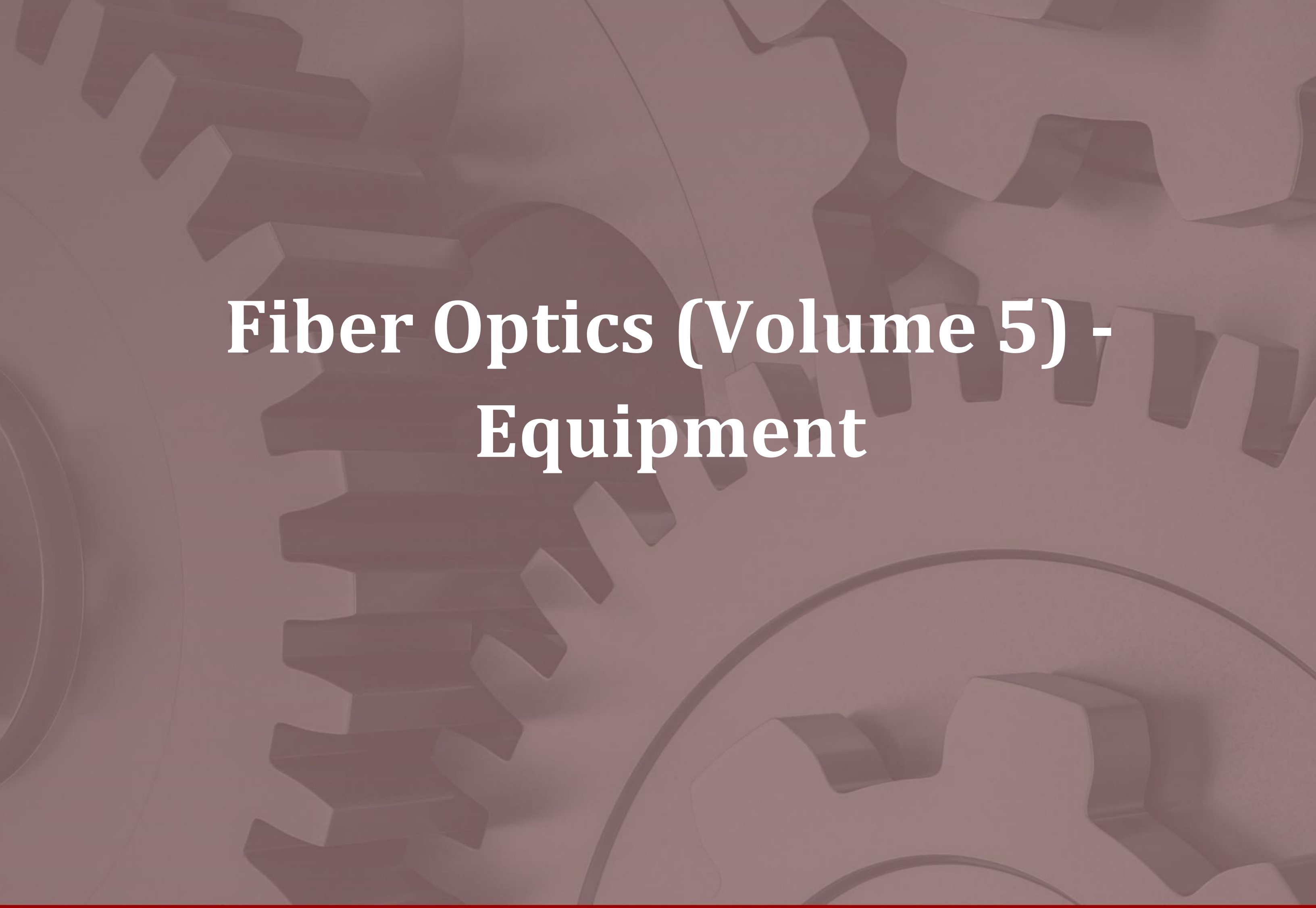

Fiber Optics (Volume 5) - Equipment

An Online Continuing Education Course for Engineers

Course Number: IC-4002

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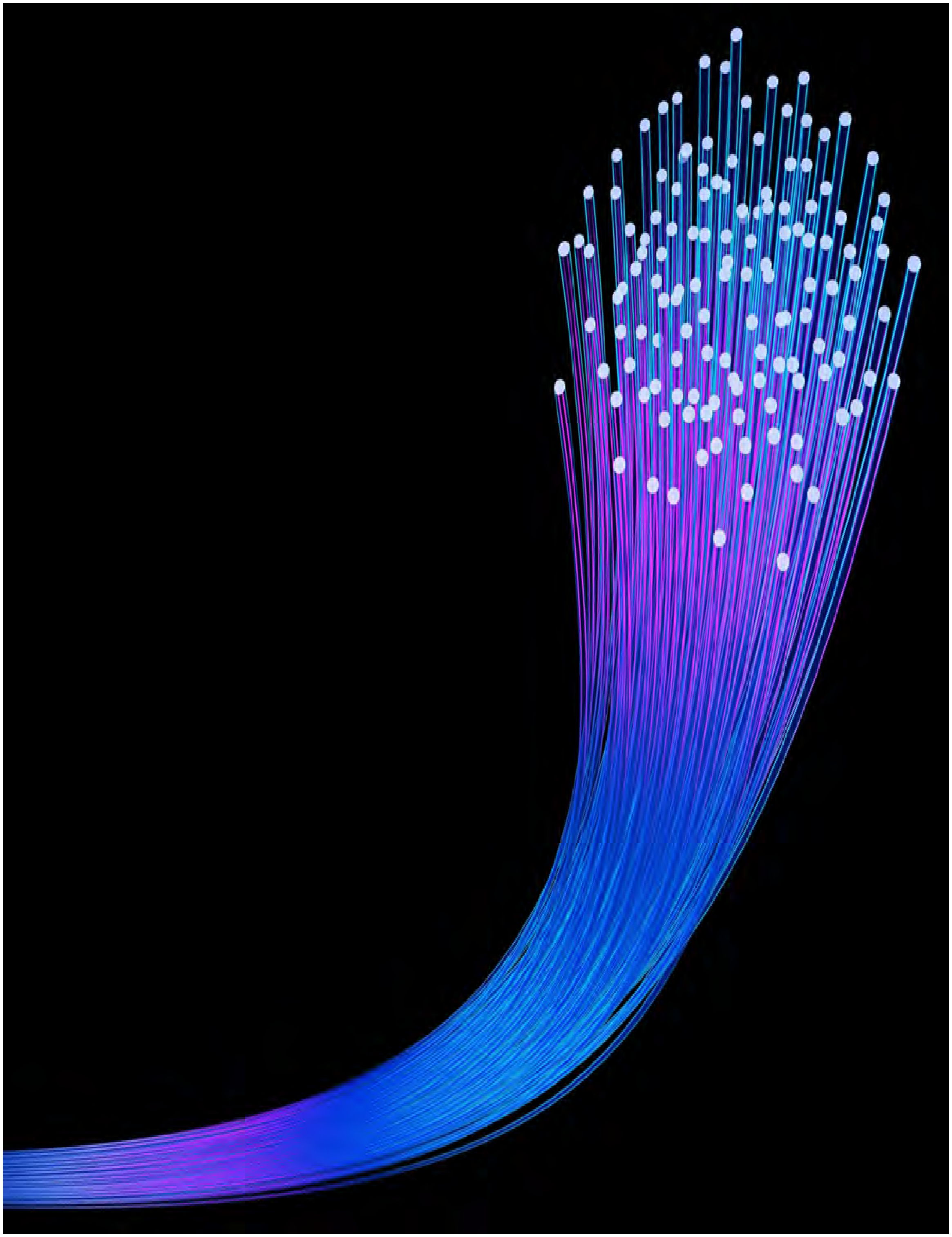

Preface

This is the fifth and final course in a series of five courses about fiber optic cable systems. The series covers fiber optics from basic light theory transmission to cables, connectors, testing, and signal transmission.

The complete series includes these five courses:

1. Fiber Optics I – Theory
2. Fiber Optics II – Cable Design
3. Fiber Optics III – Connectors
4. Fiber Optics IV – Testing
5. Fiber Optics V – Equipment

The first course, *Fiber Optics I – Theory*, is an overview of the technology of fiber optic cables, including a description of the components, history, and advantages of fiber optic cables. This course also discusses the electromagnetic theory of light and describes the properties of light reflection, refraction, diffusion, and absorption.

The second course, *Fiber Optics II – Cable Design*, explains the basic construction of fiber optic cables, including the types of cables, cable properties, and performance characteristics. The course reviews multimode, single-mode step-index and graded-index fibers, and fabrication procedures.

The third course, *Fiber Optics III – Connectors*, describes fiber optic splices, connectors, couplers, and the types of connections they form in systems. It includes a discussion on the types of extrinsic and intrinsic coupling losses, fiber alignment and fiber mismatch problems, and fiber optic mechanical and fusion splices.

