electric currents consist of discrete electric charges and optical power consists of a stream of discrete photons, both of which are capable of irregular and erratic movements, such as clustering as well as reinforcing and cancelling one another. Also, shot noise from the electronic circuits in a light source can produce equivalent surges in optical power output which will produce corresponding surges in photodetector electrical power output. Synonymous with shot effect; Schottky effect; Schottky noise.

signal. The code or pulse that represents intelligence, message, or control function conveyed over a communication system. See analog signal; digital signal; two-level optical signal.

signal format. A structure for the transmission of logical states that constitute a method of transferring information from one point to another.

signaling rate. See data signaling rate (DSR).

signaling rates. See range designation of data signaling rates (DSRs).

signal parameter. Any of the characteristics of a signal, such as the frequency, pulse length, pulse amplitude, pulse duration, polarization type, modulation type, strength, power, irradiance, or polarity.

signal-to-noise ratio. See photodetector signal-to-noise ratio.

signature. See spectrum signature.

significant instant. In a time-plot of a signal, such as a time-plot of a pulsed electromagnetic wave, an instant at which a particular type of a usually repetitive event occurs, such as a transition to a different electric field strength, power level, polarization, frequency, or phase in a modulated wave.

silica. See fused silica.

silica fiber. See hard-clad silica (HCS) fiber; plastic-clad silica (PCS) fiber.

silica process. See doped-deposited silica (DDS) process.

simulator. See equilibrium mode simulator.

single heterojunction. In a laser diode, a junction involving two energy level shifts and two refractive-index shifts. The junction provides increased confinement of radiation direction, improved control of radiative recombination, and reduced nonradiative (thermal) recombination.

single-mode fiber. An optical fiber in which only one bound mode can propagate at a given wavelength and numerical aperture. The lowest-order bound mode may be a pair of orthogonally polarized electric and magnetic fields. In order for a fiber to support only one mode, the core diameter should be about three to four wavelengths of the operating radiation and the numerical aperture must be adjusted accordingly. Thus, the ability to support one mode, that is, allow only one mode to propagate, will depend on the core radius, the numerical aperture, and the wavelength, that is, the normalized frequency (V-parameter or V-value) must be less than 4. Synonymous with monomode fiber. See dispersion-unshifted single-mode fiber. Also see multimode fiber.

single-mode launching. The insertion of an electromagnetic wave into a waveguide in such a manner that only one propagation mode is coupled into, and hence transmitted, by the guide. Single-mode launching can be accomplished by controlling the incidence angle, beam diameter, skew ray angle, source-to-waveguide gap, that is, longitudinal offset, and other parameters. Propagation of the mode will depend on waveguide dimensions, wavelength, and refractive indices of the material constituting the guide.

single-node network. A network in which all stations, user end-instruments, or other devices are interconnected via one node, such as a single-star network.

skew ray. In an optical fiber, a ray that does not intersect the optical axis. Thus, it is a ray that is not parallel to the fiber optical axis, traverses a helical path around the axis, does not intersect it, and does not lie in a meridional plane.

slab dielectric waveguide. An electromagnetic waveguide consisting of a dielectric propagation medium of rectangular cross section. The width and thickness of the guide, refractive indices, and wavelength determine the modes the guide will support and hence transmit over a long distance, that is, more than a hundred wavelengths or beyond the equilibrium length. The guide may be cladded, protected, distributed, and electronically controllable. Slab dielectric waveguides are used in integrated optical circuits (IOCs) for geometrical convenience, in contrast to the round optical fibers used in fiber optic cables for long-distance transmission. Their principle of operation is the same.

slab interferometry. A method used to measure the refractive-index profile of a dielectric waveguide, such as an optical fiber, by using an interferometer that scans across the end face, perpendicular to the optical axis, of a thin slab, that is, a short length, of the waveguide. Also see transverse interferometry. Synonymous with axial slab interferometry; axial interference microscopy.

SLD. Superluminescent diode. See superluminescent LED.

sleeve splicer. See precision-sleeve splicer.

slope. See chromatic dispersion slope; zero-dispersion slope.

Snell's law. When electromagnetic waves, such as lightwaves, pass from a given propagation medium to a medium of greater density, its path is deviated toward the normal; when passing into a medium of lesser density, its path is deviated away from the normal to the surface at the point of incidence, density being proportional to the refractive index. Snell's law is given by the relation

$$\sin\theta_1/\sin\theta_2 = n_2/n_1$$

where θ_1 is the incidence angle, θ_2 is the refraction angle, n_2 is the refractive index of the medium containing the refracted ray, and n_1 is the refractive index of the medium containing the incident ray. Also, the incidence angle and the reflection angle are equal. All angles are measured with respect to the normal.

Sonet. Synchronous optical network (Sonet) standard.

source. See borescope light source; fiber optic light source; isotropic source; line source; optical fiber source; optical source; standard optical source; video optical source.

source coupling efficiency. The maximum efficiency with which the optical power, that is, the integrated irradiance, luminous intensity, or optical power density of a lambertian radiator, such as a light-emitting diode (LED), is coupled to an optical fiber. The efficiency is given by the relation

$$\Gamma_{sc} = A_f(NA)^2/2A_s n_o^2$$

where A_f is the cross-sectional area of the fiber core; NA is the numerical aperture, which is the sine of the acceptance angle or half of the apex angle of the acceptance cone, and dependent upon the refractive indices of the core and the cladding; A_s is the cross-sectional area of the source-emitted light beam; and n_o is the refractive index of the propagation medium between the light source and the optical fiber face.

source power efficiency. In an electrically powered light source, the ratio of the optical power output to the electrical input power.

source-to-fiber coupled power. The optical power that is actually coupled from a light source into the interior of an optical fiber, given by the relation

$$P_c = P_o(\theta_a/\theta_e)T$$

where P_o is the source optical power output; θ_a is the acceptance cone apex solid angle, or collection angle, of the fiber; θ_e is the emission solid angle, beam divergence, or exit solid angle of the light source; and T is the transmission coefficient of the optical system, mostly consisting of the source-to-fiber interface. Angular misalignment loss and lateral offset loss must also be taken into account.

source type. See optical source type.

space coherence. See spatial coherence.

space-division multiplexing. A method of deriving two or more simultaneous channels by dividing available transmission media, such as a fiber optic cable, into separate circuits. In contrast to a single coaxial cable, a fiber optic cable can have hundreds of optical fibers or fiber bundles, each fiber or fiber bundle constituting a separate optical link, with little or no crosstalk among fibers or bundles. The signals in each fiber or bundle can be frequency-division multiplexed, that is, separate bandwidth channels, and time-division multiplexed, that is, separate time slots for each channel, even before they are wavelength-division multiplexed, that is, separated by color.

spatial coherence. 1. In electromagnetic waves, pertaining to a fixed phase relationship between various points in the wave propagating in a given region of space or in a given propagation medium, such that recurring relationships can be predicted everywhere in the wave within that space. 2. In fiber optic cables containing an aligned bundle or bundles, pertaining to a fixed relationship between the optical fibers at one end of a bundle relative to the fibers at the other end, such that each fiber has the same relative position with respect to all other fibers at both ends. Thus, an image focused on one end of a bundle will appear, with only limited distortion, at the other end of the bundle. Synonymous with space coherence. Also see aligned bundle.

spatial resolution. See distance resolution.

specific detectivity. A figure of merit used to characterize photodetector performance, defined as the reciprocal of the noise equivalent power (NEP), normalized to a unit area and a unit bandwidth. The specific detectivity, D^*, is given by the relation

$$D^* = (A\Delta f)^{1/2}/NEP$$

where A is the area of the photosensitive surface of the detector that is exposed to radiation, Δf is the effective noise bandwidth, and NEP is the noise equivalent power; or by the relation

$$D^* = D[A(\Delta f)]^{1/2}$$

where D is the detectivity, that is, the reciprocal of the noise equivalent power; A is the area of the photosensitive surface of the detector exposed to radiation; and Δf is the effective noise bandwidth. Synonymous with normalized detectivity; D-star.

speckle effect. A mottling effect produced by color distortion due to interference in light transmission caused by the propagation medium itself, such as an optical fiber.

speckle noise. See modal noise.

speckle pattern. An irradiance pattern, that is, a power density pattern, produced by the mutual interference of partially coherent light beams that are subject to minute temporal and spatial fluctuations. In a multimode fiber, a speckle pattern results from a superposition of mode field patterns. If the relative modal group velocities change with time, the speckle pattern will also change with time. If, in addition, differential mode attenuation (DMA) occurs, modal noise will also occur.

spectral absorptance. The absorptance of electromagnetic radiation by a material evaluated at one or more wavelengths.

spectral absorption coefficient. In the transmission of electromagnetic waves in a propagation medium, the attenuation term, a, in the relation

$$I = I_o e^{-ax}$$

where I is the radiance or the irradiance, that is, the optical power density or intensity of radiation at point x, and I_0 is the initial radiance or irradiance at the point from which x is measured, when the attenuation is caused only by absorption, and not by refraction, diffraction, scattering, dispersion, diffusion, divergence, geometric spreading, or other causes.

spectral bandwidth. See spectral width.

spectral density. In a finite bandwidth of electromagnetic radiation consisting of a continuous spectrum or of a distributed spectrum of frequencies, the optical power distribution expressed in watts per hertz of the given bandwidth.

spectral emittance. The radiant emittance plotted as a function of wavelength.

spectral dispersion. See material dispersion.

spectral irradiance. The irradiance per unit wavelength interval at a given nominal median wavelength, usually expressed as power per unit area, such as watts per square meter, per unit wavelength interval, for example, $W/(m^2 \cdot nm)$. It may be calculated as (1) the irradiance contained in an elementary range of wavelengths at a given wavelength, divided by (2) the range of wavelengths.

spectral line. In the optical spectrum, an extremely narrow range of wavelengths of light, that is, monochromatic electromagnetic radiation, generated when an atomic or molecular particle undergoes a transition from a higher to a lower energy level, such as when an electron in an atom drops from a higher, or excited, energy state to a lower or ground state. Excited states are created when an atom or molecule absorbs energy, such as the energy in photons or other forms of electromagnetic energy. In such quantum mechanical systems, only certain energy levels are possible. Only certain transitions can occur, giving rise to absorption and emission of only certain quanta of energy, as expressed by hf, where h is Planck's constant and f is the frequency of the absorbed or emitted photon. Therefore, only certain discrete wavelengths of optical radiation exist in a given spectral line.

spectral linewidth. A measure of the distribution of wavelengths, that is, the wavelength composition of the optical radiation, in a spectral line. A quantitative measure of spectral linewidth is the difference between the shortest wavelength and the longest wavelength in the spectral line. Also see spectral width.

spectral loss curve. In fiber optics, a plot that shows attenuation as a function of wavelength of light propagating in an optical fiber. Spectral loss curves should be normalized before meaningful comparisons can be made.

spectral power. See peak spectral power.

spectral radiance. The radiance per unit wavelength interval at a given nominal wavelength, expressed in watts per steradian per unit area per wavelength interval. For example, spectral radiance can be expressed as $(W/ster)/(m^2/\mu)$. It may be calculated as (1) the radiance contained in an elementary range of wavelengths at a given wavelength, divided by (2) the range of wavelengths.

spectral reflectivity. The reflectivity of a surface evaluated as a function of wavelength.

