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Application Note

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Laser Eye Safety for Telecommunications Systems

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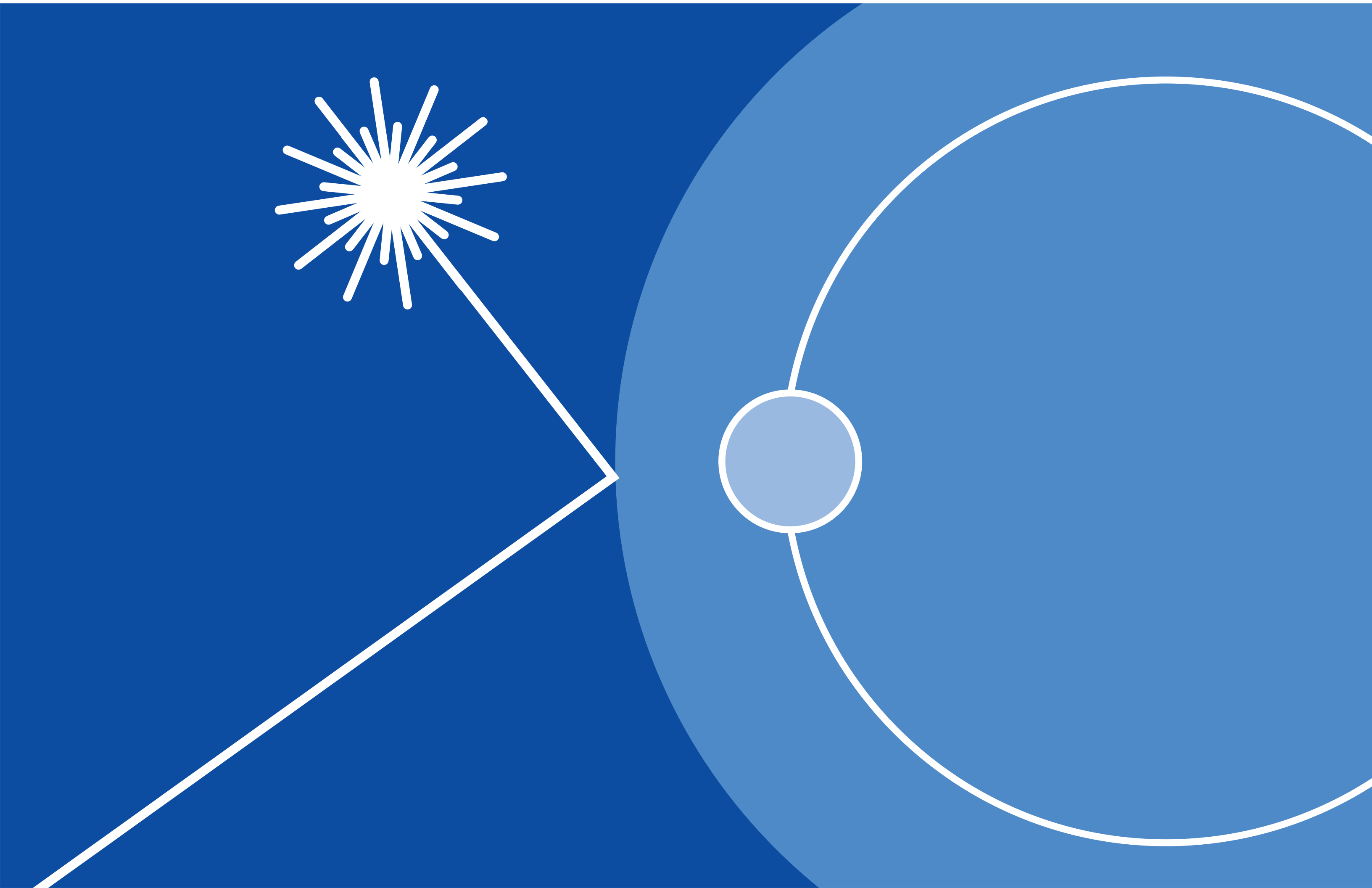

