

# Glossary Of Laser Terminology

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## A

**Ablation:** The removal of material in industrial laser cutting, or tissue in medical laser cutting, by melting, evaporation, or vaporization.

**Absorb:** To transform radiant energy into a different form, with a resultant rise in temperature.

**Absorption:** Transformation of radiant energy to a different form of energy by the interaction of matter, depending on temperature and wavelength.

**Absorption Coefficient Factor:** Describes light's ability to be absorbed per unit of path length.

**Absorption of Radiation:** - Receiving electromagnetic radiation by interaction with the material, and transforming it to different form, which is usually heat (rise in temperature). The absorption process is dependent on the wavelength of the electromagnetic radiation and on the absorbing material.

**Accessible Emission Limit:** The maximum accessible emission level limit (AEL) permitted within a particular class. AEL is determined as the product of Accessible Emission times the Maximum Permissible Exposure (MPE) using the area of the limiting aperture (7 mm for visible and near infrared lasers).

**Accessible Emission:** The magnitude of accessible laser (or other collateral) radiation of a specific wavelength or emission duration at a particular point as measured by appropriate methods and devices. Also means radiation to which human access is possible in accordance with the definitions of the laser's hazard classification.

**Accessible Radiation:** Laser radiation that can expose human eye or skin in normal usage.

**Active Medium:** Collection of atoms or molecules which can be stimulated to a population inversion, and emit electromagnetic radiation in a stimulated emission.

**Adaptive Optics:** Recent advances in deformable mirror technology and laser guide stars allows most of the distortion produced by the atmosphere to be removed. This results in near diffraction-limited performance of ground-based receiving telescopes, giving image quality similar to that produced by the Hubble Space Telescope.

**Afocal:** Literally, "without a focal length"; an optical system with its object and image point at infinity.

**Aiming Beam:** A laser (or other light source) used as a guide light. Used coaxially with infrared or other invisible light, may also be a reduced level of the actual laser used for surgery or for other applications.

**Alignment:** Laser alignment is a measure of the deviation of the optical axis of the laser beam with respect to the mechanical axis of the laser housing. Some laser diode modules feature an adjustable alignment for precise positioning applications.

**Amplification:** The process in which the electromagnetic radiation inside the active medium within the laser optical cavity increases by the process of stimulated emission or amplification of the growth of the radiation field in the laser resonator cavity. As the light wave bounces back and forth between the cavity mirrors, it is amplified by stimulated emission on each pass through the active medium.

**Amplitude:** The maximum value of the electromagnetic wave, measured from the mean to the extreme; simply stated: the height of the wave.

**Angstrom:** A unit of measure of wavelength equal to  $10^{-10}$  meter, 0.1 nanometer, or  $10^{-4}$  micrometer; no longer widely used nor recognized in the SI system of units.

**Anode:** The positive electrode of a gas laser, used for electrical excitation of the gas in the tube.

**APD Avalanche Photodetector:** The solid-state equivalent of a PMT, usually restricted to operation in the red, near-infrared and infrared part of the spectrum. For photon-counting applications, they are operated in the so-called "Geiger Mode". The device is noisier than a PMT but has greater quantum efficiency. Maximum quantum efficiencies are about 80%.

**Aperture:** A small opening through which the electromagnetic radiation passes.

**Apparent Visual Angle:** The angular subtense of the source as calculated from the source size and distance from the eye. It is not the beam divergence of the source.

**AR Coatings:** Antireflection coatings are used on optical components to suppress unwanted reflections.

**Argon:** A gas used as a laser medium. It emits blue/green light primarily at 448 and 515 nm.

**Argon Laser:** A gas laser in which argon ions are the active medium. This laser emits in the blue - green visible spectrum, primarily at 488 and 515 nm..

**Articulated Arm:** CO<sub>2</sub> laser beam delivery device consisting of a series of hollow tubes and mirrors interconnected in such a manner as to maintain alignment of the laser beam along the path of the arm.

**Attenuation:** The decrease in radiation energy (power) as a beam passes through an absorbing or scattering medium.

**Autocollimator:** A single instrument combining the functions of a telescope and a collimator to detect small angular displacements of a mirror by means of its own collimated light.

**Average Power:** The total energy imparted during exposure divided by the exposure duration.

**Aversion Response:** Movement of the eyelid or the head to avoid an exposure to a noxious stimulant, such as bright light. It can occur within 0.25 seconds and it includes the blink reflex time. Aversion response action, such as closing of the eye or movement of the head, to avoid exposure to laser light

**Axial-Flow Laser:** A laser in which an axial flow of gas is maintained through the tube to replace those gas molecules depleted by the electrical discharge used to excite the gas molecules to the lasing.

**Axicon Lens:** A conical lens which, when followed by a conventional lens, can focus laser light to a ring shape.

**Axis/Optical Axis:** The optical centerline for a lens system; the line passing through the center of curvature of the optical surfaces of a lens.

## B

**Beam Bender:** A hardware assembly containing an optical device, such as a mirror, capable of changing the direction of a laser beam; used to re-point the beam and used in "folded", compact laser systems.

**Beam Diameter:** The distance between diametrically opposed points in the cross section of a circular beam where the intensity is reduced by a factor of  $1/e$  (0.368) of the peak level (for safety standards). The value is normally chosen at  $1/e^2$  (0.135) of the peak level for manufacturing specifications.

**Beam Divergence:** Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes-of-arc or approximately 1 mil). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.

**Beam Expander:** An optical device that increases beam diameter while decreasing beam divergence (spread). In its simplest form, consists of two lenses, the first to diverge the beam and the second to re-collimate it. Also called an upcollimator.

**Beam Splitter:** An optical device used to divide the light from a laser into two separate beams - the reference beam and the object beam. It consists of a partially transparent mirror that reflects part of the laser beam and transmits the rest.

