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Optical Waveguide Communications Glossary

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OPTICAL WAVEGUIDE COMMUNICATIONS GLOSSARY

A. G. Hanson, L. R. Bloom, R. L. Gallawa, and E. M. Gray*,
and
G. W. Day and M. Young†

This document is a technical dictionary containing approximately 300 terms, concisely defined for the communication engineer, covering the field of optical fiber waveguide communications.

PREFACE

Purpose

The rapid emergence of optical waveguide communications from the laboratory into commercial systems applications has been accompanied by the growth of a specialized vocabulary. Some terms have been borrowed freely from the disciplines of optical physics and communications engineering; others have been coined independently.

In this process, inevitably, some ambiguity and impreciseness have resulted. More significantly perhaps, some terms have been used to specify a product--and are beginning to be accepted by manufacturers and users--but are not precise descriptors beyond rather narrow limits. The absence of a precise, common language among researchers, manufacturers, systems designers and users is a hindrance to effective technology development and utilization.

The goal of this glossary is to nurture such a language.

The Editorial Process

The initial data base for this glossary was prepared jointly by the National Telecommunications and Information Administration/ Institute for Telecommunication Sciences (NTIA/ITS) and the National Bureau of Standards (NBS), combining the interrelated disciplines of communications engineering, physics, and measurement standards. Further technical breadth was achieved by the contributions of these scientists and engineers:

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Choice of Title

"Optical waveguide" is used throughout this document to mean "fiber" and "optical fiber," that is, the optical transmission line. Many workers in the field consider "optical fiber waveguide" a precise and useful term because it implies a distinction between the low loss waveguides employed for communications and the optical fiber "light pipes" used for numerous other applications. Other workers consider "optical fiber waveguide" redundant. "Optical waveguide" is used in this document for brevity; however, the reader is cautioned that, in the strict sense, the term "optical waveguide" may be considered generic since it includes various other experimental devices such as mirror, gas, and lens waveguides. Broad consensus on the use of a single term might be convenient, but is relatively unimportant because most commonly used synonyms are recognizable as such.

Inaccuracies of Definitions

Definitions in this document are subjective, and--for some terms--controversial. In the evolution of a specialized language, inaccuracies occasionally develop, and, as well, definitions sometimes become imprecise.

One example of inaccuracy is the common use of the term "multimode dispersion" to describe waveform shape degradation (in the temporal plane) owing to the distinct modal group velocities in a multimode optical waveguide. When the modal powers add at the detector, the effect is degradation of wave shape. "Distortion" and "multimode distortion" are defined as follows:

Distortion:
An undesirable change of signal waveform shape.
Note. Signal distortion in an optical waveguide is caused by several dispersive mechanisms: waveguide dispersion, material dispersion, and profile dispersion. In addition, the signal suffers degradation from multimode "distortion," which is often (erroneously) referred to as multimode "dispersion."

Multimode distortion:
In an optical waveguide, that distortion resulting from the superposition of modes having differential mode delays.
Note. The term "multimode dispersion" is often used as a synonym; such usage, however, is erroneous since the mechanism is not dispersive in nature. Synonyms: Intermodal distortion; Mode (or modal) distortion. See also: Differential modal delay; Dispersion; Distortion; Mode; Multimode optical waveguide.

To correct yet another inaccuracy, this glossary recommends discontinuing the use of the term "electro-optical" as a synonym for "optoelectronic." While communications engineers may find no ambiguity, physicists may read an inaccurate meaning into the colloquial use of this borrowed term.

"Electro-optical" has been coined as a variant of the physical term "electro-optic," viz.:

Electro-optic effect:

A change in a material's refractive index under the influence of an electric field.

Note 1. Pockels and Kerr effects are electro-optic effects that are respectively linear and quadratic in the electric field strength.

Note 2. "Electro-optic" is often erroneously used as a synonym for "optoelectronic."

The term "electro-optical" is popularly used to describe a large number of devices, including sources, detectors and repeaters, in which electrical-to-optical or optical-to-electrical conversion takes place--exclusive of those devices in which the electro-optic effect takes place. A more proper existing term that is not ambiguous is "optoelectronic."

Precision of Definitions

The definition of "numerical aperture" has been limited to its classical physical meaning after considerable deliberation.

The term "numerical aperture" appeared in the fiber optics literature around 1960 and was defined as the sine of the critical angle for a step index fiber. The critical angle was the largest angle with respect to the axis for which a meridional ray entering the fiber would undergo total internal reflection at the core-cladding interface. This definition is consistent with the classical use of "numerical aperture" in imaging optics.

Early workers clearly recognized that "numerical aperture" and "critical angle," thus defined, were not adequate measures of the light collecting ability of a fiber because neither accounts for skew rays.

More recent workers have, none the less, loosely used "numerical aperture" as a means of indicating both the acceptance angle and the radiation angle of an optical waveguide. This distortion of the classical meaning of the term has resulted in a great deal of confusion, particularly in the case of graded index optical waveguides, and has further led to the use of an entire family of related terms, some of which are listed below:

acceptance numerical aperture
classical numerical aperture
effective numerical aperture
effective numerical aperture (graded index profile)
equilibrium numerical aperture
exit numerical aperture
material numerical aperture
numerical aperture (calculated)
numerical aperture (measured)
numerical aperture (90% power)
numerical aperture (10% intensity)
numerical aperture (operational)
steady state numerical aperture
transient state numerical aperture

The editors firmly believe that this confusion can be most effectively reduced by restricting "numerical aperture" to its original and precise meaning:

Numerical aperture:
NA = $\sin \theta$
where θ is, at a specified point, half the vertex angle of the largest cone of meridional rays that can enter or leave an optical element or system, and n is the refractive index of the homogeneous isotropic space that contains the specified point. The specified point is usually an object or image point.
Note. The term "numerical aperture" is often used, imprecisely, to describe an optical waveguide. The precise terms "acceptance angle" and "radiation angle" are preferred.

Three terms, none new, are substituted for use in characterizing an optical waveguide. These, with their recommended definitions, are listed below:

Acceptance angle:
For a uniformly illuminated optical waveguide, half the vertex angle of that cone within which the power coupled into a waveguide is equal to a specified fraction of the total power coupled into a waveguide.
Note. The maximum theoretical acceptance angle can be estimated on the basis of physical optics as:

$$\theta_A = \sqrt{n_1^2 - n_2^2} = n_1 \sqrt{2\Delta}$$

which is sometimes imprecisely referred to as the numerical aperture of the waveguide. In this equation, n_1 and n_2 are, respectively, the refractive index on the fiber axis and the refractive index in the cladding; Δ is the contrast, defined by the equation.

Radiation angle:
Half the vertex angle of that cone within which can be found a specified fraction of the total radiated power at any distance in the far field. Synonym: Output angle.

Radiation pattern:
The output radiation of an optical waveguide, specified as a function of angle or distance from the waveguide axis.
Note 1. Far field radiation pattern is specified as a function of angle. Near field radiation pattern is specified as a function of distance from the waveguide axis.
Note 2. Radiation pattern is a function of the length of waveguide measured, the manner in which the waveguide is excited, and the wavelength.

These acceptance/radiation parameters are, in fact, the parameters needed in systems design to compute coupling/connection losses. Measurements of radiation pattern/angle are furthermore the most common means of deriving the numerical aperture variants listed above. New measurements or new types of measurement will therefore not be required.

Scope

The selection of terms has been deliberately restrictive. With a few exceptions, telecommunication terms and physical or purely optical terms that have been rigorously defined in other glossaries, and whose meanings remain unambiguous in optical communications usage, have been purposely excluded here. Some terms have been defined with the goal of preserving meaning consistent with established usage while occasionally emphasizing a different meaning of the term as applied to optical communications.

Sources

Background literature has included numerous scientific and engineering texts, dictionaries and glossaries, standards (draft standards as well as published ones), symposium proceedings, and a large body of technical papers and journal articles. To achieve accuracy, conciseness, and format consistency, all material was rewritten; editorial integrity therefore dictates the omission of source citations.

Format

Spoken-word order is used in alphabetical listing of term names. Closely related terms are reciprocally cross-referenced by a "see also" notation following the definition of noncontiguous entries. Commonly used acronyms, synonyms, and abbreviations are similarly indicated and are also alphabetically listed as cross references, without definition.

OPTICAL WAVEGUIDE COMMUNICATIONS GLOSSARY

Absorption:
In an optical waveguide, that portion of attenuation resulting from conversion of optical power into heat.
Note. Intrinsic components consist of tails of the UV and IR absorption bands. Extrinsic components include (a) impurities, e.g., the OH^- ion and transition metal ions and, (b) defects, e.g., results of thermal history and exposure to nuclear radiation. See also: **Attenuation.**

Acceptance angle:
For a uniformly illuminated optical waveguide, half the vertex angle of that cone within which the power coupled into a waveguide is equal to a specified fraction of the total power coupled into a waveguide.
Note. The maximum theoretical acceptance angle can be estimated on the basis of physical optics as:

$$\theta_A = \sqrt{n_1^2 - n_2^2} = n_1 \sqrt{2\,\Delta}$$

which is sometimes imprecisely referred to as the numerical aperture of the waveguide. In this equation, n_1 and n_2 are, respectively, the refractive index on the fiber axis, and the refractive index in the cladding; Δ is the contrast, defined by the equation. See also: **Critical angle; Equilibrium radiation angle; Equilibrium radiation pattern; Launch numerical aperture; Numerical aperture; Optical waveguide; Radiation angle; Radiation pattern.**

Acousto-optic:
Pertaining to the interaction of light with a sound wave in a medium via a change of refractive index.
Note. The acousto-optic effect is used in devices that modulate and deflect light.

Active laser medium:
The material within a laser, such as crystal, gas, glass, liquid, or semiconductor, that emits coherent radiation (or exhibits gain phenomena) as the result of stimulated electronic or molecular transitions to lower energy states. Synonym: Laser medium. See also: Laser; Optical cavity.

Aligned bundle:
A bundle of optical fibers in which the distribution of relative spatial coordinates of each fiber is the same at the two ends of the bundle, as opposed to the random orientation of fibers in bundles typically employed as optical communication transmission lines.