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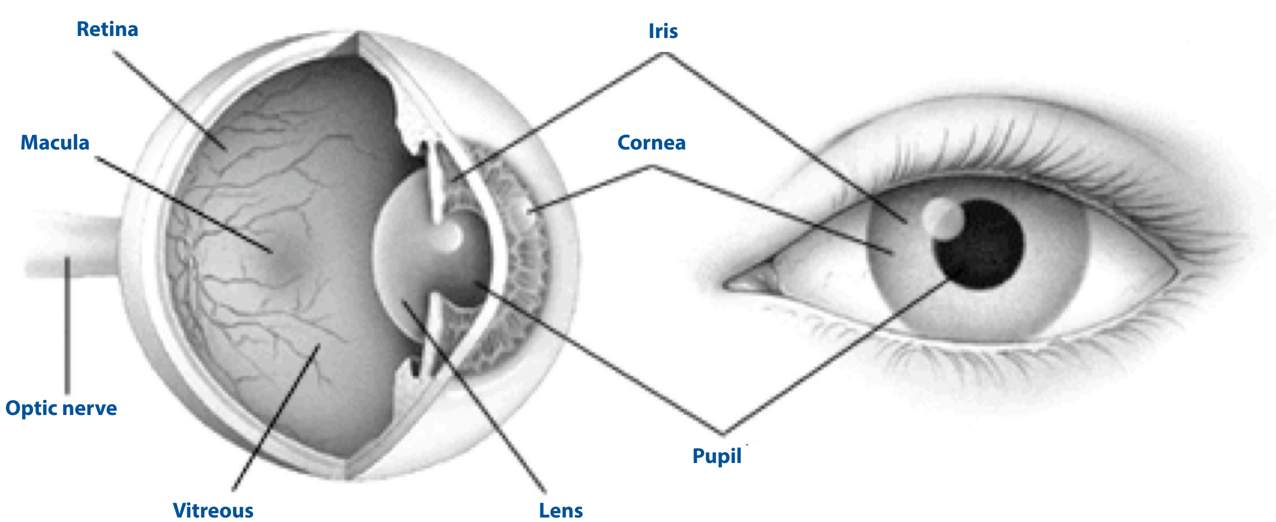
Laser Eye Safety
for Telecommunications Systems

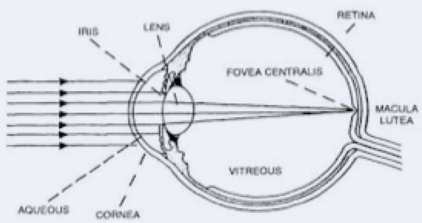
Introduction

Laser radiation predominantly causes injury via thermal effects. Even moderately powered lasers can cause injury to the eye. High power lasers can also burn the skin. Some lasers are so powerful that even the diffuse reflection from a surface can be hazardous to the eye. The coherence and low divergence angle of laser light, aided by focusing from the lens of an eye, can cause laser radiation to be concentrated into an extremely small spot on the retina. A transient increase of only 10 °C can destroy retinal photoreceptor cells. If the laser is sufficiently powerful, permanent damage can occur within a fraction of a second, literally faster than the blink of an eye. Sufficiently powerful lasers in the visible to near infrared range (400-1400 nm) will penetrate the eyeball and may cause heating of the retina, whereas exposure to laser radiation with wavelengths less than 400 nm and greater than 1400 nm are largely absorbed by the cornea and lens, leading to the development of cataracts or burn injuries.

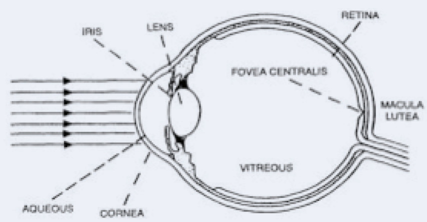


Infrared lasers are particularly hazardous, since the body's protective "blink reflex" response is triggered only by visible light. For example, some people exposed to high power Nd:YAG laser emitting invisible 1064 nm radiation, may not feel pain or notice immediate damage to their eyesight. A pop or click noise emanating from the eyeball may be the only indication that retinal damage has occurred i.e. the retina was heated to over 100 °C resulting in localized explosive boiling accompanied by the immediate creation of a permanent blind spot.

