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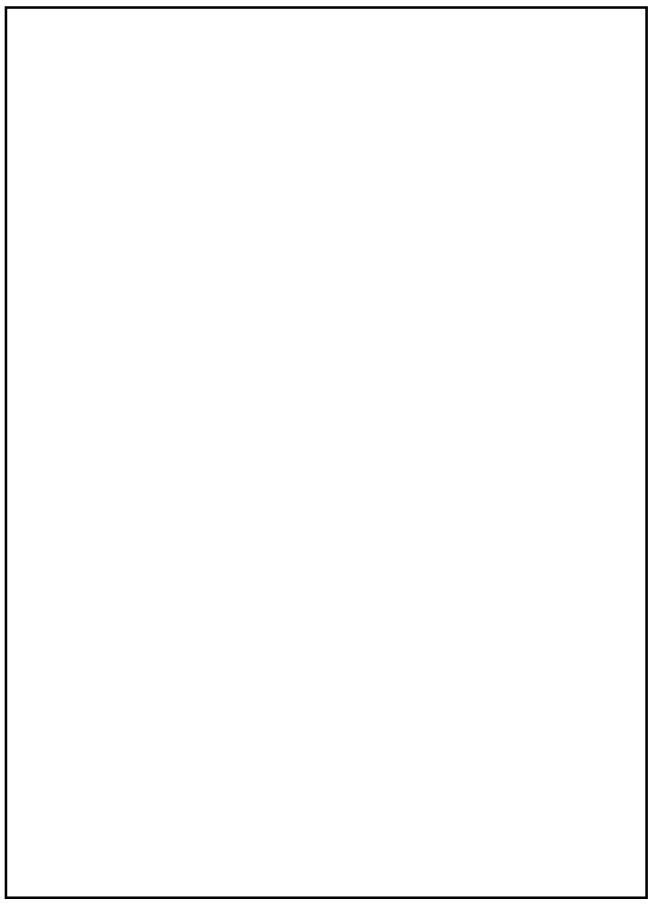
Lightwave Fundamentals



User's Guide

Computer-Based Training Course

H5265A

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Lightwave Fundamentals

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Purpose of this Course

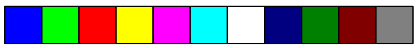
This course is designed for those who have an understanding of conventional transmission systems and now wish to learn about lightwave systems. When you have completed this course, you will have a better understanding of the terminology and functions of lightwave systems.

Conventions

The following conventions are used throughout this manual:

- **Bold** is used to emphasize important information in the text or to highlight menu selections or text to be entered from your computer's keyboard.
- *Italics* are used for titles that refer to the course and its lessons, to indicate selections to be made, or for emphasis.
- **<Keystroke>** indicates a key or combination of keys to be pressed.

Table of Contents



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Lightwave Fundamentals Computer-Based Training

- **Course Objectives**
- **The Lightwave Fundamentals Program**
- **Hardware/Software Requirements**

Course Objectives

When you have completed this course, you will be able to:

- Describe lightwave technology and its uses.
- Describe the advantages of lightwave technology.
- Explain how refraction, reflection and interference effect transmission at lightwave frequencies.
- Identify the major components of a lightwave system.
- Compare components in a lightwave system to those in a conventional system.
- Identify and compare different types of transmitters, fibers and receivers.
- Identify the particular components used in a given system.
- Associate lightwave instruments with the parameters they measure.

The Lightwave Fundamentals Program

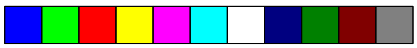
The program is accessed through the Internet at www.educatorscorner.com. Please see Chapter 2 for starting the program.

Hardware/Software Requirements

To use *Lightwave Fundamentals*, you will need a Vectra computer or an IBM PC/AT compatible computer equipped with the following:

- Internet Explorer 4.0+ and Netscape 4.0+
- Screen resolution 800 x 600
- 28.8 Kbps Modem or higher
- Flash player (plug-in)
- A Microsoft-compatible mouse
- Minimum operating environments to include NT and Unix/Linux, Windows 9x, and Macintosh OS
- 90 MHz Pentium class processor with 16 MB of memory, or Macintosh Power PC with system 7.x





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Getting Started

- **Starting the Program**

Starting the program

- Using Internet Explorer 4.0+ or Netscape 4.0+ go to www.educatorscorner.com.
- In the Educator's Corner section, click on Teacher's Tools.
- In the Lab Resources section, click on Computer Based Training.
- Within the Lightwave Fundamentals course description, click on the link to access the Lightwave Fundamentals course.