Note. The term "coherent bundle" is often employed as a synonym, and should not be confused with phase coherence or spatial coherence. Synonym: Coherent bundle. See also: Fiber bundle.

Amplitude:
The maximum value of the electric field strength of an electromagnetic wave.

Angle of deviation:
In optics, the net angular deflection experienced by a light ray after it passes through a refractive medium.

Note. The term is generally used in reference to prisms, assuming air interfaces. The angle of deviation is then the angle between the incident ray and the emergent ray. See also: Refraction.

Angstrom (A):
A unit of optical wavelength (obsolete).
1 A = 10^{-10}
1 nm = 10 A
1 μm = 10^{4} A

Note. The angstrom has been used historically in the field of optics but is not an SI unit.

Angular misalignment loss:
An optical power loss caused by angular deviation from the optimum alignment of source to optical waveguide, waveguide to waveguide, or waveguide to detector. See also: Extrinsic junction loss; Gap loss; Intrinsic junction loss; Lateral offset loss.

Antireflection coating:
A thin, dielectric or metallic film (or several such films) applied to an optical surface to reduce the reflectance and to increase the transmittance.
Note. The ideal 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 surface to which it is applied, the ideal optical thickness being one quarter of a wavelength. See also: Dichroic filter; Fresnel reflection; Reflectance; Reflection loss; Transmittance.

APD: Abbreviation for Avalanche photodiode.

Attenuation:
The diminution of signal amplitude or power.
Note. In optical waveguides, attenuation results from several mechanisms that may operate simultaneously: absorption; scattering; and losses into radiation modes. Attenuation is generally expressed in dB/km, assuming approximate uniformity with length. See also: Coupling loss; Differential modal attenuation; Equilibrium mode distribution; Extrinsic junction loss; Insertion loss; Intrinsic junction loss; Leaky modes; Macrobend loss; Material absorption; Material scattering; Microbend loss; Rayleigh scattering; Spectral window; Transmission loss; Waveguide scattering.

Attenuation coefficient:
The normalized rate of change of total optical power with respect to distance along the waveguide. It is defined by the equation

$$P(z) = P(0)\ 10^{-(\alpha z/10)}$$

where $P(z)$ is the power at distance z along the guide and $P(0)$ is the power at $z=0$; α is in dB/km if z is in km. From this equation,

$$\alpha z = -10 \log_{10}[P(z)/P(0)].$$

This assumes that α is independent of z; if otherwise, the definition must be given in terms of incremental attenuations as:

$$P(z) = P(0)\ 10^{-\frac{1}{10}\int_0^z \alpha(z)dz}$$

Attenuation limited operation:
The condition prevailing when the signal amplitude (rather than distortion) limits the communication capacity. See also: **Bandwidth limited operation; Distortion limited operation.**

Avalanche photodiode (APD):
A photodiode designed to take advantage of avalanche multiplication of photocurrent.
Note. As the reverse-bias voltage approaches the breakdown voltage, hole-electron pairs created by absorbed photons acquire sufficient energy to create additional hole-electron pairs when they collide with ions; thus a multiplication (signal gain) effect is achieved. See also: Photodiode; PIN photodiode.

Axial ray:
A light ray that travels along the optical axis. See also: Geometric optics; Meridional ray; Optical axis; Paraxial ray; Skew ray.

Backscattering:
The scattering of power into the direction opposite that of signal transmission.

Bandpass filter: See Optical filter.

Bandwidth:
A continuous range of frequencies between a lower and upper limit.

Bandwidth limited operation:
The condition prevailing when the frequency spectrum or bandwidth, rather than the amplitude (or power) of the signal, is the limiting factor in communication capability. The condition is reached when the system distorts the shape of the waveform beyond tolerable limits. For linear systems, bandwidth limited operation is equivalent to distortion limited operation. See also: Attenuation limited operation; Distortion limited operation; Linear optical element or system.

Barrier layer:
In an optical waveguide, a localized minimum in refractive index in the region of the core/cladding interface.

Baseband response function: Synonym for **Transfer function.**

Beam diameter:
The diameter of a circle, concentric with a beam, through which passes a specified fraction of the total power in the beam. The term "beam diameter" is only useful for beams that are or are assumed to be circular in cross section.

Beam divergence angle:
Half the vertex angle of that cone that encompasses a circle of diameter equal to the beam diameter at all points in the far field. Beam divergence angle is strictly only meaningful when describing the far field of beams that are or that are assumed to be circular in cross section. See also: Beam spread; Beamwidth; Collimation; Far field.

Beam spread:
The angle between two planes, within which passes a specified fraction of the total power in an optical beam. Beam spread is generally specified for two orthogonal orientations.

Note. This definition is useful in characterizing beams that are not circular in cross section. See also: Beam divergence angle.

Beamsplitter:
A device for dividing an optical beam into two or more separate beams.

Beamwidth:
The linear dimension of the region over which the beam irradiance falls within specified limits. See also: Beam divergence angle; Irradiance.

Bidirectional transmission:
Signal transmission in both directions along an optical waveguide or other component.

Birefringent medium:
A material that exhibits different indices of refraction for orthogonal linear polarizations.

Blackbody:
A totally absorbing body (that reflects no radiation). Note. In thermal equilibrium, a blackbody absorbs and radiates at the same rate; the radiation will just equal absorption when thermal equilibrium is maintained. See also: Emissivity.

Boltzmann's constant:
A constant that relates the average energy of a molecule to the absolute temperature of the environment. Defined as 1.38×10^{-23} joules/K.

Boule:
In the manufacture of optical fibers, a synonym for Preform.

Bound mode:
A propagating mode whose power is predominantly in the core of the waveguide. Synonyms: Core mode; Guided mode. See also: Cladding mode; Leaky mode; Mode; Normalized frequency; Unbound mode.

Brewster's angle:
For light incident on a plane boundary between two regions having different refractive indices, that angle of incidence at which the reflectivity of light having its electric field vector in the plane defined by the direction of propagation and the normal to the surface is zero. For propagation from medium 1 to medium 2, Brewster's angle is given by

$$\theta = \arctan (n_2/n_1)$$

Brightness:
An attribute of visual perception, in accordance with which a source appears to emit more or less light; obsolete. See also: **Radiance; Radiometry.**

Note 1. Usage should be restricted to nonquantitative statements in reference to physiological sensations and perceptions of light.

Note 2. "Brightness" was formerly used as a synonym for the photometric term "luminance" and (incorrectly) for the radiometric term "radiance".

Buffer: See **Fiber buffer.**

Bundle: See **Fiber bundle.**

Cable: See **Optical cable.**

Cable assembly: See **Multifiber cable; Optical cable assembly.**

Cavity: See **Optical cavity.**

Chemical vapor deposition (CVD) technique:
A method of fabricating optical waveguide preforms by causing vapors to react and form a deposit that may be in the form of glass particles. See also: Double crucible technique; Ion exchange technique; Preform; Rod-in-tube technique. Soot technique; Vapor phase axial deposition technique.

Chirping:
A rapid change (as opposed to long term drift) in the emission wavelength of an optical source. Chirping is most often observed in pulsed operation of a source.

Chromatic dispersion: Redundant synonym for Dispersion.

Cladding:
In an optical waveguide, a homogeneous dielectric that concentrically surrounds the core with a lower refractive index. See also: Core; Normalized frequency; Optical waveguide.

Cladding diameter:
Specified through the use of a tolerance field. See also: Core diameter; Tolerance fields.

Cladding mode:
A propagating mode whose power is predominantly in the cladding. See also: Bound mode; Leaky mode; Mode; Unbound mode.

Cladding mode stripper:
A device that employs a material having an index approximately equal to (or greater than) that of the waveguide cladding which, when applied to the waveguide, provides escape for cladding modes.

Coherence area:
The area in a plane perpendicular to the direction of propagation over which light may be considered highly coherent. Commonly the coherence area is the area over which the degree of coherence exceeds 0.88.

Note. Light is considered highly coherent when the degree of coherence exceeds 0.88, partially coherent for values less than 0.88, and incoherent for "very small" values. See also: Coherent; Degree of Coherence.

Coherence length:
The propagation distance over which a light beam may be considered coherent. If the spectral linewidth of the source is $\Delta\lambda$ and the central wavelength is λ_0, the coherence length in a medium of refractive index n is approximately $\lambda_0^2/n\Delta\lambda$. See also: Degree of coherence; Spectral linewidth.

Coherence time:
Coherence length divided by the phase velocity of light in a medium; approximately given by $\lambda_0^2/c\Delta\lambda$. See also: Coherence length; Phase velocity.

Coherent:
Characterized by a fixed phase relationship among points on an electromagnetic wave.

Note. A perfectly monochromatic wave would be perfectly coherent at all points in space. In practice, however, real waves are categorized according to their spatial coherence or their temporal (phase) coherence: A wave has a high degree of spatial coherence if the radiation is coherent at points distributed on a wavefront (or on a plane approximately normal to the direction of propagation). Likewise, a wave has high temporal coherence if the radiation is coherent at points distributed approximately along the direction of propagation. See also: Coherence area; Degree of coherence; Monochromatic.

Coherent bundle: Synonym for Aligned bundle.

Coherent radiation: See Coherent.

Collimation:
The process by which a divergent or convergent beam of radiation is converted into a beam with the minimum divergence possible for that system (ideally, a parallel bundle of rays). See also: Beam divergence angle.

Connector: See Optical waveguide connector.

Connector insertion loss: See Insertion loss.

Conservation of radiance:
A basic principle stating that no passive optical system can increase the quantity Ln^{-2} where L is the radiance of a beam and n is the local refractive index. Formerly called "conservation of brightness" or the "brightness theorem." Synonym: Radiance theorem. See also: Brightness; Radiance.

Core:
The center region of an optical waveguide through which it is intended that light be transmitted. See also: Cladding; Normalized frequency; Optical waveguide.

Core diameter:
The diameter of the waveguide at the point where the refractive index of the core exceeds that of the cladding by k times the difference between the maximum refractive index in the core and the minimum refractive index in the cladding, where k is a specified constant ($0<k<1$). Specified through the use of a tolerance field. See also: Cladding; Core; Tolerance fields.

Core mode: Synonym for Bound mode.

Cosine emission law: Synonym for Lambert's cosine law.

Coupler: See Optical waveguide coupler.

