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Standard Terminology Relating to Optical Fiber Sensing Systems[1]

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1. Scope

1.1 This terminology standard is a compilation of definitions of technical terms related to optical fiber sensing systems, used in the various sections of standards under the jurisdiction of ASTM Committee F36.

1.2 Where possible, definitions are stated as a single sentence, with necessary supplementary information as a Discussion. This approach is used to simplify explanations of the meanings of technical terms for the benefit of those not conversant with them, to facilitate a precise understanding and interpretation of F36 ASTM standards.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2233 Guide for Safety, Access Rights, Construction, Liability, and Risk Management for Optical Fiber Networks in Existing Sewers

F2303 Practice for Selection of Gravity Sewers Suitable for Installation of Optical Fiber Cable and Conduits

F2304 Practice for Sealing of Sewers Using Chemical Grouting

F2349 Practice for Operation and Maintenance of Integrated Natural Gas Pipelines and Optical Fiber Systems (Withdrawn 2017)[3]

F2350 Practice for Selection of Natural Gas Pipelines Suitable for Installation of Optical Fiber Systems (Withdrawn 2017)[3]

F2414 Practice for Sealing Sewer Manholes Using Chemical Grouting

F2454 Practice for Sealing Lateral Connections and lines from the mainline Sewer Systems by the Lateral Packer Method, Using Chemical Grouting

F2462 Practice for Operation and Maintenance of Sewers with Optical Fiber Systems

F2550 Practice for Locating Leaks in Sewer Pipes By Measuring the Variation of Electric Current Flow Through the Pipe Wall (Withdrawn 2022)[3]

F2551 Practice for Installing a Protective Cementitious Liner System in Sanitary Sewer Manholes

3. Significance and Use

3.1 Definitions in this standard are to be regarded as correct for the terms found in other ASTM standards of Committee F36. Certain terms may be found in more than one standard issued under the jurisdiction of this committee and many of these terms have been placed in this standard.

4. Terminology

4.1 *Terms and Definitions:*

absorption, *n*—the loss of some or all of the energy contained in an electromagnetic wave to the medium in which it is propagating, usually converted to heat.

acceptance angle, *n*—the maximum angle, measured from the optical fiber centerline to an incident light ray, within which the incident ray will be accepted for transmission by total internal reflection along the fiber.

DISCUSSION—If the incident angle is greater than the acceptance angle, total internal reflection will not occur and the incident ray will be lost by leakage.

access rights, *n*—agreements between various parties to obtain temporary and permanent access to property for the purpose

[1] This terminology is under the jurisdiction of ASTM Committee F36 on Technology and Underground Utilities and is the direct responsibility of Subcommittee F36.91 on Terminology.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

of constructing, maintaining, or changing optical fiber networks. F2233

accuracy, *n*—the closeness of the measured value to the true or the ideal value of the parameter being measured and is affected by both bias and precision.

acoustic wave, *n*—longitudinal waves propagated by means of adiabatic compression and decompression.

acousto-optics, *n*—the science and technology of the interactions between sound waves and light waves passing through material media, especially as applied to the modulation and deflection of laser beams by ultrasonic waves.

acrylamide, *n*—organic solid of white, odorless, acrylic resinous material available in flake-like crystals and in liquid form. The greatest use of acrylamide is as a coagulant aid in drinking water treatment. Other major uses of acrylamide are in soil stabilization, in grout for repairing sewers, and in acrylamide gels used in biotechnology laboratories. F2414

acrylate, *n*—a general term applied to various water-soluble acrylic resinous materials. F2414

adit, *n—in tunneling*, a tunnel driven from ground surface to provide access to or drainage from underground workings; a length of tunnel driven for an exploration-exploration adit.

advance, *n—in tunneling*, the forward progress in the construction of a tunnel, usually measured by the length created, or the rate of segment positioning in terms of a number per hour/day or some other timescale.

ambient temperature, *n*—the temperature of the surrounding environment or air. F2304

Angstrom, A, *n*—a unit of length equal to 10^{-1} nanometer (10^{-1} nm), 10^{-4} micron (10^{-6} mm), and 10^{-10} meter (10^{-10} m).