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Troubleshooting

- **During the Program**

Troubleshooting

Below are some problems that may occur while you are accessing or using *Lightwave Fundamentals.*

During the Program

The resolution is either too big or too small.
Make sure your screen resolution is set to 800 x 600 or better resolution.

There is not enough memory to open the browser and the course.
You may not have enough RAM. Remember, you need 16 MB.
Also, be sure that you're running extended memory drivers.

Check your connection to the Internet
Make sure you have properly connected to the Internet.

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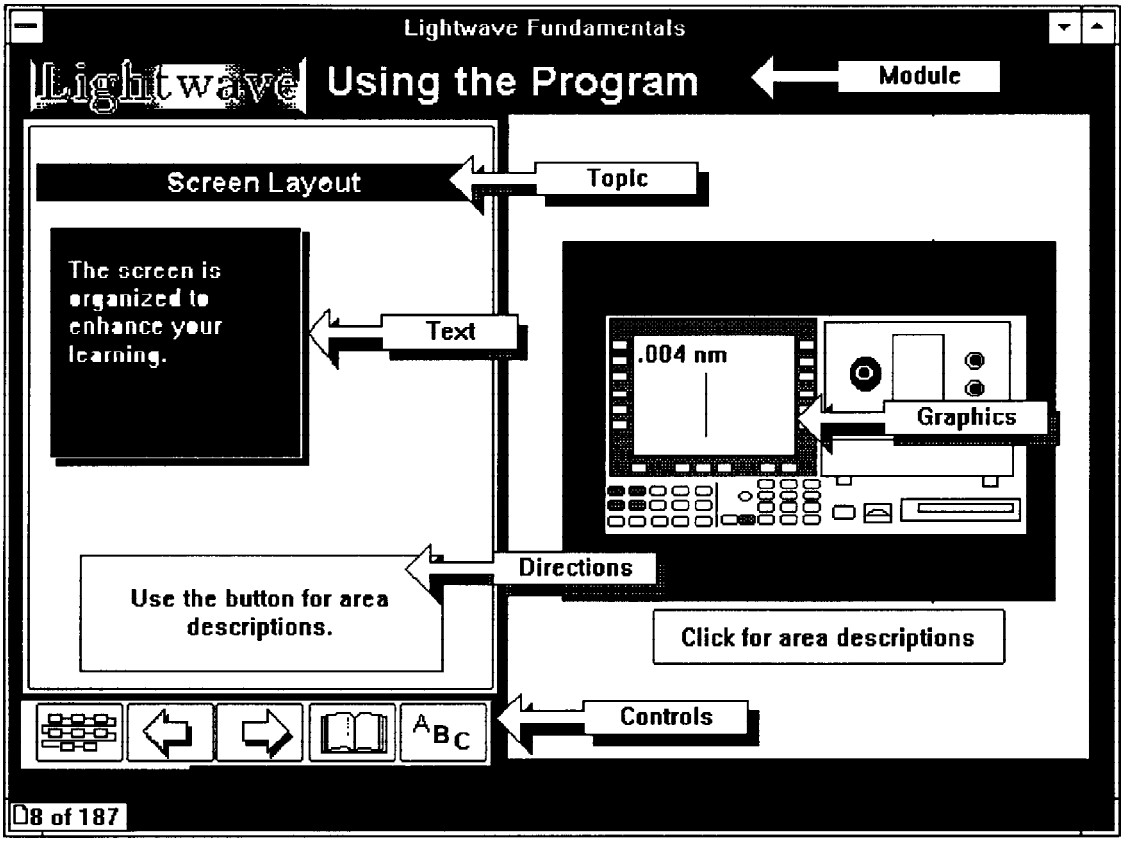
Using the Program

- **Screen Layout**
- **Navigating**
- **Glossary Feature**
- **Hotwords Feature**
- **Exiting**

Screen Layout



Text
Provides the technical material on the topic.

Topic
Tells you which topic you are currently learning.

Module
Tells you which module you are currently taking.

Directions
Tells you what to do next.

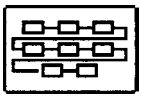
Controls
Provides you with access to other parts of the course.

Graphics
Provides the animation and graphics to illustrate the material.

Navigating

There are five controls you can use to move through Lightwave Fundamentals. They are grouped together in a row on the lower left hand part of the screens.