spectral response. 1. In fiber optics, a graph representing the specific wave-length versus detected power curve of a photodetector. The spectral response curve is typically drawn with wavelength on the ordinate axis and spectral responsivity on the abscissa. It shows the wavelength dependence of the detector. 2. The optical power output of a light source as a function of driving current or driving power, that is, the responsivity. It may be indicated as watts/ampere, lumens/(ampere-second), or lumens/coulomb.

spectral responsivity. The responsivity per unit wavelength interval at a given nominal or median wavelength, such as watts/ampere-nanometer at 1.31 μ (microns).

spectral transmittance. Transmittance evaluated at one or more wavelengths.

spectral wavelength. See peak spectral wavelength.

spectral width. The wavelength interval in which a radiated spectral quantity is a specified fraction of its maximum value. The fraction is usually taken at 0.50 of the maximum power level, or 0.707 of maximum, that is, 3 dB (decibel), current or voltage level. In a lightwave, the wavelength interval is the difference between the wavelengths at which the power level at those wavelengths is 3 dB down from the maximum power level. For example, the spectral width of a laser is an order of magnitude less than that of a light-emitting diode (LED). Optical fiber wavelengths are of the order of 1 μ (micron). Spectral widths of LEDs are of the order of 20 to 50 nm (nanometer) whereas lasers are of the order of 1 or 2 nm. Dispersion of an optical pulse in a fiber might be expressed in nanoseconds per microsecond of launched pulse per nanometer of spectral width of the light from the source. The difference of the electromagnetic frequencies corresponding to the two limiting wavelengths would express the same spectral width in hertz. If the spectral width of a laser is 1 nm, this would correspond to a spectral bandwidth of 3×10^{11} Hz. If the nominal wavelength is 1 μ, the nominal frequency is 3×10^{14} Hz. The ratio of width-to-nominal frequencies is 10^{-3} and the ratio of width-to-nominal wavelengths is also 10^{-3}. Synonymous with spectral bandwidth. Also see impulse response function; monochromatic; root-mean-square (rms) pulse broadening; root-mean-square (rms) pulse duration; root-mean-square (rms) deviation; spectral linewidth; spectral width.

spectral window. In a given propagation medium or material, a wavelength region of relatively high transmittance, surrounded by regions of low transmittance, that is, a trough in a plot of optical attenuation, caused by the material, versus wavelength. The best region of the optical spectrum for transmission is between 1.1 and 1.6 μ (micron), with spectral windows at 1.1, 1.3, and 1.55 μ. The 0.8-to-0.9-μ region is also favorable for transmission and is currently in wide use because components operating at this wavelength are more readily available. To achieve lower losses, that is, reduced attenuation rates, particularly for longhaul communications, longer wavelengths, deeper into the infrared will be required. For local area networks, such as networks in urban areas, local loops, and networks on ships and aircraft, use of the far-infrared region of the optical spectrum may not be necessary. Synonymous with transmission window.

spectrometer. A spectroscope equipped with an angle scale capable of measuring the angular deviation of radiation of different wavelengths. The spectrometer may also be used to measure angles between surfaces of optical elements.

spectroscope. An instrument capable of dispersing radiation into its component wavelengths and observing, or measuring, the resultant spectrum.

spectrum. A continuous range or group of frequencies, or groups of ranges, of waves that have something in common, for example, all frequencies that comprise a string of similar, equally spaced, rectangular pulses; all the frequencies that comprise visible light; a band of radio frequencies; or all the frequencies in a sound wave, such as a musical chord. See electromagnetic spectrum; line spectrum; optical spectrum; visible spectrum; visual spectrum.

spectrum analyzer. See lightwave spectrum analyzer.

spectrum designation of frequency. A method of referring to a range or band of communication frequencies. In American practice the designator is a two- or three-letter abbreviation for the name. In ITU practice, the designator is numeric. See table V.

TABLE V. Frequency ranges and their American and ITU designators.

Frequency Range*	American frequency band designator	ITU frequency band designator
Below 300 Hz	ELF (Extremely Low Frequency)	2
300-3000 Hz	ULF (Ultra Low Frequency)	3
3-30 kHz	VLF (Very Low Frequency)	4
30-300 kHz	LF (Low Frequency)	5
300-3000 kHz	MF (Medium Frequency)	6
3-30 MHz	HF (High Frequency)	7
30-300 MHz	VHF (Very High Frequency)	8
300-3000 MHz	UHF (Ultra High Frequency)	9
3-30 GHz	SHF (Super High Frequency)	10
30-300 GHz	EHF (Extremely High Frequency)	11
300-3000 GHz	THF (Tremendously High Frequency)	12

*Lower limit is exclusive; upper limit is inclusive.

spectrum signature. The frequencies that make up the waves emanating from a particular source, such as the frequencies (or wavelengths) in lightwaves emanating from a light-emitting diode (LED), or the frequencies contained in a sound wave emanating from a given ship.

specular reflection. Reflection from a smooth surface, curved or straight, so that there is negligible diffusion as Snell's laws of reflection and refraction are microscopically obeyed over a uniformly directed surface. Thus, only clear images that are sharp are obtained in specular reflection.

specular transmission. The propagation of lightwaves in a propagation medium such that diffusion attenuation is negligible and smooth changes in refractive indices result in refraction of rays at the microscopic level and the preservation of clear images during propagation. Specular transmission is usually desired in optical waveguides, such as optical fibers, bundles, and cables.

speed. See optical speed.

splice. See cable splice; fiber optic splice; fusion splice; mechanical splice; optical fiber splice; optical waveguide splice; waveguide splice.

splice closure. See cable splice closure.

splice housing. See fiber splice housing.

splice loss. An insertion loss caused by a splice in an optical fiber. The loss is caused primarily by angular misalignment, longitudinal offset, lateral offset, lateral eccentricity, differences in core diameter (larger to smaller), Fresnel reflection at the interface or interfaces due to refractive index mismatch, and other causes. Optical power loss caused by a single fiber optic splice can vary from a small fraction of a decibel, about 0.1 dB, to several dB. Synonymous with splicing loss.

splice organizer. See fiber-and-splice organizer.

splicer. See loose-tube splicer; precision-sleeve splicer.

splice tray. See fiber optic splice tray.

splicing. See field splicing; fusion splicing.

splicing loss. See splice loss.

splitter. See beam splitter; fiber optic splitter.

spontaneous emission. 1. Electromagnetic radiation, such as radiation from a light-emitting diode (LED) or an injection laser operating below the lasing threshold, emitted when the energy level of an internal quantum system, such as electron energy levels in a population of molecules, drops to a lower energy level without regard to the simultaneous presence of similar radiation. 2. The emission of electromagnetic radiation, such as light, that does not bear an amplitude, phase, frequency, time, or other relationship with an applied signal and is therefore a spurious, random, or noise-like form of radiation.

spot. See launch spot.

spot illumination. See fiber optic spot illumination.

spreading. See geometric spreading.

spurious emission. Electromagnetic radiation having frequencies that are outside the necessary emission bandwidth, the level of which may be reduced without affecting the corresponding transmission of information. Such emissions include harmonic emission, parasitic emission, and intermodulation products.

SRD. Super radiant diode. See superluminescent LED (SRD).

standard. See fiber distributed data interface (FDDI) standard; synchronous optical network (Sonet) standard.

standard operating condition. In the design of an optical station/regenerator section, a nominal environmental condition over which specified parameters must maintain their stated performance ratings, e.g., terminal input voltage range, room ambient temperature range, relative humidity range, electrical interfaces, optical line rate, and other parameters that may be specified as standard. Also see extended operating condition.

standard optical source. A reference optical source to which emitting and detecting devices are compared for calibration purposes. In the U.S., standard optical sources must be traceable to the

National Institute of Standards (NIST) and Technology, formerly the National Bureau of Standards (NBS).

standing wave. In contrast to a propagating wave, a wave that exists only between two points or surfaces in a spatial dimension, such as between the two ends of a transmission line, opposite surfaces of an optical cavity, or the fixed end of an elastic string, but does not propagate beyond the fixed limits. For example, a crest of a standing wave simply increases, decreases, and reverses in a transverse direction while remaining at the same spatial point on the line, in the cavity, or on the string. However, the amplitude has maxima and minima along a longitudinal direction, with a wavelength depending on the frequency, the distance between fixed points, the characteristics of the vibrating or oscillating entity, and the characteristics of the environment. In a resonant cavity, a standing electromagnetic wave can be generated by two waves propagating in opposite directions, each reflecting from opposite walls of the cavity.

star coupler. In fiber optics, a coupler that distributes optical power from one input port to two or more output ports; that combines optical power from two or more input ports and distributes it to a larger number of output ports; or that combines optical power from two or more input ports and distributes it to a smaller number of output ports. See reflective star coupler.

star-mesh network. 1. In network topology, a mesh network in which one or more nodes serve also as the central node of a star network. Inversely, a star-mesh network is a communication network configuration in which the central nodes of two or more star networks are connected together by a bus, such as by a partially- or fully-connected mesh network bus. 2. A mesh network in which a large number of local loops or data links are connected to mesh nodes that serve as network control, processing, and switching centers. Synonymous with distributed star coupled bus; multiply-connected star network.

star network. In network topology, the interconnection of nodes such that there is a direct path between each node and a central node that serves as a control node. The central node is connected directly to all endpoint nodes which usually are the locations of equipment, such as a data station, ship system, computer, display device, switchboard, or other user end-instrument.

station cable. See optical station cable.

station facility. See optical station facility.

station optical cable. See optical station cable.

station/regenerator section. See optical station/regenerator section.

statistical fiber optic cable facility loss. See statistical optical cable facility loss.

statistical loss budget constraint. In the design of an optical station/regenerator section using statistical methods, the constraint imposed by the relation

$$\mu_{G-L} > 2\sigma_{G-L}$$

where

$$\mu_{G-L} = \mu_G - \mu_L \quad \text{and} \quad \sigma_{G-L}^2 = \sigma_G^2 + \sigma_L^2$$

where μ_G is the statistical (mean) terminal/regenerator system gain in dB (decibel), μ_L is the statistical (mean) optical cable facility loss (dB), σ_G is the standard deviation of the statistical terminal/regenerator system gain (dB), and σ_L is the standard deviation of the fiber optic cable within the optical cable facility of the optical station/regenerator system section, assuming distributions are Gaussian, splice losses are uncorrelated with fiber losses, cable losses are uncorrelated from reel-to-reel, loss allowance for transmitter wavelength drift is correlated in different reels, averages and sigmas are representative over time and sample sizes are sufficient to warrant use of Gaussian statistical theory, and product distributions are reasonable Gaussian in shape. Also see loss budget constraint.

