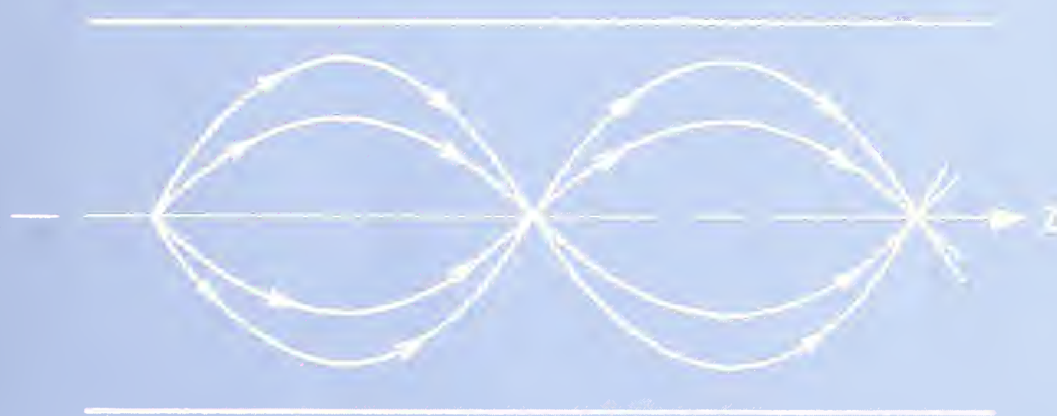
NBS HANDBOOK 140

Optical Waveguide Communications Glossary



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PREFACE

to the second edition

This is a revision of NTIA Special Publication Number SP-79-4, dated September 1979. In the 2 years since that publication, new insights into the technology have evolved, leading to the need for new terms and revisions to old terms. For this second edition, several of the old terms were deleted, more than one-third of them were revised, and more than 75 new terms were added. Clearly, then, this document is substantially different from the old one, although the basic philosophy remains the same.

As the technology matures, so also does the attitude on terms. In the first edition, we took a firm but controversial position regarding the definition of "numerical aperture". A justification of our position consumed more than a page of the Preface. In this edition, we take a more catholic view by including a definition of the numerical aperture of a fiber, something we were originally unwilling to do.

Other changes in attitude will be obvious. "Intrinsic joint loss," for example, is now defined as the loss intrinsic to the fiber, rather than to the joint or junction. "Tolerance field" was revised to make it more precise. Other, more subtle changes are less obtrusive and were introduced in the interest of developing definitions that will ultimately foster trade and commerce by ensuring a universal meaning for a given term.

There is little doubt that additional definitions are needed. We opted in favor of timeliness and (we hope) usefulness, over a more complete glossary.

R. L. Gallawa
Boulder, CO

PREFACE

to the first edition

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 works 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."

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, nonetheless, 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 θ

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.

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 ultraviolet and infrared 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:
Half the vertex angle of that cone within which optical power may be coupled into bound modes of an optical waveguide.
Note 1. Acceptance angle is a function of position on the entrance face of the core when the refractive index is a function of radius in the core. In that case, the local acceptance angle is

$$\arcsin \sqrt{n^2(r) - n_2^2}$$

where n(r) is the local refractive index and n_2 is the minimum refractive index of the cladding. The sine of the local acceptance angle is sometimes referred to as the local numerical aperture.
Note 2. Power may be coupled into leaky modes at angles exceeding the acceptance angle. See also: Launch numerical aperture; Power-law index profile.

Access coupler:
A device placed between two waveguide ends to allow signals to be withdrawn from or entered into one of the waveguides. See also: Optical waveguide coupler.

Acousto-optic effect:
A periodic variation of refractive index caused by an acoustic wave.
Note. The acousto-optic effect is used in devices that modulate and deflect light. See also: Modulation.

Active laser medium:
The material within a laser, such as crystal, gas, glass, liquid, or semiconductor, that emits coherent radiation (or exhibits gain) 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 relative spatial coordinates of each fiber are the same at the two ends of the bundle.
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.

Alpha profile:
See Power-law index profile.

Angle of deviation:
In optics, the net angular deflection experienced by a light ray after one or more refractions or reflections.
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: Reflection; Refraction.

Angle of incidence:
The angle between an incident ray and the normal to a reflecting or refracting surface. See also: Critical angle; Total internal reflection.

Angstrom (A):
A unit of optical wavelength (obsolete).
$1\ A = 10^{-10}$ meters.
Note. The angstrom has been used historically in the field of optics, but it is not an SI (International System) unit.

Angular misalignment loss:
The 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 joint loss; Gap loss; Intrinsic joint loss; Lateral offset loss.

Anisotropic:
Pertaining to a material whose electrical or optical properties are different for different directions of propagation or different polarizations of a traveling wave. See also: Isotropic.

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

APD:
Abbreviation for Avalanche photodiode.

Note. apd and a.p.d. are also used.

Attenuation:

In an optical waveguide, the diminution of average optical power.

Note. In optical waveguides, attenuation results from absorption, scattering, and other radiation. Attenuation is generally expressed in dB. However, attenuation is often used as a synonym for attenuation coefficient, expressed in dB/km. This assumes the attenuation coefficient is invariant with length. See also: Attenuation coefficient; Coupling loss; Differential mode attenuation; Equilibrium mode distribution; Extrinsic joint loss; Insertion loss; Intrinsic joint loss; Leaky modes; Macrobend loss; Material scattering; Microbend loss; Rayleigh scattering; Spectral window; Transmission loss; Waveguide scattering.

Attenuation coefficient:

The rate of diminution of average optical power with respect to distance along the waveguide. 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 the attenuation coefficient 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 attenuation as:

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

or, equivalently,

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

See also: Attenuation; Attenuation constant; Axial propagation constant.

Attenuation constant:

For a particular mode, the real part of the axial propagation constant. The attenuation coefficient for the mode power is twice the attenuation constant. See also: Attenuation coefficient, Axial propagation constant; Propagation constant.

Attenuation-limited operation:

The condition prevailing when the received signal amplitude (rather than distortion) limits performance. 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) is achieved. See also: Photodiode; PIN photodiode.

Axial propagation constant:

The propagation constant evaluated along the axis of a waveguide (in the direction of transmission).

Note. The real part of the axial propagation constant is the attenuation constant while the imaginary part is the phase constant. Synonym: Axial propagation wave number. See also: Attenuation; Attenuation coefficient; Attenuation constant; Propagation constant.

Axial propagation wave number:

Synonym for Axial propagation constant.

Axial ray:

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

Axial slab interferometry:

Synonym for Slab interferometry.

Backscattering:

The scattering of light into a direction generally reverse to the original one. See also: Rayleigh scattering; Reflectance; Reflection.

Bandpass filter:

See Optical filter.

Bandwidth:

See Fiber bandwidth.

Bandwidth-limited operation:

The condition prevailing when the system bandwidth, rather than the amplitude (or power) of the signal, limits performance. The condition is reached when the system distorts the shape of the waveform beyond specified limits. For linear systems, bandwidth-limited operation is equivalent to distortion-limited operation. See also: Attenuation-limited operation; Distortion-limited operation; Linear optical element.

Barrier layer:

In the fabrication of an optical fiber, a layer that can be used to create a boundary against OH^- ion diffusion into the core. See also: Core.