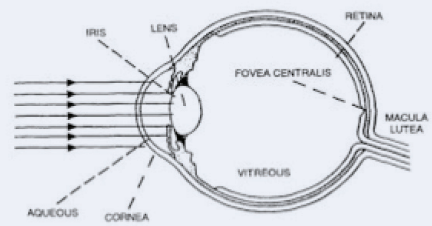
Ocular Absorption Site vs. Wavelength



Visible and ***Near-infared***
(400 - 1400nm) radiation



Mid-infared and ***Far-infared***
(1400 - 1mm) and
Far-ultraviolet
(180nm - 315nm) radiation



Near-ultraviolet
(315 - 390nm) radiation

Lasers can cause damage in biological tissues, both to the eye and to the skin, due to several mechanisms. Thermal damage, or burn, occurs when tissues are heated to the point where denaturation of proteins occurs. Another mechanism is photochemical damage, where light triggers chemical reactions in tissue. Photochemical damage occurs mostly with short-wavelength (blue and ultra-violet) light and can be accumulated over the course of hours. Laser pulses shorter than about 1 µs can cause a rapid rise in temperature, resulting in explosive boiling of water. The shock wave from the explosion can subsequently cause damage relatively far away from the point of impact. Ultrashort pulses can also exhibit self-focusing in the transparent parts of the eye, leading to an increase of the damage potential compared to longer pulses with the same energy. The eye focuses visible and near-infrared light onto the retina. A laser beam can be focused to an intensity on the retina which may be up to 200,000 times higher than at the point where the laser beam enters the eye. Most of the light is absorbed by melanin pigments in the pigment epithelium just behind the photoreceptors and causes burns in the retina. Ultraviolet light with wavelengths shorter than 400 nm tends to be absorbed by lens and 300 nm in the cornea, where it can produce injuries at relatively low powers due to photochemical damage. Infrared light mainly causes thermal damage to the retina at near-infrared wavelengths and to more frontal parts of the eye at longer wavelengths. The table below summarizes the various medical conditions caused by lasers at different wavelengths, not including injuries due to pulsed lasers.

Wavelength Range	Pathological Effect
180–315 nm (UV-B, UV-C)	photokeratitis (inflammation of the cornea, equivalent to sunburn)
315–400 nm (UV-A)	photochemical cataract (clouding of the eye lens)
400–780 nm (visible)	photochemical damage to the retina, retinal burn
780–1400 nm (near-IR)	cataract, retinal burn
1.4–3.0µm (IR)	aqueous flare (protein in the aqueous humour), cataract, corneal burn
3.0 µm–1 mm	corneal burn

Fibre Optic Safety Standards

The evolution of fiber optic components, systems and technology to address data rates in the gigabits requires the use of laser diodes in most applications due to speed requirements. Even short distance multimode systems, which in the past used LEDs, have now migrated to low cost Vertical Cavity Surface Emitting Laser sources (VCSEL). For this reason, all fiber systems must be treated as if they are carrying a laser signal. Attention on how to address Laser safety and the safe design, use, and implementation of lasers is required to minimize the risk of eye accidents. Laser classifications are based on the concept of accessible emission limits, or AEL. This is usually a maximum power level in watts, or energy level in joules that can be emitted at a specific wavelength and exposure time.

In the United States, lasers are regulated by the Center for Devices and Radiological Health, or CDRH. A branch of the FDA. the CDRH is responsible for overseeing the manufacturing, importation, performance, and safety of all medical devices as well as devices that emit certain types of electromagnetic radiation, including lasers. With lasers, the CDRH is concerned that the devices are properly labeled as to their output power and are equipped with the appropriate safety equipment if necessary.

A number of organizations have developed standards and guidelines for safely working with optical fiber, cables, and optical transmission equipment. These include the ANSI Z136.2 American National Standard for the Safe use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources and also the OSHA standard on laser safety STD-01-05-001. For international use, the IEC 60825-1 covers the safety of laser products, and the IEC 60825-2 covers the safety of optical fiber communications systems (OFCS).

The ANSI Z136.2 and the IEC 60825-2 standards divide laser devices into a set of 4 general classes and several sub-classes based on their wavelength and optical power output. The

