Fiber Optics Standard Dictionary

Second Edition

Martin H. Weik, D.Sc.

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Preface

The first edition of this dictionary was written during the years preceding 1980. No fiber optics glossary had been published by any recognized standards body. No other dictionaries in fiber optics had been published. A significant list of fiber optics terms and definitions, NBS Handbook 140, *Optical Waveguide Communications Glossary,* was issued in 1982 by the National Bureau of Standards, now the National Institute of Standards and Technology. Since then several publications by standards bodies contained fiber optics terms and definitions. In 1984 the Institute of Electrical and Electronic Engineers published IEEE Standard 812–1984, *Definitions of Terms Relating to Fiber Optics*. In 1986 the National Communication System published Federal Standard FED-STD-1037A, *Glossary of Telecommunication Terms,* containing about 100 fiber optics terms and definitions. In 1988 the Electronic Industries Association issued EIA-440A, *Fiber Optic Terminology*. All of these works were based on NBS Handbook 140 compiled 10 years earlier.

Currently the International Electrotechnical Commission is preparing IEC Draft 731, *Optical Communications, Terms and Definitions.* Work in fiber optics terminology is being contemplated in the International Organization for Standardization and the International Telecommunications Union. None of these works constitutes a comprehensive coverage of the field of fiber optics. Each was prepared by professional people representing specific interest groups. Each work was aimed at specific audiences: research activities, development activities, manufacturers, scientists, engineers, and so on. Their content is devoted primarily to fundamental scientific and technical principles and theory rather than state-of-the-art and advanced technology. Also, for a definition to be approved by committee and survive "public" review, quite often a great deal of explanatory material, examples, illustrations, and cross-references were not appended to what was called "the defining phrase." The author of this dictionary chaired over a dozen vocabulary committees in computers, communication, and information processing at international, national, federal, military, and technical society levels. He is currently serving as a consultant in fiber optics and is engaged in the preparation of military handbooks, specifications, and standards that include fiber optics glossaries such as MIL-STD 2196(SH), *Glossary Fiber Optics,* for the U.S. Navy.

Every effort was made to ensure that this dictionary be consistent with published and draft international, national, federal, industrial, and technical society standards. This comprehensive dictionary goes far beyond the combined scopes and content of the published and pending vocabulary standards. The combined standards embrace several hundred terms and definitions. This dictionary embraces several thousand. Obsolete material in the first edition has been omitted from this edition. Thousands of examples, explanations, diagrams, illustrations, and tables have been included. The latest fiber optics scientific and technical literature have been scoured for new terms and concepts. Fiber optic component and system manufacturer's technical characteristics and specifications were screened for common terms and definitions. Though not strictly fiber optics terms, some terms were included to support the definitions of fiber optics terms. These efforts have yielded hundreds of new fiber optics terms for which definitions were written based on context and the author's knowledge of the subject. Textbooks also provided source material for this dictionary. Lastly, much material originated from the spoken and written words of researchers, designers, developers, operators, manufacturers, and educators with whom the author has associated during the 10 years he has worked in the fiber optics field. The author developed terminology for the U.S. Military Communications-Electronics Board, and the National Communications System. He supported the Fiber Optic Sensors Program at the U.S. Naval Research Laboratory, the U.S. Navy Undersea Surveillance Program in fiber optics at the Space and Naval Warfare Systems Command, and the Fiber Optics Program of the Naval Sea Systems Command.

A final word on organization of this dictionary. Italicised words used in definitions are used in the sense defined in this dictionary. Each word in a multiple-word entry is cross-referenced to the definition of the complete entry. For example, under *modal power distribution* there is a "See" reference to *nonequilibrium modal power distribution*. "Also see" is used to refer the reader to closely related terms and definitions. Synonyms are referenced to the preferred term, where the definition will be found. Only the preferred terms are used in definitions. Preference is based on the recommendations of standards bodies contained in their published works.