Coupling: See Mode coupling.

Coupling loss:
The power loss suffered when coupling light from one optical device to another. See also: Angular misalignment loss; Extrinsic junction loss; Gap misalignment loss; Insertion loss; Lateral offset loss; Intrinsic junction loss;

Critical angle:
When light propagates in a homogeneous medium of relatively high refractive index (n_{high}) toward a planar interface with a homogeneous material of lower index (n_{low}), the critical angle of incidence is defined by

$$\theta_c = \sin^{-1} (n_{low}/n_{high}).$$

Note. When the angle of incidence exceeds the critical angle, the light is totally reflected by the interface. This is termed total internal reflection. See also: Acceptance angle; Reflection; Refractive index; Step index profile; Total internal reflection.

Current: See Driving current; Threshold current.

Curvature loss: Synonym for Macrobend loss.

Cut-off frequency: See **Single mode optical waveguide.**

CVD: Abbreviation for **Chemical vapor deposition.**

D*: (pronounced "D-star")
A figure of merit often used to characterize detector performance, defined as the reciprocal of noise equivalent power (NEP), normalized to unit area and unit bandwidth.

$$D^* = \sqrt{A(\Delta f)} \; / \; NEP,$$

where A is the area of the photosensitive region of the detector and Δf is the bandwidth of the modulation frequency of the incident radiation. Synonym: **Specific detectivity.** See also: **Detectivity; Noise equivalent power.**

Dark current:
The external current, under specified biasing conditions, that flows in photosensitive detectors when there is no incident radiation.

Degenerate waveguide modes:
Waveguide modes that have either the same phase or group velocity. See also: **Group degenerate modes; Group velocity; Mode; Phase degenerate modes; Phase velocity.**

Degree of coherence:
A measure of the coherence of a light source; the magnitude of the degree of coherence may be shown to be equal to the visibility of the fringes of a two-beam interference experiment, where

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

I_{max} is the intensity at a maximum of the interference pattern, and I_{min} is the intensity at a minimum.
Note. Light is considered highly coherent when the degree of coherence exceeds 0.88, partially coherent for values less than 0.88, and incoherent for "very small" values. See also: Coherence area; Coherent; Coherence length; Interference.

Density: See Optical density.

Detectivity:
The reciprocal of noise equivalent power (NEP). See also: D*; Noise equivalent power.

Dichroic filter:
An optical filter that transmits light selectively according to wavelength (most often, a high-pass or low-pass filter). See also: Optical filter.

Dichroic mirror:
A mirror that reflects light selectively according to wavelength.

Differential modal attenuation:
The differences in attenuation among modes.

Differential modal delay:
The differences in propagation delays among modes owing to their differing group velocities. Synonym: Multimode group delay. See also: Group velocity; Mode; Multimode distortion.

Differential quantum efficiency:
The slope of the light-current curve, used to describe devices that have nonlinear output-input characteristics.

Diffraction:
The deviation of a wavefront from the path predicted by geometric optics when a wavefront is restricted by an opening or an edge of an object.

Note. Diffraction occurs whenever a beam of light is restricted in any way and may still be important when the opening is many orders of magnitude larger than the wavelength. However, diffraction may be most noticeable when the opening is only somewhat larger than the wavelength. Often distinguished from interference. See also: Far field diffraction pattern; Near field diffraction pattern.

Diffraction limited:
A beam of light is diffraction limited if: a) the far field beam divergence is equal to that predicted by diffraction theory, or b) in focusing optics, the impulse response or resolution limit is equal to that predicted by diffraction theory. See also: Diffraction.

Diffuse reflection: See Reflection.

Diode laser: Synonym for Injection laser diode.

Dispersion:
A term used to describe the chromatic or wavelength dependence of a parameter. The term can be used, for example, to describe the process by which an electromagnetic signal is distorted because the various frequency (i.e., wavelength) components of that signal have different propagation characteristics. The term is also used to describe the relationship between refractive index and wavelength.

Note. Signal distortion in an optical waveguide is caused by several dispersive mechanisms: waveguide dispersion, material dispersion, and profile dispersion. In addition, the signal suffers degradation from multimode "distortion," which is often (erroneously) referred to as multimode "dispersion." See also: **Distortion; Intramodal distortion; Material dispersion; Material dispersion parameter; Multimode distortion; Profile dispersion; Profile dispersion parameter; Waveguide dispersion.**

Distortion:
An undesirable change of signal waveform shape.

Note. Signal distortion in an optical waveguide is caused by several dispersive mechanisms: waveguide dispersion, material dispersion, and profile dispersion. In addition, the signal suffers degradation from intramodal distortion and multimode "distortion" which is often (erroneously) referred to as multimode "dispersion." See also: **Dispersion; Intramodal distortion; Multimode distortion.**

Distortion limited operation:
The condition prevailing when the shape of the signal, rather than its amplitude (or power), is the limiting factor in communication capability. The condition is reached when the system distorts the shape of the waveform beyond tolerable limits. For linear systems, distortion limited operation is equivalent to bandwidth limited operation. See also: **Attenuation limited operation; Bandwidth limited operation; Distortion; Multimode distortion.**

Divergence: See **Beam divergence angle.**

Double crucible technique:
A method of fabricating an optical waveguide by melting core and clad glasses in two suitably joined concentric crucibles and then drawing a fiber from the combined melted glass. See also: Chemical vapor deposition technique; Rod-in-tube technique; Soot technique; Vapor phase axial deposition technique.

Driving current:
The electrical input current that drives a semiconductor light source. See also: Lasing threshold; Threshold current.

Efficiency: See Differential quantum efficiency; Power efficiency; Quantum efficiency.

Electric vector:
The electric field vector associated with a light wave. The electric field vector specifies the polarization and amplitude of the electric field.

Electroluminescence:
Nonthermal conversion of electrical energy into light in a liquid or solid substance. One example involves the photon emission resulting from electron-hole recombination in a pn junction. This is the mechanism involved in the injection laser. See also: Injection laser diode.

Electro-optic effect:
A change in a material's refractive index under the influence of an electric field.

Note 1. Pockels and Kerr effects are electro-optic effects that are respectively linear and quadratic in the electric field strength.

Note 2. "Electro-optic" is often erroneously used as a synonym for "optoelectronic." See also: Optoelectronic.

Emissivity:
The ratio of power radiated by a substance to the power radiated by a blackbody at the same temperature. Emissivity is a function of wavelength and temperature. See also: **Blackbody.**

Equilibrium condition: Synonym for **Equilibrium mode distribution.**

Equilibrium coupling length: Synonym for Equilibrium length.

Equilibrium length:
The length of multimode optical waveguide, excited in a specified manner, necessary to attain the equilibrium mode distribution. Synonyms: **Equilibrium coupling length; Equilibrium mode distribution length.** See also: **Equilibrium mode distribution; Mode coupling; Nonequilibrium mode distribution.**

Equilibrium mode distribution:
The distribution of power among the modes after transmission through a requisite length of multimode optical waveguide such that thereafter (in distance) the relative power distribution among the various modes remains constant.

Note. The requisite length, which typically varies from several hundred meters to a few kilometers, is dependent upon: various parameters of the waveguide; wavelength; and initial launching conditions. Synomyms: **Equilibrium condition; Steady state condition.** See also: **Equilibrium length; Mode; Mode coupling; Nonequilibrium mode distribution.**

Equilibrium mode distribution length: Synonym for **Equilibrium length.**

Equilibrium mode simulator (EMS):
A device used to create an approximation of the equilibrium mode distribution. This distribution may be achieved by using selective mode excitation or mode filters either with or without mode scramblers. See also: Equilibrium mode distribution.

Equilibrium radiation angle:
The radiation angle of an optical waveguide having an equilibrium mode distribution. See also: Acceptance angle; Equilibrium mode distribution; Numerical aperture; Radiation angle; Radiation pattern.

Equilibrium radiation pattern:
The output radiation pattern of an optical waveguide having an equilibrium mode distribution, measured as a function of angle or distance from the waveguide axis.
Note 1. Far field equilibrium radiation pattern is measured as a function of angle. Near field equilibrium radiation pattern is measured as a function of distance from the waveguide axis.
Note 2. The equilibrium radiation pattern is independent of waveguide length--beyond the equilibrium length--and excitation conditions but may be a function of wavelength. See also: Acceptance angle; Equilibrium mode distribution; Equilibrium radiation angle; Numerical aperture; Radiation angle; Radiation pattern.

Evanescent field:
A time varying electromagnetic field whose amplitude decreases monotonically but without an accompanying phase shift in a particular direction is said to be evanescent in that direction.

Extrinsic junction loss:
Those junction losses that are caused by different geometric and optical parameter mismatches when two nonidentical optical waveguides are joined. See also: **Angular misalignment loss; Gap loss; Intrinsic junction loss; Lateral offset loss.**

Far field diffraction pattern:
The diffraction pattern of a source (including the output end of an optical waveguide) observed at an infinite distance from the source. Theoretically, a far field pattern exists at distances that are large compared with s^2/λ, where s is a characteristic dimension of the source and λ is the wavelength. Example: If the source is a circle illuminated uniformly and with collimated light, then s is the radius of the circle.

Note. Except for scale, the far field diffraction pattern of a source may be observed in the focal plane of a well corrected lens. The far field pattern of a screen illuminated by a point source may be observed in the image plane of the source. Synonym: **Fraunhofer diffraction pattern.** See also: **Diffraction; Near field diffraction pattern; Near field region.**

Far field region:
The region, far from a source, where the diffraction pattern is substantially that observed at infinity. See also: **Beam divergence angle; Diffraction; Far field diffraction pattern; Near field diffraction pattern; Near field region; Radiation angle.**

Far field radiation pattern: See **Radiation pattern.**

Ferrule:
A mechanical fixture, generally a rigid tube, used to confine the stripped end of a fiber bundle or a fiber. See also: Fiber bundle.

Note 1. Typically, individual fibers of a bundle are cemented together within a ferrule of a diameter designed to yield a maximum packing fraction. See also: Packing fraction.

Note 2. Nonrigid materials such as shrink tubing may also be used for ferrules for special applications.

Fiber: See Optical fiber; Optical waveguide.