Baseband response function:

Synonym for Transfer function (of a device).

Beam diameter:
The distance between two diametrically opposed points at which the irradiance is a specified fraction of the beam's peak irradiance; most commonly applied to beams that are circular or nearly circular in cross section. Syononym: Beamwidth. See also: Beam divergence.

Beam divergence:
1. For beams that are circular or nearly circular in cross section, the angle subtended by the far-field beam diameter.
2. For beams that are not circular or nearly circular in cross section, the far-field angle subtended by two diametrically opposed points in a plane perpendicular to the optical axis, at which points the irradiance is a specified fraction of the beam's peak irradiance. Generally, only the maximum and minimum divergences (corresponding to the major and minor diameters of the far-field irradiance) need be specified. See also: Beam diameter; Collimation; Far-field region.

Beamsplitter:
A device for dividing an optical beam into two or more separate beams; often a partially reflecting mirror.

Beamwidth:
Synonym for Beam diameter.

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

Birefringence:
See Birefringent medium.

Birefringent medium:
A material that exhibits different indices of refraction for orthogonal linear polarizations of the light. The phase velocity of a wave in a birefringent medium thus depends on the polarization of the wave. Fibers may exhibit birefringence. See also: Refractive index (of a medium).

Blackbody:
A totally absorbing body (which 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.

Bolometer:
A device for measuring radiant energy by measuring the changes in resistance of a temperature-sensitive device exposed to radiation. See also: Radiant energy; Radiometry.

Boltzmann's constant:
The number k that relates the average energy of a molecule to the absolute temperature of the environment. k is approximately 1.38×10^{-23} joules/kelvin.

Bound mode:
In an optical waveguide, a mode whose field decays monotonically in the transverse direction everywhere external to the core and which does not lose power to radiation. Specifically, a mode for which

$$n(a)k \leq \beta \leq n(0)k$$

where β is the imaginary part (phase constant) of the axial propagation constant, n(a) is the refractive index at r=a, the core radius, n(0) is the refractive index at r=0, k is the free-space wavenumber, $2\pi/\lambda$, and λ is the wavelength. Bound modes correspond to guided rays in the terminology of geometric optics.
Note. Except in a monomode fiber, the power in bound modes is predominantly contained in the core of the fiber. Synonyms: Guided mode; Trapped mode. See also: Cladding mode; Guided ray; Leaky mode; Mode; Normalized frequency; Unbound mode.

Bound ray:
Synonym for Guided ray.

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

$$\arctan (n_2/n_1) \ .$$

See also: Angle of incidence; Reflectance; Refractive index (of a medium).

Brightness:
An attribute of visual perception, in accordance with which a source appears to emit more or less light; obsolete.
Note 1. Usage should be restricted to nonquantitative 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". See also: Radiance; Radiometry.

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 process in which deposits are produced by heterogeneous gas-solid and gas-liquid chemical reactions at the surface of a substrate.
Note. The CVD method is often used in fabricating optical waveguide preforms by causing gaseous materials to react and deposit glass oxides. Typical starting chemicals include volatile compounds of silicon, germanium, phosphorous, and boron, which form corresponding oxides after heating with oxygen or other gases. Depending upon its type, the preform may be processed further in preparation for pulling into an optical fiber. See also: Preform.

Chirping:
A rapid change (as opposed to long-term drift) of 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:
The dielectric material surrounding the core of an optical waveguide. See also: Core; Normalized frequency; Optical waveguide; Tolerance field.

Cladding center:
The center of the circle that circumscribes the outer surface of the homogeneous cladding, as defined under Tolerance field. See also: Cladding; Tolerance field.

Cladding diameter:
The length of the longest chord that passes through the fiber axis and connects two points on the periphery of the homogeneous cladding. See also: Cladding; Core diameter; Tolerance field.

Cladding mode:
A mode that is confined by virtue of a lower index medium surrounding the cladding. Cladding modes correspond to cladding rays in the terminology of geometric optics. See also: Bound mode; Cladding ray; Leaky mode; Mode; Unbound mode.

Cladding mode stripper:
A device that encourages the conversion of cladding modes to radiation modes; as a result, the cladding modes are stripped from the fiber. Often a material having a refractive index equal to or greater than that of the waveguide cladding. See also: Cladding; Cladding mode.

Cladding ray:
In an optical waveguide, a ray that is confined to the core and cladding by virtue of reflection from the outer surface of the cladding. Cladding rays correspond to cladding modes in the terminology of mode descriptors. See also: Cladding mode; Guided ray; Leaky ray.

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. 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 width.

Coherence time:
The time over which a propagating light beam may be considered coherent. It is equal to coherence length divided by the phase velocity of light in a medium; approximately given by $\lambda_0^2/c\Delta\lambda$, where λ_0 is the central wavelength, $\Delta\lambda$ is the spectral linewidth and c is the velocity of light in vacuum. See also: Coherence length; Phase velocity.

Coherent:
Characterized by a fixed phase relationship between points on an electromagnetic wave.
Note. A truly monochromatic wave would be perfectly coherent at all points in space. In practice, however, the region of high coherence may extend only a finite distance. The area on the surface of a wavefront over which the wave may be considered coherent is called the coherence area or coherence patch; if the wave has an appreciable coherence area, it is said to be spatially coherent over that area. The distance parallel to the wave vector along which the wave may be considered coherent is called the coherence length; if the wave has an appreciable coherence length, it is said to be phase or length coherent. The coherence length divided by the velocity of light in the medium is known as the coherence time; hence a phase coherent beam may also be called time (or temporally) coherent. See also: Coherence area; Coherence length; Coherence time; 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.

Concatenation (of optical waveguides):
The linking of optical waveguides, end to end.

Concentricity error:
When used in conjunction with a tolerance field to specify core/cladding geometry, the distance between the center of the two concentric circles specifying the cladding diameter and the center of the two concentric circles specifying the core diameter. See also: Cladding; Cladding diameter; Core; Core diameter; Tolerance field.

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." See also: Brightness; Radiance.

Core:
The central region of an optical waveguide through which light is transmitted. See also: Cladding; Normalized frequency; Optical waveguide.

Core area:
The cross sectional area enclosed by the curve that connects all points nearest the axis on the periphery of the core where the refractive index of the core exceeds that of the homogeneous cladding by k times the difference betwen the maximum refractive index in the core and the refractive index of the homogeneous cladding, where k is a specified positive or negative constant $|k|<1$. See also: Cladding; Core; Homogeneous cladding; Tolerance field.

Core center:
A point on the fiber axis. See also: Fiber axis; Optical axis.

Core diameter:
The diameter of the circle that circumscribes the core area. See also: Cladding; Core; Core area; Tolerance field.

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

Coupled modes:
Modes whose energies are shared. See also: Mode.

Coupler:
See Optical waveguide coupler.

Coupling:
See Mode coupling.

Coupling efficiency:
The efficiency of optical power transfer between two optical components. See also: Coupling loss.

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

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

$$\arcsin (n_{low} / n_{high}).$$

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; Angle of incidence; Reflection; Refractive index (of a medium); Step index profile; Total internal reflection.

Curvature loss:
Synonym for Macrobend loss.