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The writing and publishi [illegible] ry took several years, during which time the author encountered many new terms and definitions. These appear in the appendix so that the reader will have the latest word in fiber optics. The author is convinced, and hopes the reader will agree, that this dictionary will serve as the best ready-reference available today for learning, understanding, and retaining concepts in fiber optics science and technology.

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Introduction

Fiber optic technology has advanced faster and further during the 1980s than even the most optimistic workers in the field dared to predict. Hundreds of thousands of kilometers of fiber optic cable containing millions of kilometers of operational optical fibers have been installed in over a hundred countries. Fiber optic cables pulled in underground conduits, buried in ploughed trenches, strung on overhead poles, and installed in building shafts and plenums are carrying analog and digital audio, video, and data signals in long-haul trunks, metropolitan-area networks, local-area networks, and local loops. Each cable is capable of carrying tens of thousands of messages simultaneously, using time-division, frequency-division, wavelength-division, and space-division multiplexing schemes. Current trends show that optical fiber is being installed in local loops entering homes and offices. Optical fiber is competing heavily with twisted-pair wire, coaxial cable, microwave, and satellite communication systems. Studies have shown that the cost of replacing electronic systems with fiber optic systems can be recovered in a relatively short time. One such study showed that a single optical fiber to a home or office can provide sufficient transmission capacity for 50 analog broadcast-quality video channels, 4 high-definition television (HDTV) channels, 4 switched digital video channels, 25 digital audio channels, and many other miscellaneous voice, data, and service channels simultaneously without interference or crosstalk.

Experts predict that the majority of communication traffic will be fiber optic by the year 2010. Over $200 billion in new broadband systems will be installed by then. Bandwidth, a severely limited commodity at premium cost in electronic systems will effectively be "free" in fiber optic systems once a system is installed. For example, by the year 2003, experts predict integrated-services digital networks (ISDNs) will provide many gigahertz of bandwidth and many gigabits per second of data signaling rate per dollar of investment. Integrated optical circuits (IOCs) will sell for $5 each. Optical fiber will be down to 5 cents a meter, cheaper than wire and with almost unlimited traffic capacity. By the year 2000, experts predict over 600 billion voice circuit-kilometers will be on fiber, 160 billion on satellite, 16 on microwave, and 3 billion on coaxial cable, worldwide.

Why such a rapid conversion and installation rate? The primary force is economic. Fiber presents a lower cost per message-kilometer and a lower cost per bit-kilometer/second. Overall costs, including acquisition, installation, and operational, for fiber systems will be far below those of their electronic counterparts. Besides the advantage of lower cost, fiber systems have many other advantages over electronic systems. Fiber systems show almost unlimited traffic capacity; long repeaterless links; no interference or crosstalk between channels; no return circuits and ground loops; improved safety; lighter weight; reduced space; less power; longer life; high resistance to fire damage; less hazard to personnel, explosives, combustibles, and other equipment; easier installation; fewer strategic materials; and reduced documentation requirements. These advantages of fiber systems create a tremendous pressure to move rapidly toward "fiberization." The conversion and installation pace depends on many factors, including availability of capital, off-the-shelf components, knowledgeable personnel, and documentation, including standards. Confidence in the reliability and dependability of fiber optic systems has to be proven, just as in the case of electronic computers, before a particular group or organization will use fiber optic systems to meet its requirements.

Optical fibers have many other uses besides communication and data transfer. Some of these applications include sensing systems, medical instrumentation, illumination devices, display systems, and inspection devices. Components for these applications are already on the market, and the list is growing. As in all new and expanding technologies, starting in earlier days with power machinery, telegraph, and telephone, and later radio and television, the percentage of the population engaged in activities related to fiber optics will continue to increase for decades to come.