annulus, *n—in tunneling*, a ring-shaped opening, generally bounded by the outside diameter of excavated tunnel and the exterior of the final tunnel liner. F2304

aperture, *n—in optics*, a hole or an opening through which light travels.

attenuation, *n*—the decrease in optical power of a signal, or light wave, from interaction with the propagation medium, for example, absorption, reflection, diffusion, scattering, deflection, dispersion or resistance.

attenuation budget, *n*—the maximum cumulative one-way or two-way optical power loss between the interrogator and the measurement point that allows a measurement with a specified performance.

attenuation range, *n*—total cumulated optical loss (one way loss; expressed in decibels (dB)) tolerated by the DRS system without affecting the specified measurement performance more than a given factor at a given location, spatial resolution, and measurement time.

DISCUSSION—Part of the total cumulative loss can be the fiber attenuation, point defect losses introduced by components such as connectors, splices, kink in the fiber, attenuators, etc.

authorized inspector, *n*—the person(s) contracted or approved by the owner or owner's representative to do inspections. F2414

backfill, *n—in tunneling*, a material used to replace excavated soil.

bandwidth, *n*—the range of frequencies that a device is capable of handling.

beam splitter, *n*—an optical device for dividing a light beam into two separated beams.

bench, *n—in tunneling*, in situ ground at the lower face of a tunnel undergoing staged excavation.

bend loss, *n*—optical power loss in an optical fiber because signal radiation escapes through its bends, with the magnitude of optical power loss being proportional to the bending radius.

bending radius, *n*—the radius of a bend measured in a fiber optic cable.

bentonite, *n*—clay composed mainly of clay mineral 'montmorillonite,' used for synthetic reasons, due to its expanding properties when in contact with water, for example, drilling mud, binder, absorbent, groundwater barrier, etc.

bias, *n*—the difference between the measured results after averaging, less the true value.

birefringence, *n*—the separation of a light beam into two components to form two rays propagating at different velocities in the medium.

bolt pocket, *n—in tunneling*, a pre-formed recess in tunnel segment to accommodate bolts which hold segments together.

bore, *n—in tunneling*, the internal diameter of a pipe or other cylinder, single tunnel, for example, twin bore.

borehole, *n*—a hole driven into the ground to get information about the strata, or to release water pressure by vertical sand drains, or to obtain water, oil, gas, etc.

boring/bored, *n*—making a hole in the ground by means of rotating auger.

box jack/jacked box, *n—in tunneling*, a fully constructed structure that is thrust into final position from an adjacent jacking point.

Bragg cell, *n*—an acousto-optic device that is capable of modulating light waves to produce an output light wave with an imposed frequency equal to the frequency of the input signal.

Brillouin optical time domain analysis, BOTDA, *n*—double ended access to the light source and detection system for long sensing lengths combined with high strain and temperature resolution for up to 31 miles (50 km) without signal regeneration.

Brillouin optical time domain reflectometer, BOTDR, *n*—a single ended access to the source and detection system, which provides a Brillouin gain-loss-based distribution sensor much like the standard OTDR sensors which use Rayleigh scattering to the same effect. See **optical time domain reflectometer**.

Brillouin scattering, *n*—light in a medium interacts with time-dependent optical density variations and changes its frequency and path.

DISCUSSION—The density variations may be due to acoustic modes, such as phonons, or magnetic modes, such as temperature gradients. As described in classical physics, when the medium is compressed its index of refraction changes, and a fraction of the traveling light wave, interacting with the periodic refraction index variations, is deflected as in a three-dimensional diffraction grating. Since the sound wave, too, is traveling, light is also subjected to a Doppler shift, so its frequency changes.

cable, *n*—a group of insulated light conductors that are bound together, usually with a durable cable jacket.

cable jacket, *n*—the outer protective covering over insulated conductors that are bound together.

caisson, *n—in tunneling*, a watertight retaining structure, that can be used as a support of excavation for a shaft structure.

canopy tube, *n—in tunneling*, a metal tube drilled into the tunnel face above the ground to be excavated, the tube is pumped full of grout once in place; the canopy is created using multiple adjacent tubes to reduce the risk of crown failure.

catalyst, *n*—substance which markedly speeds up the cure of an adhesive when added in small quantities as compared to the amounts of primary reactants. **F2414**

caulking, *n*—one of several different processes to seal joints or seams in various structures and piping. **F2454**

character-separated value file format, CSV, *n*—synonymous with "comma separated value file," stores tabular data (numbers and text) in a sequence of characters, with no data that has to be interpreted, separated by some character or string, for example, comma or tab.

characteristic frequency and/or wavelength at reference temperature (Brillouin technologies), *n*—the frequency and/or wavelength that characterizes the sensor response at reference temperature as monitored by the interrogator.