Cutback technique:
A technique for measuring fiber attenuation or distortion by performing two transmission measurements. One is at the output end of the full length of the fiber. The other is within 1 to 3 meters of the input end, access being had by "cutting back" the test fiber. See also: Attenuation.

Cutoff wavelength:
That wavelength greater than which a particular waveguide mode ceases to be a bound mode.
Note. In a single mode waveguide, concern is with the cutoff wavelength of the second order mode. See also: Mode.

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 effective noise bandwidth. Synonym: Specific detectivity. See also: Detectivity; Noise equivalent power.

Dark current:

The external current that, under specified biasing conditions, flows in a photosensitive detector when there is no incident radiation.

Degree of coherence:

A measure of the coherence of a light source; the magnitude of the degree of coherence is equal to the visibility, V, 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; Coherence length; Coherent; Interference.

Density:

See Optical density.

Detectivity:

The reciprocal of noise equivalent power (NEP). See also: Noise equivalent power (NEP).

Dichroic filter:

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

Dichroic mirror:

A mirror designed to reflect light selectively according to wavelength. See also: Dichroic filter.

Dielectric filter:

See Interference filter.

Differential mode attenuation:

The variation in attenuation among the propagating modes of an optical fiber.

Differential mode delay:

The variation in propagation delay that occurs because of the different group velocities of the modes of an optical fiber. Synonym: Multimode group delay. See also: Group velocity; Mode; Multimode distortion.

Differential quantum efficiency:

In an optical source or detector, the slope of the curve relating output quanta to input quanta.

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 is usually most noticeable for openings of the order of a wavelength. However, diffraction may still be important for apertures many orders of magnitude larger than the wavelength. See also: Far-field diffraction pattern; Near-field diffraction pattern.

Diffraction grating:

An array of fine, parallel, equally spaced reflecting or transmitting lines that mutually enhance the effects of diffraction to concentrate the diffracted light in a few directions determined by the spacing of the lines and the wavelength of the light. See also: Diffraction.

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: Beam divergence angle; Diffraction.

Diffuse reflection:

See Reflection.

Diode laser:

Synonym for Injection laser diode (ILD).

Directional coupler:

See Tee coupler.

Dispersion:

A term used to describe the chromatic or wavelength dependence of a parameter as opposed to the temporal dependence which is referred to as distortion. The term is used, for example, to describe the process by which an electromagnetic signal is distorted because the various 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:

A change of signal waveform shape.

Note. In a multimode fiber, the signal can suffer degradation from multimode distortion. In addition, several dispersive mechanisms can cause signal distortion in an optical waveguide: waveguide dispersion, material dispersion, and profile dispersion. See also: Dispersion; Profile dispersion.

Distortion-limited operation:
The condition prevailing when the distortion of the received signal, rather than its amplitude (or power), limits performance. The condition is reached when the system distorts the shape of the waveform beyond specified 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.

Double crucible method:
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.

D-star:
See D*.

Effective mode volume:
The square of the product of the diameter of the near-field pattern and the sine of the radiation angle of the far-field pattern. The diameter of the near-field radiation pattern is defined here as the full width at half maximum and the radiation angle at half maximum intensity.
Note. Effective mode volume is proportional to the breadth of the relative distribution of power amongst modes in a multimode fiber. It is not truly a spatial volume but rather an "optical volume" equal to the product of area and solid angle. See also: Mode volume; Radiation pattern.

Electroluminescence:
Nonthermal conversion of electrical energy into light. One example is the photon emission resulting from electron-hole recombination in a pn junction such as in a light emitting diode. See also: Injection laser diode.

Electro-optic effect:
A change in the refractive index of a material 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 coupling length:
Synonym for Equilibrium length.

Equilibrium length:
For a specific excitation condition, the length of multimode optical waveguide necessary to attain equilibrium mode distribution.
Note. The term is sometimes used to refer to the longest such length, as would result from a worst-case, but undefined excitation. Synonyms: Equilibrium coupling length; Equilibrium mode distribution length. See also: Equilibrium mode distribution; Mode coupling.

Equilibrium mode distribution:
The condition in a multimode optical waveguide in which the relative power distribution among the propagating modes is independent of length. Synomym: Steady-state condition. See also: Equilibrium length; Mode; Mode coupling.

Equilibrium mode distribution length:
Synonym for Equilibrium length.

Equilibrium mode simulator:
A device or optical system used to create an approximation of the equilibrium mode distribution. See also: Equilibrium mode distribution; Mode filter.

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.

Excess insertion loss:
In an optical waveguide coupler, the optical loss associated with that portion of the light which does not emerge from the nominally operational ports of the device. See also; Optical waveguide coupler.

Extrinsic joint loss:
That portion of joint loss that is not intrinsic to the fibers (i.e., loss caused by imperfect jointing). See also: Angular misalignment loss; Gap loss; Intrinsic joint loss; Lateral offset loss.

Far-field diffraction pattern:
The diffraction pattern of a source (such as an LED, ILD, or 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 uniformly illuminated circle, then s is the radius of the circle.

Note. The far-field diffraction pattern of a source may be observed at infinity or (except for scale) in the focal plane of a well-corrected lens. The far-field pattern of a diffracting screen illuminated by a point source may be observed in the image plane of the source. Synonym: Fraunhofer diffraction pattern. See also: Diffraction; Diffraction limited.

Far-field pattern:
Synonym for Far-field radiation pattern.

Far-field radiation pattern:
See Radiation pattern.

Far-field region:
The region, far from a source, where the diffraction pattern is substantially the same as that at infinity. See also: Far-field diffraction pattern.

FDHM:
Abbreviation for full duration at half maximum. See also: Full width (duration) half maximum.

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. See also: Reference surface.

FET photodetector:
A photodetector employing photogeneration of carriers in the channel region of an FET structure to provide photodetection with current gain. See also: Photocurrent; Photodiode.

Fiber:
See Optical fiber.

Fiber axis:
The line connecting the centers of the circles that circumscribe the core, as defined under Tolerance field. Synonym: Optical axis. See also: Tolerance field.

Fiber bandwidth:
The lowest frequency at which the magnitude of the fiber transfer function decreases to a specified fraction of the zero frequency value. Often, the specified value is one-half the optical power at zero frequency. See also: Transfer function.

Fiber buffer:
A material that may be used to protect an 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. See also: Fiber bundle.

Fiber bundle:
An assembly of unbuffered optical fibers. 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; Multifiber cable; Optical cable; Optical fiber; Packing fraction.

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. Telecommunication 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 often referred to 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 faceplate used on some high-speed oscilloscopes.

Flux:
Obsolete synonym for Radiant power.

Fraunhofer diffraction pattern:
Synonym for Far-field diffraction pattern.

Frequency response:
Synonym for Transfer function (of a device).

Fresnel diffraction pattern:
Synonym for Near-field diffraction pattern.

Fresnel reflection:
The reflection of a portion of the light incident on 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 material; Reflectance; Reflection; Refractive index.

Fresnel reflection method:
The method for measuring the index profile of an optical fiber by measuring the reflectance as a function of position on the end face. See also: Fresnel reflection; Index profile; Reflectance.

Full width (duration) half maximum:
A measure of the extent of a function. Given by the difference between the two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value. The term "duration" is preferred when the independent variable is time.
Note. Commonly applied to the duration of pulse waveforms, the spectral extent of emission or absorption lines, and the angular or spatial extent of radiation patterns.