This comprehensive dictionary provides sufficient information to thoroughly familiarize anyone with the science and technology of fiber optics. At the same time it provides proper terminology and usage for students, teachers, scientists, engineers, writers, sales persons, designers, developers, manufacturers, installers, repairers, operators, and others in related fields, such as law and medicine. It is written with technical precision in theory and principles for the experienced professional and with explanations, examples, illustrations, and cross-references in laymen's language for the newcomer to the field of fiber optics. Most importantly it is consistent with international, national, federal, military, industrial, and technical society fiber optics vocabulary standards.

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The author extends his appreciation to all members of the staffs of the Defense Communications Agency (DCA), the National Communications System (NCS), the Military Communications-Electronics Board (MCEB), the Naval Research Laboratory (NRL), the Space and Naval Warfare Systems Command (SPAWARSYSCOM), the Naval Sea Systems Command (NAVSEASYSCOM), and Dynamic Systems, Incorporated (DSI), with whom he was associated during the many years of preparation of the first and second editions of this dictionary.

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MARTIN H. WEIK, D.SC.

A

aberration. See *chromatic aberration.*

absolute luminance threshold. The lowest limit of *luminance* necessary for visual perception to occur in a person with normal or average vision.

absolute luminosity curve. The plot of *spectral luminous efficiency* versus *optical wavelength.*

absorptance. See *spectral absorptance.*

absorption. In the *transmission* of *signals,* such as electrical, *electromagnetic optical,* and acoustic signals, the conversion of the transmitted energy into another form of energy, such as heat. Signal *attenuation* is not only a consequence of absorption, but also of other phenomena, such as *reflection, refraction, scattering, diffusion,* and spatial spreading. In the transmission of *electromagnetic waves,* such as *lightwaves,* absorption includes the transference of some or all of the energy contained in the wave to the substance or medium in which it is *propagating* or upon which it is *incident.* Absorbed energy from a transmitted or incident lightwave is usually converted into heat with a resultant attenuation of the *power* or energy in the wave. In *optical fibers,* intrinsic absorption is caused by parts of the *ultraviolet* and *infrared* absorption bands. Extrinsic absorption is caused by impurities, such as hydroxyl, transition metal, and chlorine ions; silicon, sodium, boron, calcium, and germanium oxides; trapped water molecules; and defects caused by thermal and nuclear radiation exposure. Synonymous with *material absorption.* See *band-edge absorption; hydroxyl ion absorption; overtone absorption; selective absorption.*

absorption coefficient. The coefficient in the exponent of the *absorption* equation that expresses *Bouger's law,* namely the b in the equation:

$$F = F_0 e^{-bx}$$

where F is the *electromagnetic (light) field strength* at the point x, and F_0 is the initial value of field strength at $x = 0$.

absorption index. The ratio of the *electromagnetic radiation absorption constant* to the *refractive index,* given by the relation:

$$K' = K\lambda/4\pi n$$

where K is the *absorption coefficient,* λ is the *wavelength* in vacuum, and n is the refractive index of the absorptive material.

absorption loss. When an *electromagnetic wave propagates* in a *propagation medium,* the loss of wave energy caused by intrinsic *absorption,* that is, by material absorption, and by impurities consisting primarily of metal and hydroxyl ions in the medium. Absorption losses may also be caused indirectly when *light* scattered by atomic defects is also absorbed.

acceptance angle. In *fiber optics,* half the vertex angle of that cone within which *optical power* may be *coupled* into *bound modes* of an *optical waveguide.* For an *optical fiber,* it is the maximum angle, measured from the longitudinal axis or centerline of the fiber to an *incident ray,* within which the ray will be accepted for *transmission* along the fiber, that is, total *(internal) reflection* of the incident ray will occur for long distances within the *fiber core.* If the acceptance angle is exceeded, optical power in the incident ray will be coupled into *leaky modes* or rays or lost by *scattering, diffusion,* or *absorption* in the *cladding.* For a cladded fiber in air, the sine of the acceptance angle is given by the square root of the difference of the squares of the *refractive indices* of the fiber core and the cladding, that is, by the relation:

$$\sin A = (n_1^2 - n_2^2)^{1/2}$$

where A is the acceptance angle and n_1 and n_2 are the refractive indices of the core and cladding, respectively. If the refractive index is a function of distance from the center of the core, then the acceptance angle at a given distance from the center is given by the relation:

$$\sin A_r = (n_r^2 - n_2^2)^{1/2}$$

where A_r is the acceptance angle at a point on the entrance face of the fiber at a distance r from the center, and n_2 is the minimum refractive index of the cladding. Sin A and sin A_r are the *numerical apertures (NA).* Unless otherwise stated, acceptance angles and numerical apertures for optical fibers are those for the center of the end face of the fiber, that is, where the refractive index, and hence the NA, is the highest. Power may be coupled into leaky modes at angles exceeding the acceptance angle, that is, at internal incidence angles less than the *critical angle.* See *maximum acceptance angle.*

acceptance-angle plotter. A device capable of varying the *incidence angle* of a narrow *light beam* that is incident upon a surface, such as the end face of an *optical fiber.* The device measures the *intensity* of the *transmitted light,* namely the light *coupled* into the fiber for each angular position of the *light source* relative to the

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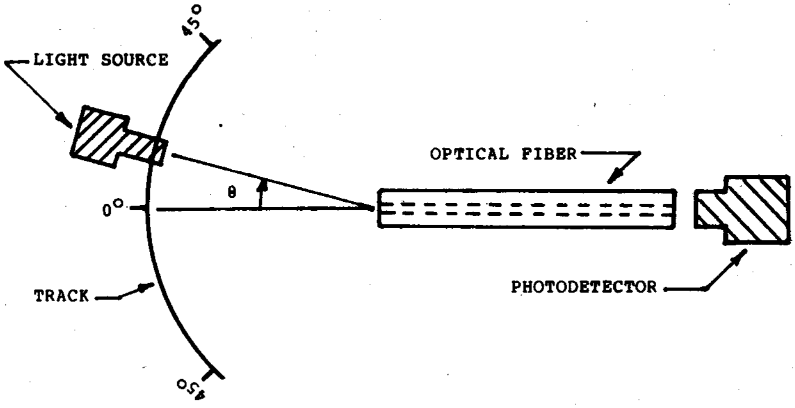
face of the fiber, that is, the incidence angle. As the incidence angle approaches half the *acceptance cone* apex angle, the *optical power* measured by a *photodetector* approaches zero. This condition defines the limit of the *acceptance angle.*



A-1. An acceptance-angle plotter.

acceptance cone. In *fiber optics,* that cone within which *optical power* may be *coupled* into the *bound modes* of an *optical waveguide.* The acceptance cone is derived by rotating the acceptance angle, that is, the maximum angle within which light will be coupled into a bound mode, about the *fiber axis.* The acceptance cone for a round *optical fiber* is a solid angle whose included apex angle is twice the acceptance angle. Rays of light that are within the acceptance cone can be coupled into the end of an optical fiber and be *totally internally reflected* as it *propagates* along the *core.* Typically, an acceptance cone apex angle is 40°. For noncircular waveguides, the acceptance cone transverse cross section is not circular, but is similar to the cross section of the fiber. (See Fig. A-2, p. 4)

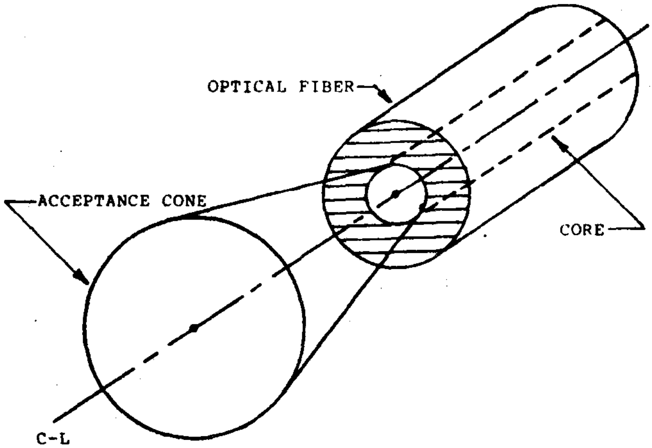
acceptance pattern. For an *optical fiber* or *fiber bundle,* a plot of *transmitted optical power* versus the *launch angle.* The total power coupled into the fiber is a function of the launch angle, the *transmission coefficient* at the fiber face, the illumination area, the *light source wavelength,* and other *launch conditions.*

access coupler. A device placed between the ends of two *waveguides* to allow *signals* to pass from one waveguide to the other.

