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Hands-on Active Learning in Fiber Optics Course

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Hands-On Active Learning in Fiber Optics Course

Abstract: This paper describes the development of learning modules of the senior elective course: Introduction to Fiber Optics and the assessment results from the 2012 course offering. Three approaches were incorporated in active learning: design, simulation, and build. Eight lab activities were developed to introduce students to the basic skills of handling optical fibers, characterizing fiber optic components, and analyzing single-channel fiber optic communication systems. Simulation software "OptiPerformer" was used to explore different fiber optic communication systems. Students designed a silica single mode optical fiber to meet the required dispersion properties using MATLAB for their mid-term project. For the final project, a long-haul optical transmission system was designed.

Keywords: Fiber Optics, optical communication systems, hands-on, active learning

Introduction

Internet applications move rapidly from transmitting photos and downloading songs to downloading and streaming high-definition videos and feature-length movies as well as high-capacity, high-performance computing. According to the Cisco Visual Networking Index, global IP traffic has increased eightfold over the past 5 years and will increase threefold over the next 5 years. It would take over 6 million years to watch the amount of video that will cross global IP networks each month in 2016 [1]. The growing demands for bandwidth and capacity require continuous upgrades in the optical communication network: the faster network speed (40Gb/s $\rightarrow$ 100Gb/s $\rightarrow$ 400Gb/s) and expanded network topologies (Long haul, Metropolitan, Access, Fiber to the Home). From the educational institutes' standpoint, we must make sure that our graduates have the knowledge and practical training to support the on-going changes.

In response to these demands, the School of Engineering at Grand Valley State University developed a three-credit senior elective course EGR458 "Introduction to Fiber Optics" in 2009 [2]. For the first two offerings, short active-learning exercises were supplemented for the lecture. Feedback from students showed that these learning exercises were effective ways in learning fiber optics and more hands-on learning materials were desired. In 2012, a course change proposal was approved to change the credit of the course from three to four. The course was revised to include hands-on learning modules which include eight lab activities, one mid-term project, and one final project. This paper details the development of these learning modules and assessment results from the 2012 course offering.

Course Overview

Optical communication networks consist of three main components: transmission medium (optical fiber), optical devices (both active and passive devices), and optical network system (Standards and system design). Each component plays an important role in transmitting information successfully. Hence in order to be able to characterize and design the optical communication systems, it is essential that students learn the fundamentals of individual network components, communication system concepts, and methodologies of system design.

The goal of the course is to introduce students to the field of fiber optics and optical fiber communication systems. The contents of the course include fundamentals of fiber optics; properties of optical fiber; optical fiber testing; active components like transmitters, receivers, and optical amplifiers; passive components like splices, couplers, and connectors; applications of fiber optics, and optical communication system design.

The course is targeted towards senior undergraduate electrical engineering students. Upon completing the course, students would be able to:

- Characterize different types of optical fibers and optical connectors
- Explain the operations of active components such as transmitters, receivers, optical amplifiers, etc
- Describe the typical characteristics of optical fibers and optical communication systems
- Calculate essential parameters of a fiber span and carry out fiber-optic measurements
- Design fiber-optic communication systems
- Communicate effectively through technical writing.

Study has shown that students learn better through active learning, which is especially true for the new generation who are equipped with all types of electronic gadgets. In the School of Engineering, we strive to provide students with active learning and hands-on experiences. It is our goal to be sure that students acquire solid foundation knowledge and ability to apply the learned knowledge to the respective field. In the first two offerings of the course, in-class activities were introduced. Students were motivated and learned more through these activities. However, often time students could not finish the activities within the allocated time. In addition, feedback from the students showed that more learning activities were desired.

In 2012, a course change proposal was approved to change the credit of the course from three to four, which allowed high quality lectures as well as hands-on learning modules be delivered to students. The hands-on learning modules include eight lab activities, one mid-term project, and one final project.

Laboratory Activities

The lab was developed to provide students with experiences from handling and cleaning optical fibers, characterizing the network components to analyzing optical fiber communication systems. Total eight lab activities were divided into three categories as follows:

1. Optical fibers, connectors, and splices
2. Characterization of optical fibers
3. Characterization of active components
4. Fiber optic communication systems

Detailed descriptions of the activities are given below.