statistical optical cable facility loss. In a single-mode optical station/regenerator section, the mean loss (dB) in the optical cable facility, i.e., in the outside plant, given by the relation

$$\mu_L = \ell_t(\mu_c + \mu_{cT} + \mu_{S\lambda}) + N_s(\mu_S + \mu_{ST})$$

and the standard deviation is given by the relation

$$\sigma_L = [\ell_t \ell_R(\sigma^2_{cmx} + \sigma^2_{cT}) + N_S(\sigma_S{}^2 + \sigma_{ST}{}^2)]^{1/2}$$

where ℓ_t is the total sheath, that is, jacket, length of spliced-fiber cable in kilometers; ℓ_R is the reel length of fiber cable in kilometers; μ_c is the mean end-of-life cable attenuation rate in decibels per kilometer (dB/km) at the transmitter nominal central wavelength; $\mu_{S\lambda}$ is the increase in mean cable attenuation rate above μ_c measured at the wavelength within the transmitter central wavelength range at which the largest mean-plus-two sigma loss occurs; μ_{cT} and σ_{cT} are the mean and standard deviation of the effect of temperature on cable loss (dB/km) at the worst-case temperature conditions over the expected cable operating temperature; σ_{cmx} is the standard deviation of cable loss (dB/km) determined at the wavelength at which the largest mean-plus-two-sigma cable loss occurs, including an allowance for uncertainty in cable loss measurements; N_s is the number of splices in the length of the cable in the optical cable facility, including the splice at the optical station facility on each end and allowances for cable repair splices; μ_{ST} and σ_{ST} are the mean and standard deviation of the effect of temperature on splices (dB/splice) at the worst-case temperature conditions over the cable operating temperature range, that must be specified for underground, buried, and aerial applications; and μ_S and σ_S are the mean and standard deviation of splice loss (dB). Synonymous with statistical fiber optic cable facility loss.

statistical terminal/regenerator system gain. In a single-mode optical station/regenerator section, the transmitter optical power less the receiver sensitivity (power) and the optical power requirements of the terminal or regenerator station facilities, such as the dispersion power penalty, the reflection power penalty, the overall safety margin, and only the power losses in cables and connectors within the station facility at both ends. The mean statistical terminal/regenerator system gain is given by the relation

$$\mu_G = P_T - P_R - P_D - R_P - M - \mu_{wdm} - \ell_{SM}\mu_{sm} - N_{con}\mu_{con}$$

and the standard deviation is given by the relation

$$\sigma_G = [\sigma^2_{pT} + \sigma^2_{PR} + \sigma^2_{WDM} + \sigma^2_{PD} + N_{con}\sigma^2_{con}]^{1/2}$$

where P_T and σ_{PT} are the mean and standard deviation transmitter power, the optical power in dBmW (decibels referred to 1 milliwatt) into the single-mode station cable on the line side of the transmitter unit fiber optic connector or splice, specified as P_{T1} and σ_{PT1} for standard operating conditions or P_{T2} and σ_{PT2} for extended operating conditions; P_R and σ_{PR} are the mean and standard deviation of the receiver sensitivity, the input optical power (dBm) to the fiber optic receiver on the line side of the receiver connector or splice, specified as P_{R1} and σ_{PR1} for standard operating conditions or P_{R2} and σ_{PR2} for extended operating conditions, that are necessary to achieve the manufacturer specified bit error ratio (BER) and includes the performance degradations caused by manufacturing variations introduced by temperature and aging drifts, maximum transmitter power penalty resulting from the use of a transmitter with a worst-case extinction ratio, and maximum transmitter power penalty resulting from use of a transmitter with a worst-case rise and fall time, but does not include the power penalty associated with dispersion; P_D and σ_{PD} are the mean and standard deviation of the dispersion power penalty (dB); R_P is the reflection power penalty (dB); M is the overall safety margin (dB); μ_{WDM} and σ_{WDM} are the mean and standard deviation of the all-inclusive loss (dB) associated with wavelength-division-multiplexing equipment at both ends, including effects of temperature, humidity and aging; ℓ_{SM} is the total length (km), and μ_{SM} is the mean attenuation rate (dB/km) for the single-mode station/regenerator cable; N_{con} is the number of single-mode connectors, not including the transmitter and receiver unit connectors; and μ_{con} and σ_{con} are the mean and standard deviation of the single-mode connector insertion loss. Also see statistical optical cable facility loss.

steady-state condition. See equilibrium modal power distribution.

step-index fiber. An optical fiber with a uniform homogeneous isotropic core and cladding refractive-index profile, with the core refractive index being greater than the cladding refractive index. There may be more than one layer of cladding each with a different refractive index. For the step-index fiber, the profile parameter, g, is infinite. Also see graded-index (GI) fiber.

step-index optical waveguide. A dielectric waveguide that has a core of uniform refractive index and one or more claddings, each with a different uniform refractive index.

step-index profile. A refractive-index profile characterized by a uniform refractive index within the core, a sharp decrease in refractive index at the core-cladding interface, and a uniform refractive index in one or more claddings. This corresponds to a power-law index profile with the profile parameter approaching infinity. See equivalent step-index (ESI) profile.

stepwise-variable optical attenuator. A device that attenuates the irradiance or radiance of lightwaves in discrete steps, each of which is selectable by some means, such as by changing sets of filter cells, rather than over a continuously variable range. For example, if fixed attenuation cells of 0, 1, 2, 6, and 10 dB (decibels) are used three at a time, all attenuations from 0 to 14 dB are achievable in steps of 1 dB. The attenuator may be inserted in an optical link to control the irradiance, that is, the intensity of light at the receiver photodetector. Also see continuously-variable optical attenuator.

stimulated emission. 1. Electromagnetic radiation, such as radiation from an injection-locked laser operating above the lasing threshold, emitted when the energy level of an internal quantum system, such as electron energy levels in a population of molecules, drops to a lower energy level when induced to do so by the simultaneous presence of radiation at the same wavelength. 2. In a laser, the emission of light caused by a signal applied to the laser such that the response is directly proportional to, and in phase coherence with, the electromagnetic field of the stimulating signal. This coherency, or correlation, between the applied signal and the response is the key to the usefulness of the laser as a fiber optic light source for optical systems.

stimulated emission of radiation. See light amplification by stimulated emission of radiation (laser).

stop-band. The frequency band of electromagnetic waves that a filter does not allow to pass. All frequencies higher than the highest in the stop-band and lower than the lowest in the stop-band are allowed to pass. If the stop band is a single frequency, or an extremely narrow band of

frequencies, the filter is called a notch filter.
strain-induced sensor. See fiber strain-induced sensor.

strength. See electric field strength; field strength; magnetic field strength; optical fiber tensile strength.

stretching. See optical pulse stretching.

stria. A defect in optical materials consisting of a sharply-defined streak of material having a slightly different refractive index than the main body of the material. Striae usually cause wave-like distortions in the images of objects seen through the material, exclusive of similar distortion caused by variations in thickness or curvature. Striae are usually caused by temperature variation, or poor mixing of ingredients, causing optical density, that is, refractive index, variations from place to place in the material.

stripe laser diode. A laser diode usually fabricated as a multiheterostructured monolithic element with deposited metallic stripes for electrical conductors to create necessary excitation, electric fields, and contacts.

stripper. See cladding mode stripper; fiber optic mode stripper.

structures. See fiber optic supporting structures.

stuffing process. See molecular stuffing process.

subscriber loop. See local loop.

superfiber. An optical fiber that has the best attributes of all the specialty fibers, such as high strength, long shelf life, precision polarization control, precision dispersion shifting, moisture resistant, high-level radiation hardness, low attenuation rate, benign cabling, and low cost.

superluminescence. The phenomenon of amplification of spontaneous emission in a gain medium, such as the medium in an avalanche photodiode, characterized by spectral line narrowing and directionality. This process is generally distinguished from lasing action by the absence of feedback and hence the absence of well-defined modal distribution of optical power. Synonymous with superluminescent effect; super radiance.

superluminescent effect. See superluminescence.

superluminescent LED (SRD). A junction-type semiconducting device that emits optical radiation caused by superluminescence.

super radiance. See superluminescence.

supporting structures. See fiber optic supporting structures.

suppressor. See optical pulse suppressor.

surface. See optical surface; reference surface.

surface center. See reference surface center.

surface-emitting LED. A light-emitting diode (LED) that emits radiation normal to the plane of the junction, that is, emission is perpendicular to the surface plane rather than from the edges of the surface plane. The surface-emitting LED has a lower output irradiance and a lower coupling efficiency to an optical fiber or integrated optical circuit (IOC) than the edge-emitting LEDs and the injection lasers. Surface- and edge-emitting LEDs provide several milliwatts of optical power in the 0.8-1.3 μ (micron) wavelength range at drive currents of 100 to 200 mA. Diode lasers at these currents provide tens of milliwatts of optical power. Synonymous with front-emitting LED; Burrus diode; Burrus LED.

surface noncircularity. See reference surface noncircularity.

surface tolerance field. See reference surface tolerance field.

surface wave. An electromagnetic wave that propagates along the interface surface between different propagation media in accordance with the geometrical shape of the surface and the properties of the propagation media near that surface, such as the electric permittivity, magnetic permeability, and electrical conductivity, whose values define the refractive indices of the media. The wave is guided by the interface surface between the two different media, such as by a refractive-index gradient in the media. The electromagnetic field components of the surface wave may exist throughout space, but become negligible within a short distance from the interface. The surface wave propagates along the interface surface without radiating away from the interface surface. Optical energy is not converted from the surface wave field to another form of energy and the wave does not have a component directed normal to the interface surface. In optical fiber transmission, evanescent waves are surface waves. In radio transmission, ground waves are surface waves that propagate close to the surface of the earth, the earth having one refractive index and the atmosphere another, thus constituting an interface surface.

susceptibility. See ambient light susceptibility.

swim. Slow, graceful, undesired movement of display elements, groups, or images about their mean or normal position on the display surface of a display device, for example, the slow movement of the display image on the fiber faceplate of a fiberscope that might be caused when the objective or object is moved slowly relative to the aligned bundle at the transmitting end, or the slow movement of the display on the screen of a CRT when the deflection plate bias voltage drifts slowly. Swim is the same as jitter, except that swim is usually slower and of larger amplitude than jitter, and usually refers to images rather than pulses. Also see jitter.

switch. See fiber optic switch; latching switch; nonlatching switch; optical switch; thin-film optical switch.

switch bounce time. The switch operating bounce time or the switch release bounce time.

switch operating bounce time. In a fiber optic switch, the time between the instant an applied actuating force or signal reaches a specified value and the instant the transmittance permanently changes 90 percent of its maximum value, minus the switch operating time.

switching center. In optical fiber communication systems, an installation in which switching equipment is used to interconnect optical links and circuits in a network for message- or circuit-switching operation. A switching center is usually located at a node in the network.

switching time. The time interval between initiation of the switch actuation method, such as application of a force field, and the settling of the active output of the switch to within 10 percent of the nominal steady state transmittance. The switching time is given by the relation

$$T_S = T_O + T_B,$$

where T_S is the switching time of the switch, T_O is the switch operating time, and T_B is the switch bounce time.

switch operating time. In a fiber optic switch, the time between the instant an applied actuating force or signal reaches a specified value and the instant the transmittance changes 90 percent of its maximum value.

switch release bounce time. In an optical switch, the time interval between the cessation of an applied actuating force or signal reaches a specified value and the time that the optical transmittance has permanently changed by 90 percent of its maximum value, minus the switch release time.

switch release time. In a fiber optic switch, the time between the instant the cessation of an applied actuating force or signal reaches a specified value and the instant the transmittance has changed by 90 percent of its maximum value.

synchronous optical network (Sonet) standard. A fiber optic communication network standard, developed by the American National Standards Institute (ANSI), in which a set of optical transmission rates and formats are established so that operating telephone companies can synchronize public telephone networks and efficiently interconnect high-speed fiber optic links using an 8-bit byte format rather than the single bit-stream format. For example, the byte format will enable the telephone network to be efficiently synchronized to an 8-bit frame so that optical signals at 45 Mbps (megabits/second) need not be demultiplexed down to 1.5 Mbps for routing signals around the network. Thus, data can be transmitted at any data signaling rate on any line. Also see fiber distributed data interface (FDDI) standard.

system. See advanced television system; enhanced-definition television (EDTV) system; fiber optic telemetry system; high-definition television (HDTV) system; imaging system; improved-definition television (IDTV) system; integrated fiber optic system; metric system; optical system; telemetry system.

system gain. See statistical terminal/regenerator system gain; terminal/regenerator system gain.

system information rate. In optical transmission systems, the bit repetition rate in bits/second internal to equipment that when acted upon by the line coding algorithm results in the optical line rate.

systems architecture. See open systems architecture.

systems interconnection. See Open Systems Interconnection (OSI) Reference Model (RM).