Fiber buffer:
A material that may be used to protect an individual optical fiber waveguide from physical damage, providing mechanical isolation and/or protection.

Note. Cable fabrication techniques vary, some resulting in firm contact between fiber and protective buffering, others resulting in a loose fit, permitting the fiber to slide in the buffer tube. Multiple buffer layers may be used for added fiber protection.

Fiber bundle:
An assembly of unbuffered optical fibers. A bundle is usually used as a single transmission channel, as opposed to multifiber cables, which contain optically and mechanically isolated fibers, each of which provides a separate channel.

Note 1. Bundles used only to transmit light, as in optical communications, are flexible and are typically unaligned.

Note 2. Bundles used to transmit optical images may be either flexible or rigid, but must contain aligned fibers. See also: Aligned bundle; Ferrule; Fiber optics; Multiwaveguide cable; Optical cable; Optical fiber; Packing fraction.

Fiber harness:
In equipment interface applications, an assembly of a number of multiple fiber bundles or cables fabricated to facilitate installation into a system.

Fiber optics (FO):
The branch of optical technology concerned with the transmission of radiant power through fibers made of transparent materials, such as glass, fused silica or plastic.

Note 1. Communications applications of fiber optics employ flexible fibers. Either a single discrete fiber or a nonspatially aligned fiber bundle may be used for each information channel. Such fibers are generally referred to in this document as "optical waveguides" to differentiate from fibers employed in noncommunications applications.

Note 2. Various industrial and medical applications employ (typically high-loss) flexible fiber bundles in which individual fibers are spatially aligned, permitting optical relay of an image. An example is the endoscope.

Note 3. Some specialized industrial applications employ rigid (fused) aligned fiber bundles for image transfer. An example is the fiber optics CRT faceplate used on some high-speed oscilloscopes. See also: Optical fiber; Optical waveguide.

Flux: Obsolete synonym for Radiant power.

FO: Abbreviation for Fiber optics.

Fraunhofer diffraction pattern: Synonym for Far field diffraction pattern.

Fresnel diffraction pattern: Synonym for Near field diffraction pattern.

Fresnel reflection:

The reflection of a portion of incident light at a planar interface between two homogeneous media having different refractive indices.

Note 1. Fresnel reflection occurs at the air-glass interfaces at entrance and exit ends of an optical waveguide. Resultant transmission losses (on the order of 4% per interface) can be virtually eliminated by use of antireflection coatings or index matching materials.

Note 2. Fresnel reflection depends upon the index difference and the angle of incidence; it is zero at Brewster's angle for one polarization. In optical elements, a thin transparent film is sometimes used to give an additional Fresnel reflection that cancels the original one by interference. This is called an antireflection coating.

See also: **Antireflection coating; Brewster's angle; Index matching materials; Reflectance; Reflection; Reflection loss; Refractive index.**

Fundamental mode:

The lowest order mode of a dielectric cylindrical waveguide, in most cases the mode designated LP_{01} or HE_{11}.

See also: **Mode.**

Fused fiber splice:

A splice accomplished by the application of localized heat sufficient to fuse or melt the ends of two lengths of optical fiber, forming, in effect, a continuous, single fiber. See also: **Mechanical splice; Splice.**

Fused silica:

Amorphous silicon dioxide.

Note. Highly refined fused silica formed by a vapor deposition process or by other means is employed in the fabrication of low loss optical waveguides. Dopants may be added via the same process to obtain suitable index variations in the optical waveguide core and cladding regions.

Gap loss:

An optical power loss caused by a space between source and optical waveguide, between axially aligned waveguides, or between waveguide and detector.

Note. For waveguide-to-waveguide coupling, it is commonly called "longitudinal offset loss." See also: **Angular misalignment loss; Extrinsic junction loss; Intrinsic junction loss; Lateral offset loss.**

Gaussian beam:

A beam of light whose radial intensity distribution is Gaussian. When such a beam is cylindrical in cross section,

$$I(r) = I(0) \exp [-(r/w)^2],$$

where r is the distance from beam center and w is the radius at which the irradiance drops to 1/e of its value on the axis.

Gaussian pulse:

A pulse that has the shape of a Gaussian distribution. In the time domain, the shape is

$$f(t) = A \exp [-(t/a)^2],$$

where A is a constant, and a is the pulse halfwidth at the 1/e points. A similar expression would hold in the frequency domain with t replaced by ν.

Geometric optics:

The science that treats the propagation of light as rays. Rays are bent at the interface between two dissimilar media, or may be curved in a medium whose refractive index is a function of position. See also: **Axial ray; Meridional ray; Optical axis; Paraxial ray; Physical optics; Skew ray.**

Graded index optical waveguide:
A waveguide having a graded index profile. See also: Graded index profile; Step index optical waveguide.

Graded index profile:
Any index profile that varies smoothly with radius. Distinguished from a step index profile. See also: Dispersion; Index profile; Mode volume; Multimode optical waveguide; Normalized frequency; Optical waveguide; Parabolic profile; Profile dispersion; Profile parameter; Refractive index; Step index profile; Power-law index profile.

Group degenerate modes:
Modes that have the same group velocity. See also: Mode; Phase degenerate modes.

Group index:
Denoted N: Velocity of light in vacuum divided by the group velocity in a medium of index n. It is related thus to the refractive index:

$$N = n - \lambda \frac{dn}{d\lambda}$$

See also: Group velocity; Material dispersion parameter.

Group velocity:
Velocity of the signal modulating a propagating electromagnetic wave. It is given by c/N where c is the velocity of light in vacuum and N is the group index. See also: Differential modal delay; Group degenerate modes; Group index; Phase velocity.

Guided mode; Synonym for Bound mode.

HE_{11} mode: See Fundamental mode.

Hybrid mode:
A mode possessing components of both electric and magnetic field vectors in the direction of propagation.
Note. Such modes correspond to skew (non-meridional) rays. See also: Mode; Skew ray; Transverse electric mode; Transverse magnetic mode.

ILD: Abbreviation for Injection laser diode.

Impulse response:
The function h(t) describing the response of an initially relaxed system to an impulse (Dirac-delta) function applied at time t = 0.
Note. The impulse response may be obtained by deconvolving the input waveform from the output waveform, or as the inverse Fourier transform of the transfer function. See also: Transfer function.

Incoherent:
Characterized by a degree of coherence significantly less than 0.88. See also: Coherent; Degree of coherence.

Index matching materials:
Transparent materials of proper refractive index used to reduce Fresnel reflections at an optical interface. See also: Fresnel reflection; Mechanical splice; Refractive index.

Index of refraction: Synonym for Refractive index.

Index profile:
In an optical waveguide, the refractive index as a function of radius. See also: Graded index profile; Parabolic profile; Power-law index profile; Profile dispersion; Profile dispersion parameter; Profile parameter; Step index profile.

Infrared (IR):
The region of the electromagnetic spectrum between the long-wavelength extreme of the visible spectrum (about 0.7 μm) and the shortest microwaves (about 1 mm). See also: Light; Ultraviolet (UV).

Injection fiber. Synonym for Launching fiber.

Injection laser diode (ILD):
A laser employing as the active medium a forward-biased semiconductor diode. Synonym: Diode laser. See also: Active laser medium; Chirping; Laser; Superradiance.

Insertion loss:
The total optical power loss in a transmission system caused by the insertion of an optical component such as a connector, splice, or coupler.

Integrated optical circuit (IOC):
A monolithic optical circuit, composed of both active and passive miniaturized components, employing planar waveguides for coupling to optoelectronic devices and providing signal processing functions such as modulation, multiplexing and switching.

Intensity:
The square of the electric field amplitude of a light wave. Intensity is proportional to irradiance and may be used in place of the term "irradiance" when only relative values are important. See also: Irradiance; Radiant intensity; Radiometry.

Interference:
In optics, the interaction of two or more beams of coherent or partially coherent light usually derived from a single source. See also: **Coherent; Degree of coherence; Diffraction.**

Intermodal distortion: Synonym for **Multimode distortion.**

Intramodal distortion:
That distortion resulting from dispersion within individual propagating modes. It is the only distortion occurring in single mode waveguides. See also: **Dispersion; Distortion.**

Intrinsic junction loss:
The total loss resulting from joining two identical optical waveguides.
Note. Factors influencing this loss include spacing loss, alignment of the waveguides, Fresnel reflection loss, end finish, etc. See also: **Angular misalignment loss; Gap loss; Extrinsic junction loss; Lateral offset loss.**

IOC: Abbreviation for **Integrated optical circuit.**

Ion exchange technique:
A method of fabricating a graded index optical waveguide by exchanging ions through the core-cladding interface. See also: **Chemical vapor deposition (CVD) technique; Double crucible technique; Graded index profile; Rod-in-tube technique; Soot technique; Vapor phase axial deposition technique.**

Irradiance:
Radiant power incident per unit area upon a surface, expressed in watts per square meter. "Power density" is colloquially used as a synonym. See also: **Beamwidth; Radiometry.**

Lambert's cosine law:
The statement that the radiance of certain idealized surfaces, known as Lambertian radiators, Lambertian sources, or Lambertian reflectors, is independent of the angle from which the surface is viewed.

Note. The radiant intensity of such a surface is maximum normal to the surface and decreases in proportion to the cosine of the angle from the normal. Synonym: **Cosine emission law.**

Lambertian radiator: See **Lambert's cosine law.**

Lambertian reflector: See **Lambert's cosine law.**

Lambertian source: See **Lambert's cosine law.**

Laser:
A device that produces optical radiation using a population inversion to provide Light Amplification by Stimulated Emission of Radiation and (generally) an optical resonant cavity to provide positive feedback. Laser radiation may be highly coherent either temporally or spatially, or both. See also: **Active laser medium; Injection laser diode; Optical cavity.**

Laser medium: Synonym for **Active laser medium.**

Lasing threshold:
The lowest excitation level at which a laser's output is dominated by stimulated emission rather than spontaneous emission.

Lateral offset loss:
A power loss caused by transverse or lateral deviation from optimum alignment of source to optical waveguide, waveguide to waveguide, or waveguide to detector. Synonym: Transverse offset loss. See also: Angular misalignment loss; Extrinsic junction loss; Gap loss; Intrinsic junction loss.