1. Optical fibers, connectors, and splices: Activities in this category aim at providing students with experiences in handling optical fibers, fiber splices, and optical connectors. The category includes four activities:

a. *Fiber Cleaning, Handling and Bending Losses:* Optical fiber communication systems differ from electrical communication systems. One biggest difference is the signal loss from the medium. We are all familiar with copper wires and copper connectors. Copper wires can be bent and connectors can be connected directly without cleaning. However, optical fibers are very sensitive to bending and optical signals transmitting through an optical connector can easily be attenuated due to misalignment. Proper procedures should be followed when handling optical fibers and connectors. The objectives of this activity are to learn how to handle/clean optical fibers and connectors and to measure the bending loss of different optical fibers. The materials needed in this activity include cleaning tape, isopropyl alcohol, lint free laboratory wipes (Kimwipes), multi-mode and single-mode optical patch cords, hand-held inspection microscope, LED sources, and optical power meters.

In this lab activity, students first learned to clean the optical fiber connectors. Defect free fiber connectors are required when connecting fiber optic cables together. Any small objects or dirt on the surface would cause signal attenuation or in some cases cause damage to the connectors. If appropriate cleaning procedure is not followed, the connectors are subject to scratching. Students were able to clean the connectors either with the cleaning tape or the lint-free wipe and isopropyl alcohol as well as to inspect the end face of the connector with the microscope.

In the second part of the activity, students studied the bending effects on the fiber loss for both multi-mode (MM) and single-mode (SM) fibers. Light was sent down the optical fiber patch cord from the LED light source and collected by the optical power meter connected at the other end of the patch cord. Circular loops with different diameters were made near one end of the patch cord. Fiber losses were recorded for different bending diameters at two different wavelengths, 850nm and 1310nm. Table 1 shows the loss table used in this activity.

Table 1 Fiber Loss Table for Multi-Mode (MM) and Single-Mode (SM) Fibers

Diameter of the loop		Loss (dB)		
inch	Name	MM @850nm	MM @ 1310nm	SM @ 1310nm
6	L_6			
4	L_4			
2	L_2			
1.5	$L_{1.5}$			
1	L_1			
0.75	$L_{0.75}$			
0.5	$L_{0.5}$			

Students learned that the smaller the bending diameter is the larger the fiber loss is. The fiber bending loss is more sensitive to the longer wavelength light. Compared to the MM fiber, the SM fiber experiences more fiber bending losses.

b. Fiber Continuity Testing and Core Size Identification: The objectives of this activity are to test the continuity of the optical fiber and to identify different optical fiber core sizes. The materials needed include inspection microscope and different optical fiber patch cords: 50/125, 62.5/125, 9/125, and plastic fiber.

The first step to take when a problem occurs with a fiber link is to test the fiber continuity. Light was sent from one end of the fiber and observed from the other end. If there is no light exiting the other end of the fiber, there is a cut somewhere in the fiber link and more sophisticated equipment can be used to identify the location of the cut.

The major difference among the optical fibers is the size of the fiber core. Most MM fibers either have a core size of 50µm or 62.5µm and most SM fibers have a core size of about 9µm. Plastic fibers can have a core size greater than 1mm. Optical signals can be greatly reduced when going from a bigger-core-sized fiber to a smaller-core-sized fiber. Hence, it is important to be able to identify different optical fibers. In this activity, students were given opportunities to identify different fibers and observe the end faces (relative sizes of the core and cladding) of the optical fibers under inspection microscope.

c. Installation of ST Connectors: Installation of optical connectors is more complicated than that of the electrical connectors. The objective of this activity is to install a ST connector onto a fiber optic cable. The materials used are ST connector assembly kits. Each step is carried out as it would be in a real world application. The key steps of the procedure include fiber preparation, fiber termination, cleaving, and polishing. Even though each step is critical, the most important of all is polishing, which ensures the end face of the fiber patch cord to be clean and free of defects. Figure 1 shows a picture of the fiber end with a ST connector assembly before the end was cleaved and polished.