The fourth course, *Fiber Optics IV – Testing*, describes the optical fiber and optical connection laboratory measurements used to evaluate fiber optic components and system performance, including the near-field and far-field optical power distribution of an optical fiber. This course also reviews optical time-domain reflectometry (OTDR).

The fifth course, *Fiber Optics V – Equipment*, explains the principal properties of an optical source and fiber optic transmitters, the optical emission properties of semiconductor light-emitting diodes (LEDs) and laser diodes (LDs), and explains the operational differences between surface-emitting LEDs (SLEDs), edge-emitting LEDs (ELEDs), superluminescent diodes (SLDs), and laser diodes.

It is not necessary to take the courses in sequence. However, for best the comprehension, it is suggested that the courses be taken in the order presented.

Introduction

This is the final volume in a five-volume series on fiber optics systems. This volume is concerned with the transmitters, receivers, and the topography of fiber optic systems.

This course discusses the *equipment* used in fiber optic systems. Equipment refers to the principal properties of an optical source and fiber optic transmitters, the optical emission properties of semiconductor light-emitting diodes (LEDs) and laser diodes (LDs), and explains the operational differences between surface-emitting LEDs (SLEDs), edge-emitting LEDs (ELEDs), superluminescent diodes (SLDs), and laser diodes.

Next, fiber optic receivers are discussed. A fiber optic receiver consists of an optical detector, an amplifier, and other circuitry. In most fiber optic systems, the optical detector is a PIN photodiode or APD. Receiver performance varies depending on the type of detector used. The amplifier is generally described as having two stages: the preamplifier and the postamplifier. The *preamplifier* is defined as the first stage of amplification following the optical detector. The *postamplifier* is defined as the remaining stages of amplification required to raise the detector's electrical signal to a level suitable for further signal processing.

The final chapter in this volume reviews the topologies of fiber optic networks. Most of our discussion up to this point has referred to simple point-to-point links. A *point-to-point* fiber optic data link consists of an optical transmitter, optical fiber, and an optical receiver. In essence, all fiber optic systems are simply sets of point-to-point fiber optic links. Different system topologies arise from the different ways that point-to-point fiber optic links can be connected between equipment. The term *topology* refers to the configuration of various equipment and the fiber optic components interconnecting them. This equipment may be computers, workstations, consoles, or other equipment. Point-to-point links are connected to produce systems with linear bus, ring, star, or tree topologies. Point-to-point fiber optic links are the basic building block of all fiber optic systems.

Chapter One: Optical Sources

In volume one of this series, we learned that a fiber optic data link has three basic functions. One function is that a fiber optic data link must convert an electrical signal to an optical signal permitting the transfer of data along an optical fiber. The fiber optic device responsible for that signal conversion is a fiber optic transmitter.

A *fiber optic transmitter* is a hybrid device. It converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber optic transmitter consists of an interface circuit, a source drive circuit, and an optical source. The interface circuit accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The source drive circuit intensity modulates the optical source by varying the current through the source.

An *optical source* converts electrical energy (current) into optical energy (light). The light emitted by an optical source is launched, or coupled, into an optical fiber for transmission. Fiber optic data link performance depends on the amount of optical power (light) launched into the optical fiber. This course attempts to provide an understanding of light-generating mechanisms within the main types of optical sources used in fiber optics.

Optical source properties

The development of efficient semiconductor optical sources, along with low-loss optical fibers, LED to substantial improvements in fiber optic communications. Semiconductor optical sources have the physical characteristics and performance properties necessary for successful implementations of fiber optic systems. It is desirable that optical sources,

- Be compatible in size to low-loss optical fibers by having a small light-emitting area capable of launching light into a fiber
- Launch sufficient optical power into the optical fiber to overcome fiber attenuation and connection losses allowing for signal detection at the receiver
- Emit light at wavelengths that minimize optical fiber loss and dispersion.
- Optical sources should have a narrow spectral width to minimize dispersion
- Allow for direct modulation of optical output power

Maintain stable operation in changing environmental conditions (such as temperature), cost less, and be more reliable than electrical devices, permitting fiber optic communication systems to compete with conventional systems semiconductor optical sources suitable for fiber optic systems range from inexpensive light-emitting diodes (LEDs) to more expensive semiconductor lasers. Semiconductor LEDs and laser diodes (LDs) are the principal light sources used in fiber optics.