1	The **lasers in class 1** are inherently safe. There is no possibility of eye damage because the output power is very low. In this case eye damage is impossible (even after hours of exposure).
1M	The **lasers in class 1M** are the same as in class 1 unless the beam is viewed with an optical instrument such as an eye-loupe (diverging beam) or a telescope (collimated beam). 
2	The **lasers in class 2** are safe. The blink reflex of the human eye (aversion response) will prevent eye damage, unless the person deliberately stares at the beam for an extended period. 
2M	The **lasers in class 2M** are the same as in class 2 and eye protection is normally afforded by the human aversion response for unaided viewing. The lasers in class 2M may be hazardous if viewed with certain optical aids such as an eye-loupe (diverging beam) or a telescope (collimated beam). 
3R	The **lasers in class 3R** can produce an eye injury under the wrong viewing conditions of the emitted light. The risk of an injury is unlikely to occur for a momentary exposure. The **lasers in class 3R** are not considered skin hazards. 
3B	The **lasers in class 3B** may be hazardous under direct or specular viewing conditions. But, lasers in class 3B are not a diffuse reflection hazard. Most powerful lasers in this class may also present a fire hazard and can lightly burn skin. 
4	The **lasers in class 4** can start a fire and when the emitted laser light interacts with certain materials it can produce smoke and fumes that may be a breathing hazard or create plasma radiation. Eye or skin damage is likely to occur if exposed to the direct or reflected beam. An exposure to scattered or diffuse light can also be hazardous. 

first version of the standard was published in 1988 at a time when laser-based fiber optic communications systems were very simple. They used only two wavelengths, 1310 and 1550 nanometers, at maximum power levels well under 10 milliwatts. The standard was the first written specifically for fiber optic communications systems.

Under the ANZI 136.2 standard, an end-to-end fiber optic system is considered a Class 1 laser product because under normal conditions the laser emissions are completely enclosed. It is not until the fiber is broken or a connector is unplugged that a person may be exposed to laser radiation which may be potentially hazardous. Therefore, the hazard level for each optical port must be individually assessed, and control measures defined. To address such situations, the standard defines the hazard level as the potential optical hazard at any accessible location within a fiber system, depending on the level of the radiant energy that could become accessible. Hazard levels are assigned values from 1 to 4 based on the customary laser accessible emission limits, or AELs.

Personal Protective Equipment

Laser Safety Eyewear Courtesy Laservision USA

To safely work with optical fibers, a wide variety of personal protective equipment and other safety tools will be needed. All personnel must conform to federal, state and local laws requiring personal protection equipment to be worn while performing specific operations. This equipment includes specialty eyewear for use with lasers. Protective eyewear in the form of glasses or goggles with appropriate filters can protect the eyes from direct or reflected laser light. If the optical power is high enough, the use of goggles, which provide better protection from the sides, are a better choice.

Eyewear must be selected for the specific type of laser, to block or attenuate in the appropriate wavelength range. Laser protective eyewear is rated for optical density, or OD, which is the base-10 logarithm of the attenuation factor by which the optical filter reduces beam power. For example, eyewear rated as OD 3 will reduce the beam power at the specified wavelength range by a factor of 1,000.

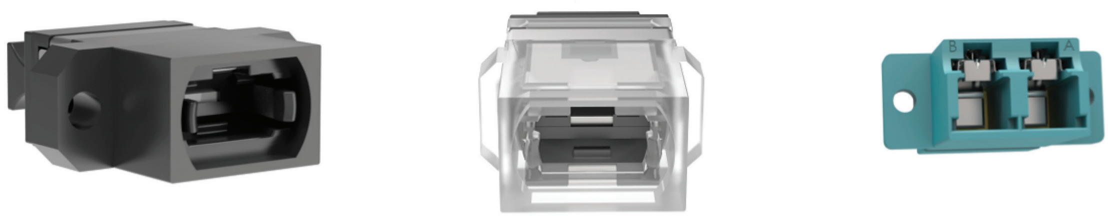
OD	Attenuation	Transmission
1	10	0.1
2	100	0.01
3	1,000	0.001
4	10,000	0.0001
5	100,000	0.00001
6	1,000,000	0.000001

In addition to an optical density sufficient to reduce beam power to below the maximum permissible exposure, laser eyewear used where direct exposure is possible should be able to withstand a direct hit from the laser beam for at least 10 seconds without breaking. The wavelengths and optical densities are usually printed on the glasses or goggles, often near the top. This safety eyewear differs from that used with lasers because it is not concerned with attenuating light, but rather keeping foreign objects and particles from entering the eyes.