**Beam:** A collection of rays that may be parallel, convergent, or divergent.

**Bins:** A bin has a bandpass filter response with certain frequency bandwidth. A spectral analysis requires the signal to be divided into a large number of bins. The signal power spectral density at each bin frequency is thereby measured.

**Blink Reflex:** (See Aversion Response).

**Brewster Windows:** Windows at the ends of a gas laser or windows in the transmissive end (or both ends) of the laser tube, made of transparent optical material and set at Brewster's angle in gas lasers to achieve zero reflective loss for one axis of plane.

**Brightness:** The visual sensation of the luminous intensity of a light source. The brightness of a laser beam is most closely associated with the radiometric concept of radiance.

## C

**Calorimeter:** An instrument which measures the energy, usually as heat, generated by absorption of the laser beam.

**Carbon Dioxide (CO<sub>2</sub>) Laser:** A gas laser in which CO<sub>2</sub> molecules are the active medium. This laser emits in the infrared spectrum, with the strongest emission line at 10.6  $\mu\text{m}$ . It can be operated in either CW or pulsed mode.

**Cathode:** The negative electrode of a gas laser used for electrical excitation of the gas in the tube.

**Closed Installation:** Any location where lasers are used which will be closed to unprotected personnel during laser operation.

**Coaxial Gas:** A shield of inert gas flowing over the target material to prevent plasma oxidation and absorption, to blow away debris, and to control heat reaction. The gas jet has the same axis as the beam so the two can be aimed together.

**Coherence:** A property of electromagnetic waves which are in phase in both time and space. Coherent light has monochromaticity and low beam divergence, and can be concentrated to high power densities. Coherence is needed for interference processes like holography.

**Coherence:** The alignment between light wave wavelength and the position of that wave in its oscillation cycle. When the crests and troughs of several light waves are in alignment, they are coherent.

**Collimated Light:** Light rays that are parallel. Collimated light is emitted by many lasers. Diverging light may be collimated by a lens or other device.

**Collimation:** Ability of the laser beam to not spread significantly (low divergence) with distance.

**Collimator:** Optical device consisting of two lenses separated by the sum of their focal length. It is used to provide desired beam diameter to meet specific beam delivery requirements.

**Combiner Mirror:** The mirror in a laser which combines two or more wavelengths into a coaxial beam.

**Continuous Mode:** The duration of laser exposure is controlled by the user (by foot or hand switch).

**Continuous Wave (CW) Constant:** Steady-state delivery of laser power: a laser which with a continuous output that is greater than or equal to 0.25 s.

**Continuous Wave:** Continuous Wave (CW) transmission is when there is an electromagnetic carrier wave present and the message signal, be it voice, video or data, is impressed upon the carrier by modulating its amplitude, phase or frequency. It is the system employed for terrestrial radio and TV transmissions. When the wave is unmodulated, the signal is highly monochromatic. The average power in the modulated wave is approximately that in the unmodulated carrier component.

**Controlled Area:** A locale where the activities of those within are subject to control and supervision for the purpose of laser radiation hazard protection.

**Convergence:** The bending of light rays toward each other, as by a positive (convex) lens.

**Corrected Lens:** A compound lens that is made measurably free of aberrations through the careful selection of its dimensions and materials.

**Crystal:** A solid with a regular array of atoms. Sapphire (Ruby Laser) and YAG (Nd:YAG laser) are two crystalline materials used as laser sources.

**Current Regulation:** Laser system regulation in which discharge current is kept constant.

**Current Saturation:** The maximum flow of electrical current in a conductor; in a laser, the point at which further electrical input will not increase laser output.

**CW:** Abbreviation for Continuous Wave; the continuous-emission mode of a laser as opposed to pulsed operation.

## D

**Depth of Field:** The working range of the beam in or near the focal plane of a lens; a function of wavelength, diameter of the unfocused beam, and focal length of the lens.

**Depth of Focus:** The distance over which the focused laser spot has a constant diameter and thus constant irradiance.

**Diachronic Filter:** Filter that allows selective transmission of colors desired wavelengths.

**Diffraction:** A wave property which creates deviation from a straight line when the beam passes near an edge of an opaque object. Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

**Diffraction Limited:** Electromagnetic waves diffract around the edges of opaque objects, or on passing through or reflecting off a finite aperture, like a dish, lens or mirror. Even if such a wave is perfectly collimated, so that the beam emitted is parallel, it will eventually spread out. The larger the aperture in relation to the wavelength, the smaller the beam spread. An electromagnetic beam is said to be "diffraction limited" when it is so collimated that it cannot be made more narrow in the near-field. Receivers are also said to be "diffraction limited" when the energy is focused into the smallest possible spot size at the focal plane. An optical receiver that is not "diffraction limited" may be said to be a "light bucket" - it collects photons, but cannot concentrate them into a very small tightly focused spot.

**Diffuse Reflection:** Takes place when different parts of a beam incident on a surface are reflected over a wide range of angles in accordance with Lambert's law. The intensity will fall off as the inverse of the square of the distance away from the surface, and also obey a cosine law of reflection.

**Diffuser:** An optical device or material that homogenizes the output of light causing a very smooth, scattered, even distribution over the area affected.

**Diode Laser:** A laser that emits coherent light through the injection of electric current into a semiconductor diode.

**Diode:** An electronic device that conducts a current in only one direction.

**Divergence:** The angular measurement of laser beam spread with distance. The projected dot of a laser will increase in size the farther it is projected. Laser divergence is measured in milliradians (mrad).

**Dosimetry:** Measurement of the power, energy, irradiance, or radiant exposure of light delivered to tissue.

**Drift (Angular):** Any unintended change in direction of the beam before, during, and after warm-up; measured in mrad.

**Drift:** All undesirable variations in output (either amplitude or frequency).

**Duty:** Cycle ratio of total "on" duration to total exposure duration for a repetitively pulsed laser.

## E

**Electric Vector:** The electric field associated with a light wave which has both direction and amplitude.

**Electromagnetic Radiation (Spectrum):** A wave which propagates in vacuum with the speed of light, and composed of simultaneous oscillations of electric field and magnetic field perpendicular to each other, and perpendicular to the direction of propagation of the beam. Created by accelerating electric charge, and includes X-rays, visible spectrum, infrared spectrum, microwave, etc.