acoustic sensor. See *optical fiber acoustic sensor.*

acoustic transducer. See *optoacoustic transducer.*

acoustooptic effect. A variation of the *refractive index* of a material caused by acoustic waves. The changes are also produced in *diffraction gratings* or *phase* pat-



A-2. The **acceptance cone** of an *optical fiber.* The *acceptance angle* is one-half the acceptance cone apex angle. All *light rays* within the cone will be accepted by the fiber. The amount of light that can be *coupled* into and *transmitted* by the fiber is a function of the *launch conditions*, the *fiber numerical aperture*, and the *wavelength*.

terns produced in a *propagation medium* in which a *lightwave* is propagating when the medium is subjected to a sound wave, due to *photoelastic* changes that occur in the material composing the propagation medium. The acoustic waves may be created by a force developed by an impinging sound wave, for example by the piezoelectric effect, or by magnetostriction. The effect can be used to *modulate* a *light* beam in a material because of the changes that occur in light velocities, *reflection* and *transmission coefficients, acceptance angles, critical angles,* and transmission *modes* resulting from changes in the refractive index caused by the acoustic wave.

acoustooptics. The branch of science and technology devoted to the interactions between sound waves and *light* in a solid medium. Sound waves can be made to *modulate,* deflect, and focus *lightwaves* by causing a variation in the *refractive index* of the medium. Also see *electrooptics; magnetooptics; optooptics; photonics.*

acquisition time. The elapsed time between the instant of application of the leading edge of an input *signal* and stabilization of the corresponding output signal of a device.

action. In *quantum* mechanics, the product of the total energy in a stream of *photons* and the time during which the flow occurs, expressed by the relation:

$$A = h \sum_{i=1}^{m} f_i n_i t_i$$

where f_i is the *i*th frequency; n_i is the number of photons of the *i*th frequency; t_i is the time duration of the *i*th frequency summed over all the frequencies, photons, and time durations of each in a given light beam or beam pulse; and *h* is *Planck's constant.*

activated chemical-vapor-deposition process. See plasma-activated chemical-vapor-deposition (PACVD) process.

active connector. See optical fiber active connector.

active device. A device that contains a source of energy or that requires a source of energy other than that contained in input *signals,* the output of which is a function of present and past input signals that *modulate* the output of the energy source. Examples of *fiber optic* active devices include operational amplifiers, repeaters, oscillators, phototransistors, *lasers, optical masers,* photomultipliers, and *photodetectors.*

active laser medium. The material in a *laser,* such as a crystal, gas, glass, liquid, or semiconductor, that emits *optical radiation.* Radiation from a laser is usually *coherent,* that is, has a high *coherence degree,* and results from stimulated electronic, atomic, or molecular energy transitions from higher to lower energy levels. The action is maintained by causing *population inversion.*

active material. See *optically active material.*

active optical device. A device capable of performing one or more operations on *lightwaves* with *wavelengths* in or *near* the *visible region* of the *electromagnetic spectrum* through the use of input energy, such as electrical or acoustic energy, in addition to that contained in the waves being operated upon. Examples of active optical devices include *fiber optic transmitters, receivers, repeaters, switches, active multiplexers,* and *active demultiplexers.*

active optical fiber. An *optical fiber* designed to be used as the gain (*lasing*) medium in a *fiber laser,* that is, an optical fiber amplifier.