T

tap. 1. To remove a part of the signal energy from a line, such as an optical fiber carrying optical pulses. Tapping may be authorized for purposes of establishing a signal line, or it may be clandestine, though clandestine tapping of optical fiber is difficult to accomplish without detection. 2. The physical connection to a signal line that removes part of the signal energy in a line, such as a branch or coupler.

taper. See optical taper.

tapered fiber. An optical fiber whose cross section increases, or decreases, with distance along the optical axis of the fiber.

tapoff. See optical tapoff.

target resolution. See borescope target resolution.

T-coupler. See tee coupler.

TDM. Time-division multiplexing.

TE. Transverse electric.

technique. See cutback technique; near-field scanning technique; rod-in-tube technique.

tee coupler. In fiber optics, a coupler that connects three ports and operates in such a manner that optical power into any one port is distributed to the other, or power into any two ports can be combined and sent out on the third. In effect, it is a three-port star coupler. Synonymous with T-coupler.

telemetry. The branch of science and technology devoted to measuring a quantity or quantities, such as motion, pressure, temperature, humidity, radiation, sound, smoke, flame, or toxic fumes, transmitting the measurements to a distant station, and there indicating, interpreting, or recording the measured values.

telemetry system. A system, usually consisting of (1) a sensor, that is, a data source that measures the absolute values and variations of a physical variable, such as acceleration, pressure, temperature, fluid flow, humidity, radiation, sound, smoke, flame, or toxic fumes; (2) a data sink that receives, converts, displays, or otherwise processes the data, such as a photodetector and indicator; and (3) a data link that connects the source to the sink. Usually the sensor is at a remote location and the sink is at another location where the data can be interpreted, displayed, recorded, or used. In some systems, signals can be sent from the sink, or other location, to the sensor to reset, calibrate, test, or otherwise control the sensor. See fiber optic telemetry system.

telephone service. See plain old telephone service (POTS).

television system. See advanced television system; enhanced-definition television (EDTV) system; high-definition television (HDTV) system; improved-definition television (IDTV) system.

TEM mode. Transverse electromagnetic mode.

TE mode. Transverse electric mode.

Tempest-proofed fiber optic cable. Fiber optic cable that has been tested and certified to meet U.S. National Security Agency and military standards in regard to emission levels of optical radiation.

template. See four-concentric-circle near-field template; four-concentric-circle refractive-index template.

temporal coherence. See time coherence.

tensile strength. See optical fiber tensile strength.

tension sensor. See fiber tension sensor.

terahertz. 10^{12} hertz, abbreviated THz.

term. See attenuation term; phase term.

terminal/regenerator system gain. In a single-mode fiber optic transmission system, the transmitter optical power less the receiver sensitivity (power) and the optical power requirements of the terminal or regenerator station facilities, such as the dispersion power penalty, the reflection power penalty, the overall safety margin, and only the power losses in cables and connectors within the station facility at both ends. The terminal/regenerator system gain is given by the relation

$$G = P_T - P_R - P_D - R_P - M - U_{wdm} - \ell_{sm}U_{sm} - N_{con}U_{con}$$

where P_T is the transmitter power, P_R is the receiver sensitivity (power), P_D is the dispersion power penalty, R_P is the reflection power penalty, M is the overall safety margin, U_{wdm} is the worst-case value of all losses associated with wavelength-division multiplexing equipment at both ends, ℓ_{sm} is the fiber length in the stations, U_{sm} is the worst-case end-of-life loss (dB/km) of the single-mode cable at both stations, N_{con} is the number of fiber optic connectors within the stations (inside plants), and U_{con} is the loss (dB) per connector. G is used to overcome all the losses, L, in the optical cable facility (outside plant), which lies between the two stations of the optical station/regenerator section. When designing a system, G must be equal to or greater than L for the section to function satisfactorily, that is, the relation

$$G > L$$

must hold. L, the sum of all the losses in the optical cable facility (outside plant) of the section expressed in dB, is given by the relation

$$L = \ell_t(U_c + U_{cT} + U_\lambda) + N_s(U_S + U_{ST})$$

where ℓ_t is the total sheath, that is, jacket, length of spliced-fiber cable (km), U_c is the worst-case end-of-life cable attenuation rate (dB/km) at the transmitter nominal central wavelength, U_λ is the largest increase in cable attenuation rate that occurs over the transmitter central wavelength range, U_{cT} is the effect of temperature on the end-of-life cable attenuation rate at the worst-case temperature conditions over the cable operating temperature range, N_s is the number of splices in the length of the cable in the optical cable facility, including the splice at the optical station facility on each end and allowances for cable repair splices, U_S is the loss (decibels/splice) for each splice, and U_{ST} is the maximum additional loss (dB/splice) caused by temperature variation. P_T and P_R are expressed in dB referenced to a common power unit, such as milliwatts, because they are single-ended in regard to optical power, but all the losses that contribute to L are double-ended and thus are simply expressed in dB. See statistical terminal/-regenerator system gain. Also see optical cable facility loss.

termination. See optical waveguide termination.

terminus. A device that is used to terminate an electrical conductor or dielectric waveguide, such as an optical fiber, and that provides a means of positioning and holding the conductor or waveguide within a connector. In fiber optics, the term contact is deprecated. See fiber optic terminus.

testing. See qualification testing.

test method. See alternative test method (ATM); fiber optic test method (FOTM); reference test method (RTM).

test procedure. See fiber optic test procedure (FOTP).

test set. See optical loss test set (OLTS).

TE wave. Transverse electric wave.

theorem. See sampling theorem.

theoretical resolving power. The maximum possible resolving power determined by diffraction, frequently measured as an angular resolution determined from the relation

$$A = 1.22\lambda/D$$

where A is the limiting resolution angle in radians, λ is the free-space wavelength of the light at which the resolution is determined, and D is the effective diameter of the aperture.

thermal noise. The noise generated by thermal agitation of electrons in a conductor. The noise power, P, in watts, is given by the relation

$$P = kT(\Delta f)$$

where k is Boltzmann's constant, T is the conductor temperature in kelvins, and Δf is the bandwidth in hertz. Thermal noise is distributed equally throughout the electromagnetic frequency spectrum. Synonymous with Johnson noise.

thickness. See optical thickness.

thin film. See optical thin film.

thin-film optical modulator. A device made of multilayered films of dielectric materials and other materials in which electrooptic, electroacoustic, magnetooptic, magnetostrictive, or other effects are used to modulate a lightwave. Thin-film optical modulators are used as component parts of integrated optical circuits (IOCs).

thin-film optical multiplexer. A multiplexer consisting of layered dielectric materials and other materials in which electrooptic, electroacoustic, magnetooptic, magnetostrictive, or other effects are used to multiplex lightwave signals. Thin-film optical multiplexers are used as components parts of integrated optical circuits (IOCs).

thin-film optical switch. A switch in which electrooptic, electroacoustic, magnetooptic, magnetostrictive, or other effects are used to switch lightwaves in order to perform logic functions, such as AND, OR, and NEGATION. The thin dielectric films usually support only one mode and are used as component parts of integrated optical circuits (IOCs).

thin-film optical waveguide. An optical waveguide made of dielectric or semiconductor material consisting of thin layers of materials with differing refractive indices. The lower-refractive-index material on the outside serves as the substrate as well as the cladding. Thin-film optical waveguides usually support only one mode and operate from laser sources for effective launching of lightwaves into the thin films. Various combinations of thin-film waveguides, lasers, modulators, switches, directional couplers, filters, and other components may be light-coupled to form integrated optical circuits (IOCs) which may be optically or electrically powered.

thin-film waveguide. See periodically-distributed thin-film waveguide.

third-harmonic nonlinear material. See third-order nonlinear material.

third-order nonlinear material. In fiber optics, pertaining to certain transparent materials, such as special glasses, polymers, and organic materials, that generate a third harmonic frequency when energized with optical signals. The generation of third harmonic frequencies means switching speeds of fewer than 100 femtoseconds. The process is also lossless and thus can be repeated many times. An exit wave can be frequency mixed and output beams can be considerably different from input beams. For example, at the exit point of an integrated optical circuit waveguide, different signals can be switched to different ports. Synonymous with third-harmonic nonlinear material.

threshold. See absolute luminance threshold; lasing threshold.

threshold current. In a laser, the driving current corresponding to the lasing threshold.

threshold frequency. In optoelectronic devices, the frequency of incident radiant energy below which there is no photoemissive effect created in the illuminated material. Thus, if the photon frequency is less than the threshold frequency, it will not have sufficient energy to overcome the work function of the material it strikes. If no photon in a beam has sufficient energy to overcome the work function of the material it strikes, there will be no photoemissive effect no matter how many nor at what rate photons strike the material. Also see work function.

THz. Terahertz, equal to 10^{12} Hz.

tight-jacketed cable. In fiber optics, a fiber optic cable in which the coated optical fibers are not free to assume their own position within the jacket but are completely constrained by the jacket.

time. See acquisition time; coherence time; fall time; group delay time; real time; rise time; switch bounce time; switch operating bounce time; switch operating time; switch release time; switch release bounce time.

time between failures. See mean time between failures (MTBF).

time between outages. See mean time between outages (MTBO).

time coherence. In waves, such as acoustic and electromagnetic waves, pertaining to the existence of a correlation between the phases of two waves or between the phases of one wave at one point in space at two or more instants of time. Thus, the phase relationships are such that they can be calculated and predicted everywhere over a time period. Synonymous with temporal coherence.

time-coherent light. Lightwaves in which the amplitude, phase, polarization, or other characteristic at any point in space and time can be predicted given the values of the same characteristics at any previous time at that same point.

time-division demultiplexing. A method of reversing the process of time-division multiplexing. Thus, messages, conversations, packets, blocks, or other units of data that time-shared one channel are each assigned separate channels so that they can each be routed to a different destination, that is, a form of serial-to-parallel conversion.

time-division multiplexing (TDM). A method of deriving two or more apparently simultaneous channels from a given frequency spectrum in a propagation medium connecting two or more points by assigning discrete time intervals in sequence to each of the individual channels, that is, a form of parallel-to-serial conversion. During a given time interval, the entire available frequency spectrum can be used by the channel to which it is assigned. In general, time-division multiplexing systems use pulse transmission. The multiple pulse train may be considered to be the interleaved pulse trains of the individual channels. The individual channel pulses may be modulated either in an analog or a digital manner. Thus, individual signals from separate sources share the time of a circuit by being assigned time slots on the circuit. In fiber optic data links a single optical fiber can share its time among a large number of sources. For example, if each source is assigned 1 μs (microsecond) out of each ms (millisecond), 1,000 sources can be accommodated by the single fiber. Of course, the individual sources can be frequency-division multiplexed, giving rise to many more channels. The lightwaves in the optical fiber can also be wavelength-division multiplexed, that is, a different color lightwave for each channel, giving rise to even more channels.

time-domain reflectometer. See optical time-domain reflectometer (OTDR).

time domain reflectometry. See optical time domain reflectometry.

time jitter. The short-term variation or instability in the duration of a specified interval or in the occurrence time of a specific event, such as a signal transition from one significant condition to anther. When viewed with reference to a fixed time frame, the signal transition moves back and forth on the time axis, that is, a shifting of a significant instant.

time to failure. See mean time to failure (MTTF).

time to repair. See mean time to repair (MTTR).

time to service restoral. See mean time to service restoral (MTTSR).

tip length. See borescope tip length.