Launch angle:
The angle between the light input propagation vector and the optical axis of an optical fiber or fiber bundle.

Launch numerical aperture (LNA):
The numerical aperture of an optical system used to couple (launch) power into an optical waveguide.
Note 1. 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.
Note 2. LNA is one of the parameters that determine the initial distribution of power among the modes of an optical waveguide. See also: Acceptance angle.

Launching fiber:
A fiber or fibers used in conjunction with a source to excite the modes of a fiber in a particular fashion.
Note. Launching fibers are most often used in test systems to improve the precision of measurements. Synonym: Injection fiber. See also: Mode; Pigtail.

Leaky modes:
In an optical waveguide, those modes that are weakly bound to the core of the waveguide and have comparatively high loss as a result of tunneling. See also: Bound mode; Cladding mode; Mode; Unbound mode.

LED: Abbreviation for Light emitting diode.

Light:
1. In a strict sense, the region of the electromagnetic spectrum that can be perceived by human vision, designated the visible spectrum and nominally covering the wavelength range of 0.4μm to 0.7μm.
2. In the laser and optical communication fields, custom and practice have extended usage of the term to include the much broader portion of the electromagnetic spectrum that can be handled by the basic optical techniques used for the visible spectrum. This region has not been clearly defined but, as employed by most workers in the field, may be considered to extend from the near-ultraviolet region of approximately 0.3μm, through the visible region, and into the mid-infrared region of 3.0μm to 30μm. See also: Infrared (IR); Optical spectrum; Ultraviolet (UV).

Light current: See Photocurrent.

Light emitting diode (LED):
A pn junction semiconductor device that emits incoherent optical radiation when biased in the forward direction.

Light ray:
The path of a given point on a wavefront. The direction of a light ray is generally normal to the wavefront. See also: Geometric optics.

Lightguide: Synonym for Optical waveguide.

Line source:

1. In the spectral sense, an optical source that emits one or more spectrally narrow lines as opposed to a continuous spectrum. See also: **Monochromatic.**
2. In the geometric sense, an optical source whose active (emitting) area forms a spatially narrow line.

Line spectrum:

An emission or absorption spectrum consisting of one or more narrow spectral lines, as opposed to a continuous spectrum. See also: **Monochromatic; Spectral line; Spectral linewidth.**

Linear optical element or system:

One in which the radiant power output is proportional to the radiant power input, and no new optical wavelengths or modulation frequencies are generated.

Note 1. The proportionality constant can vary with source wavelength and modulation frequency.

Note 2. A linear element can be described in terms of a transfer function and an impulse response function.

Linearly polarized (LP) mode:

A mode for which the field components in the direction of propagation are small compared to components perpendicular to that direction.

Note. Each LP mode consists of several phase degenerate modes. The LP description (which is an approximation for weakly guiding waveguides) becomes more accurate as the difference between the maximum and minimum values of the refractive index becomes a smaller fraction (typically <2%) of the mean index value across the profile. See also: **Mode; Phase degenerate mode; Weakly guiding optical waveguide.**

Linewidth: See **Spectral linewidth.**

LNA: Abbreviation for **Launch numerical aperture.**

Longitudinal offset loss: See Gap loss.

Loss: See Absorption; Angular misalignment loss; Attenuation; Backscattering; Extrinsic junction loss; Gap loss; Insertion loss; Intrinsic junction loss; Lateral offset loss; Macrobend loss; Material scattering; Microbend loss; Nonlinear scattering; Rayleigh scattering; Reflection loss; Transmission loss; Waveguide scattering.

LP mode: Abbreviation for Linearly polarized mode.

LP_{01} mode: See Fundamental mode.

Macrobend loss:
In an optical waveguide, that portion of the total loss attributable to macrobending. Synonym: Curvature loss. See also: Microbend loss.

Macrobending:
In an optical waveguide, all macroscopic axial deviations of the waveguide from a straight line, as opposed to microbending. See also: Microbending.

Magneto-optic:
Pertaining to a change in a material's refractive index under the influence of a magnetic field. Magneto-optic materials generally are used to rotate the plane of polarization.

Material absorption: See Absorption.

Material dispersion:
That dispersion attributable to the wavelength dependence of the refractive index of material used to form the waveguide. Material dispersion is characterized by a parameter M which is defined below. See also: Dispersion; Distortion; Profile dispersion; Profile dispersion parameter; Waveguide dispersion.

Material dispersion parameter (M):

$$M(\lambda) = -1/c \ (dN/d\lambda) = \lambda/c \ (d^2n/d\lambda^2)$$

where n is the refractive index,
N is the material group index: $N=n-\lambda(dn/d\lambda)$,
λ is the wavelength and,
c is the velocity of light in vacuum.

Note 1. For many present optical waveguide materials, M is zero at a specific wavelength λ_0, usually found in the 1.2 to 1.5μm range. The sign convention is such that M is positive for wavelengths shorter than λ_0 and negative for wavelengths longer than λ_0.

Note 2. Pulse broadening caused by material dispersion in an optical fiber is given by M times spectral linewidth ($\Delta\lambda$), except at $\lambda \cong \lambda_0$ (see Note 1). See also: Group index.

Material scattering:
In an optical waveguide, that part of the total scattering attributable to the properties of the bulk materials used for waveguide fabrication.

Note. Material scattering may be either intrinsic scattering resulting from frozen-in inhomogeneities, or extrinsic scattering resulting from impurities. See also: Rayleigh scattering; Scattering; Waveguide scattering.

Mechanical splice:
An optical waveguide splice accomplished by external fixtures or materials, rather than by thermal fusion. Index matching material may be applied between the two fiber ends. See also: Fused fiber splice; Index matching material.

Meridional ray:
A ray that crosses through the optical axis of an optical waveguide (in contrast with a skew ray). See also: Axial ray; Geometric optics; Numerical aperture; Optical axis; Paraxial ray; Skew ray.

Microbend loss:
In an optical waveguide, that portion of the total loss that is attributable to microbending. See also: Macrobend loss.

Microbending:
In an optical waveguide, sharp curvatures involving local axial displacements of a few micrometers and spatial wavelengths of a few millimeters. Such bends may result from waveguide coating, cabling, packaging, installation, etc. See also: Macrobending.

Misalignment loss: See Angular misalignment loss; Gap loss; Lateral offset loss.

Mode:
In any cavity or transmission line, one of the allowed electromagnetic field distributions. The field pattern of a given mode depends on the wavelength, refractive index, and cavity or waveguide geometry. See also: Bound mode; Cladding mode; Degenerate waveguide modes; Differential modal attenuation; Differential modal delay; Equilibrium mode distribution; Equilibrium mode simulator; Fundamental mode; Group degenerate modes; Hybrid mode; Leaky modes; Linearly polarized mode; Mode volume; Multimode distortion; Multimode laser; Multimode optical waveguide; Phase degenerate modes; Single mode optical waveguide; Transverse electric mode; Transverse magnetic mode; Unbound mode.

Mode coupling:
In an optical waveguide, the exchange of power among modes.

Note. Mode coupling reaches equilibrium after propagation over a finite distance that is designated the equilibrium length. See also: **Equilibrium length; Equilibrium mode distribution; Mode; Mode scrambler.**

Mode dispersion: Often erroneously used as a synonym for Mode distortion.

Mode (or modal) distortion: Synonym for **Multimode distortion.**

Mode filter:
A device used to attenuate certain modes.

Mode mixer: Synonym for **Mode scrambler.**

Mode scrambler:
A device for inducing mode coupling. Synonym: **Mode mixer.** See also: **Mode coupling.**

Mode volume:
The number of propagating modes that an optical waveguide will support; for $V \gtrsim 5$, approximately given by $V^2/2$ and $(V^2/2)(g/(g+2))$, respectively, for step index and power-law profile waveguides, where g is the profile parameter. See also: **Mode; Normalized frequency; Power-law index profile; Step index profile.**

Modulation:
A controlled variation with time of any property of a wave for the purpose of transferring information.

Monochromatic:
An idealized concept referring to a single frequency or wavelength. In practice, radiation is never perfectly monochromatic but, at best, displays a narrow band of wavelengths. See also: Coherent; Line source; Spectral linewidth.

Monomode optical waveguide: Synonym for Single mode optical waveguide.

Multifiber cable:
An optical cable that contains two or more optical waveguides, each of which provides a separate information channel. See also: Fiber bundle; Optical cable assembly.

Multifiber connector:
An optical connector designed to mate two multifiber cables, providing simultaneous optical alignment of all individual waveguides.
Note: Optical coupling between aligned waveguides may be achieved by various techniques including proximity butting (with or without index matching materials), and the use of relay optics (solid or liquid lenses).

Multilayer dielectric filter:
An optical filter consisting of a sequence of thin layers of transparent material with controlled thicknesses and refractive indices. See also: Dichroic filter.

Multimode distortion:
In an optical waveguide, that distortion resulting from the superposition of modes having differential modal delays.

Note. The term "multimode dispersion" is often used as a synonym; such usage, however, is erroneous since the mechanism is not dispersive in nature. Synonyms: Intermodal distortion; Mode (or modal) distortion. See also: Differential modal delay; Dispersion; Distortion; Mode; Multimode optical waveguide.

Multimode group delay: Synonym for Differential modal delay.

Multimode laser:
A laser that produces simultaneous emission at two or more discrete wavelengths and/or in two or more transverse modes. See also: Laser; Mode.

Multimode optical waveguide:
An optical waveguide that will allow more than one bound mode to propagate.

Note. May be either a graded index or step index waveguide. See also: Bound mode; Index profile; Mode; Mode volume; Multimode distortion; Normalized frequency; Power-law index profile; Single mode optical waveguide; Step index optical waveguide.

Multiplexing: See Wavelength division multiplexing (WDM).

NA: Abbreviation for Numerical aperture.

Near field diffraction pattern:
The diffraction pattern observed close to a source or aperture, as distinguished from far field diffraction pattern. Synonym: Fresnel diffraction pattern. See also: Diffraction; Far field region; Far field diffraction pattern.

Near field region:
The region close to a source, or aperture. The diffraction pattern in this region typically differs significantly from that observed at infinity and varies with distance from the source. See also: Far field diffraction pattern; Far field region.

Near field radiation pattern: See Radiation pattern.