**Electromagnetic Spectrum:** The range of frequencies and wavelengths emitted by atomic systems. The total spectrum includes radio waves as well as short cosmic rays. Frequencies cover a range from 1 Hz to perhaps as high as 1020 Hz.

**Electromagnetic Wave:** A disturbance which propagates outward from an electric charge that oscillates or is accelerated. Includes radio waves, X-rays, gamma rays; and infrared, ultraviolet, and visible light.

**Electron Volt [eV]:** A unit of energy: The amount of energy that the electron acquires while accelerating through a potential difference of 1 [Volt].  $1 \text{ [eV]} = 1.6 \times 10^{-19} \text{ [Joule]}$ .

**Electron:** Negatively charged particle of an atom.

**Embedded Laser:** A laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the system's lower classification is appropriate to the engineering features limiting accessible emission.



**Emergent Beam Diameter:** Diameter of the laser beam at the exit aperture of the system in centimeters (cm) defined at  $1/e$  or  $1/e^2$  irradiance points.

**Emission:** Act of giving off radiant energy by an atom or molecule.

**Emissivity:** The ratio of the radiant energy emitted by any source to that emitted by a blackbody at the same temperature.

**Emittance:** The rate at which emission occurs.

**Enclosed Laser Device:** Any laser or laser system located within an enclosure which does not permit hazardous optical radiation emission from the enclosure. The laser inside is termed an "embedded laser".

**Energy (Q):** The capacity for doing work. Energy is commonly used to express the output from pulsed lasers and it is generally measured in Joules (J). The product of power (watts) and duration (seconds). One watt-second = one Joule.

**Energy:** The product of power (watts) and duration (seconds). One watt-second = one Joule.

**Energy Source:** High voltage electricity, radio waves, flashes of light, or another laser used to excite the laser medium.

**Enhanced Pulsing:** Electronic modulation of a laser beam to produce high peak power at the initial stage of the pulse. This allows rapid vaporization of the material without heating the surrounding area. Such pulses are many times the peak power of the CW mode (also called "Superpulse").

**Excimer Laser:** A gas laser which emits in the UV spectrum. The active medium is an "Excited Dimer" which does not have a stable ground state.

**Excitation:** Energizing the active medium to a state of population inversion.

**Excited State:** Atom with an electron in a higher energy level than it normally occupies.

**Extended Source:** An extended source of radiation can be resolved into a geometrical image in contrast with a point source of radiation, which cannot be resolved into a geometrical image. A light source whose diameter subtends a relatively large angle from an observer.

## F

**Failsafe Interlock:** An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.

**Fan Angle:** The measure of angular spread of a line-generating laser. The fan angle determines the line length produced at a certain distance. CALPAC line-generating lasers have a 90° fan angle. A 90° fan angle will produce a line length that is 2x the projection distance (e.g. a 10 foot long line when projected from 5 feet).

**Femtoseconds :**  $10^{-15}$  seconds. 1 fs = 0.000,000,000,000,001 seconds.

**Fiber Optics:** A system of flexible quartz or glass fibers that use total internal reflection (TIR) to pass light through thousands of glancing (total internal) reflections.

**Film:** Whether photographic or holographic, film consists of light sensitive chemicals (the emulsion) spread on a surface. A film's resolution measures the ability to distinguish between details. Because holographic films must be able to record very detailed information, they have a resolving power of 50 or more times that of photographic film. They require either exposure to a high-intensity pulsed laser or a long exposure to a continuous wave laser. Holographic film is developed in a manner similar to photographic film, by bathing it in a series of chemical agents.

**Flash Lamp:** A tube typically filled with krypton or xenon. Produces a high intensity white light in short duration pulses.

**Fluence:** Fluence measures the laser energy absorbed per unit of area treated. Fluence is affected by beam energy / power density, laser pulse duration, wavelength and absorption of the tissue. Fluence is measured by Joules /  $\text{cm}^2$  and this equals laser pulse energy (J) divided by focal spot area ( $\text{cm}^2$ ).

**Fluorescence:** Emission of light of particular wavelength, as a result of absorption of light at shorter wavelength. It is a property of some materials; each material has a specific wavelength of absorption and emission.

**Flux:** The radiant, or luminous, power of a light beam; the time rate of the flow of radiant energy across a given surface.

**F-Number:** The focal length of lens divided by its usable diameter. In the case of a laser, the usable diameter is the diameter of the laser beam or a smaller aperture which restricts a laser beam.

**Focal Length:** Distance between the center of a lens and the point on the optical axis to which parallel rays of light are converged by the laser.

**Focal Point:** That distance from the focusing lens where the laser beam has the smallest diameter.

**Focus:** As a noun, the point where rays of light meet which have been reflected by a mirror or refracted by a lens, giving rise to an image of the source. As a verb, to adjust focal length for the clearest image and smallest spot size.

**Fraunhofer Lines:** Fraunhofer was the inventor of the diffraction grating. He assigned letters to the black absorption lines in the Solar Spectrum. These resonance lines arise from energy absorption by elements in the outer atmospheres of stars that are cooler than the stellar gases below.

**Frequency:** The number of times that the wave oscillates per second (the number of periods of oscillations per second). Also, the number of light waves passing a fixed point in a given unit of time, or the number of complete vibrations in that period of time.