TM. Transverse magnetic.

TM mode. Transverse magnetic mode.

TM wave. Transverse magnetic wave.

tolerance. See diameter tolerance.

tolerance area. See cladding tolerance area; core tolerance area.

tolerance field. The region between two curves used to specify the tolerance in the size of a component. When specifying the size of optical fiber cladding, the tolerance field is the annular region between the two concentric circles of the diameter $D + \Delta D$ and $D - \Delta D$. The first is the smallest circle that circumscribes the outer surface of the homogeneous cladding; the second is the largest circle that fits within the outer surface of the homogeneous cladding. When specifying the core size, the tolerance field is the annular region between the two concentric circles with diameters of $d + \Delta d$ and $d - \Delta d$. The first is the smallest circle that circumscribes the core area; the second is the largest circle that fits within the core area. The cladding circles may not necessarily be concentric with the core circles. See reference surface tolerance field.

tool. See fiber-cutting tool.

total harmonic distortion. When a single frequency signal of specified power is applied to the input of a system or component, such as a length of optical fiber, a transmitter, or a receiver, the ratio of the sum of the powers of all harmonic frequencies to the power of the fundamental frequency signal at the output. This ratio is measured under specified conditions and is expressed in decibels. The harmonic frequencies do not include the fundamental frequency, that is, the input frequency. The distortion is caused by the nonlinearity of the component or system.

total internal reflection. See total reflection.

total (internal) reflection sensor. See frustrated total (internal) reflection sensor.

total reflection. Reflection that occurs when an electromagnetic wave strikes an interface surface between propagation media with different properties at incidence angles greater than the critical angle. At these incidence angles, there is no refracted wave, except that at the critical angle, there is a wave that propagates along the interface surface. In an optical fiber, the incident ray is in the core and the refractive index of the core is higher than that of the cladding. When the incidence angle is greater than the critical angle, the incident ray will be totally reflected back into the medium of incidence, that is, back into the core. Synonymous with total internal reflection.

trajectory. See ray trajectory.

transceiver dispersion. See maximum transceiver dispersion.

transducer. See optoacoustic transducer.

transfer function. A mathematical statement expressing the transfer characteristics of a system, subsystem, equipment, or component. Thus, the transfer function is such that when it operates on the input the output will be fully determined or described. Thus, the transfer function is the ratio of the output function to the input function of the device. For an optical fiber, the transfer function may be the ratio of the output optical power to the input optical power as a function of modulation frequency. In general, for a linear system, the transfer function and the impulse response are related through the Fourier transform pair, commonly given by the relations

$$H(f) = \int_{-\infty}^{+\infty} h(t)e^{i\omega t}dt$$

where H(f) is the ratio of output optical power to the input optical power as a function of modulation frequency, f is the frequency, t is time, and h(t), given by the relation

$$h(t) = \int_{-\infty}^{+\infty} H(f)e^{-\omega t}df$$

where $\omega = 2\pi f$. H(f) is often normalized to H(0) and h(t) to the relation

$$h_n(t) = \int_{-\infty}^{+\infty} h(t)dt$$

which by definition is H(0). Synonymous with baseband response function; frequency response function. See optical fiber transfer function (OFTF).

transfer network. See data transfer network (DTN); fiber optic data transfer network.

transient attenuation rate. 1. In a multimode dielectric waveguide, such as an optical fiber, a change in the attenuation rate with distance along the guide between the entrance face and the equilibrium length, that is, the equilibrium modal power distribution length. The change can be an increase or a decrease in the attenuation rate with distance. Within this length, the attenuation rate changes with distance because of the over or under excitation of the lossy high-order propagating modes. Beyond this length, the attenuation rate does not change with distance along the guide. Thus, this change, that is, "transient" condition, occurs as a function of distance. 2. At a point between the entrance face of a multimode dielectric waveguide, such as an optical fiber, and the equilibrium length, that is, the equilibrium modal power distribution length, a temporary change in the attenuation rate at the point, usually occurring during the rise and fall time of optical pulses or by temporal changes in environmental conditions. This transient occurs as a function of time.

transimpedance. The ratio of the output voltage to the input current of a device, such as a photodetector transimpedance amplifier. See optical transimpedance.

transimpedance amplifier. See photodetector transimpedance amplifier.

transition fiber. An optical element of such geometric shape at input and output ends that it enables coupling between elements of different cross-sectional shape, such as coupling between an element with a rectangular cross section and an element with a round cross section. For example a transition fiber may be used to couple a thin-film optical waveguide to a round optical fiber, the transition fiber having a smooth transition from a rectangular to a round cross section.

transmission. 1. The transfer or transport of electrical, optical, or any other form of power from one location to another over electrical conductors, such as wires; or waveguides, such as optical fibers. Purposes of transmission include transfer of energy from one point to another or transfer of signals that represent information. 2. The dispatching of a signal, message, or other form of information by means of wire, optical fiber, radio, heliograph, semaphore, horns, or any other means, using one or more modes such as telegraphy, telephony, or facsimile. See bidirectional transmission; specular transmission.

transmission coefficient. 1. The ratio of the transmitted field strength to the incident field strength when an electromagnetic wave is incident upon an interface surface between dielectric propagation media with different refractive indices. For example, if, at oblique incidence, the electric field component of an incident plane-polarized electromagnetic wave is parallel to the interface surface, the transmission coefficient is given by the relation

$$T = 2m_2\cos A/(m_2\cos A + m_1\cos B)$$

where m_1 and m_2 are the reciprocals of the refractive indices of the incident and transmitted media, respectively, and A and B are the incidence and refraction angles, respectively. This is one of the Fresnel equations. The sum of the reflection coefficient and the transmission coefficient is not necessarily unity. 2. The ratio between the amplitude of the transmitted wave and the amplitude of the incident wave. 3. A number indicating the probable performance of a portion of a transmission circuit. The value of the transmission coefficient is inversely related to the quality of the link or circuit. Synonymous with refraction coefficient. Also see reflection coefficient.

transmission loss. The decrease in power level of a signal during transmission from one point to another within a component, from the output of one component to the input of another component, or from one point to another in a propagation medium. The loss is usually expressed in decibels, which requires that the loss must first be expressed as a ratio of the power levels at the two points. The number of decibels of transmission loss is given by the relation

$$10 \log_{10} (P_o/P_i)$$

where P_o/P_i is the ratio of the output power at one point to the input power at the other point, such as the output power divided by the input power of a transmission line, connector, or other component. Also see insertion loss.

transmission medium. See propagation medium.

transmission window. See spectral window.

transmissivity. The intrinsic transmittance per unit length of a material at a given wavelength, excluding the reflectance from inner or outer surfaces. The term is no longer in common use. Also see transmittance.

transmittance. In optics, when an electromagnetic wave, such as a lightwave, is incident upon an interface surface between propagation media with different refractive indices, the ratio of transmitted power to incident power. The conditions under which the transmittance and reflectance occurs should be stated, such as the wavelength composition and polarization of the incident wave, the geometrical distribution of the reflecting surface or surfaces, and the composition of the media on both sides of the reflecting surface. In optics, the transmittance is often expressed as a percent or as transmittance density, the base-10 logarithm of the reciprocal of the transmittance. In communications, it is usually expressed in decibels. See coupler transmittance; spectral transmittance. Also see transmissivity.

transmittance change. See induced attenuation.

transmittance density. See optical density.

transmitted power. The energy per unit time propagated through or across a specified area in a direction perpendicular to the area, such as might be transmitted through a wire or fiber optic cable. Since the instantaneous power can vary with time at a point, various values of power can be measured, such as the peak envelope power; the average power over an area or over time; the radiance, that is, the power radiated in a given solid angle; the irradiance, that is, the power density; the total power radiated by a source; or the power in a specified portion or band of the frequency spectrum, such as, for an electromagnetic wave, only the power in the infrared region of the spectrum.

transmitter. A device that generates, usually modulates, and dispatches a signal for control, communication, or other purpose, such as a unit consisting of a modulator, a laser, and an optical fiber pigtail for connection to a fiber optic cable; or a unit consisting of a microphone, amplifier, modulator, and antenna for transmitting radio signals. See electrooptic transmitter; fiber optic transmitter; optoelectronic transmitter; optical transmitter.

transmitter central wavelength range. In a fiber optic transmitter, the range of wavelengths between the minimum and maximum wavelength limits of the total worst-case variation of the transmitter nominal central wavelengths caused by manufacturing, temperature, aging, and any other factors when operated under standard or extended operating conditions.

transmitter information descriptor. A unique descriptor from which information about a transmitter can be determined, such as the manufacturer, terminal equipment association, system design application (single-mode, multimode), operating wavelength, output power level, source type, temperature controller, FCC classification (Class I, Class II, etc), and manufacturer product change designation (issue, revision).

transmitter optical connector. The optical connector provided at the output of an optical transmitter that is attached to the transmitter pigtail. The transmitter optical connecter description should include the manufacturer, type (biconic, FC, etc.) model number, classification (multimode, single-mode), and mating connector model number.

transmitter optical power. The worst-case minimum value of optical power (dBm) coupled into a fiber optic cable on the line side of the fiber optic transmitter connector under specified standard or extended operating conditions using standard measurement procedures. The worst-case minimum value combines manufacturing, temperature, and aging variations in a worst-case fashion.

transparency. A property of an entity that allows another entity to pass through it without altering either one or both of the entities, such as (1) the quality of a material that allows lightwaves to pass through without absorption or scattering, (2) the property that allows the transmission of signals without changing their electrical characteristics or coding beyond the limits specified by the design, (3) a component in a communication system whose operation is independent of the codes used in representing the information being transmitted, or (4) the film on which an image is placed so that the image can be projected on a screen without alteration of the image.

transport layer. In open systems architecture, the layer that provides functions and facilities for the actual movement of data among network elements, such as among user end-instruments; among land vehicle, ship, aircraft, or spacecraft systems, subsystems, and control panels; and among network nodes. Optical fiber systems can be used to implement the transport layer and the physical layer. Also see Open Systems Interconnection (OSI) Reference Model (RM).

transverse compression sensor. See fiber transverse compression sensor.

transverse electric (TE). Pertaining to an electromagnetic wave in which the electric field vector is perpendicular to the direction of propagation and therefore, in an optical fiber, always perpendicular to the longitudinal axis of the fiber regardless of the direction of the magnetic field vector.

transverse electric (TE) mode. In an electromagnetic wave propagating in a waveguide, a mode whose electric field vector is normal to the direction of propagation and whose magnetic field vector is not normal to the direction of propagation. In an optical fiber, transverse electric and transverse magnetic modes correspond to meridional rays. Also see transverse magnetic (TM) mode.