Control your course this way:


takes you to the Main Menu.


takes you to the previous screen.


takes you to the next screen.


takes you to the Glossary.

takes you to Review of Lightwave Basics.

There is also a page box in the lower left corner which you can use to go to any page of the course. To use the page box, click on it, type the page number you want to go to and press <Enter>.

Returning

The Glossary and Review of Lightwave Basics buttons will take you to those parts of the course for review or reference. You can return from these sections to the exact location you left at any time by clicking the appropriate button.

To return from the Glossary, click the Return button.
To return from Review of Lightwave Basics, click the


button.

Glossary

The Glossary alphabetically lists and defines all the technical lightwave terms presented in the course. Each screen in the Glossary covers listings under two letters of the alphabet (the first screen covers A-B, the second, C-D and so on) except the last, which covers W-Z.

A column of tabs which you can click to select any letter pair you want is provided on the right side of each Glossary screen.

Scroll the Glossary page up and down to run through all the listings for the letter pair selected.

To move to the listings for the next (or previous) letter pair, you can also click the page ahead or page back arrow at the bottom of the screen.

Remember, clicking the Return button will place you exactly where you were in the course before you entered the Glossary.

Hotwords

Technical terms concerning lightwave systems may be hotwords.
The cursor will change from an arrow to a window when positioned on a hotword. Clicking on a hotword will display a short definition of the term. (The Glossary will contain a more detailed definition.)

Exiting

You can exit the program from any screen by selecting the system menu box from the upper left corner and, from the menu, selecting Close.

You can also close by using the <ALT> + <F4> key combination.

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Course Contents

- **Module Descriptions**

Contents

The course provides a basic understanding of the terminology and function of lightwave systems.

It has eight modules (not counting Using the Program, which describes how to use the course). We recommend that you take them together in order, but you can also choose the specific modules you want to learn.

Module 1 What is Lightwave Technology?
describes lightwave technology and some of its applications.

Module 2 Conventional Vs. Lightwave
compares the function and capabilities of a lightwave system to a conventional system.

Module 3 Review of Lightwave Basics reviews the basic physics involved with lightwave technology.

Module 4 Transmitters describes categories of transmitters and their capabilities.

Module 5 Fibers describes different types of optical fibers and their characteristics.

Module 6 Receivers describes two categories of receivers and their capabilities.

Module 7 Systems describes different applications of lightwave technology to systems and their associated test and measurement tools.

Module 8 Review Questions
tests your understanding of the course.

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Appendix

- **Lightwave Measurements Matrix**
- **Glossary of Lightwave Terms**

Lightwave Measurements Matrix

Shaded blocks indicate which lightwave measurements made by products.

	Products						
Power	■	■					
Loss/gain	■	■					
Fiber attenuation							
Wavelength		■					
Spectrum		■					
Spectral Loss/gain		■					
Linewidth			■				
Modulation			■		■		
Responsivity	■			■			
AM Response			■	■	■	■	
Extinction Ratio					■		
FM response			■				
Distortion			■		■		
Chirp		■	■				
Jitter					■	■	
Noise/RIN		■	■				
Noise figure		■	■				
Phase				■			
Length/Delay				■	■		■
Dispersion				■			
Splice loss							
Optical return loss	■			■			■
Electrical match				■			
Polarization							
Polarization dependence							
BER						■	

Lightwave Measurements Matrix

Shaded blocks indicate which lightwave measurements made by products.

	Products					
Power	■	■	■			
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Responsivity						
AM Response						
Extinction Ratio						
FM response						
Distortion						
Chirp						
Jitter						
Noise/RIN						
Noise figure						
Phase						
Length/Delay				■		■
Dispersion	■					
Splice loss				■		■
Optical return loss				■		
Electrical match						
Polarization	■					
Polarization dependence	■	■				
BER		■				

Glossary of Lightwave Terms

A/D
Analog to digital signal conversion.

Absorption
In an optical waveguide, that portion of attenuation resulting from the conversion of optical energy into heat.

Angle of Acceptance
The angle over which the core of an optical fiber accepts incoming light; generally measured from the axis of the core.

Angle of Incidence
The angle formed between a ray of light striking a surface and the normal to that surface at the point of incidence.

Angle of Reflection
The angle formed between the normal to a surface and the reflected ray. This angle lies in a common plane with the angle of incidence and is
equal to it.