DISCUSSION—As Brillouin frequency varies with wavelength of the light source, this also changes the temperature and strain coefficients for various sensing fibers. Therefore, characteristic frequency and the wavelength at a specified reference temperature and at zero strain are usually provided by the complete system producers.

chemical grout, *n*—injection repair media other than cementitious grout that may be multicomponent, with or without additives, and based on either polyurethane resin or acrylic resin. **F2414**

circumferential joint, *n—in tunneling*, a joint (typically between segments) which runs circumferentially relative to the tunnel bore.

cladding, *n—in optics*, optical transparent material over the core of the optical fiber, with a refractive index lower than that of the core, to provide total internal reflectance.

coherence length, *n*—the coherence time of a light beam multiplied by the velocity of the light.

coherence time, *n*—if t is the time a light beam takes to become coherent, and t + Δt is the time at which the light beam loses its coherent properties, Δt is the coherence time.

coherent light, *n*—light which has predictable parameters at any point in time or space, for example, laser light.

combined sewers, *n*—sewers that carry both wastewater and storm or surface water. **F2303**

compensation grouting, *n—in tunneling*, a method of reversing ground settlements by injecting grout into the ground.

competent person, *n*—a person properly trained in the safety aspects of an activity. **F2233**

conductor, *n*—a transparent medium that is capable of transmitting or conveying light waves by total internal reflection.

conduit, *n*—plastic tubing used to house optical fiber cable that is connected to, but not inside of, a pipeline. **F2349, F2462**

confined space, *n*—an enclosed area that is large enough and so configured that a person can bodily enter and has the following characteristics: its primary function is something other than human occupancy; has restricted entry and exit. (Restricted entry and exit is a physical configuration which requires the use of hands or contortion of the body to enter into or exit from the confined space.) **F2233**

connector, *n*—coupling device attached to the end of a fiber so that it can be mechanically connected to equipment or mated with another connector to join two fibers together by aligning their cores to minimize signal loss.

connector insertion loss, *n*—the power loss due to the insertion of a connector between two elements.

constructability, *n*—the term used to denote the condition of a completed set of plans and specifications for an optical fiber network and its impact to the host utility, which have been prepared with an analysis of practical, feasible methods of construction. **F2233**

contractor, *n*—usually, the entity in charge of construction of the new tunnel or other infrastructure that may impact the utility. **F2551**

control agent, *n*—substance added which controls the viscosity or flow properties of the material it is added to. **F2414**

convergence, *n—in tunneling*, a measurement of the inward movements of tunnel walls, often monitored to provide information on the performance of the lining during construction.

conveyor, *n—in tunneling*, used to remove excavated material from a tunnel face or shaft.

core, *n*—the primary light-conducting region of an optical fiber. The refractive index of the core is higher than its cladding, the condition necessary for total internal reflection.

coupler, *n*—a mechanical connector that is used to interconnect two or more optical fibers.

coupler 3-dB, *n*—a coupler that splits the optical energy in an optical waveguide into two equal parts and couples each part into a separate waveguide; ideally distributes 50 % of the input optical power to each of the output channels.

coupling, *n*—the connection between elements, whether physical or across a gap, where energy from one element is transferred to one or more other elements.

coupling loss, *n*—the power loss caused by the coupling.

coupling ratio, *n*—the ratio of the output power to the input power.

covered tasks, *n*—an activity, identified by the operator, that is performed on a pipeline; is an operations and maintenance task; is performed as a requirement of this part and affects operation or integrity of the pipeline. F2349

critical angle, *n*—measured angle between the incident ray and the normal to the reflecting surface where total internal reflection begins.

