

AC 2009-385: FIBER OPTICS COURSE FOR UNDERGRADUATE ELECTRICAL ENGINEERING STUDENTS

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Fiber Optics Course for Undergraduate Electrical Engineering Students

Abstract

This paper describes in detail the course objectives, outline, and assessment. The course introduces students to the fundamentals of fiber optics, properties of optical fibers, passive and active optical devices, and optical communication systems design. In completion of the course, students will be able to apply knowledge of mathematics and physics in the area of fiber optics, carry out experiments and analyze data, and utilize the techniques and skills learned for real life engineering practice. The course takes the format of lecture plus lab activities. Students not only gain knowledge in this area but also obtain hands-on experiences on splicing optical fiber, diagnosing the health of a fiber link, and designing a single-channel optical communication system. Initial student feedback indicates that the course goals have been successfully met.

Introduction

In recent years, many applications in the areas of video, voice and data transmission call for high-speed, high-bandwidth and reliable telecommunication network. Web applications such as iTunes, YouTube, and MySpace are generating an increasingly higher use of bandwidth. Enterprises' computing system throughput is doubling about every two years¹. To meet the demand, optical fiber has emerged as the leading telecommunication media and fiber optics and opto-electronic devices have become important basic components in optical communication networks. As the demand on bandwidth continues to grow, optical networks need to be expanded and optimized to support the growth.

The demand for students with knowledge in fiber optics is growing rapidly. In the Electrical and Computer Engineering (ECE) advisory board meetings, representatives from industry expressed the need of students in fiber optics area. To respond to industry needs, School of Engineering at Grand Valley State University developed a new EE elective course titled "Introduction to Fiber Optics" which was first offered in Summer 2008.

In this paper, a brief overview of fiber optic network is presented first, followed by detailed description of course objectives, outline, and assessment and future modifications.

Overview of Optical Communication Network

Today's optical communication network carries a mixture of voice, video, and data signals. The distance that signals travel ranges from less than a mile to thousands of miles. To better manage different signals, optical communication network is classified into four sub-networks. They are undersea network, long-haul network, metropolitan network, and access network as illustrated in Figure 1.

Undersea network crosses the ocean and connects continents. The optical fibers used in this network are special submarine fiber optic cables. These cables span hundreds or thousands of miles linked by optical amplifiers, repeaters and regenerators. Submarine cables and related

components must meet extreme environmental and performance requirements. Reliability and transmission capacity are top priority in this network due to high cost of repairing and operation.

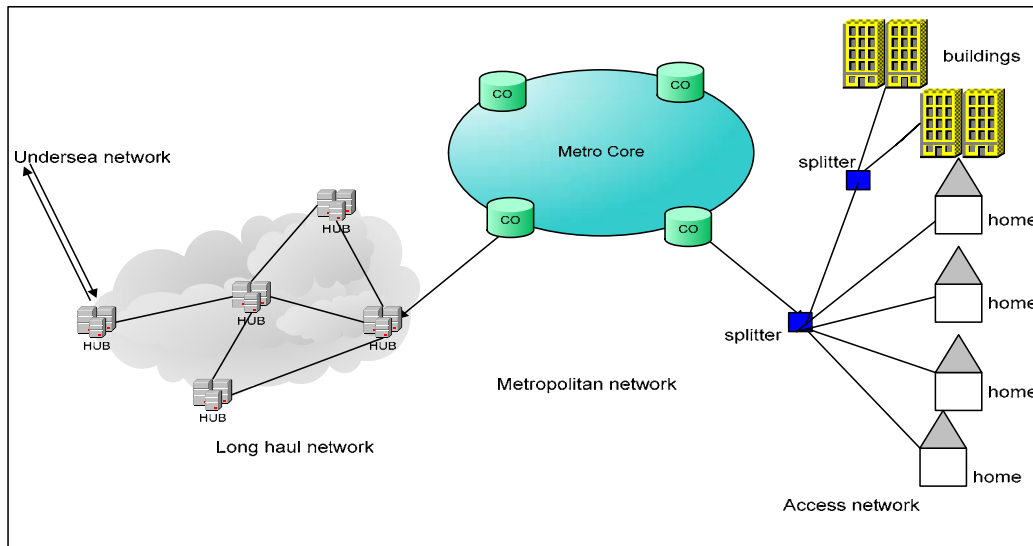


Figure 1 Typical optical communication network topology

Long haul networks connect major urban centers or traffic hubs. Signals in this network typically run a few hundred miles. Due to the more accessible terrestrial environment, optical fibers and related components do not have the same stringent requirements as their submarine counterparts. Typical long haul networks are mesh-like network and signals are transmitted using Dense Wavelength Division Multiplication (DWDM) technology.