Angle of Refraction
The angle formed between a refracted ray and the normal to the surface. This angle lies in a common plane with the angle of incidence.

APD
See Avalanche Photodiode.

Attenuation
The reduction of signal magnitude between two points of interest. Usually expressed in decibels.

Attenuation Curve
Attenuation (dB) per distance (km) of a particular fiber, expressed as a function of wavelength.

Glossary of Lightwave Terms

Avalanche Photodiode
A photodiode which has detection and amplification stages. The incident photons undergo amplification because electrons within the diode multiply by knocking additional electrons loose from the lattice structure as they accelerate through an electric field.

Bandwidth
In fiber optics (lightwave) this typically refers to the highest modulation frequency at which the signal power decreases to one half (3 dB) of the value at the baseband zero-frequency.

Beam Divergence
The deviation from an ideal parallel beam.

BW*Distance Product
Bandwidth * Distance = Constant. Based on the inverse relationship between signal transmission bandwidth of a communications link and the link length. The constant expresses the information carrying capacity of the technologies used by the link; constant does not necessarily hold true for short distances.

c_o
Speed of light in vacuum: $2.99 * 10^8$ m/sec

CATV
Community Antenna Television (Cable TV)

Chromatic Dispersion
Pulse broadening caused by the differences in propagation in a fiber due to wavelength. Measured in multiples of nano or picoseconds that pulse broadens per km (length of fiber) per nm (spectral width of source). Primary components are material and waveguide dispersion.

Glossary of Lightwave Terms

Cladding
Material with lower index of refraction surrounding the light carrying core with a higher index of refraction to achieve total reflection.

Coherent
Term to describe electromagnetic waves all of the same wavelength and with a fixed-phase relationship.

Connector
A device that allows fibers to be joined temporarily with each other.

Conventional System
To differentiate the newer technology lightwave (fiber optics) systems, the more traditional “pure” electrical systems are termed conventional systems.

Core
The inner, light-carrying part of a fiber. The core has a higher index of refraction than the surrounding cladding to achieve total reflection.

Coupling Efficiency
A measure to describe the proportion of light energy that can be transferred from one device into another one. Typically expressed in %.

Critical Angle
The angle at which light undergoes total reflection at the boundary of two transparent materials when traveling from an optically more dense towards an optically less dense material.

D/A
Digital to analog signal conversion.

dB/km
Loss per km (attenuation per km) expressed in decibels.

Detector
Common name for a device which generates electrical current when illuminated by light (photon-current).

DFB Laser
Distributed Feedback Laser. Incorporates a corrugated design along the active layer in order to achieve a very narrow spectral width, typically in the subnanometer (0.004 nm) range.

Dispersion
Term used for pulse broadening, or an increase in pulse duration. May be specified by impulse response, root-mean-square pulse broadening, or full-duration-half-maximum pulse broadening.

Dispersion-Shifted Fiber
A fiber designed to alter its waveguide dispersion characteristics in order to shift the zero dispersion wavelength to another value (typically 1550 nm) that minimizes both attenuation and chromatic dispersion.

Doped
In semiconductors, refers to the addition of impurities to achieve desired semiconductor characteristics.

Electromagnetic Waves
Oscillating electrical and magnetic fields (perpendicular to one another) which propagate at the speed of light.

Electronvolt (eV)
Energy expression equivalent to an electron passing through a potential difference of one volt in a vacuum; used in expressing photonic energy.

ELED
Edge emitting LED. It has a higher output radiance and better coupling efficiency than an SLED.

EMI
Electro Magnetic Interference. Noise in electric conductors generated/ induced by electrical and magnetic fields.

EMR
Electro Magnetic Radiation. See Electromagnetic Waves.

Fabry-Perot Laser Diode
Active region has two parallel mirrors that form a cavity in which only certain wavelengths can exist/resonate. Its output spectrum is approximately 4-7 nm wide.

FDDI
Fiber Distributed Data Interface. FDDI is a fiber optics communication ring topology network developed by the American National Standards Institute (ANSI). Data transmission is at a rate of 100 MBit/s.

Fiber
General term. Today's fibers are made out of either plastic or glass. All fibers are composed of both core and cladding. There are numerous different types of fibers on the market; each one has an application-specific "background." Examples: single-mode, multimode, dispersion shifted, graded index, plastic-clad, polarization maintaining, tapered fibers, etc.