active optics. The development and use of *optical* components whose characteristics are controlled during their operational use in order to modify the characteristics of *lightwaves propagating* within them. Controlled lightwave characteristics include *wavefront* direction, *polarization, modal power distribution, electromagnetic field strength,* or the *path* they take. Also see *fixed optics.*

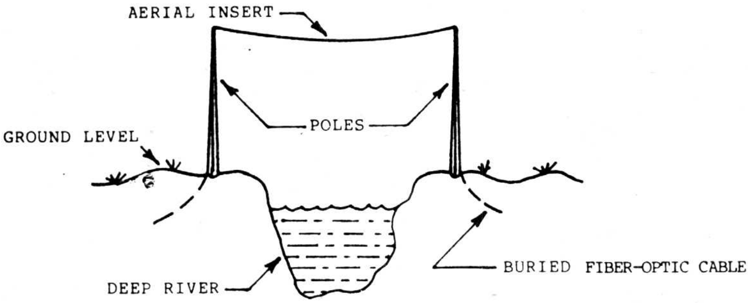
actuation method. The way in which a motive force must be applied to a switch to place it into its various states.

actuator. A device that provides the motive force that must be applied to a switch to place it into its various states.

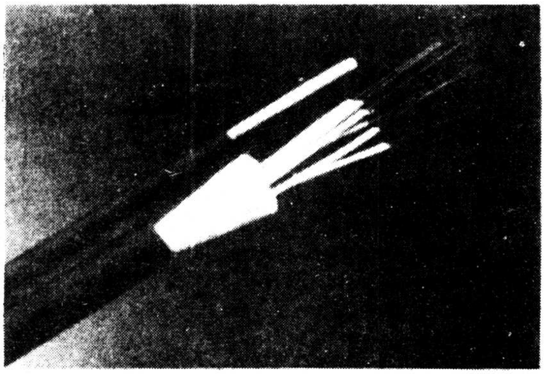
adjusting. See *self-adjusting.*

advanced television system. A television system in which an improvement in performance has been made to an existing television system to create the advanced system. The improvement may or may not result in a system that is compatible with the original system or with other present systems. Some features and technical characteristics of the original system on which the advanced system is based may be included in the advanced system. Also see *enhanced-definition television (EDTV) system; high-definition television (HDTV) system; improved-definition television (IDTV) system.*

aerial insert. In a buried cable run, a raising of the cable followed by an overhead run usually on poles, followed by a return to the ground, in places where it is not possible or practical to bury a cable, such as might be encountered in crossing a deep ditch, canal, river, or subway line.



A-3 An **aerial insert** in a buried *fiber optic cable.*



A-4. A figure 8 aerial messengered *fiber optic cable* with rugged tight *buffering*. The cable can be used for fully-aerial systems or for **aerial inserts**. (Courtesy Optical Cable Corporation).

aerial optical cable. An *optical cable* designed for use in overhead suspension devices, such as towers or poles.

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. Synonymous with *coherent bundle.*

alignment sensor. See *fiber axial-alignment sensor.*

all-glass fiber. An *optical fiber* whose *core* and *cladding* consist entirely of glass.

all-plastic fiber. An *optical fiber* whose *core* and *cladding* consist entirely of plastic. Most fibers are of glass core and glass cladding.

alternative test method (ATM). In *fiber optics,* a test method in which a given characteristic of a specified class of fiber optic devices, such as *optical fibers, fiber optic cables, connectors, photodetectors,* and *light sources,* is measured in a manner consistent with the definition of this characteristic; it gives reproducible results that are relatable to the reference test method and is relatable to practical use. Synonymous with *practical test method.* Also see *reference test method.*

ambient light susceptibility. The *optical power* that enters a device from ambient illumination *incident* upon the device. It may be measured in absolute power, such as microwatts, or in *dB* relative to the incident ambient optical power. For example, in a *fiber optic connector* or *rotary joint,* it is the ambient optical power that leaks into the *optical path* in the component.