Metropolitan networks or metro core networks interconnect central offices (CO) in heavily populated metropolitan areas. Connections are arranged in a ring called metro core loop which carries the large volume of data traffic. Metro networks usually span less than 200 miles. Many are within 100-mile range and hence fewer optical amplifiers are required. Signals are frequently added to or dropped from the core loop. Most metro networks use full spectrum Coarse Wavelength Division Multiplication (CWDM) technology to carry signals.

Connected with metro networks are access networks which connect carrier's central office (CO) to individual homes and businesses. Traditionally, twisted pairs or coax cables (copper) are used to transmit signals. However, the inherent narrow bandwidth feature of copper wires limits the network's transmission ability. Efforts have been made to bring optical fiber to the home (FTTH). The topology of access network shown in Figure 1 is a typical Passive Optical Networks (PONs) used today². Optical line terminal (OLT) in central office sends downstream signals through fiber to the neighborhood where a passive component, splitter, distributes signals to individual homes or small businesses. The Optical Network Terminal (ONT) at home contains receivers to receive downstream optical signals and transmitters to send upstream signals at a lower data rate. According to Lightwave Magazine³, Passive Optical Network (PON) revenue reached its second consecutive record high in the third-quarter in 2008, growing 64% over the same period in 2007. It indicated that "Despite the weakening economy, we are still forecasting annual GPON revenue to grow more than 50% in 2009".

Course Objectives

As indicated in the overview, optical communication networks comprise three main parts: transmission medium (optical fiber), optical devices (optical transmitters and receivers, optical amplifiers, splitters, etc.), optical network system (Standards and system design). Students must understand the fundamentals of individual network components, and network concepts and Standards to be able to characterize and design the system.

The course is designed for senior undergraduate electrical engineering students. The objectives of the course are:

- Demonstrate an understanding of light propagating through an optical fiber
- Characterize different types of optical fibers and optical connectors
- Explain the operation of active components such as light sources, transmitter, receiver, optical amplifier, regenerator
- Demonstrate an understanding of the concepts and definitions of fiber optics and optical communication systems
- Calculate signal attenuation, dispersion, and optical reflection loss through a fiber span;
- Carry out Fiber-Optic measurements;
- Design fiber-optic communication systems.

Course Contents

The topics are grouped into three main sections: transmission medium (optical fiber), optical devices, and fiber optic communication systems. The outline of the course is listed below⁴.

- Fundamentals of Fiber Optics
- Optical Fibers
- Optical Sources
 - Light-emitting diode
 - Semiconductor lasers
- Transmitters
- Receivers
- Optical Amplifiers, Repeaters and Regenerators
- Passive Optical Components
- Fiber Optic Measurements:
 - power loss, OTDR, CD, PMD, BERT
- Introduction to communication system concepts
- Communication system design
 - Power budget analysis
 - Dispersion analysis
 - Bit error rate analysis

In the first section, different types of optical fibers are studied and refractive index profiles are compared. These include step-index fiber vs. graded-index fiber, multimode fiber vs. single mode fiber, and standard single mode fiber vs. dispersion-shifted fiber vs. polarization

maintaining fiber. Emphasis is placed on exploring the properties of optical fibers that are important for light transmission. The key concepts are attenuation, dispersion, and light collection and propagation. The mechanisms of attenuation and dispersion are explained in detail. In addition, different characterization methods are introduced including Optical Time-Domain Reflectometer (OTDR), Chromatic Dispersion (CD), and Polarization-Mode Dispersion (PMD). Measurement procedures are demonstrated and results are analyzed.

At the end of this section, students are expected to understand related concepts and be able to calculate total fiber loss, event loss, fiber attenuation, optical reflection loss, chromatic dispersion, and polarization-mode dispersion.

In the second section, optical components, commonly used in optical communication networks, are introduced. These include active components and passive components. Light sources, transmitters and receivers are the focus for active components and connectors, splices, and couplers for passive components. In terms of active components, students are expected to know the operation and performance considerations of light sources and photo-detectors and be able to design simple transmitter and receiver circuits. In terms of passive components, students should be able to know different structures of connectors and mechanisms of connector and splice losses.

The last section covers optical communication systems. System and optical networking concepts, such as modulation, multiplexing, transmission capacity, transmission topology, cost and reliability, help students know how signals are transmitted and how systems perform. Power budgeting, loss budgeting, Bit-Error-Rate budgeting, and transmission capacity budgeting are key to optical communication system design. Both cost and performance are the concerns in system design and often times trade-offs have to be made. Wavelength Division Multiplication (WDM) technology is essential in today's networks. Issues related to dense WDM and coarse WDM are discussed. At the end of this section, students are expected to design a single channel multi-building campus network and single channel undersea network with the given specifications.