Fiber Optics
The branch of optical technology concerned with the transmission of radiant power through fibers made of transparent materials such as glass or plastic.

Fiber Optics Cable
Looks like conventional cable. Its purpose is to protect (package) the hair-thin fiber to provide easier handling.

Gamma Rays
Electromagnetic waves, but at much higher frequencies than lightwaves and x-rays: approximately 10^{10} - 10^{12} GHz, 0.3 to 30 pm (picometer), range.

GigaHertz
One billion cycles per second.

GIMM Fiber
Graded-index multimode fiber.

Graded Index Fiber
A gradual change of the fiber's core index of refraction from the center of the fiber (larger) towards the core-cladding boundary (lower).

Hole
A vacancy in the semiconductor lattice where an electron has moved from the valence band to the conduction band. A hole acts like a positive electron charge with current-carrying capabilities.

Hz
Hertz; describes the number of recurring events per second; one cycle per second.

Imperfections
Inevitable changes in the geometry of a fiber, caused by pressure, tension, stress, etc.

Incoherent
Adjacent waves emitted by the same source which do not have any fixed-phase relationship with one another.

Index of Refraction (IOR)
The ratio of the speed of light in a vacuum to the speed of light in a material, always equal to or greater than 1.

Typically expressed as $n = c_o / c_{material}$

c_o: Speed of light in a vacuum

$c_{material}$: Speed of light in a material

Infrared (IR)
Oscillating electromagnetic radiation which is located between approximately 800 and 100,000 nm, 3 THz to 375 THz, within the electromagnetic spectrum. The IR region is typically subdivided into three categories: near IR = 800 to 3,000 nm, middle IR = 3,000 to 30,000 nm, and far IR = 30,000 to 100,000 nm.

Insertion Loss
Loss which occurs when a signal travels through a device. In lightwave, typically measured in dB.

Interference
The resulting space distribution that results when electromagnetic waves are superimposed.

Intrinsic Region
In a PIN diode, refers to the lightly doped region separating the p- and n-regions.

LAN
Local Area Network. A LAN interconnects many nodes, with each node representing one or more users.

Laser
Acronym for Light Amplification by Stimulated Emission of Radiation. A semiconductor diode that emits highly coherent radiation (light).

Lateral Offset
The biggest contributor to insertion loss in each connector pair.

LD
See Laser

LED
See Light Emitting Diode.

Light Emitting Diode
A semiconductor diode that emits incoherent light through spontaneous emission at the p-n junction.

Lightwave
Term used to differentiate fiber optics technology from microwave technology.

Material Dispersion
Pulse broadening caused by the wavelength dependence of the fiber's index of refraction. Measured in nano- or picoseconds of pulse broadening per km (length of fiber) per nm (spectral width of source). Component of chromatic dispersion.

MBits/s
Megabits/s. One million bits per second.

MHz
One million cycles per second.

Microwaves
Oscillating electromagnetic radiation which is located in the electromagnetic spectrum between approximately 1 and 100 GHz, 3 to 300 mm.

Modal Dispersion
See Multimode Dispersion

Mode
One possible path of a propagating electromagnetic field (wave) through a waveguide such as a fiber.

Modulation Rate
Denotes the frequency with which the carrier is varied.

Modulation
Controlled variation of amplitude, or frequency, or phase, etc., for the sole purpose of transferring information.

Multimode Dispersion
Pulse broadening caused by the differences in propagation of different modes in a fiber. Measured in multiples of nano- and picoseconds that pulse broadens per km (length of fiber).

Multimode Fiber
A waveguide which propagates multiple modes of electromagnetic fields.

nm
Nanometer, that is, 1 billionth of a meter, 10^{-9} m

Noise
Generally describes a source which generates unwanted signals disturbing the information carrying signal.

Normal
Perpendicular to surface. The angle of incident, reflected or refracted rays are typically measured from the ray towards the normal.

Numerical Aperture (NA)
Defined as the sine of half the maximum angle of acceptance of a fiber or a lens.

Optical Spectrum
Oscillating electromagnetic radiation which is located in the electromagnetic spectrum between approximately 800 and 10,000 nm, 375 and 3,000 THz. The term optical spectrum combines the “visible light” and the near infrared ranges.

Glossary of Lightwave Terms

OSA
Optical Spectrum Analyzer. An instrument that provides its user with information about the spectral components of an optical signal.