transverse electric (TE) wave. An electromagnetic wave propagating in a propagation medium, or in free space, in such a manner that the electric field vector is directed entirely transverse, that is, perpendicular, to the direction of propagation, hence there is no electric field vector component in the direction of propagation, but there is a component of the magnetic field vector in the direction of propagation. Thus, in a waveguide, the electric field vector is entirely transverse and does not have a longitudinal component, but the magnetic field does have a longitudinal component. In optical systems, the propagation medium is usually a waveguide with a uniform cross section in the longitudinal direction. Also see transverse magnetic (TM) wave.

transverse electromagnetic (TEM) mode. An electromagnetic wave whose electric field vector and magnetic field vector are both normal, that is, perpendicular, to the direction of propagation.

transverse electromagnetic (TEM) wave. An electromagnetic wave whose electric field vector and magnetic field vector, although varying in time at every point in the space occupied by the wave whether in free space or in a material propagation medium, are contained in a local plane at that point. The orientation of the plane is independent of time. Thus, in general, the orientation of the local plane is different for different points in space or material media, the exception to this being the special case of a uniform plane-polarized electromagnetic wave, in which case all the polarization planes are parallel.

transverse interferometry. A method used to measure the refractive-index profile of a dielectric waveguide, such as an optical fiber, by placing a short length of the guide in an interferometer and illuminating it in a direction transverse to the optical axis. Also see slab interferometry. Normally a computer is used to interpret the interference pattern obtained when making the measurement.

transverse magnetic (TM). Pertaining to an electromagnetic wave in which the magnetic field vector is perpendicular to the direction of propagation of the wave and therefore, in an optical fiber, always perpendicular to the longitudinal axis of the fiber regardless of the direction of the electric field vector.

transverse magnetic (TM) mode. In an electromagnetic wave, a mode whose magnetic field vector is perpendicular to the direction of propagation and whose electric field vector is not perpendicular to the direction of propagation. In an optical fiber, transverse magnetic modes and transverse electric modes correspond to meridional rays. Also see transverse electric (TE) mode.

transverse magnetic (TM) wave. An electromagnetic wave propagating in a propagation medium or in free space in such a manner that the magnetic field vector is directed entirely normal, that is, perpendicular, to the direction of propagation, hence there is no magnetic field vector component in the direction of propagation, but there is an electric field vector component in the direction of propagation. Thus, in a waveguide, the magnetic field vector is entirely transverse and does not have a longitudinal component, but the electric field does have a longitudinal component. For optical systems, the propagation medium is usually a waveguide with a uniform cross section in the longitudinal direction. Also see transverse electric (TE) wave.

transverse mode. See lowest-order transverse mode.

transverse offset loss. See lateral offset loss.

transverse propagation constant. The propagation constant evaluated along a direction perpendicular to the waveguide longitudinal axis. The transverse propagation constant for a given mode can vary with the transverse coordinates.

transverse scattering method. A method for measuring the refractive index profile of an optical waveguide, such as an optical fiber or preform, by illuminating the guide coherently and transversely to its longitudinal axis, and examining the far-field irradiance pattern. A computer is used to interpret the pattern of scattered light obtained.

trap. See optical fiber trap.

trapped electromagnetic wave. An electromagnetic wave that enters a layer of material on both sides of which is a layer of material with a lower refractive index such that, if the wave is propagating parallel, or nearly parallel to the surfaces of the layers, the wave will be forced to remain in the layer it has entered as long as the incidence angles that the rays make with the local surfaces it encounters are greater than the critical angle, thus obtaining total (internal) reflection.

trapped mode. See bound mode.

trapped ray. See guided ray.

tray. See fiber optic splice tray.
tree network. In network topology, a network configuration in which there is one and only one path between any two nodes.

triangular-cored optical fiber. An optical fiber consisting of a core whose cross section is shaped like a triangle with bowed convex sides placed in a hollow jacket or cladding tube such that only the vertices of the core touch the inner walls of the jacket or cladding. Air surrounds the core and performs the function of the cladding.

tube. See bait tube.

tunable laser. A laser whose spectral emission wavelength, that is, the wavelengths that make up its spectral width, can be varied. The spectral range of some lasers can be varied continuously across a broad spectral range, such as an organic dye or optical parametric-oscillator laser. Others are stepwise tunable, such as carbon dioxide lasers and other molecular lasers. Emission of these lasers can be tuned to one of several wavelengths, that is, one of several spectral lines.

tunneling mode. See leaky mode.

tunneling ray. See leaky ray.

two-level optical signal. A modulated lightwave carrier that is at either one of two different optical power levels, that is, irradiance, optical power density, or electric field strength levels, at a point at any given instant. For example, a lightwave carrier that is turned on and off, depending on whether a 1 or a 0 is being transmitted at any given instant.

Twyman-Green interferometer. An interferometer in which an observer sees a contour map of an emergent electromagnetic wavefront based on the wavelength of the light that is entering the system.

type. See optical detector type; optical source type.

U

u. The symbol often used in lieu of μ or μm to indicate micrometers or microns, that is, 10^{-6} m (meter). The symbol um is also used to indicate microns.

ultralow-loss fiber. 1. Optical fiber that has an attenuation rate approaching that caused only by Rayleigh scattering. 2. Optical fiber that has a potential optical attenuation rate less than 0.01 dB/km (decibel/kilometer), perhaps as low as 0.002 dB/km, the attenuation being limited only by Rayleigh scattering, perhaps operating at a window in the 2-to-5-μ-(micron)-wavelength region of the optical spectrum, that is, wavelengths in the near- and middle-infrared regions of the electromagnetic spectrum, such as might be obtained from certain halogen glasses like zirconium fluoride glasses.

ultraviolet (UV). Pertaining to the region of the electromagnetic spectrum in which wavelengths are shorter than those of the visible spectrum, but longer than x-rays. The ultraviolet region extends from about 1 nm (nanometer), which is the beginning of the optical spectrum, to about 400 nm, that is, the beginning of the visible region, or 0.001 to 0.4 μ (micron). Because the frequency of ultraviolet radiation is higher than that of the visible region, the rays, that is, the photons, can kill some living organisms, such as some germs and bacteria, and can have a damaging effect on human cells if exposure time and irradiance is sufficiently high. Because of the higher frequencies, attenuation rates in glass are higher for the shorter-than-visible ultraviolet wavelengths and, because of the lower frequencies, attenuation rates are lower for the infrared, hence the interest in the use of infrared in longhaul optical fiber communication systems. Also see ultraviolet fiber optics.

ultraviolet fiber optics. Fiber optics involving the use of ultraviolet (UV) light in optical components designed to handle UV light. Uses include medical engineering, medicine, measurements, materials testing, sterilization, photo-chemistry, genetics, security, and secondary emission (fluorescence) applications. Also see ultraviolet.

ultraviolet light. Radiation in the ultraviolet region of the electromagnetic spectrum, namely electromagnetic waves that have wavelengths between 1 and 400 nm (nanometer), or between 0.001 and 0.4 μ (micron). The lightwave region of the electromagnetic spectrum lies between 0.3 to 3 μ, which is the region in which the techniques and components designed for the visible spectrum, 0.4 to 0.8 μ, also apply. Thus, only the narrow region between 0.3 and 0.4 μ might be considered ultraviolet light, and the remaining portion of the ultraviolet region, from 0.001 to 0.3 μ, might be considered as ultraviolet radiation.

unaligned bundle. A bundle of optical fibers in which the spatial relationship among the fibers may vary along the bundle and the spatial relationship among the ends of the fibers at one end of the bundle is not the same as at the other end. Thus, an unaligned bundle, that is, an incoherent bundle, cannot be used to transmit an image, but it can be used for signaling or illumination. Synonymous with incoherent bundle.

unbound mode. In an electromagnetic wave propagating in a waveguide, a mode that is not a bound mode. In optical fibers, unbound modes include leaky modes, that is, radiation modes. Also see bound mode; cladding mode; leaky mode; leaky ray.

undercompensated optical fiber. An optical fiber whose refractive-index profile is adjusted so that the high-order propagating modes arrive at the end of the fiber after the low-order modes, as in the case of the uncompensated fiber, that is, a fiber in which no deliberate effort is made to compensate for dispersion. Higher-order modes propagate faster than lower-order modes in a propagation medium with a given refractive index. In an undercompensated fiber they are made to travel longer paths in higher-index medium and hence are delayed so they arrive at the end after the lower order modes which are made to travel shorter paths in lower-refractive index material. Higher-order modes have higher eigenvalues in the solution of the wave equations. Higher order modes also have higher frequencies and shorter wavelengths than lower order modes. Also see compensated optical fiber; overcompensated optical fiber.

uniformly distributive coupler. A fiber optic coupler in which optical power input to each input port is distributed equally among the output ports, and the optical power input to each output port is not distributed equally among the input ports. Also see nonuniformly distributive coupler.

uniform plane-polarized electromagnetic wave. A plane-polarized electromagnetic wave whose electric and magnetic field strength vector amplitudes are independent of the coordinate direction perpendicular to the direction of propagation, that is, they are independent of the transverse coordinates, but are dependent on the longitudinal coordinates in the direction of propagation.

uniform refractive-index profile. See linear refractive-index profile.

unshifted fiber. See dispersion-unshifted fiber.

unshifted single-mode fiber. See dispersion-unshifted single-mode fiber.

user end-instrument. A device connected to the terminals of a circuit and used to convert electrical, optical, acoustic, or other types of signals, into usable information, or vice versa, such as a telephone, control panel, computer, or remote data terminal. Optical data transfer networks in land-based communication systems, aircraft communication and control systems, and shipboard communication and control system, local area networks, and other optical fiber communication systems, are designed to allow communication among users by means of their end-instruments, such as intercoms, telephones, and data terminals. From the point of view of the communication system, equipment, such as computers, aircraft and ship propulsion systems, and sensor systems may also be considered as user end-instruments connected together by a communication or control network.

UV. Ultraviolet.

V

vacancy defect. In the somewhat ordered array of atoms and molecules of optical propagation media, such as the glass used in optical fibers, a site at which an atom or molecule is missing in the array. The defect will be a scattering center, and cause diffuse reflection, heating, and absorption, all of which will contribute to optical attenuation.

VAD. Vapor-phase axial deposition.

VAD process. Vapor-phase axial deposition process.

vapor deposition. See outside vapor deposition (OVD).

vapor deposition process. See chemical vapor deposition (CVD) process; modified chemical vapor deposition (MCVD) process; plasma-activated chemical vapor deposition (PACVD) process.

vapor-phase axial deposition (VAD) process. A chemical vapor deposition (CVD) process in which dopants in vapor form are axially deposited on substrates, such as glass tubes, to make a preform from which optical fibers may be pulled.

vapor-phase oxidation process. See axial vapor-phase oxidation (AVPO) process; chemical vapor-phase oxidation (CVPO) process; inside vapor-phase oxidation (IVPO) process; outside vapor-phase oxidation (OVPO) process.

variable optical attenuator. See continuously-variable optical attenuator; stepwise-variable optical attenuator.

velocity. See group velocity; phase-front velocity; phase velocity.

vector. See electric field vector; magnetic field vector; Poynting vector.