DISCUSSION—Total internal reflection continues for all angles greater than the critical angle.

critical radius, *n*—the radius of curvature of an optical fiber containing an axially propagated light wave at which microbend losses begin to occur.

cross passage, *n*—*in tunneling*, a small tunnel used to connect between adjacent tunnel bores in a multiple-bore tunnel.

cross-sensitivity, *n*—the unwanted change of measured result due to the influence of physical factors other than the measured parameters.

crown, *n*—*in tunneling*, the highest point of the internal curved surface of a tunnel cross section.

culvert, *n*—small channel or drain used to carry water beneath an obstacle.

cured-in-place pipe, CIPP, *n*—a trenchless rehabilitation method used to repair existing pipelines.

DISCUSSION—The cured in place lining process consists of a flexible resin-saturated felt tube made of polyester or another resin, fiberglass cloth or a number of other materials suitable for resin impregnation, which is inverted or pulled into a damaged pipe. Little to no digging is involved in this trenchless process, which potentially allows this method to be more cost-effective and less disruptive than traditional "dig and replace" pipe repair methods. Once flexible resin impregnated lining is installed in damaged pipe, hot water, UV light, ambient cured or steam is used to cure the resin and form a tight-fitting, jointless and corrosion-resistant replacement pipe.

cutterhead, *n*—*in tunneling*, the head at the front of a tunnel boring machine used for cutting into the ground.

DISCUSSION—The cutterhead is designed for specific soil types, for example, hard rock, soft ground, high pressure, etc.

cut and cover tunnel, *n*—*in tunneling*, a method of tunnel construction involving excavating a trench, installing the structure and covering it over, generally used for shallow tunnels.

data link, *n*—a communication link suitable for transmission of data, which does not include the data source and the data sink.

decibel, dB, *n*—a gain or attenuation factor, measured as 10 times the log of a power ratio.

delay distortion, *n*—in a waveform or signal that contains two or more different frequencies, that is, different wavelengths, such as that occurs in the spectral width of an optical pulse, distortion caused by the difference in arrival times of the frequencies at the output of a transmission system, for example, as at the end of a fiber optic link.

demodulation, *n*—the extraction of the original signal from the carrier.

designated control point, DCP, *n*—specific documented locations in the pipeline system where the operations plan designates the control of gas. F2349

detector, *n*—a device that responds to a signal and reproduces the signal in a new form, usually in a form that is easier to process.

dewatering, *n*—the removal of water from soils, normally carried out with well points alone, or in combination with an impermeable cut-off wall.

diaphragm wall, *n*—a concrete retaining wall (usually reinforced) constructed by installing adjacent panels of concrete underground, using the following method: excavate panel opening under pressure from drilling mud; lower reinforcement cage into place (if applicable); pour concrete into the hole, displacing the drilling mud.

diffraction, *n*—the bending of radio, sound, or light waves around an edge; typically aperture edges.

diffuse reflectance spectroscopy, DRS, *n*—non-invasive technique that measures the characteristic reflectance spectrum produced as light passes through a medium, by measuring absorption and scattering.

discharge hose, *n*—a flexible tubing that facilitates outflow through which the hot water or steam condensate is released after flowing through the CIPP liner that is being cured.

discrete thermal elements, *n*—temperature monitoring components that are not continuous.

dispersion, *n*—*in optics*, wavelength dependent time-of-flight of an optical signal resulting from the fact that the index of refraction of a fiber is wavelength dependent, that is, if the refractive index, n, of a medium on the wavelength, l, then dispersion = dn/dl.

distance measurement range, *n*—maximum distance (specified in length units) from the DTS output connector along the

fiber optic sensor within which the instrument measures a temperature with specified measurement performance under defined conditions.