To help students understand basic concepts taught in class and put knowledge in use and gain hands-on experiences with optical fiber and optical components, both classroom demonstrations and laboratory activities are developed.

Classroom Demonstrations: OTDR, CD, and PMD measurements

T-BERT 8000 test sets were purchased from JDS Uniphase Corporation. These test sets were brought to classroom to demonstrate OTDR, CD, and PMD measurements. The mechanisms of OTDR, CD, and PMD are briefly discussed below, along with the key concepts that students are required to learn.

The OTDR is used to characterize total loss, attenuation and reflection of the fiber span. It launches a short duration laser pulse into the fiber under test. As the optical pulse propagates along the fiber, they encounter Fresnel reflections and Rayleigh scattering from the fiber connection sites and the fiber itself, respectively. As a result, a fraction of the signal is reflected

back in the opposite direction. By measuring the arrival time of the returned light, the locations and magnitudes of faults are determined and the fiber span is characterized. Students are required to understand the mechanism and operation of OTDRs and know what the performance parameters are. Ultimately, they are able to perform an OTDR test and analyze the backscatter trace and the health of the fiber link.

A typical OTDR trace is shown in Figure 2 where attenuation is plotted as a function of fiber length. Figure 2 shows that attenuation of the fiber under test at the measured wavelength (1550 nm) is 0.2 dB/km. This fiber link is failed due to high splice losses (higher than 0.3 dB) and high connector losses (higher than 0.5 dB).

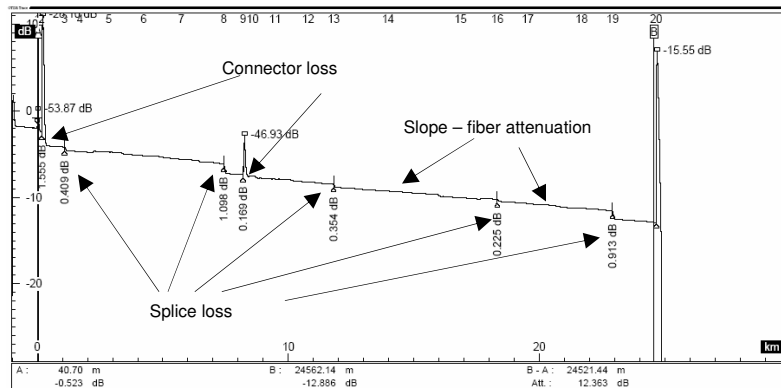


Figure 2 An OTDR trace at 1550 nm for a fiber span of 24.5 km

To obtain accurate event losses, bi-directional OTDR trace analysis technique is often used. To perform bi-directional OTDR, signals are launched from both ends of the fiber and event losses are averaged. A typical bi-directional OTDR trace is shown in Figure 3.

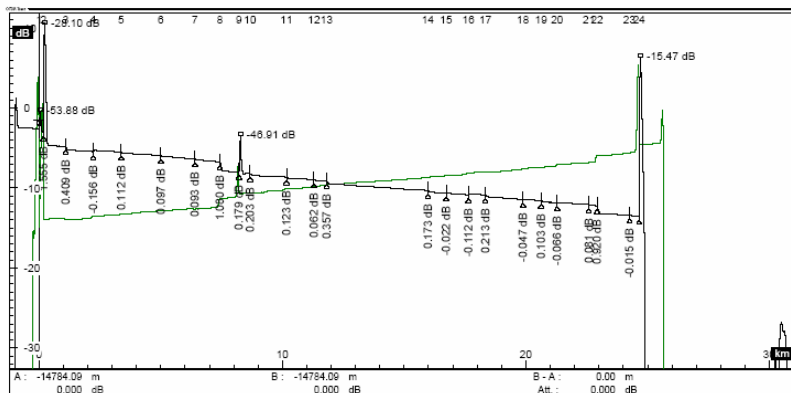


Figure 3 Bi-directional OTDR traces

Chromatic dispersion is often a limiting factor in long haul and undersea networks⁵. CD is the variation in propagation delay with wavelength, which is critical in DWDM transmission. There are different methods to characterize chromatic dispersion. Commonly used are pulse delay method and phase shift method. The pulse delay method is a one-ended fiber test method where OTDR is utilized. The arrival times of reflected signals at different wavelengths are compared

and the group delay and chromatic dispersion are calculated. Phase shift method is based on measuring the phase comparison, from a broadband source, of different wavelengths. The system uses amplitude modulation techniques and has a high temporal precision at high modulation frequencies. Both methods are explored and their advantages and disadvantages are summarized. Figure 4 illustrates the block diagram of CD measurement using phase shift method.