Verdet constant. The constant of proportionality, that is, the V, in the equation that defines the Faraday effect, which is given by the relation

$$\theta = VB\int dl = V\mu H\int dl$$

where θ is the rotation angle of the polarization plane of plane-polarized light propagating in a medium, V is the Verdet constant, B is the magnetic flux density in the medium, μ is the magnetic permeability of the medium, and H is the magnetic field strength at the point in the medium at which the path-length differential, dl, is taken. The integrand is the dot (scalar) product. Thus, if the magnetic field is parallel to the propagation path, such as occurs when an optical fiber is parallel to a magnetic field, the magnitude of the rotation angle is directly proportional to the product of the path length and the magnetic flux density, or for nonferrous substances such as glass, the product of the path length and the magnetic field strength because the magnetic permeability of glass is unity. Typical units for the Verdet constant are degrees/-centimeter-tesla, degrees/meter-oersted, or radians/meter-tesla, depending on the units used for the variables in the solution integral of the Faraday equation. Also see magnetooptic effect.

video. In communication systems, such as optical fiber communication systems, pertaining to a capability to transmit or process signals having frequencies that lie within that part of the frequency band that is employed for the representation of pictures that change in accordance with events occurring in real time. Video frequency bands range nominally from 100 kHz to several megahertz and are generally used for television transmission.

video disk. See optical video disk (OVD).

video optical detector. In a video-signal optical-fiber transmission system, a device that converts an optical video signal in an optical fiber or other optical propagation medium to an electrical video signal in a wire or other electrical propagation medium.

video optical source. In a video-signal optical-fiber transmission system, a device that converts an electrical video signal in a wire or other electrical propagation medium to an optical video signal in an optical fiber or other optical propagation medium.

view field. See borescope view field.

viewing angle. See borescope axial viewing angle.

visible spectrum. The portion of the electromagnetic frequency spectrum to which the human retina is sensitive and by which humans see. The visible spectrum is considered to extend from a wavelength of 400 to 800 nm (nanometer), that is, 0.4 to 0.8 μ (micron), in air, which corresponds to a frequency band of $3.75\text{-}7.50 \times 10^{14}$ Hz. The visible spectrum lies between the ultraviolet and the infrared regions, the visible wavelengths being longer than the ultraviolet and shorter than the infrared.

visible radiation. Electromagnetic radiation with wavelengths in the visible spectrum.

visual spectrum. The band of color produced when white light is decomposed into its wavelength components by means of dispersion. For example, the rainbow produced by a cloud of water droplets suspended in air or the spread of colors produced by a prism or cut diamond when illuminated by white light are examples of visual spectra.

vitreous silica. See fused silica.

V number. See normalized frequency.

voice. In communication systems, pertaining to a capability or characteristic to detect, transmit, or process signals with frequencies that lie within the frequency band employed for the representation of speech. Voice frequency bands range from about 300 to about 3,400 Hz (hertz).

voltage. See noise voltage.

voltaic effect. See photovoltaic effect.

voltaic photodetector. See photovoltaic photodetector.

volume. See effective mode volume; mode volume.

V-parameter. See normalized frequency.

V-value. See normalized frequency.

W

wave. See clockwise polarized wave; counterclockwise polarized wave; electromagnetic wave; evanescent wave; guided wave; Hertzian wave; indirect wave; leaky wave; left-hand polarized electromagnetic wave; lightwave; plane (electromagnetic) wave; plane-polarized electromagnetic wave; right-hand polarized electromagnetic wave; standing wave; surface wave; transverse electric (TE) wave; transverse magnetic (TM) wave; trapped electromagnetic wave; uniform plane-polarized electromagnetic wave.

wave equation. The equation, derived from Maxwell's equations, the constitutive relations, and the vector algebra, that relates the electromagnetic field of an electromagnetic wave time and space derivatives with the propagation medium electric permittivity and magnetic permeability in a region without electrical charges or currents, that is, in a charge-free dielectric propagation medium, such as that of an optical fiber. The solution of the wave equation yields the electric and magnetic field strengths everywhere in the medium in which the wave is propagating. The wave equation is given by the relation

$$\nabla^2 H - \mu\epsilon\partial^2 H/\partial t^2 = 0$$

or by the relation

$$\nabla^2 E - \mu\epsilon\partial^2 E/\partial t^2 = 0$$

in a current-and-charge-free electrically-nonconducting medium, that is, dielectric medium, where E is the electric field strength, H is the magnetic field strength, ϵ is the electric permittivity, μ is the magnetic permeability, usually equal to 1, and $\partial^2/\partial t^2$ is the second partial derivative with respect to time. The ∇ is the vector spatial derivative operator. When the wave equation for uniform plane waves is transformed into Cartesian coordinates, the scalar equations for the electric and magnetic field strengths in the transverse directions (x and y for a wave propagating in the z direction) are obtained in terms of propagation distance and propagation medium parameters, namely the electric permittivity and magnetic permeability. These are the Helmholtz equations. They are ordinary differential equations. Their solutions are simple exponential functions whose exponents are the propagation constants. For example, the relation

$$(d^2/dz^2)E_x - \Gamma^2 E_x = 0$$

is one of the Helmholtz equations derivable from the wave equation. A solution of this Helmholtz equation is the relation

$$E_x = E_{xo}e^{-\Gamma z}$$

where $\Gamma = -\omega^2\mu\epsilon$, μ being the magnetic permeability, ϵ the electric permittivity, and $\omega = 2\pi f$, where f is frequency. In transparent dielectric media, $\mu = 1$. Thus, the relative refractive index is given by the relation

$$n_r = \epsilon_r^{1/2}$$

where ϵ_r is the electric permittivity relative to a vacuum, or approximately to air. The wave equation, the derived Helmholtz equations, and their solutions apply to electromagnetic waves propagating in optical waveguides. Their eigenvalues give rise to many possible modes of which only a limited number can be supported by an optical fiber.

wavefront. A theoretical surface normal to an electromagnetic ray as it propagates from a source, the surface passing though those parts of all the radiating waves that have the same phase, that is, all points on a wavefront surface have the same optical path length from the source. Hence, it is the locus of all points of the wave where the electric and magnetic field components, that is, electric and magnetic field vectors, have the same phase at the same time. For parallel rays, the wavefront is a plane. For waves diverging from or converging on a point, the wavefront is spherical. The wavefront at a given point in space is perpendicular to the direction of propagation. The electric and magnetic field vectors at a point in space define a plane, that plane being tangent to the wavefront surface at that point.

waveguide. A device capable of guiding an electromagnetic or sound wave along a prescribed path, such as an optical fiber or a transmission line consisting of a hollow or dielectric-filled metallic conductor, generally rectangular, elliptical, or circular in shape, within which electromagnetic waves can propagate. See circular dielectric waveguide; closed waveguide; dielectric waveguide; diffused optical waveguide; multimode waveguide; open waveguide; optical waveguide; periodically-distributed thin-film waveguide; planar diffused waveguide; slab dielectric waveguide; step-index optical waveguide; thin-film optical waveguide.

waveguide connector. See optical waveguide connector.

waveguide coupler. See optical waveguide coupler.

waveguide delay distortion. In an electromagnetic wave, such as a lightwave, propagating in a waveguide, the distortion in received signals caused by the differences in group delay time for each wavelength or each propagation mode, causing an increase in pulse duration, that is, pulse broadening or spreading, or causing distortion of analog signals, as the wave propagates along the guide.

waveguide dispersion. For each mode of an electromagnetic wave or for an optical pulse propagating in a waveguide, the dispersion caused by the dependence of the phase and group velocities on wavelength as a consequence of the geometric properties of the waveguide. For circular dielectric waveguides, such as optical fibers, the dependence is on the ratio a/λ, where a is the core radius, that is, one-half the core diameter, and λ is the wavelength.

waveguide isolator. A passive attenuator in which transmission losses are much greater in one direction than in the other, thus causing absorption of end reflections, backscatter, and noise. Certain such nonreciprocal properties can be obtained from some ferrite materials.

waveguide scattering. Scattering other than material scattering in a waveguide, such as an optical fiber. Waveguide scattering is caused by variations of geometry and variations in the refractive index profile of the waveguide.

waveguide splice. A permanent joint between the transmission elements of two waveguides so that signals may pass from one waveguide to the other with minimal loss, for example, a joint between the cores and claddings of two optical fibers. See optical waveguide splice.

waveguide termination. See optical waveguide termination.

wave impedance. In an electromagnetic wave propagating in a propagation medium, the ratio of the electric field strength to the magnetic field strength at the point and instant of observation. The characteristic impedance of a plane-polarized electromagnetic wave in free space is 377 ohms. From Maxwell's equations, the characteristic impedance in a linear, homogeneous, isotropic, dielectric, and electric-charge-free propagation medium is given by the relation

$$Z = (\mu/\epsilon)^{1/2}$$

where μ is the magnetic permeability and ϵ is the electric permittivity; $\mu = 4\pi \times 10^{-7}$ H/m (henries per meter) and $\epsilon = (1/36\pi) \times 10^{-9}$ F/m (farads per meter), from which 120π ohms, that is 377 ohms is obtained for free space. For many dielectric media, such as glass, the electric permittivity, that is, the dielectric constant, ranges from about 2 to 7. However, the refractive index is the square root of the electric permittivity. The characteristic impedance of dielectric materials is 377/n, where n is the refractive index. Also see refractive index.

wavelength. 1. For a sinusoidal wave, the distance, usually expressed in meters, between points of corresponding phase of two consecutive cycles. The wavelength, λ, is also given by the relation

$$\lambda = v/f$$

where v is the propagation velocity and f is the frequency. 2. For any periodic type of wave, the distance between corresponding points, such as positive-peak values, in two consecutive cycles of the wave. If the propagation velocity and repetition rate of the wave is known, the wavelength can be calculated from the relation

$$\delta = s/r$$

where s is the speed and r is the repetition rate. See cable cutoff wavelength; cutoff wavelength; long wavelength; maximum cable cutoff wavelength; minimum cable cutoff wavelength; nominal central wavelength; peak spectral wavelength; short wavelength; zero-dispersion wavelength; zero-material-dispersion wavelength.

wavelength-dependent attenuation rate characteristic. A plot of the variation of the attenuation rate (dB/km) of optical fiber as a function of the wavelength (u) of the energizing light source. The plot usually also shows the minimum, nominal, and maximum wavelength in the spectral width of the source. The characteristic is used to determine the increase in attenuation rate that has to be allowed for in the design of an optical station/regenerator section. The increase in attenuation rate to be used in the design is the maximum value, which may occur at the minimum or maximum wavelength, or anywhere in between, relative to the nominal central wavelength.

wavelength-division multiplexing (WDM). In fiber optics when referring to lightwaves, multiplexing that is similar to frequency-division multiplexing, a multiplexing system in which the available transmission wavelength range is divided into narrow bands and each is used as a separate channel. Because an optical fiber can support more than one wavelength of light at the same time, each wavelength can be separately modulated and used as a separate transmission channel as long as a combination of dispersive components, such as prisms and photodetectors on the receiving end are wavelength-sensitive or spatially distributed for demultiplexing. In fiber optics, such frequency-division multiplexing (FDM) is called wavelength-division multiplexing (WDM), because lightwaves are more often described, measured, and controlled in terms of wavelength rather than frequency. Use of the term WDM also avoids confusion with the possible use of FDM in assembling baseband signals that are to be transmitted over an optical link at each of the many possible operating optical wavelengths. Optical frequencies are high enough for these multiplexing schemes to be accomplished during assigned time slots on a single optical fiber. Thus, time-division multiplexing (TDM), along with space-division multiplexing (SDM), can all take place concurrently with FDM and WDM on a single optical link with a single-fiber optical cable.

wavelength measurement. See central wavelength measurement.

wavelength modulation (WM). A method of changing the wavelength of an electromagnetic wave in accordance with the instantaneous value of an input signal. The wavelength may be varied by direct input to the source or externally after launching.

wavelength range. See transmitter central wavelength range.

wave number. The reciprocal of the wavelength of a single-frequency sinusoidal wave, such as a single-frequency uniform plane-polarized electromagnetic wave or monochromatic lightwave. The wave number is used for waves in or near the visible spectrum, because wavelength is more readily measured than frequency, but it is frequency, proportional to wave number, that is directly related to energy. For example, photon energy is given by the relations

$$PE = hf = hkc$$

where h is Planck's constant, k is the wave number, and c is the velocity of light. The wave number turns out to be the number of wavelengths per unit distance in the direction of propagation. Also see wave parameter.

wave parameter. In periodic waves, such as electromagnetic waves, the wave parameter is given by the relationship

$$p = 2\pi/\lambda$$

where π is approximately 3.1416 and λ is the wavelength. Also see wave number.