## G

**Gain:** A measure of the increase in forward transmitter power of an antenna or telescope with respect to that of an isotropic radiator. An antenna is said to have a "directivity" since it directs more energy in one direction. It is proportional to the aperture area of the telescope and inversely proportional to the square of the wavelength. Even small optical telescopes can have very high gain, since the wavelength is so small. Typically a 10 meter diameter visible telescope has a gain of about 1015 (150 dB), while a 100 meter diameter microwave dish operating at 10 GHz has a gain of only 108 (80 dB). This is a difference of a factor of 107 (70 dB), i.e., 10 million times.

**Gas Discharge Laser:** A laser containing a gaseous lasing medium in a glass tube in which a constant flow of gas replenishes the molecules depleted by the electricity or chemicals used for excitation.

**Gas Laser:** A laser in which the active medium is a gas. The gas can be composed of molecules (like CO<sub>2</sub>), Atoms (like He-Ne) or ions (like Ar<sup>+</sup>).

**Gated Pulse:** A discontinuous burst of laser light, made by timing (gating) a continuous wave output, usually in fractions of a second.

**Gaussian Curve:** Statistical curve showing a peak with normal even distribution on either side. May either be a sharp peak with steep sides, or a blunt peak with shallower sides. Used to show power distribution in a beam. The concept is important in controlling the geometry of the laser impact.

**Ground State:** Lowest energy level of an atom or molecule.

## H

**Half-Power Point:** The value on either the leading or trailing edge of a laser pulse at which the power is one-half of its maximum value.

**Heat Sink:** A substance or device used to dissipate or absorb unwanted heat energy.

**Helium-Neon (He-Ne) Laser:** A gas laser in which Helium (He) and Neon (Ne) atoms are the active medium. This laser emits primarily in the visible spectrum, primarily at 633 [nm], but also have some lines in the near infrared. Used widely for alignment, recording, printing, and measuring.

**Hertz (Hz):** Unit of frequency in the International System of Units (SI), abbreviated Hz; replaces cps for cycles per second.

**Heterodyne Detection:** An interferometer in which the two signals differ in frequency and cause a beat frequency to be produced. Usually, one signal is a powerful local oscillator.

**Hologram:** An interference phenomena captured on a plate (or film). It can contain enormous amount of information and a three-dimensional image can be constructed from it. Unlike photography which records an image as seen from a single viewpoint, a hologram is a record of an image as seen from many viewpoints. Also, a photographic film or plate containing interference patterns created by the coherence of laser light. A three-dimensional image may be reconstructed from a hologram. There are transmission, reflection or integral holograms.

**Holography:** A medium for bending and focusing light that uses the interference of monochromatic objects and reference waves to record and reproduce multiple two-dimensional images for three-dimensional viewing.

## I

**Image:** The optical reproduction of an object, produced by a lens or mirror. A typical positive lens converges rays to form a "real" image which can be photographed. A negative lens spreads rays to form a "virtual" image which can't be projected.

**Incident Light:** A ray of light that falls on the surface of a lens or any other object. The "angle of incidence" is the angle made by the ray with a perpendicular (normal) to the surface.

**Infrared Radiation (IR):** Invisible electromagnetic radiation with wavelengths which lie within the range of wavelength from 700 nm to 1mm. This region is often broken up into IR-A, IR-B, and IR-C.

**Infrared Spectrum (IR):** Invisible electromagnetic radiation between 0.7-1,000 [ $\mu\text{m}$ ].

**Injection Laser:** See Diode Laser. A type of laser which produces its output from semiconductor materials such as GaAs.

**Integrated Radiance:** Product of the exposure duration times the radiance. Also known as pulsed radiance.

**Intensity:** The magnitude of radiant energy.

**Interference pattern:** When two waves overlap, their amplitudes add at every point. This results in an interference pattern which records the relative phase relationship between the two waves, storing each individual wave's characteristics. This is how a hologram works.

**Interferometer:** A system containing two or more signals that are combined in phase to cause interference.

**Interstellar Dispersion:** The velocity of propagation of electromagnetic waves depends upon frequency. Thus, unless the wave is highly monochromatic, the energy in the wave arrives at the receiver at differing times. This can severely limit the modulation bandwidth, since the process of modulating data onto an electromagnetic carrier wave broadens its bandwidth.

**Interstellar Scintillation:** Electromagnetic waves as they propagate through the interstellar media suffer frequency-selective fading. The resulting corrupted signal is said to undergo scintillation effects. The higher the modulation bandwidth the worse the effect.

**Intrabeam Viewing:** The viewing condition whereby the eye is exposed to all or part of a direct laser beam or a specular reflection.

**Ion Laser:** A laser in which the active medium is composed of ions of a noble gas (gas such as argon or krypton.). The gas is usually excited by high discharge voltage at the ends of a small bore tube.

**Ionizing Radiation:** Radiation commonly associated with X-ray or other high energy electromagnetic radiation which will cause DNA damage with no direct, immediate thermal effect. Contrasts with non-ionizing radiation of lasers.

**Irradiance (E):** Radiant flux (radiant power) per unit area incident upon a given surface. Units: watts per square centimeter. Sometimes referred to as power density.

**Irradiation:** Exposure to radiant energy, such as heat, X -rays, or light.

## J

**Joule (J):** A unit of energy (1 watt-second) used to describe the rate of energy delivery. It is equal to 1 watt-second or 0.239 calorie. A basic unit of energy. A 1 watt transmitter radiates 1 Joule of energy every second.  $\text{Joule/cm}^2$  is a unit of radiant exposure used in measuring the amount of energy incident upon a unit area.

## K

**KTP (Potassium Titanyl Phosphate):** A crystal used to change the wavelength of an Nd:YAG laser from 1060 nm (infrared) to 532 nm (green).

## L

**Lambertian Surface:** An ideal diffuse surface whose emitted or reflected radiance (brightness) is dependent on the viewing angle.