Fundamental mode:
The lowest order mode of a waveguide. In fibers, the mode designated LP_{01} or HE_{11}. See also: Mode.

Fused quartz:
Glass made by melting natural quartz crystals; not as pure as vitreous silica. See also: Vitreous silica.

Fused silica:
Synonym for Vitreous silica. See also: Fused quartz.

Fusion splice:
A splice accomplished by the application of localized heat sufficient to fuse or melt the ends of two lengths of optical fiber, forming a continuous, single fiber.

FWHM:
Abbreviation for full width at half maximum. See also: Full width (duration) half maximum.

Gap loss:
That optical power loss caused by a space between axially aligned fibers.
Note. For waveguide-to-waveguide coupling, it is commonly called "longitudinal offset loss." See also: Coupling loss.

Gaussian beam:
A beam of light whose electric field amplitude distribution is gaussian. When such a beam is circular in cross section, the amplitude is

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

where r is the distance from beam center and w is the radius at which the amplitude is 1/e of its value on the axis; w is called the beamwidth. See also: Beam diameter.

Gaussian pulse:
A pulse that has the waveform of a gaussian distribution. In the time domain, the waveform is

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

where A is a constant, and a is the pulse half duration at the 1/e points. See also: Full width (duration) half maximum.

Geometric optics:
The treatment of propagation of light as rays.
Note. Rays are bent at the interface between two dissimilar media or may be curved in a medium in which 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 in the core. See also: Graded index profile; Step index optical waveguide.

Graded index profile:
Any refractive index profile that varies with radius in the core. Distinguished from a step index profile. See also: Dispersion; 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 index (Denoted N):
For a given mode propagating in a medium of refractive index n, the velocity of light in vacuum, c, divided by the group velocity of the mode. For a plane wave of wavelength λ, it is related thus to the refractive index:

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

See also: Group velocity; Material dispersion parameter.

Group velocity:
1. For a particular mode, the reciprocal of the rate of change of the phase constant with respect to angular frequency.

Note. The group velocity equals the phase velocity if the phase constant is a linear function of the angular frequency.
2. Velocity of the signal modulating a propagating electromagnetic wave. See also: Differential mode delay; Group index; Phase velocity.

Guided mode:
Synonym for Bound mode.

Guided ray:
In an optical waveguide, a ray that is completely confined to the core. Specifically, a ray at radial position r having direction such that

$$0 \le \sin \theta(r) \le [n^2(r) - n^2(a)]^{1/2}$$

where $\theta(r)$ is the angle the ray makes with the waveguide axis, n(r) is the refractive index, and n(a) is the refractive index at the core radius. Guided rays correspond to bound (or guided) modes in the terminology of mode descriptors. Synonyms: Bound ray; Trapped ray. See also: Bound mode; Leaky ray.

HE_{11} mode:
Designation for the fundamental mode of an optical fiber. See Fundamental mode.

Heterojunction:
A junction between semiconductors that differ in their doping level conductivities, and also in their atomic or alloy compositions. See also: Homojunction.

Homogeneous cladding:
That part of the cladding wherein the refractive index is constant within a specified tolerance, as a function of radius. See also: Cladding; Tolerance field.

Homojunction:
A junction between semiconductors that differ in their doping level conductivities but not in their atomic or alloy compositions. See also: Heterojunction.

Hybrid mode:
A mode possessing components of both electric and magnetic field vectors in the direction of propagation.
Note. Such modes correspond to skew (nonmeridional) 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. The root-mean-square (rms) duration, σ_{rms}, of the impulse response is often used to characterize a component or system through a single parameter rather than a function:

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

$$\text{where } M_0 = \int_{-\infty}^{\infty} h(t)\, dt$$

$$T = 1/M_0 \int_{-\infty}^{\infty} t h(t)\, dt.$$

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: Root-mean-square (rms) pulse duration; Transfer function.

Inclusion:
Denoting the presence of extraneous or foreign material.

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

Index dip:
A decrease in the refractive index at the center of the core, caused by certain fabrication techniques. Sometimes called profile dip. See also: Refractive index profile.

Index matching material:
A material, often a liquid or cement, whose refractive index is nearly equal to the core index, used to reduce Fresnel reflections from a fiber end face. See also: Fresnel reflection; Mechanical splice; Refractive index.

Index of refraction:
Synonym for Refractive index (of a medium).

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).

Injection fiber:
Synonym for Launching fiber.

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

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

Integrated optical circuit (IOC):
An optical circuit, either monolithic or hybrid, composed of active and passive components, used for coupling between optoelectronic devices and providing signal processing functions.

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. See also: Coherent; Degree of coherence; Diffraction.

Interference filter:
An optical filter consisting of one or more thin layers of dielectric or metallic material. See also: Dichroic filter; Interference; Optical filter.

Interferometer:
An instrument that employs the interference of light waves for purposes of measurement. See also: Interference.

Intermodal distortion:
Synonym for Multimode distortion.

Intramodal distortion:
That distortion resulting from dispersion of group velocity of a propagating mode. It is the only distortion occurring in single mode waveguides. See also: Dispersion; Distortion.

Intrinsic joint loss:
That loss, intrinsic to the fiber, caused by fiber parameter (e.g., core dimensions, profile parameter) mismatches when two nonidentical fibers are joined. See also: Angular misalignment loss; Extrinsic joint loss; Gap loss; Lateral offset loss.

IOC:
Abbreviation for Integrated optical circuit.

Ion exchange technique:
A method of fabricating a graded index optical waveguide by an ion exchange process. See also: Chemical vapor deposition technique; Double crucible method; Graded index profile.

IR:
Abbreviation for Infrared.

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: Radiometry.

Isolator:
A device intended to prevent return reflections along a transmission path.
Note. The Faraday isolator uses the magneto-optic effect.

Isotropic:
Pertaining to a material whose electrical or optical properties are independent of direction of propagation and of polarization of a traveling wave. See also: Anisotropic; Birefringent medium.

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 temporally, or spatially, or both. See also: Active laser medium; Injection laser diode; Optical cavity.

Laser diode:
Synonym for Injection laser diode.

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. See also: Laser; Spontaneous emission; Stimulated 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.

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

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; Launch angle.

Launching fiber:
A fiber used in conjunction with a source to excite the modes of another 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 mode:
In an optical waveguide, a mode whose field decays monotonically for a finite distance in the transverse direction but which becomes oscillatory everywhere beyond that finite distance. Specifically, a mode for which

$$[n^2(a)k^2 - (\ell/a)^2]^{1/2} \leq \beta \leq n(a)k$$

where β is the imaginary part (phase term) of the axial propagation constant, ℓ is the azimuthal index of the mode, n(a) is the refractive index at r=a, the core radius, and k is the free-space wavenumber, $2\pi/\lambda$, and λ is the wavelength. Leaky modes correspond to leaky rays in the terminology of geometric optics.
Note. Leaky modes experience attenuation, even if the waveguide is perfect in every respect. Synonym: Tunnelling mode. See also: Bound mode; Cladding mode; Leaky ray; Mode; Unbound mode.