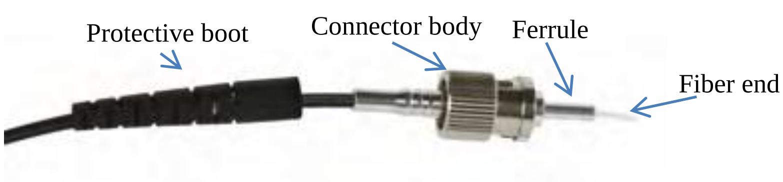

Figure 1 The ST connector assembly before cleaving and polishing

d. Fiber Splice Assembly for Plastic Optical Fibers: The objective of the activity is to join two fiber cable ends using a mechanical splice. Mechanical splices come in a variety of forms. The splice used in this activity is a capillary type splice in which two fiber ends are inserted. Figure 2 shows a cross-sectional view of the splice with one fiber end inserted and the other to be inserted. The Fresnel loss is kept to a minimum by applying index-matching gel to each end of the fiber. The compression technique such as a mechanical crimp is used to hold the fibers in place. The fiber splice is then evaluated with the splice loss calculated from the output power of the patch cord before and after the splice is made. In this activity, students not only learned how to splice optical fibers but also learned how to determine the splice loss from the output power measurements.

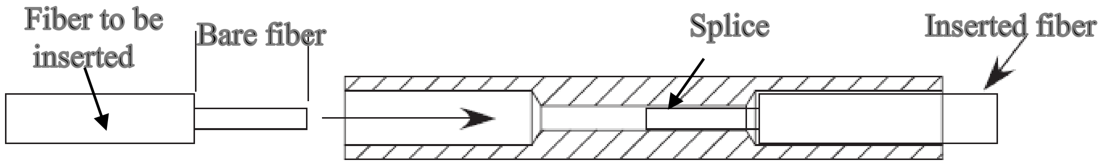

Figure 2 The cross-sectional view of the mechanical splice

2. Characterization of Optical Fibers: One of the most important properties of optical fibers is attenuation. Light propagating down the optical fiber interacts with the materials of the optical fiber and undergoes absorption and scattering. Absorption of light is dependent on the composition of the fiber. Silica has little absorption at wavelength of greater than 1.7μm. However trace metals and water in silica introduce high absorption of light between wavelength of 0.8μm and 1.48μm. Rayleigh scattering caused fiber loss is also wavelength dependent, which is proportional to λ^{-4}. It sets a lower limit on short-wavelength attenuation. The infrared absorption is responsible for the absorption in the long wavelength range. The single mode optical fiber loss as a function of wavelength can be seen in Figure 3 [3].

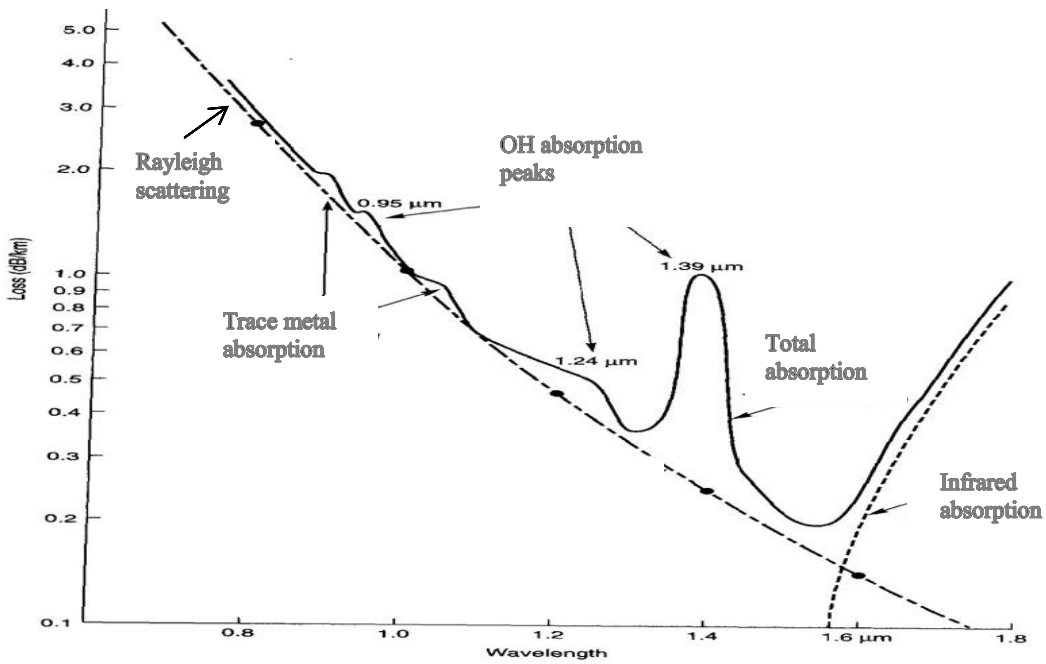

Figure 3 The fiber loss as a function of wavelength (Courtesy of Jeff Hecht)