OTDR
Optical Time Domain Reflectometer. An instrument that characterizes a fiber by launching short pulses into the fiber and measuring the backscattered and reflected light.

Particle - Wave Duality
An expression which refers to the equivalence of the particle (photon) and wave models used to explain many lightwave phenomena. One can be transformed into the other by using Planck's constant (see Photon).

Photodiode
A device that proportionally converts light energy into electrical current.

Photon
A quantum of electromagnetic energy. The energy of a photon can be described as : $E = h * f$
h: Planck's constant
f: Frequency.

Pigtail(ed)
The piece of fiber attached to a component, such as a transmitter or receiver, to allow for easier connection to a system.

PIN Photodiode
A photodiode with an intrinsic region that separates the p- and n-doped regions. A less expensive, less sensitive receiver for lightwave applications.

Propagation
The motion of a wave through a transparent medium, such as a fiber, water, air, etc.

Quadratic Sum
Describes how to add two summands, for example, $(a^2 + b^2)$.

Rayleigh Scattering
Rayleigh scattering is caused by very small (compared to the wavelength) variations of the index of refraction due to inhomogeneities of the fiber material and its molecular structure.

Receiver
A device which consists of several components such as photodetector, drive circuits, etc. In a receiver, the optical signal (photons) is converted into an electrical current for further processing.

Recombination
The movement of an electron in a semiconductor material from the conduction band to a hole in the valence band resulting in the release of energy.

Reflection
The change in direction of an incident electromagnetic wave at the boundary of two different optical media. The wave is either partially or totally reflected back from the boundary.

Refraction
The bending of an electromagnetic wave when it passes from one optical medium to another one with a different index of refraction.

Repeater
A receiver-transmitter pair that detects, reshapes, and amplifies weak signals for retransmission.

Resonant Cavity
In a semiconductor diode (laser diode), the area formed by reflective facets in which the lasing phenomenon can take place. The physical dimensions of the resonant cavity determine the wavelengths which can oscillate and exist.

Scattering
See Rayleigh Scattering

Sensitivity
The minimum input signal that can be converted to an output signal considering certain SNR or BER constraints.

SI MM Fiber
Step-index multimode fiber.

SI SM Fiber
Step-index single mode fiber.

Single Mode Fiber
A circular waveguide through which only one mode can propagate.

SLED
Surface Light Emitting Diode. An LED that emits light from a hole etched in its surface.

Snell's Law
Describes the relationship between the index of refraction of two optical materials n_1 and n_2 and their refraction angles α_1 and α_2
$n_1/n_2 = \sin(\alpha_2)/\sin(\alpha_1)$

Spectral Width
Describes the range of spectral components of a lightwave signal. It is either measured at the FWHM (Full-Width-Half-Maximum) of the spectrum or by using the statistical RMS (Root-Mean-Square) method.

Splice
A method to join fibers permanently with one another. This method is mostly used outdoors and/or when low reflections are mandatory.

Spontaneous Emission
Describes the spontaneous release of photons when electrons change energy states.

Step-Index Fiber
A fiber in which the IOR changes in a step function at the core-cladding boundary.

Stimulated Emission
Describes photon emission caused when a passing photon stimulates an electron to move from a higher energy level to a lower one. When this occurs, the electron emits a photon which is equal in energy and in phase with the stimulating photon. Term forms a part of the LASER acronym.

THz (Terahertz)
One trillion cycles per second.

Transmitter
A device which consists of several components, such as a source, driving circuitry, etc. It converts the incoming electrical signal into a lightwave signal, which can be coupled into a fiber.

Ultraviolet (UV)
Oscillating electromagnetic radiation which is located within the electromagnetic spectrum between 1 and 400 nm, which is the frequency band of 0.75 to 300 * 10^{15} Hz.

Visible Light
Oscillating electromagnetic radiation which is located within the electromagnetic spectrum between approximately 400 and 800 nm, which is the frequency band of 375 to 750 THz.

Waveguide Dispersion
Pulse broadening due to the propagation differences in core and cladding for a particular wavelength. Measured in multiples of nano- or picoseconds of pulse broadening per km (length of fiber) per nm (spectral width of source). A component of chromatic dispersion.

Wavelength
The distance between two adjacent in-phase points of an electromagnetic wave.

X-Rays
Oscillating electromagnetic radiation which is located within the electromagnetic spectrum between approximately 0.3 to $300*10^{18}$ Hz which is the wavelength band of 0.001 to 1 nm.