Safety Features in Modern Optical Components

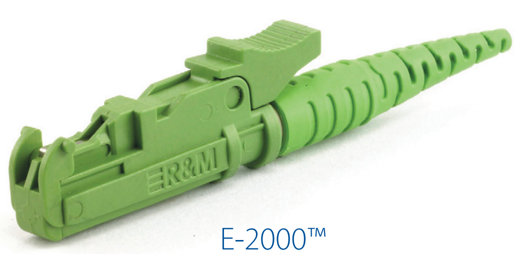
Protection to those working on energized fibers and patching solutions is an important consideration in the design of today's fiber optic components and systems. System designers are more often calling out for devices that offer some level of protection beyond the standard warning labels and safety handling guidelines. Uncapped fiber ports can be commonplace in networks as adapter dust caps regularly go missing once a connector is installed and then a change is required and the patch cable is moved.

To address these issues, component manufacturers have installed shutters internally on some fiber optic mating adapters. Early generation product provided eye safety, yet dust ingress protection remained an issue and contact between the ferrule end face and the shutter was an issue in some designs. Recent advancements have solved this issue through improved shutter design that prevents dust from entering the critical area of an adapter when unmated and allow for insertion of the connector without any contact between the shutter and the connector ferrule.

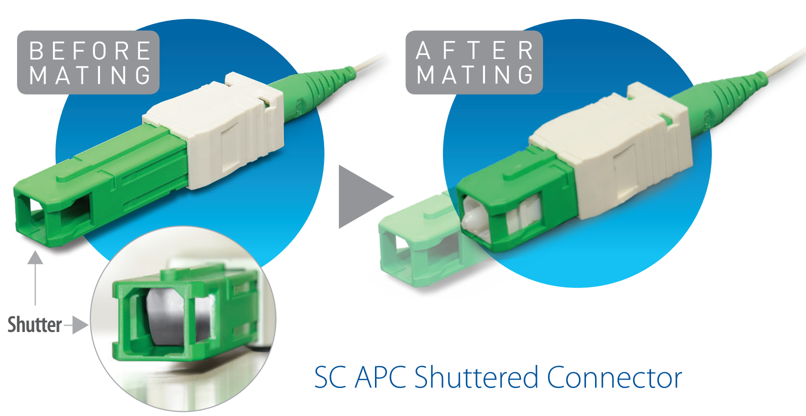


SENKO's Shuttered MPO and LC Adapters

As a compliment to the shuttered adapters, some connector designs are implementing an integral shutter for additional protection. The E-2000™ and SC APC connectors are examples of two currently available solutions.



E-2000™



SC APC Shuttered Connector

Biography

Bernard Lee

Bernard is a senior telecommunications and business strategy professional with more than 15 years of global experience in telecommunication & data communications arena especially in the field of optical fibre communications. He is currently the Regional Technology Director at SENKO Advanced Components Bernard is an Expert at the International Electrotechnical Commission (IEC), a Chartered Engineer (CEng) accredited by the Engineering Council of UK, a Professional Engineer (PEng) registered with the Board of Engineers Malaysia and also a BICSI Registered Communications Distribution Designer (RCDD). In the past 15 years, Bernard has designed, commission and audited numerous communications networks.

Eric Staley

Eric is a Product Manager at SENKO Advanced Components and has been with the company since 2007. Prior to joining SENKO, he was involved in Sales with a major cable assembly manufacturer, a national distributor of electrical and communication products and has over 20 years of experience in the fiber optic industry.

Larry Johnson

Larry Johnson started his career in the early days of fiber optics in 1977. As fiber optics specialist for Tektronix he was involved with the early development of fiber optic test equipment and test & measurement standards for the TIA and ANSI including the ANSI Z.136.2 "Safe Use of Optical Fiber Communication Systems Utilizing Laser Diodes and LED Sources" standard. In 1986 he founded The Light Brigade and researched and wrote over twenty courses on fiber optics. In 2008 he founded FiberStory to focus on the history of fiber optics. Larry provides expertise through FiberStory he is also a member of multiple industry technology committees including the Utility Telecom Council (UTC) and the Fiber Broadband Association (FBA). For the Optical Fiber Conference (OFC) coordinated by the Optical Society of America (OSA) he has provided many specialty courses including fiber optic safety. He also coordinates special events including the FTTH and Test & Measurement centers and also moderates panels on various topics. In 2018 he wrote the chapter on "Fiber Optic Safety in Telecommunications" for CRC Press's "Understanding Laser Accidents" book. He is also the Fiber Optic Columnist writing a monthly article for ISE Magazine focusing on fiber optics for service providers.

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