This category includes one activity:

a. Characterizing Fiber Attenuation: The objectives of this activity are to measure the power of light transmitted through the optical fiber and to determine the attenuation of the fiber. The materials used include red and green LEDs, phototransistors, sidelooker device housing, optical fiber, digital multimeter (DMM), and power supply.

The cutback technique is used in determining the fiber attenuation. The experimental setup is illustrated in Figure 4 where the DMM is connected in series with the phototransistor. The current measured by the DMM is proportional to the output power of the optical fiber. The input and output power of the fiber is related through, $P_o = P_i e^{-\alpha l}$, where P_o is the output power, P_i is the launch power, α is the fiber attenuation, and l is the length of the fiber. With two different fiber lengths (keeping the same launch condition), the fiber attenuation can be determined by $\alpha = \frac{1}{l_1 - l_2} \ln(\frac{P_{o2}}{P_{o1}})$.

In this activity, students learned how to use the cutback technique to determine the fiber attenuation. They also learned the dependence of fiber attenuation on the wavelength of the light source as well as the relationship of the phototransistor collector current and the fiber output power.

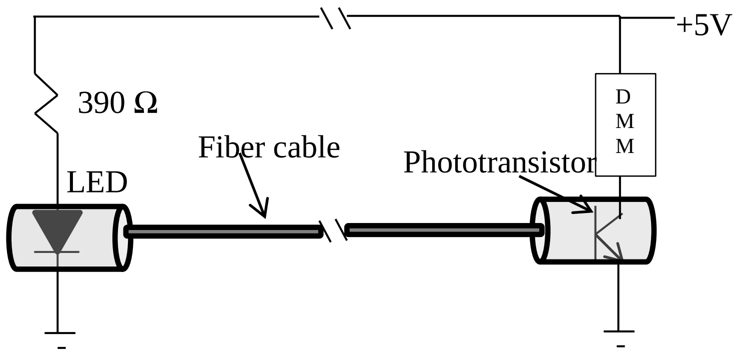

Figure 4 The experimental setup to determine the fiber attenuation

3. Characterization of Active Components: Activities in this category aim at characterizing optical transmitters and optical receivers. This category includes two activities.

a. *Fiber Optic Transmitters:* The objective of this activity is to study the transmitter circuits used in both digital and analog optical transmission systems. Materials include red and IR LEDs, NPN and PNP transistors, switching diodes, assorted resistors, capacitors, function generator, multimeter, oscilloscope, and power supply.

Students began the activity with determining the current – voltage (I-V) characterization of the LEDs and found the forward voltage for the required current flowing through the LED. They then built two digital fiber optic transmitter circuits to characterize the rise time, fall time, and 3-dB bandwidth. Students were also given the opportunity to explore the analog transmitter circuits. Compared to the digital transmitter circuits, the analog circuits require good linearity and adequate bandwidth for the range of input signals. A circuit suitable for driving a LED in a color video application was used and the input signal range without distortion was recorded along with the 3-dB bandwidth.

b. *Fiber Optic Receiver Amplifier Design:* In the optical transmission systems, optical signals are transmitted through optical fiber and received by the photodetectors which convert optical signals to electric currents. Since most electronic circuits use voltages rather than current, transimpedance amplifiers are often inserted to convert electric currents from photodetectors to electric voltages. The objective of this activity is to design and characterize the basic transimpedance amplifier circuits.

The simplest transimpedance circuit is made of only one resistor. The advantage of this circuit is simple and easy to construct. The biggest drawback is the high loading effects. The drawback of the one resistor circuit can readily be overcome using operational amplifier (op-amp). Figure 5 illustrates an optical receiver circuit implemented with LM741. The photodiode (PD) is connected to the inverting input terminal of the op-amp and the feedback resistor, R_f, is placed between the output and the input terminals. The transimpedance gain is determined by the feedback resistor. Both the input resistance and the output resistance of the circuit are near zero.