**Laser:** An acronym for Light Amplification by Stimulated Emission of Radiation. A laser device is an optical cavity, with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. A device which produces an intense beam of light with the unique properties of coherence, collimation and monochromaticity. Lasers can operate in the infrared, visible and ultraviolet regions of the optical spectrum. Some, called continuous wave lasers, produce a continuous beam of light. Others, called pulsed lasers, emit more light in brief pulses.

**Laser Accessories:** The hardware and options available for lasers, such as secondary gases, Brewster windows, Q-switches, electronic shutters, and optical components used to control laser radiation.

**Laser Class:** In order to regulate laser safety, the Center for Devices & Radiological Health (CDRH) classifies lasers into different categories based on wavelength and output power.

**Laser Diode Module:** A complete laser assembly including all circuits, a laser diode, and optics packaged in a protective housing. All that is required for operation is an appropriate external power supply.

**Laser Medium (Active Medium):** Material used to emit the laser light and for which the laser is named.

**Laser Oscillation:** The buildup of the coherent wave between laser cavity end mirrors producing standing waves.

**Laser Pulse:** A discontinuous burst of laser radiation, as opposed to a continuous beam. A true laser pulse achieves higher peak powers than that attainable in a CW output.

**Laser Rod:** A solid-state, rod-shaped lasing medium in which ion excitation is caused by a source of intense light (optical pumping) such as a flashlamp. Various materials are used for the rod, the earliest of which was synthetic ruby crystal.

**Laser Safety Officer (LSO):** One who has authority to monitor and enforce measures to the control of laser hazards, and effect the knowledgeable evaluation and control of laser hazards.

**Laser System:** An assembly of electrical, mechanical, and optical components which includes a laser. Under the U.S. Federal Standard, a laser in combination with its power supply (energy source).

**Leading Edge Spike:** The initial pulse in a series of pulsed laser emissions, often useful in starting a reaction at the target surface. The trailing edge of the laser power is used to maintain the reaction after the initial burst of energy.

**Lens:** A curved piece of optically transparent material which depending on its shape is used to either converge or diverge light.

**Lenses:** Lenses are devices that redirect light. In photography, lenses are used to focus an image for the film. Holographers use lenses to widen a laser's beam to illuminate the entire object being holographed.

**Light:** Usually refers to the visible spectrum. The range of electromagnetic radiation frequencies detected by the eye, or the wavelength range from about 400 to 700 nanometers. The term is sometimes used loosely to include radiation beyond visible spectrum limits.

**Light Bucket:** An optical receiving telescope that collects photons but is not diffraction limited. Its effective field-of-view is larger than a diffraction limited telescope and cannot discriminate particularly well from background noise photons. This may not be a problem if the expected pulsed laser beacon signal is very strong.

**Light Regulation:** A form of power regulation in which output power is monitored and maintained at a constant level by controlling discharge current.

**Limiting Angular Subtense:** The apparent visual angle which divides intrabeam viewing from extended-source viewing.

**Limiting Aperture:** The maximum circular area over which radiance and radiant exposure can be averaged when determining safety hazards.

**Limiting Exposure Duration:** An exposure duration which is specifically limited by the design or intended use(s).

**Longitudinal (Axial) Modes:** Specific wavelengths in the laser output, determined by standing waves within the laser cavity. Only longitudinal modes under the laser gain curve, above the laser threshold, are found in the laser output. Individual longitudinal modes are produced by standing waves within a laser cavity.

**Lossy Medium:** A medium which absorbs or scatters radiation passing through it.

## M

**Mach-Zehnder Interferometer (MZI):** The most common form of interferometer consisting of a fiber optic or integrated optic device that contains an optical power splitter and combiner. There are two distinct optical paths between the power splitter and combiner. Optical interference takes place at the power combiner, so that phase modulation introduced into either of the two arms or paths in the interferometer, produces phase to intensity conversion at the output of the interferometer.

**Maximum Permissible Exposure (MPE):** The level of laser radiation to which person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

**Meniscus Lens:** A lens which has one side convex, the other concave.

**Metastable State:** The state of an atom, just below a higher excited state, which an electron occupies momentarily before destabilizing and emitting light. The upper of the two lasing levels.

**Micrometer:** A unit of length in the International System of Units (SI) equal to one millionth of a meter. Often referred to as a "micron".

**Micron:** An abbreviated expression for micro meter which is the unit of length equal to 1 millionth of a meter ( $10^{-6}$  [m]).

**Microprocessor:** A digital chip (computer) that operates, controls, and monitors some lasers.

**Milliamperes (mA):** A unit of electrical current equal to one-thousandth of an ampere.

**Milliradian (mrad):** A unit of angular measure equal to one thousandth of a radian (1 radian = 57.295 degrees). 1 milliradian [mrad] = 0.057°.



**Milliwatt (mW):** A unit of power equal to one-thousandth of a watt.

**Mode locked:** A method of controlling the length of the output laser pulse. Produces very short ( $10^{-12}$  [sec]) bursts of pulses.

**Mode:** A term used to describe how the power of a laser beam is geometrically distributed across the cross section of the beam. Also used to describe the operating mode of a laser such as continuous or pulsed.

**Modulation:** The ability to superimpose an external signal on the output beam of the laser as a control.

**Monochromatic Light:** Theoretically, light at one specific wavelength. Practically, light with very narrow bandwidth. The light out of a laser is the most monochromatic source known. No light is absolutely single frequency since it will have some bandwidth. Lasers provide the narrowest of bandwidths that can be currently achieved.

**Multichannel Scaler:** An instrument with a large number of channels for analyzing a signal in small time slots. Used for nuclear, particle and photon counting.

**Multichannel Spectrum Analyzer (MCSA):** An instrument with a large number of channels for analyzing a signal in small frequency bins. Used for rapid radio frequency analysis.

**Multimode:** Laser emission at several closely spaced frequencies.

## N

**Nanometer (nm):** A unit of length in the International System of Units (SI) equal to one billionth of a meter. Is the usual measure of light wavelengths. Visible light ranges from about 400 nm in the purple to about 700 nm in the deep red.