Leaky ray:
In an optical waveguide, a ray for which geometric optics would predict total internal reflection at the core boundary, but which suffers loss by virtue of the curved core boundary. Specifically, a ray at radial position r having direction such that

$$n^2(r) - n^2(a) \leq \sin^2\theta(r)$$

and

$$\sin^2\theta(r) \leq [n^2(r)-n^2(a)] / [1-(r/a)^2\cos^2\phi(r)]$$

where $\theta(r)$ is the angle the ray makes with the waveguide axis, n(r) is the refractive index, a is the core radius, and $\phi(r)$ is the azimuthal angle of the projection of the ray on the transverse plane. Leaky rays correspond to leaky (or tunnelling) modes in the terminology of mode descriptors. Synonym: Tunnelling ray. See also: Bound mode; Cladding ray; Guided ray; Leaky 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 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. See also: Incoherent.

Light ray:
The path of a 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 width.

Linear element:
A device for which the output electric field is linearly proportional to the input electric field and no new wavelengths or modulation frequencies are generated. A linear element can be described in terms of a transfer function or 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. The LP description is an approximation which is valid for weakly guiding waveguides, including typical telecommunication grade fibers. See also: Mode; Weakly guiding fiber.

Linewidth:
See Spectral width.

LNA:
Abbreviation for Launch numerical aperture.

Longitudinal offset loss:
See Gap loss.

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

LP mode:
Abbreviation for Linearly polarized mode.

LP_{01} mode:
Designation of the fundamental LP mode. See Fundamental mode.

Macrobend loss:
In an optical waveguide, that loss attributable to macrobending. Macrobending usually causes little or no radiative loss. Synonym: Curvature loss. See also: Macrobending; Microbend loss.

Macrobending:
In an optical waveguide, all macroscopic deviations of the axis from a straight line; distinguished from microbending. See also: Macrobend loss; Microbend loss; 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 the material dispersion parameter M. See also: Dispersion; Distortion; Material dispersion parameter; 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 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 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 a unit length of optical fiber is given by M times spectral linewidth ($\Delta\lambda$), except at $\lambda = \lambda_0$, where terms proportional to $(\Delta\lambda)^2$ are important. (See Note 1.) See also: Group index; Material dispersion.

Material scattering:
In an optical waveguide, that part of the total scattering attributable to the properties of the materials used for waveguide fabrication. See also: Rayleigh scattering; Scattering; Waveguide scattering.

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

Meridional ray:
A ray that passes through the optical axis of an optical waveguide (in contrast with a skew ray, which does not). See also: Axial ray; Geometric optics; Numerical aperture; Optical axis; Paraxial ray; Skew ray.

Microbend loss:
In an optical waveguide, that loss 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.
Note. Microbending can cause significant radiative losses and mode coupling. See also: Macrobending.

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

Modal noise:
Noise generated in an optical fiber system by the combination of mode dependent optical losses and fluctuation in the distribution of optical energy among the guided modes or in the relative phases of the guided modes. Synonym: Speckle noise. See also: Mode.

Mode:
In any cavity or transmission line, one of those electromagnetic field distributions that satisfies Maxwell's equations and the boundary conditions. The field pattern of a mode depends on the wavelength, refractive index, and cavity or waveguide geometry. See also: Bound mode; Cladding mode; Differential mode attenuation; Differential mode delay; Equilibrium mode distribution; Equilibrium mode simulator; Fundamental mode; Hybrid mode; Leaky modes; Linearly polarized mode; Mode volume; Multimode distortion; Multimode laser; Multimode optical waveguide; Single mode optical waveguide; Transverse electric mode; Transverse magnetic mode; Unbound mode.

Mode coupling:
In an optical waveguide, the exchange of power among modes. The exchange of power may reach statistical equilibrium after propagation over a finite distance 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 Multimode distortion.

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

Mode filter:
A device used to select, reject, or attenuate a certain mode or modes.

Mode mixer:
Synonym for Mode scrambler.

Mode scrambler:
1. A device for inducing mode coupling in an optical fiber.
2. A device composed of one or more optical fibers in which strong mode coupling occurs.
Note. Frequently used to provide a mode distribution that is independent of source characteristics or that meets other specifications. Synonym: Mode mixer. See also: Mode coupling.

Mode stripper:
See Cladding mode stripper.

Mode volume:
The number of bound modes that an optical waveguide is capable of supporting; for $V>5$, 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, and V is normalized frequency. See also: Effective mode volume; Mode; Normalized frequency; Power-law index profile; Step index profile; V number.

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

Monochromatic:
Consisting of a single wavelength or color. In practice, radiation is never perfectly monochromatic but, at best, displays a narrow band of wavelengths. See also: Coherent; Line source; Spectral width.

Monochromator:
An instrument for isolating narrow portions of the spectrum.

Monomode optical waveguide:
Synonym for Single mode optical waveguide.

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

Multifiber joint:
An optical splice or 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 lenses.

Multilayer filter:
See Interference filter.

Multimode distortion:
In an optical waveguide, that distortion resulting from differential mode delay.

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: Distortion.

Multimode group delay:
Synonym for Differential mode delay.

Multimode laser:
A laser that produces emission in two or more transverse or longitudinal 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; Mode; Mode volume; Multimode distortion; Normalized frequency; Power-law index profile; Single mode optical waveguide; Step index optical waveguide.

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.
Note. The pattern in the output plane of a fiber is called the near-field radiation pattern. Synonym: Fresnel diffraction pattern. See also: Diffraction; Far-field diffraction pattern; Far-field region.

Near-field pattern:
Synonym for Near-field radiation pattern. See Radiation 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.

Near-field scanning:
The technique for measuring the index profile of an optical fiber by illuminating the entrance face with an extended source and measuring the point-by-point radiance of the exit face. See also: Refracted ray method.

Noise equivalent power (NEP):
At a given modulation frequency, wavelength, and for a given effective noise bandwidth, the radiant power that produces a signal-to-noise ratio of 1 at the output of a given detector.
Note 1. Some manufacturers and authors define NEP as the minimum detectable power per root unit bandwidth; when defined in this way, NEP has the units of watts/(hertz)$^{1/2}$. Therefore, the term is a misnomer, because the units of power are watts. See also: D*; Detectivity.
Note 2. Some manufacturers define NEP as the radiant power that produces a signal-to-dark-current noise ratio of unity. This is misleading when dark-current noise does not dominate, as is often true in fiber systems.

Nonlinear scattering:
Direct conversion of a 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), 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 the maximum refractive index in the core and refractive index of the homogeneous cladding, respectively. In a fiber having a power-law profile, the approximate number of bound modes is $(V^2/2)[g/(g+2)]$, where g is the profile parameter. Synonym: V number. See also: Bound mode; Mode volume; Parabolic profile; Power-law index profile; Single mode optical waveguide.

Numerical aperture (NA):
1. The sine of the vertex angle of the largest cone of meridional rays that can enter or leave an optical system or element, multiplied by the refractive index of the medium in which the vertex of the cone is located. Generally measured with respect to an object or image point and will vary as that point is moved.
2. For an optical fiber in which the refractive index decreases monotonically from n_1 on axis to n_2 in the cladding the numerical aperture is given by

$$NA = \sqrt{n_1^2 - n_2^2}$$

3. Colloquially, the sine of the radiation or acceptance angle of an optical fiber, multiplied by the refractive index of the material in contact with the exit or entrance face. This usage is approximate and imprecise, but is often encountered. See also: Acceptance angle; 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." See also: Anisotropic.