Noise equivalent power (NEP):
At a given modulation frequency and for a given bandwidth, the radiant power that produces a signal-to-noise ratio of 1 at the output of a given detector. In this sense, the minimum detectable power at the given frequency and for the given bandwidth.

Note. Some manufacturers and authors define NEP as the minimum detectable power per unit bandwidth; when defined in this way, NEP has the units of watts/(hertz)$^{1/2}$. Therefore, use of the term NEP for a quantity whose units are watts/(hertz)$^{1/2}$ is a misnomer, because the units of power are watts. See also: D*; Detectivity.

Nonequilibrium mode distribution:
That distribution of modes prevailing in a length of waveguide shorter than the equilibrium length. See also: Equilibrium mode distribution.

Nonlinear scattering:

Direct conversion of a single photon from one wavelength to one or more other wavelengths. In an optical waveguide, nonlinear scattering is usually not important below the threshold irradiance for stimulated nonlinear scattering.

Note. Examples are Raman and Brillouin scattering. See also: **Photon.**

Normalized frequency:

A dimensionless quantity (denoted by V), mathematically given by

$$V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2}$$

where a is waveguide core radius, λ is wavelength in vacuum, and n_1 and n_2 are refractive indices at the waveguide axis and in the cladding, respectively. The number of bound modes in a waveguide is approximately proportional to V^2; in a step index waveguide, the number of modes is $V^2/2$; in a parabolic guide, $V^2/4$. Synonym: **V number.** See also: **Bound mode; Mode volume; Parabolic profile; Single mode optical waveguide.**

Numerical aperture (NA):

$$NA = n \sin \theta$$

where θ is, at a specified point, half the vertex angle of the largest cone of meridional rays that can enter or leave an optical element or system, and n is the refractive index of the homogeneous isotropic space that contains the specified point. The specified point is usually an object or image point.

Note. The term "numerical aperture" is often used, imprecisely, to describe an optical waveguide. The precise terms "acceptance angle" and "radiation angle" are preferred. See also: **Acceptance angle; Equilibrium radiation angle; Equilibrium radiation pattern; Launch numerical aperture; Meridional ray; Radiation angle; Radiation pattern.**

Optic axis:

In an anisotropic medium, a direction of propagation in which orthogonal polarizations have the same phase velocity. Distinguished from "optical axis."

Optical axis:

In a cylindrically symmetric waveguide, the optical axis is the axis of geometric symmetry of the core. Distinguished from "optic axis."

Note 1. In rare cases, an optical system will contain one or more elements (usually mirrors) whose axes are tilted with respect to one another. In such cases the optical axis is ill defined but could be taken to follow the line segments that join the centers of the aperture stops of the tilted components.

Note 2. The optical axis of a waveguide is the axis of the waveguide and therefore need not be a straight line. See also: Axial ray; Meridional ray; Optical waveguide; Paraxial Ray; Skew ray.

Optical blank:

A casting consisting of an optical material molded into the desired geometry for grinding, polishing, or (in the case of optical waveguides) drawing to the final optical/mechanical specifications. See also: Preform.

Optical cable:

A fiber, multiple fibers, or fiber bundle in a structure fabricated to meet optical, mechanical, and environmental specifications. Synonym: Optical fiber cable.

Optical cable assembly:

A cable that is connector terminated. Generally, a cable that has been terminated by a manufacturer and is ready for installation.

Optical cavity:
A region bounded by two or more reflecting surfaces, referred to as mirrors, end mirrors, or cavity mirrors, whose elements are aligned to provide multiple reflections. The resonator in a laser is an optical cavity. Synonym: Resonant cavity. See also: Active laser medium; Laser.

Optical conductor: Synonym for Optical waveguide (Deprecated).

Optical connector: See Optical waveguide connector.

Optical coupler: See Optical waveguide coupler.

Optical data bus:
A data bus using optical waveguides and optical waveguide components.

Optical density:
A measure of the transmittance of an optical element expressed by: $\log_{10}(1/T)$ or $-\log_{10}T$, where T is transmittance. The analogous term $\log_{10}(1/R)$ is called reflection density.

Note. The higher the optical density, the lower the transmittance. Optical density times -10 is equal to transmission loss expressed in decibels; for example, the transmission loss of -3 dB is equal to the optical density of 0.3. See also: Transmission loss; Transmittance.

Optical detector:
A transducer that generates an electrical signal that is a function of irradiance.

Optical fiber:
Any filament or fiber, made of dielectric materials, that guides light whether or not it is used to transmit signals. See also: **Fiber bundle; Fiber optics; Optical waveguide; Signal.**

Optical fiber cable: Synonym for **Optical cable.**

Optical fiber waveguide: Synonym for **Optical waveguide.**

Optical filter:
An element that transmits a range of wavelengths and blocks adjacent wavelengths. See also: **Dichroic filter; Multilayer dielectric filter.**

Optical link:
Any optical transmission channel designed to interconnect two end terminals (constituting a circuit in communications terminology) or to be connected in series (as part of a circuit) with other channels.
Note. Sometimes terminal hardware (e.g., transmitter/receiver modules) is included in the definition.

Optical path length:
In a medium of constant refractive index n, the product of the geometrical distance and the refractive index. If n is a function of position, then

$$\text{optical path length} = \int n\,ds,$$

where ds is an element of length along the path. This expression simplifies to n if the medium has a constant refractive index. See also: **Optical thickness.**

Optical power: Colloquial synonym for **Radiant power.**

Optical repeater:
In an optical waveguide communication system, an optoelectronic device or module that receives an input optical signal, converts it into an electrical signal, amplifies this signal (or, in the case of a digital signal, reshapes, retimes, or otherwise reconstructs the signal) and reconverts it into an optical signal for retransmission.

Optical spectrum:
Bandwidth limits have not been rigidly defined, but, as employed by most workers in the field, the region of the electromagnetic spectrum within the wavelength region extending from the vacuum ultraviolet at 40 nm to the far infrared at 1 mm.

Optical thickness:
Applied to thin films, the physical thickness times the refractive index. See also: **Optical path length.**

Optical waveguide:
1. Any structure capable of guiding optical power.
2. In optical communications, generally a fiber designed to transmit optical signals. Synonyms: **Lightguide; Optical conductor (deprecated); Optical fiber waveguide; Optical waveguide fiber.** See also: **Cladding; Core; Fiber bundle; Fiber optics; Multimode optical waveguide; Optical fiber; Single mode optical waveguide; Tapered fiber optical waveguide.**

Optical waveguide connector:
A device whose purpose is to transfer optical power between two optical waveguides or bundles, and that is designed to be connected and disconnected repeatedly. See also: **Multifiber connector.**

Optical waveguide coupler:
1. A device whose purpose is to distribute optical power among three or more ports. See also: Star coupler; Tee coupler.
2. A device whose purpose is to couple optical power between a waveguide and a source or detector.

Optical waveguide fiber: Synonym for Optical waveguide.

Optical waveguide splice:
A permanent joint whose purpose is to couple optical power between two waveguides. See also: Fusion splice; Mechanical splice.

Optically active material:
A material that has the ability to rotate the plane of polarization of light that propagates through it.
Note. An optically active material exhibits different refractive indices for left and right circular polarizations (circular birefringence).

Optoelectronic:
Pertaining to a device that responds to optical power, emits or modifies optical radiation, or utilizes optical radiation for its internal operation. Any device that functions as an electrical-to-optical or optical-to-electrical transducer.
Note 1. Photodiodes, LEDs, injection lasers and integrated optical elements are examples of optoelectronic devices commonly used in optical waveguide communications.
Note 2. "Electro-optical" is often erroneously used as a synonym.

Output angle: Synonym for Radiation angle.

Packing fraction:
In a fiber bundle, the ratio of the aggregate fiber core area to the total cross-sectional area (usually within the ferrule) including cladding and interstitial areas. See also: Ferrule; Fiber bundle.

Parabolic profile:
A power-law index profile with the profile parameter, g, equal to 2. Synonym: Quadratic profile. See also: Graded index profile; Index profile; Multimode optical waveguide; Power-law index profile; Profile parameter.

Paraxial ray:
A ray that is close to and nearly parallel with the optical axis.

Note. For purposes of computation, the angle between the ray and the optical axis is small enough for sin θ or tan θ to be replaced by θ (radians). See also: Axial ray; Geometric optics; Meridional ray; Skew ray.

Peak wavelength:
The wavelength at which the radiant intensity of a source is a maximum. Peak wavelength is typically expressed in nanometers.

Phase coherence: See Coherent.

Phase degenerate modes:
Modes that have the same phase velocity. See also: Group degenerate modes; Linearly polarized mode; Mode.

Phase velocity:
Velocity of the signal modulating a propagating electromagnetic wave. It is given by c/n where c is the velocity of light in vacuum and n is the refractive index. See also: Coherence time; Group velocity; Phase degenerate modes.

Photoconductivity:
The conductivity increase exhibited by some nonmetallic materials, resulting from the free carriers generated when photon energy is absorbed in electronic transitions. The rate at which free carriers are generated, the mobility of the carriers, and the length of time they persist in conducting states (their lifetime) determine the amount of conductivity change. See also: Photoelectric effect.

Photocurrent:
The current that flows through a photosensitive device (such as a photodiode) as the direct result of exposure to radiant energy internal gain mechanisms, such as in an avalanche photodiode, may enhance or increase the electron flow but are distinct mechanisms. See also: Dark current.

Photodiode:
A diode having a current-vs-voltage characteristic that is dependent on the level of optical power incident on the device. Photodiodes are used for the detection of optical power and for the conversion of optical power to electrical power. See also: Avalanche photodiode (APD); PIN photodiode.

Photoelectric effect:
External photoelectric effect: The emission of electrons from the irradiated surface of a material into a vacuum or a gas. Synonym: Photoemissive effect.

Photoemissive effect: Synonym for Photoelectric effect.

Photon:
A quantum of electromagnetic energy. The energy of a photon is $h\nu$ where h is Planck's constant and ν is the optical frequency. See also: **Nonlinear scattering; Planck's constant.**

Photovoltaic effect:
The production of a voltage across a pn junction resulting from the absorption of photon energy. The potential is caused by the internal drift of hole-electron pairs; hence the phenomenon leads to direct conversion of a part of the absorbed energy into a usable voltage.