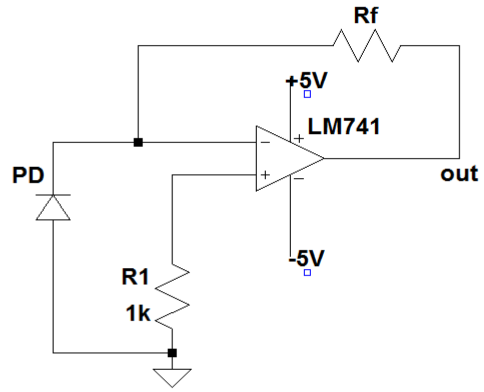

Figure 5 The transimpedance amplifier circuit implemented with the op-amp

The performance of the receiver circuit was analyzed when the feedback resistor value was changed from 10kΩ to 47kΩ to 100kΩ. In addition, a 1nF capacitor was added between the output terminal and the ground and both the rise time and fall time were compared with those without the capacitor. Students learned that the higher the value of the feedback resistor is the longer the rise time is. By adding the capacitor in the output circuit loop, the rise time is increased. Hence minimizing the parasitic load resistors and capacitors is critical in designing the high bandwidth optical receiver circuits.

4. Fiber Optic Communication Systems: Basic fiber optic communication systems include the transmitter, optical fiber, optical amplifiers, and the optical receiver. To evaluate the performance of the system, expensive equipment such as psudo-random binary sequence (PRBS) generator and bit-error-rate (BER) tester are required. When these equipment are not readily available, simulation software often provides an alternative way of studying the fiber optic communication systems. In this course, OptiPerformer was selected to study the performance of fiber optic communication systems [4]. This category includes two activities:

a. *OptiPerformer #1*: The objective of this activity is to study the bit-error-rate (BER) and Q-factor. The BER is a key performance parameter of the optical communication system. It is defined as the probability of a bit being incorrectly identified by the decision circuit of the receiver. Q-factor is related to the BER: the smaller the BER is the higher the Q-factor is. Q-factor of 6 corresponds to the BER of 10^{-9}. Figure 6 shows the system setup to evaluate the

BER and Q-factor in OptiPerformer [5]. The light generated from the CW laser is modulated by the Mach-Zehnder modulator based on the data generated from the PRBS generator. The signal is transmitted through the optical fiber, received by the photodiode and evaluated by the BER tester. The optical attenuator is inserted to simulate different length of the optical fiber. By changing the attenuation of the attenuator, the minimum BER and maximum Q-factor as a function of attenuation are determined. In addition, the minimum BER versus the maximum Q factor is also obtained.

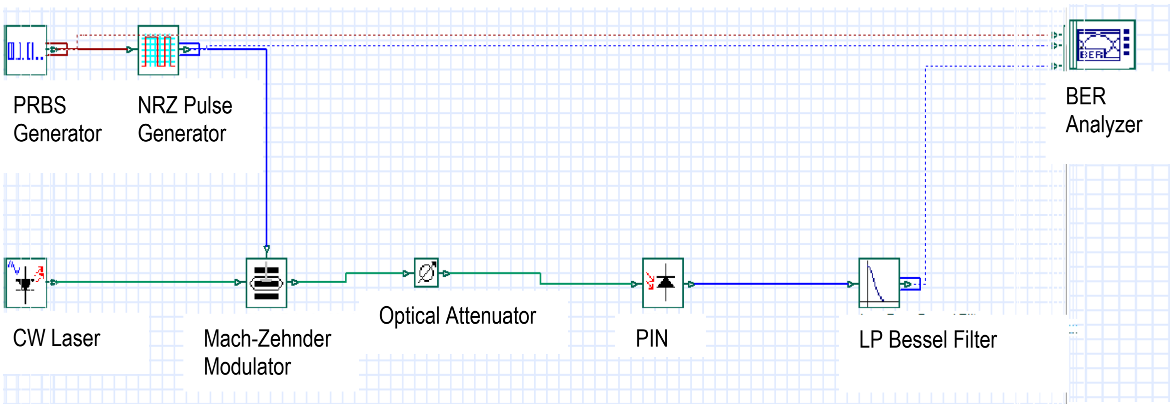

Figure 6 The BER test setup

b. *OptiPerformer #2:* The objective of this activity is to study the return-to-zero (RZ) and non-return-to-zero (NRZ) modulation format transmission in 40Gb transmission system. The system consists of optical transmitter, 1000km single-mode optical fiber, optical amplifier (EDFA), dispersion compensated fiber (DCF), and optical receiver. Figure 7 illustrates the RZ modulation format transmission [5]. Due to the many components involved in the system, the receiver portion is not shown. Both the self-phase modulation and amplification ASE noise are considered and the chromatic dispersion is compensated with post-dispersion compensation scheme.