Optical axis:
In an optical waveguide, synonymous with "fiber axis."

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. See also: Fiber bundle; Optical cable assembly.

Optical cable assembly:
An optical cable that is connector terminated. Generally, an optical cable that has been terminated by a manufacturer and is ready for installation. See also: Fiber bundle; Optical cable.

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 combiner:
A passive device in which power from several input fibers is distributed among a smaller number (one or more) of input fibers. See also: Star coupler.

Optical conductor:
Deprecated synonym for Optical waveguide.

Optical connector:
See Optical waveguide connector.

Optical coupler:
See Optical waveguide coupler.

Optical data bus:
An optical fiber network, interconnecting terminals, in which any terminal can communicate with any other terminal. See also: Optical link.

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, an optical density of 0.3 corresponds to a transmission loss of 3 dB. See also: Transmission loss; Transmittance.

Optical detector:
A transducer that generates an output signal when irradiated with optical power. See also: Optoelectronic.

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.

Optical fiber cable:
Synonym for Optical cable.

Optical fiber waveguide:
Synonym for Optical waveguide.

Optical filter:
An element that selectively transmits or blocks a range of wavelengths.

Optical link:
Any optical transmission channel designed to connect two end terminals or to be connected in series with other channels.
Note. Sometimes terminal hardware (e.g., transmitter/receiver modules) is included in the definition. See also: Optical data bus.

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,

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

where ds is an element of length along the path.
Note. Optical path length is proportional to the phase shift a light wave undergoes along a path. 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 a signal, amplifies it (or, in the case of a digital signal, reshapes, retimes, or otherwise reconstructs it) and retransmits it. See also: Modulation.

Optical spectrum:
Generally, the electromagnetic spectrum within the wavelength region extending from the vacuum ultraviolet at 40 nm to the far infrared at 1 mm. See also: Infrared; Light.

Optical thickness:
The physical thickness of an isotropic optical element, times its refractive index. See also: Optical path length.

Optical time domain reflectometry:
A method for characterizing a fiber wherein an optical pulse is transmitted through the fiber and the resulting light scattered and reflected back to the input is measured as a function of time. Useful in estimating attenuation coefficient as a function of distance and identifying defects and other localized losses. See also: Rayleigh scattering; Scattering.

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. See also: Cladding; Core; Fiber bundle; Fiber optics; Multimode optical waveguide; Optical fiber; Single mode waveguide; Tapered fiber 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 joint; Optical waveguide coupler.

Optical waveguide coupler:
1. A device whose purpose is to distribute optical power among two 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 preform:
See Preform.

Optical waveguide splice:
A permanent joint whose purpose is to couple optical power between two waveguides.

Optical waveguide termination:
A configuration or a device mounted at the end of a fiber or cable which is intended to prevent reflection. See also: Index matching material.

Optically active material:
A material that can rotate the polarization of light that passes through it.
Note. An optically active material exhibits different refractive indices for left and right circular polarizations (circular birefringence). See also: Birefringent medium.

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. See also: Electro-optic effect; Optical detector.

Output angle:
Synonym for Radiation angle.

Packing fraction:
In a fiber bundle, the ratio of the aggregate fiber cross-sectional 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; 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, θ, between the ray and the optical axis is small enough for $\sin \theta$ or $\tan \theta$ to be replaced by θ (radians). See also: Light ray.

PCS:
Abbreviation for Plastic clad silica.

Peak wavelength:
The wavelength at which the radiant intensity of a source is maximum. See also: Spectral line; Spectral width.

Phase coherence:
See Coherent.

Phase constant:
The imaginary part of the axial propagation constant for a particular mode, usually expressed in radians per unit length. See also: Axial propagation constant.

Phase velocity:
For a particular mode, the ratio of the angular frequency to the phase constant. See also: Axial propagation constant; Coherence time; Group velocity.

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) are some of the factors that 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 result of exposure to radiant power. Internal gain, such as that in an avalanche photodiode, may enhance or increase the current flow but is a distinct mechanism. See also: Dark current; Photodiode.

Photodiode:
A diode designed to produce photocurrent by absorbing light. Photodiodes are used for the detection of optical power and for the conversion of optical power to electrical power. See also: Avalanche photodiode (APD); Photocurrent; PIN photodiode.

Photoelectric effect:
1. External photoelectric effect: The emission of electrons from the irradiated surface of a material. Synonym: Photoemissive effect.
2. Internal photoelectric effect: Photoconductivity.

Photoemissive effect:
Synonym for (external) 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.

Photon noise:
Synonym for Quantum noise.

Photovoltaic effect:
The production of a voltage difference across a pn junction resulting from the absorption of photon energy. The voltage difference is caused by the internal drift of holes and electrons. See also: Photon.

Physical optics:
The branch of optics that treats light propagation as a wave phenomenon rather than a ray phenomenon, as in geometric optics.

Pigtail:
A short length of optical fiber, permanently fixed to a component, used to couple power between it and the transmission fiber. See also: Launching fiber.

PIN photodiode:
A diode with a large intrinsic 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.

Planck's constant:
The number h that relates the energy E of a photon with the frequency ν of the associated wave through the relation $E = h\nu$. $h = 6.626 \times 10^{-34}$ joule second. See also: Photon.

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

Plastic clad silica fiber:
An optical waveguide having silica core and plastic cladding.

Power:
See Irradiance; Radiant intensity; Radiant power.

Power density:
Colloquial synonym for Irradiance.

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

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

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

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

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 homogeneous cladding, a is the core radius, and g is a parameter that defines the shape of the profile.
Note 1. α is often used in place of g. Hence, this is sometimes called an alpha profile.
Note 2. 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 is around 2. When g increases without limit, the profile tends to a step index profile. See also: Graded index profile; Mode volume; Profile parameter; Step index profile.

Preform:
A glass structure from which an optical fiber waveguide may be drawn. See also: Chemical vapor deposition technique; Ion exchange technique; Optical blank.

Primary coating:
The material in intimate contact with the cladding surface, applied to preserve the integrity of that surface. See also: Cladding.

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

Profile dispersion:
1. In an optical waveguide, that dispersion attributable to the variation of refractive index contrast with wavelength, where contrast refers to the difference between the maximum refractive index in the core and the refractive index of the homogeneous cladding. Profile dispersion is usually characterized by the profile dispersion parameter, defined by the following entry.
2. In an optical waveguide, that dispersion attributable to the variation of refractive index profile with wavelength. The profile variation has two contributors: (a) variation in refractive index contrast, and (b) variation in profile parameter. See also: Dispersion; Distortion; Refractive index profile.

Profile dispersion parameter (P):

$$P(\lambda) = \frac{n_1}{N_1} \frac{\lambda}{\Delta} \frac{d\Delta}{d\lambda}$$

where n_1, N_1 are, respectively, the refractive and group indices of the core, and $n_1\sqrt{1-2\Delta}$ is the refractive index of the homogeneous cladding, $N_1 = n_1 - \lambda(dn_1/d\lambda)$, and Δ is the refractive index constant. Sometimes it is defined with the factor (-2) in the numerator. See also: Dispersion.