**Nanosecond:** One billionth of a second. Longer than a picosecond or femtosecond, but shorter than a microsecond. Associated with Q-switched lasers.

**Nd:Glass Laser:** A solid-state laser of neodymium glass offering high power in short pulses in which a Nd doped glass rod is used as a laser active medium, to produce 1064 nm wavelength.

**Nd:YAG Laser:** A solid-state laser in which Neodymium doped Yttrium Aluminum Garnet is used as a laser active medium, to produce 1064 nm wavelength. YAG is a synthetic crystal.

**Near Field Imaging :**A solid-state laser imaging technique offering control of spot size and hole geometry, adjustable working distance, uniform energy distribution, and a wide range of spot sizes.

**Neodymium (Nd):** The rare earth element that is the active element in Nd:YAG lasers and Nd:Glass lasers.

**Noise:** Unwanted minor currents or voltages in an electrical system.

**Nominal Hazard Zone (NHZ):** The nominal hazard zone describes the space within which the level of the direct, reflected, or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

**Nominal Ocular Hazard Distance (NOHD):** The axial beam distance from the laser where the exposure or irradiance falls below the applicable exposure limit.

## O

**Object:** The subject matter or figure imaged by, or seen through, an optical system.

**Object beam:** The light from a laser beam that illuminated the object and is reflected to the holographic film.

**Opacity:** The condition of being non-transparent.

**Open Installation:** Any location where lasers are used which will be open to operating personnel during laser operation and may or may not specifically restrict entry to observers.

**Operating Voltage:** The range of specified input voltage required to operate a laser. Laser operating voltage is measured in volts (V).

**Operation:** The performance of the laser or laser system over the full range of its intended functions (normal operation).

**Optic Disc:** The portion of the optic nerve within the eye which is formed by the meeting of all the retinal nerve fibers at the level of the retina.

**Optical:** That part of the electromagnetic spectrum covering the spectral range from the far-infrared to the ultra-violet. It is a superset of the visible and infrared spectral regimes.

**Optical Cavity (Resonator):** Space between the laser mirrors where lasing action occurs.

**Optical Density:** A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

**Optical Fiber:** A filament of quartz or other optical material, capable of transmitting light along its length by multiple internal reflections and emitting it at the end.

**Optical Pumping:** - The excitation of the active medium in a laser by the application of light, rather than electrical discharge. Light can be from a conventional source like Xenon or Krypton lamp, or from another laser.

**Optical Resonator:** - The mirrors (or reflectors) making up the laser cavity including the laser rod or tube. The mirrors reflect light back and forth to build up amplification.

**Optically Pumped Lasers:** A type of laser that derives energy from another light source such as a xenon or krypton flashlamp or other laser source.

**Output Coupler:** The part of the laser which enable light to come out of the laser. Usually it is a partially reflecting mirror at the end of the laser optical cavity.

**Output Power:** The energy per second (measured in watts) emitted from the laser in the form of coherent light.

## P

**Phase:** The position of a wave in space, measured at a particular point in time. Waves are in phase with each other when all the troughs and peaks coincide and are "locked" together. The result is a reinforced wave in increased amplitude (brightness).

**Phased-Array Receiver:** A collection of spaced antennas, dishes, mirrors or lenses that when the individuals signals collected are properly summed in the correct phase, can act in unison with the diffraction-limited beam performance of a single element as large as the extreme dimensions of the array. This is also sometimes referred to as an "interferometer".

**Phased-Array Transmitter:** A collection of spaced antennas, dishes, mirrors or lenses that when properly excited in the correct phase, can act in unison with the diffraction-limited beam performance of a single element as large as the extreme dimensions of the array.

**Photocoagulation:** Use of the laser beam to heat tissue below vaporization temperatures with the principal objective being to stop bleeding and coagulate tissue.

**Photometer:** An instrument which measures luminous intensity.

**Photon:** In quantum theory, the elemental unit of light, having both wave and particle behavior. It has motion, but no mass or charge. The photon energy (E) is proportional to the EM wave frequency ( $\nu$ ) by the relationship  $E=h\nu$ , where "h" is Planck's constant ( $6.63 \times 10^{-34}$  Joule-sec). Also, particle with energy equal to a single quanta. The energy of the particle is proportional to frequency. Electromagnetic energy may sometimes be considered to be wave-like, and at other

times, particle-like. At frequencies above the millimeter-wave band, the energy is more often considered to be carried by photons, rather than by waves. The energy in a photon is given by the product  $h \times f$ , where  $h$  is Planck's constant and  $f$  is the frequency. Usually, radio-frequency energy is not described in terms of photons due to the fact that even for very low intensities, the number of radio-frequency photons arriving per second is large and receiver system noise is dominated by the thermal  $kT$  component, where  $k$  is Boltzmann's constant ( $1.38 \times 10^{-23}$  J/K) and  $T$  is the temperature in degrees K. Since optical frequencies are some five orders of magnitude higher than microwave frequencies, each optical photon is far more energetic than its microwave counterpart. Optical receiver noise is often dominated by the quantum  $hf$  component.

**Photonics:** The electronic technology involving light and photons at all wavelengths between the far-infrared and the ultra-violet. Also called "Optoelectronics".

**Photosensitizers:** Chemical substances or medications which increase the sensitivity of the skin or eye to irradiation by optical radiation, usually to UV.

**Picosecond:** A period of time equal to  $10^{-12}$  seconds.

**Pigment Epithelium:** A layer of cells at the back of the retina containing pigment granules, i.e., a cloud of charged particles surrounding a laser impact.

**Plasma Shield:** The ability of plasma to stop transmission of laser light.

**PMT Photomultiplier Tube.** A low-noise vacuum device requiring high voltages to accelerate electrons and producing very high gains. Can detect individual photons. One detected photon on the photo-cathode can produce a very short pulse containing millions of photoelectrons. PMTs usually operate between the blue and red regions of the visible spectrum, with greater quantum efficiency in the blue-green region, depending upon photo-cathode materials. Maximum quantum efficiencies are about 25%.

