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**IEEE Standard Definitions of
Terms Relating to Fiber Optics**

Sponsor

**Fiber Optics Committee of the
IEEE Communications Society**

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Foreword

(This Foreword is not a part of IEEE Std 812-1984, IEEE Standard Definitions of Terms Relating to Fiber Optics.)

This document is based on the NTIA-SP-79-4 Optical Waveguide Communications Glossary, issued in September 1979 by the U.S. Department of Commerce; its updated version issued in the latter part of 1981; and the input from Project 812 Ad Hoc Working Group in April 1981. The contributors to the final document include A. G. Hanson, L. R. Bloom, R. L. Galawa, E. M. Gray, G. W. Day, M. Young, A. H. Cherin, T. L. Gower, C. K. Kao, F. P. Kapron, B. S. Kawasaki, R. L. Lebduska, R. E. Love, P. Reitz, M. Kincaid, J. G. Nault, F. Sladen, J. Masterson, J. Fridman, D. Stone, and G. P. Kurpis.

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Suggestions for improvement of this standard will be welcomed. They should be sent to the Secretary

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IEEE Standard Definitions of Terms Relating to Fiber Optics

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 impurities: for example, the OH⁻ ion and transition metal ions; and defects: for example, results of thermal history and exposure to nuclear radiation. *See:* attenuation.

acceptance angle. Half the vertex angle of that cone within which optical power may be coupled into bound modes of an optical waveguide. *Notes:* (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

$n(r)$ = local refractive index

n_2 = minimum refractive index of the cladding

The sine of the local acceptance angle is sometimes referred to as the local numerical aperture. (2) Power may be coupled into leaky modes at angles exceeding the acceptance angle. *See:* 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 A device placed between two waveguide ends to allow signals to be withdrawn from or entered into one of the waveguides.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:* 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:* 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. *Syn:* laser medium. *See:* 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. *Syn:* coherent bundle. *See:* 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:* reflection; refraction.

angle of incidence. The angle between an incident ray and the normal to a reflecting or refracting surface. *See:* critical angle; total internal reflection.

angstrom (Å). A unit of optical wavelength (obsolete).

$$1 \text{ Å} = 10^{-10} \text{ m}$$

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:* **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:* **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:* **dichroic filter; Fresnel reflection; reflectance; transmittance.**

APD. *See:* **avalanche photodiode.**

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 decibels (dB). However, attenuation is often used as a synonym for attenuation coefficient, expressed as dB/km. This assumes the attenuation coefficient is invariant with length. *See:* **attenuation coefficient; coupling loss; differential mode attenuation; equilibrium mode distribution; extrinsic 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

$P(z)$ = power at distance z along the guide

$P(0)$ = power at $z = 0$

α = attenuation coefficient in dB/km if z is in km. From this equation,

$$\alpha z = -10 \log_{10} \left[\frac{P(z)}{P(0)} \right]$$

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

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

or, equivalently,

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

See: **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:* **attenuation coefficient; axial propagation constant; propagation constant.**

attenuation-limited operation. The condition prevailing when the received signal amplitude (rather than distortion) limits performance. *See:* **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:* **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. *Syn:* **axial propagation wave number.** *See:* **attenuation; attenuation coefficient; attenuation constant; propagation constant.**

axial propagation wave number. *See:* **axial propagation constant.**

axial ray. A light ray that travels along the optical axis. *See:* **geometric optics; fiber axis; meridional ray; paraxial axis; skew ray.**

axial slab interferometry. *See:* slab interferometry.

backscattering. The scattering of light into a direction generally reverse to the original one. *See:* 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:* 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:* core.

baseband response function. *See:* 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. *Syn:* beamwidth. *See:* 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:* beam diameter; collimation; far-field region.

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

beamwidth. *See:* 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:* 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:* emissivity.

bolometer. A device for measuring radiant energy by measuring the changes in resistance of a temperature-sensitive device exposed to radiation. *See:* 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 $1.38 \cdot 10^{-23}$ J/K.

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 = imaginary part (phase constant) of the axial propagation constant

$n(a)$ = refractive index at $r = a$

the core radius $n(0)$ = refractive index at $r = 0$

k = free-space wavenumber $2\pi/\lambda$

λ = 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. *Syn:* guided mode; trapped mode. *See:* cladding

mode; guided ray; leaky mode; mode; normalized frequency; unbound mode.

bound ray. *See: 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: 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. *Notes:* (1) Usage should be restricted to nonquantitative reference to physiological sensations and perceptions of light. (2) *Brightness* was formerly used as a synonym for the photometric term *luminance* and (incorrectly) for the radiometric term *radiance*. *See: 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, phosphorus, 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: preform.*

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

chromatic dispersion. *See: dispersion.*

cladding. The dielectric material surrounding the core of an optical waveguide. *See: 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: 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: 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: 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: 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: 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: 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: 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 = central wavelength

$\Delta\lambda$ = spectral linewidth

c = velocity of light in vacuum

See: coherence length; phase velocity.

coherent. Characterized by a fixed phase relationship between points on an electromagnetic wave. *Note:* A truly monochromatic wave is 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: coherence area; coherence length; coherence time; degree of coherence; monochromatic.*

coherent bundle. *See: 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: 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: 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 = radiance of a beam

n = local refractive index

Formerly called *conservation of brightness* or the *brightness theorem*. *See: brightness; radiance.*

core. The central region of an optical waveguide through which light is transmitted. *See: 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 between 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: cladding; core; homogeneous cladding; tolerance field.*

core center. A point on the fiber axis. *See: fiber axis; optical axis.*

core diameter. The diameter of the circle that circumscribes the core area. *See: cladding; core; core area; tolerance field.*

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

coupled modes. Modes whose energies are shared. *See: mode.*

coupler. *See: optical waveguide coupler.*

coupling. *See: mode coupling.*

coupling efficiency. The efficiency of optical power transfer between two optical components. *See: coupling loss.*

coupling loss. The power loss suffered when coupling light from one optical device to another. *See: 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

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

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: acceptance angle; angle of incidence; reflection; refractive index (of a medium); step index profile; total internal reflection.*

curvature loss. *See: 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 m–3 m of the input end, access being had by *cutting back* the test fiber. *See: 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: mode.*

CVD. *See: 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.

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

where

A = area of the photosensitive region of the detector

(Δf) = effective noise bandwidth

Syn: specific detectivity. *See: 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

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

I_{max} = intensity at a maximum of the interference pattern

I_{min} = 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: coherence area; coherence length; coherent; interference.*

density. *See: optical density.*

detectivity. The reciprocal of noise equivalent power (NEP). *See: 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: optical filter.*

dichroic mirror. A mirror designed to reflect light selectively according to wavelength. *See: 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. *Syn: multimode group delay.* *See: group velocity; mode; multimode distortion.*