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

Propagation constant:
For an electromagnetic field mode varying sinusoidally with time at a given frequency, the logarithmic rate of change, with respect to distance in a given direction, of the complex amplitude of any field component.
Note. The propagation constant is a complex quantity.

Pulse broadening:
An increase in pulse duration.
Note. Pulse broadening may be specified by the impulse response, the root-mean-square pulse broadening, or the full-duration-half-maximum pulse broadening. See also: Impulse response; Root-mean-square pulse broadening; Full width (duration) half maximum.

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 points is commonly used, as is the rms pulse duration. 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.

Quadratic profile:
Synonym for Parabolic profile.

Quantum efficiency:
In an optical source or detector, the ratio of output quanta to input quanta. Input and output quanta need not both be photons.

Quantum noise:
Noise attributable to the discrete or particle nature of light. Synonym: Photon noise.

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

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 incidance:
See Irradiance.

Radiant intensity:
Radiant power 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. The prefix is often dropped and the term

"power" is used. Colloquial synonyms: Flux; Optical power; Power; Radiant flux. See also: Radiometry.

Radiation angle:

Half the vertex angle of the cone of light emitted by a fiber.

Note. The cone is usually defined by the angle at which the far-field irradiance has decreased to a specified fraction of its maximum value or as the cone within which can be found a specified fraction of the total radiated power at any point in the far field. Synonym: Output angle. See also: Acceptance angle; Far-field region; Numerical aperture.

Radiation mode:

In an optical waveguide, a mode whose fields are transversely oscillatory everywhere external to the waveguide, and which exists even in the limit of zero wavelength. Specifically, a mode for which

$$\beta \leq [n^2(a)k^2-(\ell/a)^2]^{1/2}$$

where β is the imaginary part (phase term) of the axial propagation constant, ℓ is the azimuthal index of the mode, n(a) is the refractive index at r=a, the core radius, and k is the free-space wavenumber, $2\pi/\lambda$, where λ is the wavelength. Radiation modes correspond to refracted rays in the terminology of geometric optics. Synonym: Unbound mode. See also: Bound mode; Leaky mode; Mode; Refracted ray.

Radiation pattern:

Relative power distribution as a function of position or angle.

Note 1. Near-field radiation pattern describes the radiant emittance ($W \cdot m^{-2}$) as a function of position in the plane of the exit face of an optical fiber.

Note 2. Far-field radiation pattern describes the irradiance as a function of angle in the far field region of the exit face of an optical fiber.

Note 3. Radiation pattern may be a function of the length of the waveguide, the manner in which it is excited, and the wavelength. See also: Far-field region; Near-field region.

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: Optical power	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 excitance	W	Power emitted (into a full sphere) per unit area	$W \cdot m^{-2}$
Radiant intensity	I	Power per unit solid angle	$W \cdot sr^{-1}$
Radiance	L	Power per unit angle per unit projected area	$W \cdot sr^{-1} \cdot m^{-2}$
Spectral radiance	L_λ	Radiance per unit wavelength interval at a given wavelength	$W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$

Ray:
See Light ray.

Rayleigh scattering:
Light scattering by refractive index fluctuations (inhomogeneities in material density or composition) that are small with respect to wavelength. The scattered field is inversely proportional to the fourth power of the wavelength. See also: Material scattering; Scattering; Waveguide scattering.

Reference surface:
That surface of an optical fiber which is used to contact the transverse-alignment elements of a component such as a connector. For various fiber types, the reference surface might be the fiber core, cladding, or buffer layer surface.
Note. In certain cases the reference surface may not be an integral part of the fiber. See also: Ferrule; Optical waveguide connector.

Reflectance:
The ratio of reflected power to incident power.
Note. In optics, frequently expressed as optical density or as a percent; in communication 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:
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.

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.

Refracted near-field scanning method:
See Refracted ray method.

Refracted ray:
In an optical waveguide, a ray that is refracted from the core into the cladding. Specifically a ray at radial position r having direction such that

$$\frac{n^2(r) - n^2(a)}{1 - (r/a)^2\cos^2\phi(r)} \leq \sin^2\theta(r)$$

where $\phi(r)$ is the azimuthal angle of projection of the ray on the transverse plane, $\theta(r)$ is the angle the ray makes with the waveguide axis, n(r) is the refractive index, n(a) is the refractive index at the core radius, and a is the core radius. Refracted rays correspond to radiation modes in the terminology of mode descriptors. See also: Cladding ray; Guided ray; Leaky ray; Radiation mode.

Refracted ray method:
The technique for measuring the index profile of an optical fiber by scanning the entrance face with the vertex of a high numerical aperture cone and measuring the change in power of refracted (unguided) rays. Synonym: Refracted near-field scanning method. See also: Refraction; Refracted ray.

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 (of a medium).

Refractive index (of a medium):
Denoted by n, the ratio of the velocity of light in vacuum to the phase velocity in the medium. Synonym: Index of refraction. See also: Cladding; Core; Critical angle; Dispersion; Fresnel reflection; Fused silica; Graded index optical waveguide; Group index; Index matching material; 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 fiber.

Refractive index contrast:
Denoted by Δ, a measure of the relative difference in refractive index of the core and cladding of a fiber, given by

$$\Delta = (n_1^2 - n_2^2) / 2n_1^2$$

where n_1 and n_2 are, respectively, the maximum refractive index in the core and the refractive index of the homogeneous cladding.

Refractive index profile:
The description of the refractive index along a fiber diameter. See also: Graded index profile; Parabolic profile; Power-law index profile; Profile dispersion; Profile dispersion parameter; Profile parameter; Step index profile.

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

Regenerator:
Synonym for Regenerative repeater.

Repeater:
See Optical repeater.

Resonant cavity:
See Optical cavity.

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 amperes 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.

Root-mean-square (rms) deviation:
A single quantity characterizing a function given, for f(x), by

$$\sigma_{rms} = [1/M_0 \int_{-\infty}^{\infty} (x-M_1)^2 f(x)\, dx]^{1/2}$$

$$\text{where } M_0 = \int_{-\infty}^{\infty} f(x)dx$$

$$M_1 = 1/M_0 \int_{-\infty}^{\infty} xf(x)dx$$

Note. The term rms deviation is also used in probability and statistics, where the normalization, M_0, is unity. Here, the term is used in a more general sense. See also: Impulse response; Root-mean-square (rms) pulse broadening; Root-mean-square (rms) pulse duration; Spectral width.

Root-mean-square (rms) pulse broadening:
The temporal rms deviation of the impulse response of a system. See also: Root-mean-square (rms) deviation; Root-mean-square (rms) pulse duration.

Root-mean-square (rms) pulse duration:
A special case of root-mean-square deviation where the independent variable is time and f(t) is pulse waveform. See also: Root-mean-square deviation.

Scattering:
The change in direction of light rays or photons after striking a small particle or particles. It may also be regarded as the diffusion of a light beam caused by the inhomogeneity of the transmitting medium. See also: Leaky modes; Material scattering; Mode; Nonlinear scattering; Rayleigh scattering; Refractive index (of a medium); Unbound mode; Waveguide scattering.

Semiconductor laser:
Synonym for Injection laser diode (ILD).

Sensitivity:
Imprecise synonym for Responsivity. In optical system receivers, the minimum power required to achieve a specified quality of performance in terms of output signal-to-noise ratio or other measure.