**Pockel's Cell :** An electro-optical crystal used as a Q-switch.

**Point Source:** Ideally, a source with infinitesimal dimensions. Practically, a source of radiation whose dimensions are small compared with the viewing distance.

**Pointing Errors:** Beam movement and divergence, due to instability within the laser or other optical distortion.

**Polarization:** Vibration of the electric field vector in specific direction perpendicular to the direction of propagation of the wave. Also, restriction of the vibrations of the electromagnetic

field to a single plane, rather than the innumerable planes rotating about the vector axis. Various forms of polarization include random, linear, vertical, horizontal, elliptical and circular.

**Polarized Light:** They are nonstandard on industrial lasers, but some polarizing element must be used if a polarized output is desired.

**Population Inversion:** A state in which a substance has been energized, or excited, so that more atoms or molecules are in a higher excited state than in a lower resting state. This is a necessary prerequisite for laser action.

**Power:** The rate of energy delivery in a unit of time, expressed in watts (Joules per second).

Thus: 1 [Watt] = 1 [Joule]/1 [sec].

**Power Density:** Laser output per unit area, such as watts per square centimeter ( $W/cm^2$ ).

**Power Meter:** An accessory used to measure laser beam power.

**Protective Housing:** A protective housing is a device designed to prevent access to radiant power or energy.

**Pulse Duration:** The "on" time of a pulsed laser. It may be measured in terms of millisecond, microsecond, or nanosecond as defined by half-peak-power points on the leading and trailing edges of the pulse.

**Pulse Frequency:** The rate at which pulses are generated. Pulse frequency is expressed in pulses per second (Hz).

**Pulse Length:** Time, expressed in fractions of seconds, in which energy is delivered.

Application Report shows the electrical input pulse length, which corresponds to the half height of the leading and trailing edges of the optical pulse.

**Pulse Mode:** Operation of a laser when the beam is intermittently on in fractions of a second.

**Pulse Modulation:** A method akin to digital modulation where the intensity of a carrier is modulated between two states, either maximum or zero. If the pulse width is small and the repetition rate slow, the peak power in the pulse can be vastly above that of the mean power. For instance, if a pulse of 1 nanosecond ( $10^{-9}$  sec) duration is transmitted every second, then the peak power is 1 billion times or 109 (90 dB) above the mean power. It is very easy for this "lighthouse" laser beacon to outshine a star during each brief flash. During each flash, the rate at which photons arrive at the receiver is much higher than from the stellar or sky backgrounds. For the example given, this ratio can be as high as 10 million times.

**Pulse Position Modulation (PPM):** A means of encoding digital data by varying the position of a bit in a word that has M bit positions.

**Pulse Repetition Frequency (PRF) or Rate:** The number of pulses produced per second by a laser.

**Pulse:** A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.

**Pulsed Laser:** A laser which delivers energy in the form of a single pulse, or train, of laser pulses.

**Pulsing:** Electrical modulation of a laser power supply to produce discreet pulses of energy at a given pulse length and pulse period (pulse repetition rate).

**Pump:** To excite the lasing medium. Pumping Addition of energy (thermal, electrical, or optical) into the atomic population of the laser medium, necessary to produce a state of population inversion.

## Q

**Q-Switch:** A device that has the effect of a shutter to control the laser resonator's ability to oscillate. Control allows one to spoil the resonator's "Q-factor", keeping it low to prevent lasing action. When a high level of energy is stored, the laser can emit a very high-peak-power pulse.

**Q-Switched Laser:** A laser which store energy in the active medium, to produce short pulse with high energy. It is done by blocking the resonator ability to oscillate, keeping the "Q-Factor" of the optical cavity low.

**Quantum Efficiency:** The ratio of hole-electron pairs or photoelectrons to the number of photons received by a photodetector. The quantum efficiency can be as high as 80% for an APD and 25% for a PMT.

## R

**Radian:** A unit of angular measure equal to the angle subtended at the center of a circle by a chord whose length is equal to the radius of the circle.

**Radiance Brightness:** The radiant power per unit solid angle and per unit area of a radiating surface.

**Radiant Energy (Q):** Energy in the form of electromagnetic waves usually expressed in units of Joules (watt-seconds).

**Radiant Energy:** Laser energy emitted, expressed in joules (J).

**Radiant Exposure (H):** The total energy per unit area incident upon a given surface. It is used to express exposure to pulsed laser radiation in units of  $\text{J}/\text{cm}^2$ .

**Radiant Flux:** The time rate of flow of radiant energy in units-watts: One [1] watt = 1 Joule-per-second. The rate of emission or transmission of radiant energy.

**Radiant Intensity:** The radiant power expressed per unit solid angle about the direction of the light.

**Radiant Power:** Laser power emitted, expressed in watts (W).

**Radiation:** In the context of optics, electromagnetic energy is released; the process of releasing electromagnetic energy.

**Radiometry:** A branch of science which deals with the measurement of radiation.

**Rayleigh Scattering:** Scattering of radiation in the course of its passage through a medium containing particles, the sizes of which are small compared with the wavelength of the radiation.

**Reference Beam:** The portion of a laser beam that goes directly to the holographic film. The interference pattern that results from the object beam meeting the reference beam at the holographic film is recorded on the film.

**Reflectance Reflectivity:** The ratio of the reflected radiant power to the incident radiant power.

**Reflection:** The return of radiant energy (incident light) by a surface, with no change in wavelength.

**Reflection Hologram:** One that forms an image by reflected light. Reflection holograms are lit from the front, reflecting the light to the viewer.

**Refraction:** The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. The bending of incident rays as they pass from one medium to another (e.g., air to glass).