DISCUSSION—This supporting parameter is closely related to the attenuation range of the instrument. In test cases used to prove or verify the reported specifications, the total fiber length shall be equal to or greater than the specified distance measurement range (equal to or greater than twice the distance measurement range in the loop configuration).

distortion, *n—in electronics*, to reproduce or amplify (a signal) inaccurately by changing the frequencies or unequally changing the delay or the amplitude of the components of the output wave.

distributed acoustic sensing, DAS, *n*—a system using fiber optic cables to provide distributed strain sensing over its entire length.

distributed optical fiber sensing system, DOFSS, *n*—a system using optical fiber cable as a sensor, without discrete elements such as wound mandrels or fiber Bragg gratings, that is sensitive over its entire length to deliver spatially continuous and resolvable data on the desired measured parameters.

distributed temperature gradient sensing, DTGS, *n*—a system using optical fiber cable to measure temperature temporal and spatial gradients using thermal strain and thermo-optic effects.

distributed temperature sensing, DTS, *n*—devices which measure temperatures by means of optical fibers function as liner sensors, temperatures are measured along the optical sensor cable to provide a continuous profile.

distribution lines, *n*—a pipeline other than a gathering or transmission line. F2349

drift, *n*—a slow change in time of the monitoring characteristics of the measurement system.

drill and blast, *n—in tunneling*, the excavation of a tunnel, shaft, or cavern in rock using explosive charges place in holes drill in the face.

durability, *n*—a quality of a manufactured component of a measurement system or of the entire measurement system measured by how well it withstands a sustained period of specified operation.

earth pressure balance machine, EPBM, *n—in tunneling*, a type of tunnel boring machine which retains a prescribed amount of excavated soil in the cutterhead, in an effort to equal the pressure in front of the machine, this method reduces the risk of soil running into the machine causing excessive settlements above.

electromagnetic interference, EMI, *n*—the interference caused in a circuit by radiation through coupling.

electrostriction, *n—in optics*, physical mechanism that accounts for a material density change induced by an electric field in an isotropic body.

DISCUSSION—Electrostrictive pressure is the result of electrostriction, an acoustic wave created by the propagation of the two light waves, specifically the Stokes (probe) wave and the pump wave.

electro-optic device, *n*—a device that converts electronic signals to optic signals or optic signals to electronic signals.

emergency incident, *n*—an emergency incident may involve fire, damage to underground facilities, explosion, gas leak, injury, death, gas outage, district pressure problems, hazardous or toxic material spills, or response by fire, police, or other agencies. F2349

engineer, *n*—the licensed professional engineer registered in the state where the work is being done designated by the owner/operator of the utility or the tunnel, to represent the owner's/operator's interests during the ground movement monitoring process or pipe renovation process. F2303

environmental temperature repeatability, *n*—difference of the measured constant fiber optic sensor temperature at a specified instrument temperature (for example, nominal operating temperature) before and after temperature cycling of the instrument across the entire instrument operating temperature range.

environmental temperature stability, *n*—difference of the measured constant fiber optic sensor temperature before, during and after temperature cycling of the DTS instrument across the entire instrument operating temperature range.

DISCUSSION—Worst case environmental temperature effect, high/low environmental temperature effect, and environmental temperature repeatability are derived from this definition.

evanescent wave, *n*—the wave radiating away from the fiber at sharp bends in the optical fiber where the radius of the bend is less than the critical bending radius.

exfiltration, *n*—leaking or weeping to the external areas outside the barrier from a source inside the barrier. F2414

expanded gasket procedure, EGP, *n*—the sealing of joints, cracks, or holes by soaking dry, oil-free oakum with chemical grout and forcing the oakum/resin plug into the opening until it sets. F2414

expanded lining, *n—in tunneling*, primary lining that consists of segments that are expanded circumferentially against the surrounding ground.

extrados, *n*—the outside face of a structure element.

eye, *n—in tunneling*, the start of a tunnel, normally at a junction between a shaft and a tunnel.