WDM. Wavelength-division multiplexing.

weakly guiding fiber. An optical fiber in which the difference between the maximum and the minimum refractive index is small, usually less than 1 percent.

wet-mateable connector. A connector that can be mated and demated underwater, usually many times and under high pressure, without deleterious effects on the quality of the connection. For example, a fiber optic connector that can be connected and disconnected many times on the ocean bottom would be a wet-mateable connector.

white light. Electromagnetic waves having a spectral distribution, that is, energy distribution, among the wavelengths such that the color sensation to the average human eye is identical to that of average noon sunlight.

wideband. Pertaining to a frequency band that is wide relative to the particular frequency or frequency band under consideration. For example, a band 60 kHz wide at a midband frequency of 50 MHz would be wide, because the bandwidth of 60 kHz is greater than 0.1 percent of the midband frequency, whereas at a midband frequency of 10 Ghz, the same 60-kHz band would be considered narrow because it is only 0.0006 percent of the midband frequency.

width. See spectral width.

width distortion. See pulse-width distortion.

window. See spectral window.

WM. Wavelength modulation.

work function. The amount of energy required to free an electron from an atom in a given material, usually measured in electron-volts. If a photon has an energy greater that the work function of the material it strikes, it will be capable of freeing an electron from that material. The freed electron will possess kinetic energy equal to the difference between the energy of the photon and the material work function. The work function of a material is given by the relation

$$W = hf_o$$

where h is Planck's constant and f_o is the threshold frequency required to release an electron from the material. Also see photoelectric equation.

working diameter. See borescope working diameter.

working length. See borescope working length.

worst-case chromatic dispersion over wavelength range. See worst-case dispersion coefficient.

worst-case dispersion coefficient. In a single-mode optical station and optical cable facility, the worst-case end-of-life dispersion coefficient (in psec/(nm-km)) that corresponds to the greater absolute value of (1) the difference between the lower limit of the transmitter light source central wavelength range and the lower limit of the fiber zero-dispersion wavelength range, and (2) the difference between the upper limit of the transmitter light source central wavelength range and the upper limit of the fiber zero-dispersion wavelength range. The ranges are caused by manufacturing tolerances, temperature and humidity variations, and aging. Synonymous with worst-case chromatic dispersion over wavelength range.

woven fiber optics. The application of textile-weaving and fiber optic techniques for producing special-effect devices, such as reproducible-image guides, image dissectors, color image panels, high-speed alphanumeric display surfaces, and distributed-fiber sensors.

W-type fiber. An optical fiber that has two or more concentric layers of cladding, in which the fiber core usually has the highest refractive index and the inner-most cladding has the lowest refractive index. This fiber has several advantages, such as reduced bending losses, over conventionally-cladded fibers that have a stepped- or graded refractive index that decreases all the way from the core optical axis to the outer surface. For example, cladding modes in the inner-most cladding can be stripped off as in a cladding mode stripper.

wye coupler. In fiber optics, a coupler with one input port and two output ports. Synonymous with Y-coupler.

X Y Z

x-ray. A ray of electromagnetic waves that has a wavelength between 0.001 and 1×10^{-9} m (meter), between 0.001 and 1 nm (nanometer), or between 0.000001 and 0.001 μ (micron) and therefore a frequency in free space between 0.3 to 300×10^{18} Hz (hertz). X-ray wavelengths are shorter than those of ultraviolet light. Because the energy of a photon is given as Planck's constant times the frequency, the energy of an x-ray photon is sufficient to penetrate deeply into solids, ionize gases, and destroy molecular structures, such as those of living tissues. They can have sufficient energy to pass through a substance with negligible attenuation, except for highly dense substances, such as lead and gold. X-rays must be used with great care. They are used to produce images of materials they pass through in transit to sensitive film. The x-ray photos thus produced indicate variations in transmittance of the material. Also see optical spectrum.

XX/YY restricted launch. In the launching of a light beam from a light source into an optical fiber, a launch with an XX percent launch spot size and source aperture equal to YY percent of the fiber numerical aperture. Also see launch spot; numerical aperture.

Y-coupler. See wye coupler.

Zehnder fiber optic sensor. See Mach-Zehnder fiber optic sensor.

zero dispersion. Pertaining to a waveguide in which an electromagnetic wave is propagating such that all modes in the wave have the same end-to-end propagation delay. The refractive index is different for each of the various wavelengths contained in the spectral width of the source. The refractive-index profile of the guide can be adjusted so that the geometric path taken by each mode is different, the faster modes taking longer geometric paths and the slower modes shorter geometric paths, resulting in all modes arriving at the far end at the same time. Thus, the optical path length, that is, the product of the geometric distance and the refractive index, of all the modes is the same, which reduces the signal distortion by waveguide dispersion to nearly zero. The geometric distance is the actual measured distance over which a given mode propagates. If the proper operating wavelength is chosen, material dispersion can also be reduced to nearly zero, resulting in a zero-dispersion waveguide at a particular wavelength. In a single-mode optical fiber, there is a singular case in which the total dispersion (psec/(nm-km) is identically equal, or nearly equal, to zero. For an appropriate refractive index profile, zero dispersion will occur at a specific wavelength. The wavelength at which zero dispersion occurs will vary with manufacturing tolerances, temperature, humidity, and aging. Also see zero-material-dispersion wavelength.

zero-dispersion slope. In an optical fiber, the slope (psec/(nm^2-km)) of the global fiber dispersion characteristic at the wavelength at which zero dispersion occurs. The zero-dispersion slope is used to calculate the upper and lower limiting values of the global dispersion coefficient. The zero-dispersion slope will vary with manufacturing tolerances, temperature and humidity variations, and aging. It is the value of the chromatic dispersion slope at the zero-dispersion wavelength of the waveguide, usually expressed by the relation

$$S_o = S(\lambda_o)$$

where S_o is the zero dispersion slope, $S(\lambda)$ is the chromatic dispersion slope as a function of wavelength, and λ_o is the zero-dispersion wavelength of the waveguide.

zero-dispersion wavelength. For a lightwave propagating in a single-mode optical fiber with an appropriate refractive-index profile, the wavelength at which zero, or nearly zero, dispersion occurs. The zero-dispersion wavelength will have a maximum and minimum value among fibers and over time because of manufacturing tolerances, temperature and humidity variations, and aging. It is the wavelength at which the fiber chromatic dispersion coefficient, $D(\lambda)$, or the material dispersion coefficient, $M(\lambda)$, is zero. In single-mode fibers, the zero-dispersion wavelength is the wavelength at which the total dispersion is zero.

zero-material-dispersion wavelength. In an optical waveguide, the electromagnetic wavelength at which there will be no material dispersion. The wavelength usually occurs at that point in the electromagnetic frequency spectrum at which the electronic band-edge absorption, extending from where the ultraviolet ceases and infrared absorption begins. The absorptions occur in the visible spectrum and are primarily caused by oxides of silicon, sodium, boron, calcium, germanium, and other elements, and by hydroxyl ions. For zero dispersion in an optical waveguide, the refractive-index profile must be such that the guide is compensated for zero dispersion at this wavelength. Also see zero dispersion.

zone. See dead zone.

4. GENERAL REQUIREMENTS

This section is not applicable to this standard.

5. DETAILED REQUIREMENTS

This section is not applicable to this standard.

6. NOTES

(This section contains information of a general or explanatory nature that is helpful, but not mandatory.)

6.1 Intended use. The intended uses of this standard are to (1) standardize fiber optics terminology in military standards, specifications, handbooks, test procedures, and other military technical, management, and administrative documents, (2) assist communicating fiber optics concepts, and (3) provide information on fiber optics science and technology, particularly for persons engaged in military systems acquisition.

6.2 Organization. The same lexicographical rules used by most standards bodies, particularly the American National Standards Institute, were used to organize this glossary. The basic standard definitions consist of a defining phrase. The defining phrase is followed by notes, explanatory remarks, examples, synonyms, and cross-references to other entries. All words in a multiple-word entry are indexed with "See references" to the definition. Acronyms and abbreviations are defined at their respective alphabetical position in the main listing of section 3.

6.3 Subject term (key word) listing.

Optics
Optronics
Photonics
Electrooptics
Electromagnetics

Preparing activity:
Navy-SH
(Project 60GP-N007)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER	2. DOCUMENT TITLE
MIL-STD-2196(SH)	GLOSSARY, FIBER OPTICS

3a. NAME OF SUBMITTING ORGANIZATION

b. ADDRESS *(Street, City, State, ZIP Code)*

4. TYPE OF ORGANIZATION *(Mark one)*

- ☐ VENDOR
- ☐ USER
- ☐ MANUFACTURER
- ☐ OTHER *(Specify)*: ______

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional

c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional

8. DATE OF SUBMISSION *(YYMMDD)*

(TO DETACH THIS FORM, CUT ALONG THIS LINE.)

DD FORM 1426, 82 MAR

PREVIOUS EDITION IS OBSOLETE.

INSTRUCTIONS: In a continuing effort to make our standardization documents better, the DoD provides this form for use in submitting comments and suggestions for improvements. All users of military standardization documents are invited to provide suggestions. This form may be detached, folded along the lines indicated, taped along the loose edge *(DO NOT STAPLE)*, and mailed. In block 5, be as specific as possible about particular problem areas such as wording which required interpretation, was too rigid, restrictive, loose, ambiguous, or was incompatible, and give proposed wording changes which would alleviate the problems. Enter in block 6 any remarks not related to a specific paragraph of the document. If block 7 is filled out, an acknowledgement will be mailed to you within 30 days to let you know that your comments were received and are being considered.

NOTE: This form may not be used to request copies of documents, nor to request waivers, deviations, or clarification of specification requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

(Fold along this line)

(Fold along this line)

DEPARTMENT OF THE NAVY

COMMANDER
NAVAL SEA SYSTEMS COMMAND (SEA 55Z3)
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20362

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO. 12503 WASHINGTON D. C.

POSTAGE WILL BE PAID BY THE DEPARTMENT OF THE NAVY

COMMANDER
NAVAL SEA SYSTEMS COMMAND (SEA 55Z3)
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20362