amplification by stimulated emission of radiation. See *light amplification by stimulated emission of radiation (LASER).*

amplifier. See *fiber amplifier.*

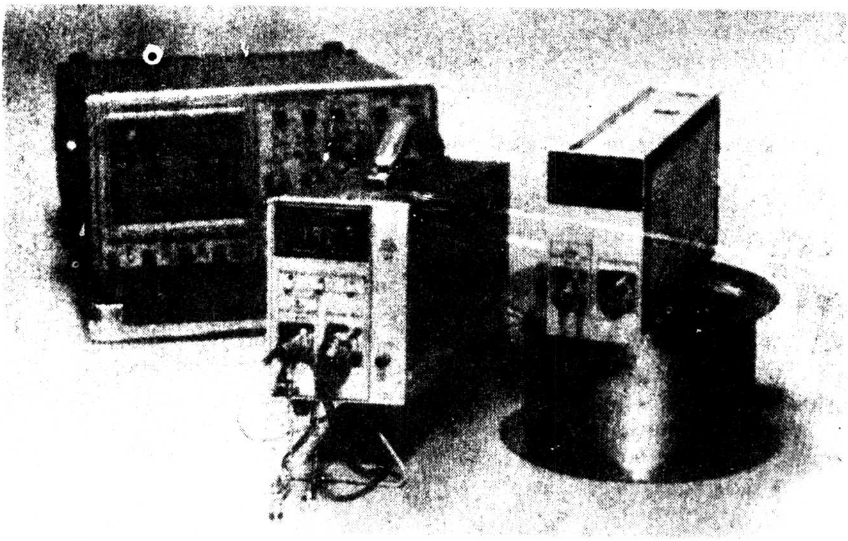
amplitude. See *pulse amplitude.*

amplitude distortion. *Distortion* of a *signal* in a system, subsystem, or device when the output amplitude is not a linear function of the input amplitude under specified operating conditions.

amplitude modulation. See *pulse-amplitude modulation (PAM).*

analog data. *Data* represented by a physical quantity that is considered to be continuously variable and whose magnitude is made directly proportional to the data or to a suitable function of the data. Also see *digital data.*

analog signal. A nominally continuous *signal* that varies in a direct correlation with the instantaneous *value* of a physical variable. For example, the *optical* output *signal* of a *light source* whose *intensity* is a function of a continuous acoustic or electrical input signal, or the continuous *photocurrent* output signal of a *photodetector* whose photocurrent is a function of a continuous optical input signal. Also see *digital signal.*



A-5. The OR500 Series Receivers and OT500 Series Transmitters, a set of electrical-optical and optical-electrical converters for use in analyzing *optical* **analog signals** in time and *frequency* domains. The *receivers* cover the 0.700-0.1550-μ *(micron) wavelength* range with a frequency response out to 1.5 GHz on *multimode* or *single-mode optical fibers. Transmitters* operate at 0.825, 0.850, or 11.3 μ on multimode fibers. (Courtesy Tektronix).

analyzer. See *lightwave-spectrum analyzer.*

angle. See *acceptance angle; borescope articulation angle; borescope axial viewing angle; Brewster angle; deviation angle; exit angle; critical angle; incidence angle; launch angle; maximum acceptance angle; radiation angle; refraction angle.*

angle of incidence. See *incidence angle.*

angle plotter. See *acceptance-angle plotter.*

angstrom (Å). A unit of *wavelength.* 1 Å = 10^{-10} m (meter). The angstrom is not an SI (International System) unit.

angular misalignment loss. An *optical power loss* caused at a joint, such as at a *splice* or *connector,* because the axes of the *optical fibers* are not parallel, that is, there is an angular deviation of the optical axes of the two fibers being joined. The loss can be from source to fiber, fiber to fiber, or fiber to detector. It is considered extrinsic to the fiber.

anisotropic. Pertaining to material whose properties, such as *electric permittivity, magnetic permeability,* and *electrical conductivity,* are not the same in every direc-

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