Physical optics:
The branch of optics in which light propagation is treated as a wave phenomenon rather than a ray phenomenon, as in geometric optics. See also: **Geometric optics.**

Pigtail:
A short length of optical fiber used to couple power between an optoelectronic component and the transmission fiber. See also: **Launching fiber.**

PIN photodiode:
A diode with a large intrinsic (very lightly doped) region sandwiched between p and n doped semiconducting regions. Photons absorbed in this region create electron-hole pairs that are then separated by an electric field, thus generating an electric current in a load circuit. See also: **Avalanche photodiode (APD); Photodiode.**

Planck's constant:
(denoted h): $h = 6.626 \times 10^{-34}$ joule second.

Plane wave:
A wave whose surfaces of constant phase are parallel planes normal to the direction of propagation and infinite in extent.

Power: See Irradiance; Power efficiency; Radiant power.

Power density: Colloquial synonym for Irradiance.

Power-law index profile:
A class of graded index profiles characterized by the following equations:

$$n(r) = n_1 (1-2\Delta (r/a)^g)^{1/2} \qquad r \leq a$$

$$n(r) = n_2 = n_1 (1-2\Delta)^{1/2} \qquad r \geq a$$

$$\text{where } \Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

where $n(r)$ is the refractive index as a function of radius, n_1 is the refractive index on axis, n_2 is the refractive index of the cladding, a is the core radius, and g is a parameter that defines the shape of the profile.

Note. For this class of profiles, multimode distortion is smallest when g takes a particular value depending on the material used. For most materials, this optimum value falls around 2. When g is very large, the profile becomes a step index profile. See also: Graded index profile; Index profile; Mode volume; Profile parameter; Step index profile.

Preform:
A glass structure from which an optical fiber waveguide may be drawn. See also: Boule; Chemical vapor deposition technique; Ion exchange technique; Optical blank; Rod-in-tube technique; Soot technique; Vapor phase axial deposition technique.

Profile: See Graded index profile; Index profile; Parabolic profile; Power-law index profile; Step index profile.

Profile dispersion:
In an optical waveguide, that dispersion attributable to the variation of refractive index profile with wavelength. See also: Dispersion; Material dispersion; Waveguide dispersion.

Profile dispersion parameter (P):

$$P(\lambda) = \frac{n_o}{N_o} \frac{\lambda}{\Delta} \frac{d\Delta}{d\lambda}$$

where n_o, N_o are respectively the refractive and group indices at the core center, and $n_o\sqrt{1-2\Delta}$ is the phase index at the core edge or cladding. The expression is uniquely specified for power-law index profiles. Sometimes it is defined with the factor (-2) in the numerator.

Profile parameter:
The shape-defining parameter, g, for a power-law index profile. See also: Power-law index profile.

Pulse distortion: See Distortion.

Pulse duration:
The time between a specified reference point on the first transition of a pulse waveform and a similarly specified point on the last transition. The time between the 10%, 50%, or 1/e power points are commonly used, as is the rms pulse duration; therefore, the measurement level must be stated in quantitative use of the term. See also: **Root mean square pulse duration.**

Pulse length: Often erroneously used as a synonym for **Pulse duration.**

Pulse width: Often erroneously used as a synonym for **Pulse duration.**

Q switch:
A device that prohibits oscillation of a laser until the energy stored in the active medium increases to a desired level.

Note. In a pulsed laser, a Q switch increases peak power by shortening pulse duration; the device provides shorter and more powerful pulses than would be possible by direct electrical or optical switching. Q switching is most effective with glass or crystal cavity lasers and some varieties of gas lasers.

Quadratic profile: Synonym for **Parabolic profile.**

Quantum efficiency:
A dimensionless measure of the efficiency of conversion or utilization of optical energy, being the average number of charged carriers produced for each incident photon.

Quantum limited operation:
Operation wherein the minimum detectable signal is limited by quantum noise.

Quantum noise:
Any noise attributable to the discrete nature of electromagnetic radiation. Examples include shot noise, photon noise and recombination noise. See also: Shot noise.

Radiance:
Radiant power, in a given direction, per unit solid angle per unit of projected area of the source, as viewed from that given direction. Radiance is expressed in watts per steradian per square meter. See also: Brightness; Conservation of radiance; Radiometry.

Radiance theorem: Synonym for Conservation of radiance.

Radiant emittance:
Radiant power emitted into a full sphere (4π steradians) by a unit area of a source; expressed in watts per square meter. Synonym: Radiant exitance. See also: Radiometry.

Radiant energy:
Energy that is transferred via electromagnetic waves, i.e., the time integral of radiant power; expressed in joules. See also: Radiometry.

Radiant exitance: Synonym for Radiant emittance.

Radiant flux: Synonym for Radiant power; obsolete.

Radiant incidence: See Irradiance.

Radiant intensity:
Applied to a point source only, the time rate of transfer of radiant energy per unit solid angle, expressed in watts per steradian. See also: Intensity; Radiometry.

Radiant power:
The time rate of flow of radiant energy, expressed in watts. When exclusive concern with the optical spectrum is assumed, the prefix is often dropped and the term "power" is used. Colloquial synonyms: Flux; Optical power; Power; Radiant flux.

Radiation angle:
Half the vertex angle of that cone within which can be found a specified fraction of the total radiated power at any distance in the far field. Synonym: Output angle. See also: Acceptance angle; Equilibrium radiation angle; Equilibrium radiation pattern; Far field region; Numerical aperture.

Radiation pattern:
The output radiation of an optical waveguide, specified as a function of angle or distance from the waveguide axis.
Note 1. Far field radiation pattern is specified as a function of angle. Near field radiation pattern is specified as a function of distance from the waveguide axis.
Note 2. Radiation pattern is a function of the length of waveguide measured, the manner in which the waveguide is excited, and the wavelength. See also: Acceptance angle; Equilibrium radiation angle; Equilibrium radiation pattern; Far field region; Near field region; Numerical aperture.

Radiative mode: Synonym for Unbound mode.

Radiometry:

The science of radiation measurement. The basic quantities of radiometry are listed below.

RADIOMETRIC TERMS

TERM NAME	SYMBOL	QUANTITY	UNIT
Radiant energy	Q	Energy	joule (J)
Radiant power Synonym: Radiant Flux	ϕ	Power	watt (W)
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 Synonym: Radiant exitance	W	Power emitted (into a full sphere) per unit area	$W \cdot m^{-2}$
Radiant intensity	I	Power per unit solid angle	$W \cdot steradian^{-1}$
Radiance	L	Power per unit solid angle per unit projected area	$W \cdot steradian^{-1} \cdot m^{-2}$
Spectral radiance	L_λ	Radiance per unit wavelength interval at a given wavelength	$W \cdot steradian^{-1} \cdot m^{-2} \cdot nm^{-1}$

Ray: See **Light ray.**

Rayleigh scattering:
Scattering by submicroscopic inhomogeneities (fluctuations in material density or composition) in refractive index. A feature of Rayleigh scattering is that the scattered field is inversely proportional to the fourth power of the wavelength. See also: **Material scattering; Waveguide scattering; Scattering.**

Reflectance:
The ratio of reflected power to incident power.
Note. In optics, frequently expressed as optical density or as a percent; in communications applications, generally expressed in dB. Reflectance may be defined as specular or diffuse, depending on the nature of the reflecting surface. Formerly: "reflection." See also: **Reflection; Reflection loss; Reflectivity.**

Reflection:
The abrupt change in direction of a light beam at an interface between two dissimilar media so that the light beam returns into the medium from which it originated. Reflection from a smooth surface is termed specular, whereas reflection from a rough surface is termed diffuse. See also: **Critical angle; Reflectance; Reflectivity; Total internal reflection.**

Reflection loss:
Total loss from reflections at the junction between two optical components. See also: **Antireflection coating; Fresnel reflection; Reflectance; Reflectivity.**

Reflectivity:
The reflectance of the surface of a material so thick that the reflectance does not change with increasing thickness; the intrinsic reflectance of the surface, irrespective of other parameters such as the reflectance of the rear surface. No longer in common usage. See also: **Reflectance.**

Refraction:
The bending of a beam of light in transmission through an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded index medium). See also: Angle of deviation; Refractive index.

Refractive index:
The ratio of the velocity of light in vacuum to the phase velocity in a medium, a function of wavelength; denoted by n. May also be defined as the square root of relative permitivity. Synonym: Index of refraction. See also: Cladding; Core; Critical angle; Dispersion; Fresnel reflection; Fused silica; Graded index optical waveguide; Group index; Index matching materials; Index profile; Linearly polarized mode; Material dispersion; Mode; Normalized frequency; Numerical aperture; Optical path length; Power-law index profile; Profile dispersion; Scattering; Step index optical waveguide; Weakly guiding optical waveguide.

Regenerative repeater:
A repeater that is designed for digital transmission. See also: Optical repeater.

Repeater: See Optical repeater.

Responsivity:
The ratio of an optical detector's electrical output to its optical input, the precise definition depending on the detector type; generally expressed in amps per watt or volts per watt of incident radiant power.
Note. "Sensitivity" is often incorrectly used as a synonym.

rms pulse duration: See Root mean square (rms) pulse duration.

Rod-in-tube technique:
A method of fabricating an optical waveguide by placing a rod in a tube and drawing the rod and the tube to form a fiber. See also: Chemical vapor deposition technique; Double crucible technique; Ion exchange technique; Vapor phase axial deposition technique.

Root-mean-square (rms) pulse duration:
A measure of the duration of a pulse waveform. Specifically

$$\sigma_{rms} = \left[\frac{1}{A}\int (t-T)^2 \; S(t) \; dt\right]^{\frac{1}{2}}$$

where S(t) is the amplitude of the pulse as a function of time, A is given by

$$A = \int S(t) \; dt,$$

and T is the central time, given by

$$T = \int t \; S(t) \; dt$$

Note. The $\int dt$ implies integration over all time.