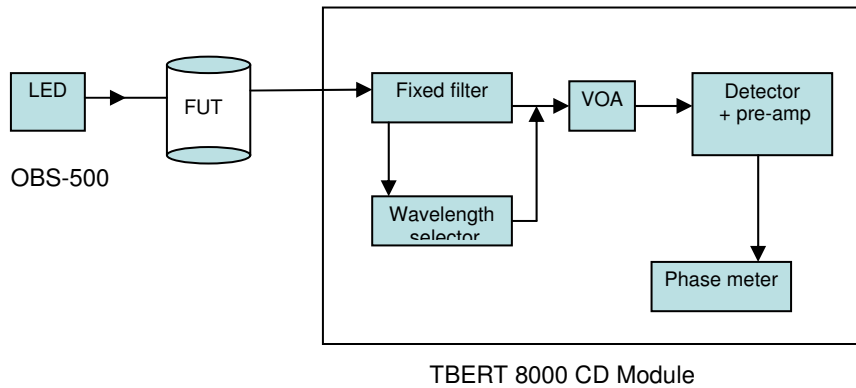


Figure 4 Block diagram of CD measurement using phase shift method

Polarization Mode Dispersion (PMD) is another limiting factor in long haul and undersea networks. It is caused by the interaction between light and material properties of the fiber. Different polarization modes of light travel along the fiber at slightly different speeds, which causes light pulses to spread out. PMD measurement is based on measuring mean Differential Group Delay (DGD) and PMD coefficient using equipment that is based on interferometric method. Figure 5 shows the setup of the PMD measurement where a broadband light source is connected to one end of the fiber under test and PMD analyzer is connected to the other end.



Figure 5 Experimental setup for PMD measurements

Laboratory Activities

Feedbacks from industry partners indicated that engineers who worked with electrical cables and components have hard time to handle optical fibers and components. The first laboratory activity is devoted to cleaning, handling optical fibers. The list of the activities is shown below:

- Fiber continuity and core size identification
The objective of this activity is to learn the procedure of fiber cleaning and handling, to test the continuity of optical fiber, and to identify different fiber core sizes using inspection microscope
- Optical connector installation and patch cord fabrication
The objective of this activity is to learn the structures of optical connectors, to install, terminate and polish ST connectors and fabricate a multimode patch cord
- Measurement of connector and fiber bending losses and fiber attenuation
The objective is to measure the mated connector losses, different bending losses, total losses and fiber attenuation using optical sources and power meters
- Fiber splice installation and splice loss measurement
The objective is to learn different techniques of fiber splice, to install a fiber-to-fiber mechanical splice, and to measure and calculate splice loss
- Characterization of LEDs and laser diodes
The objective is to measure the output power of LEDs/laser diodes as a function of drive current and to measure the threshold current of laser diodes as a function of temperature

Materials and equipment needed for these laboratory activities include:

- Patch cords with different fiber sizes, 50/125, 62.5/125, 9/125, and plastic fiber
- Inspection microscope, OLS-5 optical sources and OLP-5 power meters
- ST connector assembly kits
- Multimode and single mode fiber cables
- Fiber-to-fiber mechanical splices

Assessment and Future Modifications

At the end of Summer 2008, the course as well as the instructor was evaluated by the students. Table 1 lists key assessment results (six students).

1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree

Questions	1	2	3	4	5
The course was taught well				50%	50%
The sequence of topics seemed logical to me			17%	33%	50%
The exams and other assignments made me think rather than just memorize				67%	33%
I had considerable interest in this course at the end of the semester			17%	33%	50%
I enjoyed taking this course			17%	16%	67%
I have benefited by having this instructor			17%	16%	67%
This instructor motivated me to do my best work for this class				67%	33%

Table 1 Student evaluation results at the end of the semester

Students also indicated “great lab activities” and “it was interesting to see how fibers actually acted in real life”. When asked about course improvements, students indicated that more lab activities would be a great help. In the next offering, new laboratory activities in the areas of active optical devices and optical communication systems will be added. More assessment data will be available and discussed after a few offerings.

Summary

In summary, a new course on fiber optics was developed for undergraduate electrical engineering students to respond to the rapid growing industry need. The course covers a broad spectrum ranging from optical components to optical communication systems. In addition to the lecture, classroom demonstrations and laboratory activities are incorporated. The course was offered for the first time in Summer 2008. The preliminary assessment results showed that the objectives of the class were successfully met. Due to the fact that fiber optic technology is constantly evolving, both the course contents and laboratory activities will undergo continuous revision.

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