**Repetitively Pulsed Laser:** A laser with multiple pulses of radiant energy occurring in sequence with a PRF  $> 1$  Hz.

**Resonator:** The mirrors (or reflectors) making up the laser cavity, including the laser rod or tube. The mirrors reflect light back and forth to build up amplification.

**Rotating Lens:** A beam delivery lens designed to move in a circle and thus rotate the laser beam around a circle.

**Ruby Laser:** The first laser type; a crystal of sapphire (aluminum oxide) containing trace amounts of chromium oxide as an active medium.

## S

**Scanning Laser:** A laser having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.

**Scintillation:** This term is used to describe the rapid changes in irradiance levels in a cross section of a laser beam produced by atmospheric turbulence.

**Secured Enclosure:** An enclosure to which casual access is impeded by an appropriate means (e.g., door secured by lock magnetically or electrically operated, by a latch, or by screws).

**Semiconductor Laser:** (See Diode Laser). A type of laser which produces its output from semiconductor materials such as GaAs.

**Solid Angle:** The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians (sr).

**Solid State Laser:** A laser in which the active medium is in solid state (usually not including semiconductor lasers).

**Source:** The term "source" means either laser or laser-illuminated reflecting surface, i.e. source of light.

**Spectral Response:** The response of a device or material to monochromatic light as a function of wavelength.

**Specular Reflection:** A mirror-like reflection.

**Spontaneous Emission:** Decay of an excited atom to a ground or resting state by the random emission of one photon. The decay is determined by the lifetime of the excited state.

**Spot Size:** The mathematical measurement of the radius of the laser beam.

**Stability:** The ability of a laser system to resist changes in its operating characteristics. Temperature, electrical, dimensional, and power stability are included.

**Steradian (sr):** The unit of measure for a solid angle.

**Stimulated Emission:** Coherent emission of radiation, stimulated by a photon absorbed by an atom (or molecule) in its excited state. Also, when an atom, ion, or molecule capable of lasing is



excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same energy, the second atom will be stimulated to emit a photon.

**Superpulse:** Electronic pulsing of the laser-driving circuit to produce a pulsed output (250-1000 times per second), with peak powers per pulse higher than the maximum attainable in the continuous wave mode. Average powers of superpulsed lasers are always lower than the maximum in continuous wave. Process often used on CO<sub>2</sub> surgical lasers.

## T

**TEA Laser:** An acronym for Transversely Excited Atmospheric laser. This CO<sub>2</sub> gas laser uses a transverse flow of gas and operates at higher pressures than other gas lasers, generally near atmospheric pressure. The result is a higher energy beam.

**TEM: Abbreviation for Transverse Electromagnetic Modes.** Used to designate the cross-sectional shape of the beam. The radial distribution of intensity across a beam as it exits the optical cavity.

**TEM<sub>00</sub>:** The lowest order transverse mode possible. The power distribution across the beam is of a bell-shaped (Gaussian) shape.

**Thermal Relaxation Time:** The time to dissipate the heat absorbed during a laser pulse.

**Threshold:** The input level at which lasing begins during excitation of the laser medium.

**Transmission:** Passage of electromagnetic radiation through a medium.

**Transmission Hologram:** One that forms an image from the light passing through the holographic emulsion. Transmission holograms are lit from behind, bending the light as it passes through the hologram to your eyes.

**Transmittance:** The ratio of transmitted radiant energy to incident radiant energy, or the fraction of light that passes through a medium.

**Transverse Electro-Magnetic (TEM) Mode:** Used to designate the shape of a cross section of a laser beam.

**Transverse Mode:** The geometry of the power distribution in a cross section of a laser beam.

**Tunable Dye Laser:** A laser whose active medium is a liquid dye, pumped by another laser or flash lamps, to produce various colors of light. The color of light may be tuned by adjusting optical tuning elements and/or changing the dye used.

**Tunable Laser:** A laser system that can be "tuned" to emit laser light over a continuous range of wavelengths or frequencies.

## U

**Ultraviolet (UV) Radiation:** Electromagnetic radiation with wavelengths between soft X-rays and visible violet light, often broken down into UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (100-280 nm).

## V

**Vaporization:** Conversion of a solid or liquid into a vapor.

**Vignetting:** The loss of light through an optical element when the entire bundle of light rays does not pass through; an image or picture that shades off gradually into the background.

**Visible Radiation:** Light - electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths which lie in the range between 400 nm and 700 nm. The peak of the human spectral response is about 555 nm.

## W

**Wall Plug Efficiency:** The ratio of the transmitter output power, be it microwave or optical, to the (electrical) power consumed by the transmitter.

**Watt/cm<sup>2</sup>:** A unit of irradiance used in measuring the amount of power per area of absorbing surface, or per area of CW laser beam.

**Watt:** A unit of power (equivalent to one Joule per second) used to express laser power.

**Wave:** A sinusoidal undulation or vibration; a form of movement by which all radiant electromagnetic energy travels.

**Wavelength:** The length of the light wave, usually measured from crest to crest, which determines its color. Common units of measurement are the micrometer (micron), the nanometer, and the Angstrom unit.

**White Light:** Light that contains most of the wavelengths in the visible spectrum, such as light from the sun or from a spotlight. White light is incoherent, while laser light is coherent. A white light transmission hologram, or rainbow hologram, is one which can be displayed using ordinary white light. Early holograms required viewing with coherent laser light.

**Window:** A piece of glass (or other material) with plane parallel sides which admits light into or through an optical system and excludes dirt and moisture.

## X

**X-ray Laser:** A device that uses stimulated emission to produce coherent X-rays.

## Y

**YAG (Yttrium Aluminum Garnet):** A widely used solid-state crystal which is composed of yttrium and aluminum oxides which is doped with a small amount of the rare-earth neodymium.

## Z

**Z-Cavity:** A term referring to the shape of the optical layout of the tubes and resonator inside a laser.

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