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 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.

Single mode optical waveguide:
An optical waveguide in which only the lowest order bound mode (which may consist of a pair of orthogonally polarized fields) 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.
Note. In practice, the orthogonal polarizations may not be associated with degenerate modes. Synonym: Monomode optical waveguide. See also: Bound mode; 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.

Slab interferometry:
The method for measuring the index profile of an optical fiber by preparing a thin sample that has its faces perpendicular to the axis of the fiber, and measuring its index profile by interferometry. Synonym: Axial slab interferometry. See also: Interferometer.

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*.

Speckle noise:
Synonym for Modal noise.

Speckle pattern:
A power intensity pattern produced by the mutual interference of partially coherent beams that are subject to minute temporal and spatial fluctuations.
Note. In a multimode fiber, a speckle pattern results from a superposition of mode field patterns. If the relative modal group velocities change with time, the speckle pattern will also change with time. If, in addition, differential mode attenuation is experienced, modal noise results. See also: Modal noise.

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

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

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

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

Spectral width:
A measure of the wavelength extent of a 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 magnitude 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 spectral width is a special case of root-mean-square deviation where the independent variable is wavelength (λ), and $f(\lambda)$ is a suitable radiometric quantity. See also: Root-mean-square (rms) deviation.
Note 3. The relative spectral width $(\Delta\lambda)/\lambda$ is frequently used, where $\Delta\lambda$ is obtained according to Note 1 or Note 2. See also: Coherence length; Line spectrum; Material dispersion;

Spectral window:
A wavelength region of relatively high transmittance, surrounded by regions of low transmittance. 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 device in which power from one or several input waveguides is distributed amongst a larger number of output optical waveguides. See also: Optical combiner; Tee coupler.

Steady-state condition:
Synonym for Equilibrium mode distribution.

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

Step index profile:
A refractive 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; Mode volume; Multimode optical waveguide; Normalized frequency; Optical waveguide; Refractive index (of a medium); Total internal reflection.

Stimulated emission:
Radiation emitted when the internal energy of a quantum mechanical system drops from an excit-

ed level to a lower level when induced by the 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.

Superluminescent LED:
An emitter based on stimulated emission with amplification but insufficient feedback for oscillation to build up. See also: Spontaneous emission; Stimulated 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; Stimulated emission.

Surface wave:
A wave that is guided by the interface between two different media or by a refractive index gradient in the medium. The field components of the wave may exist (in principle) throughout space (even to infinity) but become negligibly small within a finite distance from the interface.
Note. All guided modes, but not radiation modes, in an optical waveguide belong to a class known in electromagnetic theory as surface waves.

Tap:
A device for extracting a portion of the optical signal from a fiber.

Tapered fiber waveguide:
An optical waveguide whose transverse dimensions vary monotonically with length. Synonym: Tapered transmission line.

Tapered transmission line:
Synonym for Tapered fiber waveguide.

TE mode:
Abbreviation for Transverse electric mode.

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

TEM mode:
Abbreviation for Transverse electromagnetic mode.

Temporal coherence:
See Coherent.

Temporally coherent radiation:
See Coherent.

Thin film waveguide:
A transparent dielectric film, bounded by lower index materials, capable of guiding 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 field:
1. In general, the region between two curves (frequently two circles) used to specify the tolerance on component size.
2. When used to specify fiber cladding size, the annular region between the two concentric circles of diameter $D+\Delta D$ and $D-\Delta D$. The first circumscribes the outer surface of the homogeneous cladding; the second (smaller) circle is the largest circle that fits within the outer surface of the homogeneous cladding.
3. When used to specify the core size, the annular region between the two concentric circles of diameter $d+\Delta d$ and $d-\Delta d$. The first circumscribes the core area; the second (smaller) circle is the largest circle that fits within the core area.
Note. The circles of definition 2 need not be concentric with the circles of definition 3. See also: Cladding; Core; Concentricity error; Homogeneous cladding.

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

Transfer function (of a device):
The complex function, H(f), equal to the ratio of the output to input of the device as a function of frequency. The amplitude and phase responses are, respectively, the magnitude of H(f) and the phase of H(f).
Note 1. For an optical fiber, H(f) is taken to be the ratio of output optical *power* to input optical *power* as a function of modulation frequency.
Note 2. For a linear system, the transfer function and the impulse response h(t) are related through the Fourier transform pair, a common form of which is given by

$$H(f) = \int_{-\infty}^{\infty} h(t)\exp(i2\pi ft)\,dt$$

and

$$h(t) = \int H(f)\exp(2\pi ft)\,df$$

where f is frequency. Often H(f) is normalized to H(0) and h(t) to

$\int h(t)dt$, which by definition is H(0). Synonyms:

Baseband response function; Frequency response. See also: Impulse response.

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

Transmittance:
The ratio of transmitted power to incident power. *Note.* In optics, frequently expressed as optical density or percent; in communications applications, generally expressed in dB. Formerly called "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 an optical fiber, TE and TM modes correspond to meridional rays. See also: Meridional ray; Mode.

Transverse electromagnetic (TEM) mode:
A mode whose electric and magnetic field vectors are both normal to the direction of propagation. See also: Mode.

Transverse interferometry:
The method used to measure the index profile of an optical fiber by placing it in an interferometer and illuminating the fiber transversely to its axis. Generally, a computer is required to interpret the interference pattern. See also: Interferometer.

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.

Transverse propagation constant:
The propagation constant evaluated along a direction perpendicular to the waveguide axis.
Note. The transverse propagation constant for a given mode can vary with the transverse coordinates. See also: Propagation constant.

Transverse scattering:
The method for measuring the index profile of an optical fiber or preform by illuminating the fiber or preform coherently and transversely to its axis, and examining the far-field irradiance pattern. A computer is required to interpret the pattern of the scattered light. See also: Scattering.

Trapped mode:
See Bound mode.

Trapped ray:
Synonym for Guided ray.

Tunnelling mode:
Synonym for Leaky mode.

Tunnelling ray:
Synonym for Leaky ray.

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. See also: Infrared; Light.

Unbound mode:
Any mode that is not a bound mode; a leaky or radiation mode of the waveguide. Synonym: Radiative mode. See also: Bound mode; Cladding mode; Leaky mode.

V number:
Synonym for Normalized frequency.

Visible spectrum:
See Light.

Vitreous silica:
Glass consisting of almost pure silicon dioxide (SiO_2). Synonym: Fused silica. See also: Fused quartz.

Wavefront:
The locus of points having the same phase at the same time.

Waveguide dispersion:
For each mode in an optical waveguide, the term used to describe the process by which an electromagnetic signal is distorted by virtue of the dependence of the phase and group velocities on wavelength as a consequence of the geometric properties of the waveguide. In particular, for circular waveguides, the dependence is on the ratio (a/λ), where a is core radius and λ is wavelength. See also: Dispersion; Distortion; Material dispersion; Multimode distortion; Profile dispersion.

Waveguide scattering:
Scattering (other than material scattering) that is attributable to variations of geometry and index profile of the waveguide. See also: Material scattering; Nonlinear scattering; Rayleigh scattering; Scattering.

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

Weakly guiding fiber:
A fiber for which the difference between the maximum and the minimum refractive index is small (usually less than 1%).

Window:
See Spectral window.

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