Fabry Perot interferometer, *n*—a high resolution multiple beam interferometer especially sensitive to linear motion of the mirrors.

face dowel, *n—in tunneling*, a rod of steel or fiberglass inserted into the tunnel face to provide temporary support and assist in limiting face movement.

face loss, *n—in tunneling*, the loss of material from the face of a tunnel.

failure criteria of the sensor, *n*—the measurement uncertainty due to overstressing, overheating, and other factors leading to results or data that are unreliable.

fault, *n*—*in geology*, a crack in the earth's crust resulting from the displacement of one side with respect to the other on the scale of observation.

fiber, *n*—optical: any type of optical fiber.

fiber loss, *n*—power loss in an optical fiber, usually expressed in dB/km.

fiber optic, *n*—pertaining to optical fiber systems, such as sensors and communication systems.

fiber optic array, *n*—device that connects optical fibers to optical waveguide devices which are necessary for wavelength division multiplexing applications.

fiber optic cable, *n*—optical fibers incorporated into a cable.

fiber optic data link, *n*—a data link consisting of a modulated light source, a fiber optic cable, and a photo-detector.

fiber optic sensor, *n*—a sensor in which light is modulated by a specified environmental variable.

fiber optic sensor cable, *n*—cable formed using one or more strands of optical fiber to sense physical or other parameters of interest and/or transmit data.

fiber optic sheath, *n*—an outer protective covering over an optical fiber, or a cable.

fiber optic splice, *n*—a non-separable junction, usually formed by fusing the end of one optical to another.

fiber optics, FO, *n*—the theories and practices of using the technologies for control and guidance of optical power.

fiber to the x, FTTX, *n*—a generic term for any broadband network architecture using optic fiber to provide all or part of the local loop used for last mile communications.

frequency-division multiplexing, FDM, *n*—multiplexing in which the transmission frequency range is divided into narrow bands, each used as a separate channel.

fusion splicing, *v*—is the process of fusing or welding together two fibers, usually by an electric arc.

gas, *n*—*utilities*, natural gas. **F2350**

gauge length, GL, *n*—is the length of the measured structure over which the sensor gathers information. For example, if the sensor is anchored at two fixed points *L* cm apart, then the GL is *L*. If a sensor of length *l* is continuously-fixed in or to a measured structure of length *L*, then GL depends on the method of attachment to the measured structure and is a function of the mechanical properties of both the sensor and its surrounding; it is generally longer than *l* but shorter than, *L*.

graded-index fiber, *n*—an optical fiber with a refractive index that gets progressively lower as the distance increases along the normal to the fiber axis.

greenfield settlement, *n*—vertical downward movement of the ground solely due to the loss of soil caused by tunneling.

groundwater, *n*—water beneath the surface of the ground.

grout, *n*—*in soil and rock grouting*, a material injected into a soil or rock formation to change the physical characteristics of the formation, usually made of sand, water, and cement.

grout, *n*—*in tunneling*, a construction material used to improve ground conditions, fill voids in the ground or embed reinforcing bars, as well as fill the annulus between the excavated tunnel and the exterior of the final tunnel liner, usually made of sand, water, and cement.

heat differential, *n*—measurement of small temperature differences reliably performed by detecting the phase difference with the interference light and using a thermally symmetric configuration.

heterodyne detection, *n*—signal detection based on the mixing of two frequencies.

heterodyning, *n*—the mixing of an electromagnetic wave of one frequency with a wave of another frequency to produce a beat, usually for demodulation.

high/low environmental temperature effect, *n*—difference of the measured constant fiber optic sensor temperature at the high and low temperature limit of the instrument temperature operating range.

high-pressure distribution system, *n*—a distribution system in which the gas pressure in the main is higher than the pressure normally provided to the customer (that is, higher than utilization pressure). **F2350**

homodyne detection, *n*—signal detection based on the use of only one frequency.

homogeneous curing, *n*—equal curing rate in all directions and positions of a material.

host pipe, *n*—*in reference to CIPP*, the original damaged pipe containing the installed CIPP liner.

hot spot, *n*—length of fiber optic sensor (ΔL) which is exposed by a measurable temperature change ΔT which is significantly bigger than the instrument temperature repeatability and which is confirmed by reference temperature devices in the two thermal chambers.

hot tapping, *n*—a procedure for cutting or tapping into a gas pipeline under pressure. **F2349**

hydrophilic grout, *n*—grout that will absorb and react with the water it comes into contact with. **F2414**

hydrophobic grout, *n*—grout that will repel water. **F2414**

incident ray, *n*—a ray of light that strikes the surface of an object.

incident wave, *n*—a wave that impinges on a discontinuity, particle, or body, or on a medium having different propagation characteristics.