Operating wavelength

Fiber-optic communication systems operate in the 850-nm, the 1300-nm, and the 1550-nm wavelength windows. Semiconductor sources are designed to operate at wavelengths that minimize optical fiber absorption and maximize system bandwidth. By designing an optical source to operate at specific wavelengths, absorption from impurities in the optical fiber, such as hydroxyl ions (oh^-), can be minimized. Maximizing system bandwidth involves designing optical fibers and sources that minimize chromatic and intermodal dispersion at the intended operational wavelength.

Initially, the material properties of semiconductor optical sources provided for optical emission in the 850-nm wavelength region. An 850-nm operational wavelength avoids fiber absorption loss from oh^- impurities near the 900-nm wavelength. Light sources for 850-nm systems were originally semiconductor LEDs and lasers. Currently, most 850-nm systems use LEDs as a light source. LEDs operating at 850-nm provide sufficient optical power for short-distance, low-bandwidth systems. However, multimode fiber dispersion, the relatively high fiber attenuation, and the LED's relatively low optical output power prevent the use of these devices in longer-distance, higher bandwidth systems.

The first development allowing the operational wavelength to move from 850 nm to 1300 nm was the introduction of multimode graded-index fibers.

Multimode graded-index fibers have substantially lower intermodal dispersion than multimode step-index fibers. Systems operating at 850 nm cannot take full advantage of the fiber's low intermodal dispersion because of high chromatic dispersion at 850 nm. However, the use of multimode graded-index fibers allows 850-nm LEDs to operate satisfactorily in short-distance, higher bandwidth systems.

Following the enhancements in multimode fiber design, next-generation LEDs were designed to provide optical emission in the 1300-nm region. Multimode graded-index fiber systems using these LEDs can operate over longer distances and at higher bandwidths than 850-nm systems. Longer distances and higher bandwidths are possible because fiber material losses and dispersion are significantly reduced in the 1300-nm region.

Advances in single-mode fiber design and construction sped the development of semiconductor LEDs, and LDs optimized for single-mode fibers. Single-mode fibers have very low dispersion values. However, existing LEDs were unable to focus and launch sufficient optical power into single-mode fibers for long-haul, very high-bandwidth communication systems. New semiconductor LEDs and LDs capable of operating with single-mode fibers at 1300 nm were developed to take advantage of the very low value of dispersion of single-mode fibers. Additionally, LEDs and LDs operating at 1550 nm were developed to take advantage of the fiber's lowest loss.

Semiconductor light-emitting diodes and laser diodes

Semiconductor LEDs emit *incoherent light*. Spontaneous emission of light in semiconductor LEDs produces light waves that lack a fixed-phase relationship. Light waves that lack a fixed-phase relationship are referred to as *incoherent light*. Spontaneous emission of light is discussed in more detail later. The use of LEDs in single-mode systems is severely limited because they emit unfocused incoherent light. Even LEDs developed for single-mode systems are unable to launch sufficient optical power into single-mode fibers for many applications. LEDs are the preferred optical source for multimode systems because they can launch sufficient power at a lower cost than semiconductor LDs.

Semiconductor LDs emit *coherent light*. LDs produce light waves with a fixed-phase relationship (both spatial and temporal) between points on the electromagnetic wave. Light waves having a fixed-phase relationship are referred to as coherent light. Stimulated emission of light is discussed later. Since semiconductor LDs emit more focused light than LEDs, they can launch optical power into both single-mode and multimode optical fibers. However, LDs are usually used only in single-mode fiber systems because they require more complex driver circuitry and cost more than LEDs.

Optical power produced by optical sources can range from microwatts (μw) for LEDs to tens of milliwatts (mw) for semiconductor LDs. However, it is not possible to effectively couple all the available optical power into the optical fiber for transmission.

The amount of optical power coupled into the fiber is the relevant optical power. It depends on the following factors:

- The angles over which the light is
- The size of the core size
- The alignmen
- The coupling refractive index profile)

Typically, semiconduc) to 15 degrees. Semiconductor LEDs g losses of several decibels can easily occ fiber, especially with LEDs.

Source-to-fiber coupling ver. The coupling efficiency depends on th . Coupling efficiency also depends on the coup

Source-to-fiber coupling itting region of the light source. If the fiber e egion, it is referred to as *butt coupling*. If the s acceptance pattern, source-to-fiber co small lens between the source and fiber. Lensing when coupling both LEDs and LDs to optical fibers.