Scattering:
The deflection of light from the path it would follow if the refractive index were uniform or gradually graded.
Note 1. Scattering is caused primarily by microscopic or submicroscopic fluctuations in refractive index.
Note 2. In a waveguide, scattering results in mode coupling, one effect of which is to transfer power from bound modes into leaky and radiative modes, and into backward traveling modes. An observable effect is light emerging from the sides of the guide, resulting in signal attenuation. See also: Leaky modes; Material scattering; Mode; Nonlinear scattering; Rayleigh scattering; Refractive index; Unbound mode; Waveguide scattering.

Self focusing fiber: Synonym for Graded index optical waveguide.

Semiconductor laser: Synonym for Injection laser.

Sensitivity: Imprecise synonym for Responsivity.

Shot noise:
Noise caused by current fluctuations due to the discrete nature of charge carriers and random and/or unpredictable emission of charged particles from an emitter.
Note. There is often a (minor) inconsistency in notation when referring to shot noise in an optical system: many authors refer to shot noise loosely when speaking of the mean square shot noise current (amp^2) rather than noise power (watts). See also: Quantum noise.

Signal:
The information or intelligence that is transferred over a communications system by electrical or optical means.

Single mode optical waveguide:
An optical waveguide in which only one bound mode can propagate at the wavelength of interest. In step index guides, this occurs when the normalized frequency, V, is less than 2.405. For power-law profiles, single mode operation occurs for normalized frequency, V, less than approximately $2.405\sqrt{(g+2)/g}$, where g is the profile parameter. Synonym: Monomode optical waveguide. See also: Bound mode; Index profile; Mode; Multimode optical waveguide; Normalized frequency; Power-law index profile; Profile parameter; Step index optical waveguide.

Skew ray:
A ray that does not intersect the optical axis of a system (in contrast with a meridional ray). See also: Axial ray; Geometric optics; Hybrid mode; Meridional ray; Optical axis; Paraxial ray.

Soot technique:
A method of fabricating an optical waveguide preform by forming small glass particles (soot) and depositing the particles on the surface of a cylinder. See also: Chemical vapor deposition technique; Double crucible technique; Ion exchange technique; Rod-in-tube technique; Vapor phase axial deposition technique.

Source efficiency:
The ratio of emitted optical power of a source to the input electrical power.

Spatial coherence: See Coherent.

Spatially aligned bundle: See Aligned bundle.

Spatially coherent radiation: See Coherent.

Specific detectivity: Synonym for D*.

Spectral irradiance:
Irradiance per unit wavelength interval at a given wavelength, expressed in watts per square meter per micrometer. See also: Irradiance; Radiometry.

Spectral line:
A narrow range of emitted or absorbed wavelengths. See also: Line source; Line spectrum; Monochromatic.

Spectral linewidth:
A measure of the purity of a spectral line occurring in a line spectrum.

Note 1. One method of specifying the spectral linewidth is the full width at half maximum (FWHM), specifically the difference between the wavelengths at which the spectral emittance or absorption drops to one half of its maximum value. This method may be difficult to apply when the line has a complex shape.

Note 2. Another method of specifying the spectral linewidth is the rms width, given by

$$\Delta\lambda = \left[\frac{1}{A}\int(\lambda-\lambda_o)^2 S(\lambda)\ d\lambda\right]^{\frac{1}{2}}$$

where $S(\lambda)$ is a suitable radiometric quantity, A is given by

$$A = \int S(\lambda)d\lambda$$

and λ_o is the central wavelength given by

$$\lambda_o = \frac{1}{A}\int\lambda S(\lambda)\ d\lambda$$

Note 3. The relative spectral linewidth $(\Delta\lambda)/\lambda$ is frequently used. See also: Coherence length; Line spectrum; Material dispersion; Spectral bandwidth.

Spectral radiance:
Radiance per unit wavelength interval at a given wavelength, expressed in watts per steradian per square centimeter per micrometer. See also: Radiance; Radiometry.

Spectral responsivity:
Responsivity per unit wavelength interval at a given wavelength. See also: Responsivity.

Spectral window:
A wavelength region at which relatively minimal attenuation of an optical signal is experienced. Synonym: Transmission window.

Spectrum: See Optical spectrum.

Specular reflection: See Reflection.

Splice: See Optical waveguide splice.

Splice loss: See Insertion loss.

Spontaneous emission:
Radiation emitted when the internal energy of a quantum mechanical system drops from an excited level to a lower level without regard to the simultaneous presence of similar radiation.
Note. Examples of spontaneous emission include: 1) radiation from an LED, and 2) radiation from an injection laser below the lasing threshold. See also: Injection laser diode; Light emitting diode; Stimulated emission; Superradiance.

Star coupler: A passive coupler whose purpose is to distribute optical power from one port among all ports (reflection star) or a set of all other ports (transmission star). See also: Tee coupler.

Steady state condition: Synonym for Equilibrium mode distribution.

Step index optical waveguide:
An optical waveguide having a step index profile . See also: Graded index optical waveguide; Step index profile.

Step index profile:
An index profile characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface.

Note. This corresponds to a power-law profile with profile parameter, g, approaching infinity. See also: Critical angle; Dispersion; Graded index profile; Index profile; Mode volume; Multimode optical waveguide; Normalized frequency; Optical waveguide; Refractive index; Total internal reflection.

Stimulated emission:
Radiation emitted when the internal energy of a quantum mechanical system drops from an excited level to a lower level as induced by the simultaneous presence of radiant energy at the same frequency. An example is the radiation from an injection laser diode above lasing threshold. See also: Spontaneous emission.

Superradiance:
Amplification of spontaneously emitted radiation in a gain medium, characterized by moderate line narrowing and moderate directionality.

Note. This process is generally distinguished from lasing action by the absence of positive feedback and hence the absence of well-defined modes of oscillation. See also: Laser; Spontaneous emission.

Tapered fiber waveguide:
A waveguide that is tapered along its length; i.e., one whose transverse dimensions vary monotonically with length. Synonym: **Tapered transmission line.**

TE mode: Abbreviation for **Transverse electric mode.**

Tee coupler:
A passive coupler that connects three ports. See also: **Star coupler.**

Temporal coherence: See **Coherent.**

Temporally coherent radiation: See **Coherent.**

Thin film waveguide:
An optically transparent dielectric film that, when bounded by lower index material, forms a core that guides light. See also: **Optical waveguide.**

Threshold current:
The driving current corresponding to lasing threshold. See also: **Lasing threshold.**

Time coherence: See **Coherent.**

TM mode: Abbrevation for Transverse magnetic mode.

Tolerance fields:
A method of specifying dimensional tolerances for an optical waveguide core and cladding, utilizing four circles, concentric about the axis of the waveguide. The two smallest circles, having diameters $d \pm \Delta d$, inscribe and circumscribe the core-cladding interface. The two largest circles, having diameters $D \pm \Delta D$, inscribe and circumscribe the outer surface of the cladding. See also: Cladding; Core.

Total internal reflection:
The reflection that occurs when light strikes an interface at incident angles (with respect to the normal) greater than the critical angle. See also: Critical angle; Step index optical waveguide.

Transducer:
A device that converts one form of energy (optical, electrical, thermal, or mechanical) into another.

Transfer function:
A complex function (magnitude and phase) equal to the ratio of output to input as a function of modulation frequency.
Synonym: Baseband response function. See also: Impulse response.

Transmission loss:
Total loss encountered in transmission through a system. See also: Attenuation; Optical density; Reflection loss; Transmittance.

Transmission window: Synonym for Spectral window.

Transmissivity:
The transmittance of a unit length of material, at a given wavelength, excluding the reflectance of the surfaces of the material; the intrinsic transmittance of the material, irrespective of other parameters such as the reflectances of the surfaces. No longer in common usage. See also: Transmittance.

Transmittance:
The ratio of transmitted power to incident power.
Note. In optics, frequently expressed as optical density or a percent; in communications applications, generally expressed in dB. Formerly "transmission." See also: Antireflection coating; Optical density; Transmission loss.

Transverse electric (TE) mode:
A mode whose electric field vector is normal to the direction of propagation.
Note. In a planar dielectric waveguide (as within an injection laser diode), the field direction is parallel to the core-cladding interface and normal to the direction of propagation. In an optical waveguide, TE and TM modes correspond to meridional rays. See also: Meridional ray; Mode.

Transverse magnetic (TM) mode:
A mode whose magnetic field vector is normal to the direction of propagation.
Note. In a planar dielectric waveguide (as within an injection laser diode), the field direction is parallel to the core-cladding interface. In an optical waveguide, TE and TM modes correspond to meridional rays. See also: Meridional ray; Mode.

Transverse offset loss: Synonym for Lateral offset loss.

Ultraviolet (UV):
The region of the electromagnetic spectrum between the short-wavelength extreme of the visible spectrum (about 0.4 μm) and 0.04 μm. In optical waveguide communications, the nominal wavelength region may be considered to be between 0.2 and 0.4 μm. See also: **Infrared; Light.**

Unbound mode:
A mode whose power is predominantly outside the core of the waveguide. Synonym: Radiative mode. See also: Bound mode; Cladding mode; Leaky mode; Mode.

V number: Synonym for **Normalized frequency.**

VAD: Abbreviation for **Vapor phase axial deposition.**

Vapor phase axial deposision (VAD) technique:
A method of fabricating an optical waveguide preform by forming small glass particles and depositing the particles on the end of a rod. See also: **Chemical vapor deposition technique; Double crucible technique; Ion exchange technique; Rod-in-tube technique; Soot technique.**

Visible spectrum: See **Light.**

Wavefront:
A continuous surface that is a locus of points having the same phase at a given instant.

Waveguide dispersion:
For each mode in an optical waveguide, that portion of total dispersion attributable to the dependence of the phase and group velocities on the geometric properties of the waveguide in particular, for circular waveguides, on the ratio (a/λ), where a is core radius and λ is wavelength. See also: Dispersion; Distortion; Material dispersion; Multimode distortion; Profile dispersion.

Wavelength division multiplexing (WDM):
The provision of two or more channels over a common optical waveguide, the channels being differentiated by wavelength.

Waveguide scattering:
Scattering (other than material scattering) that is attributable to waveguide design and fabrication. See also: Material scattering; Nonlinear scattering; Rayleigh scattering; Scattering.

Weakly guiding optical waveguide:
A fiber waveguide for which the difference in refractive index between the core and cladding is small (usually less than 1%).

Window: See Spectral window.

Y coupler: See Tee coupler.

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