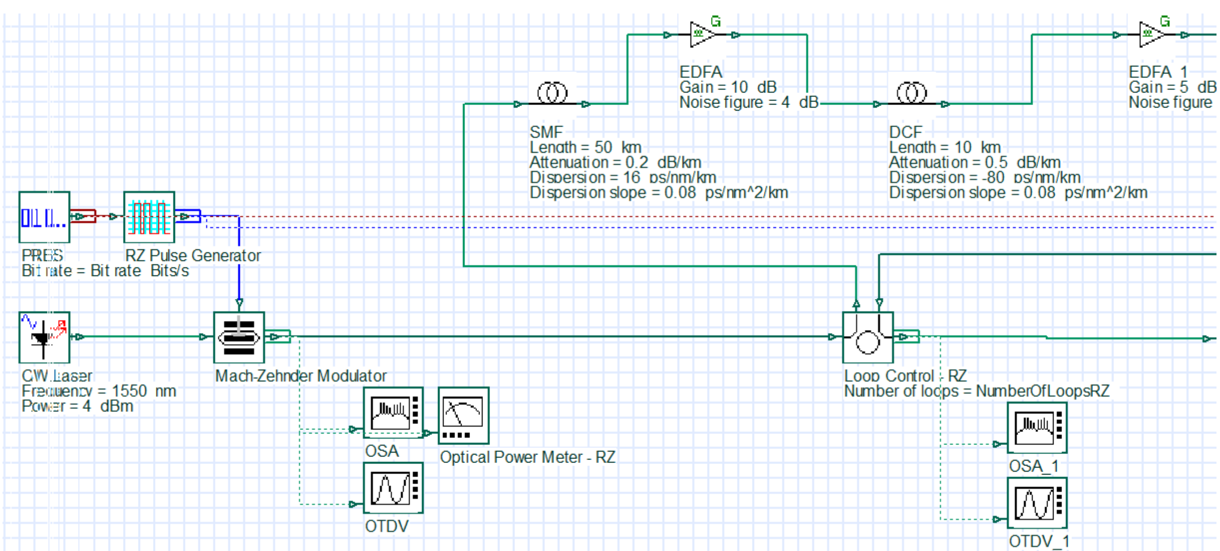

Figure 7 Part of the 40Gb fiber optic transmission system with RZ modulation format

Both the BER and Q-factor were evaluated with different input optical power. The results showed that the optimal input power with the RZ system is 0.3mW and is 0.17mW with the NRZ system. The maximum Q-factor and the eye diagram of the RZ modulation format are illustrated in Figure 8.

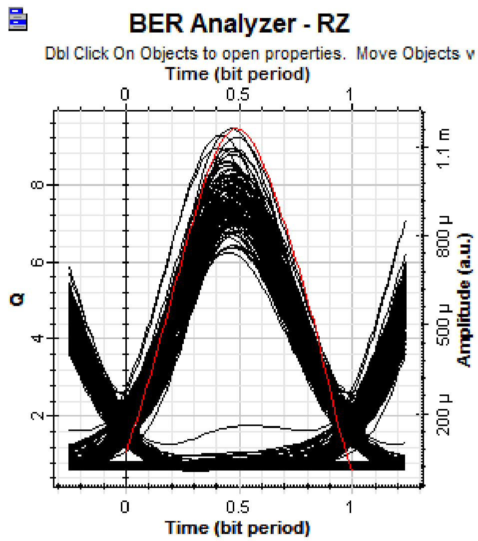

Figure 8 The maximum Q-factor and eye diagram from the BER analyzer

Mid-Term Project

A mid-term project was assigned to make students more familiar with the optical fiber properties and design processes. The objective of the project is to design a silica single-mode optical fiber to meet the required dispersion properties.

Students were to design a SM fiber for the long haul wavelength-division-multiplexing (WDM) system with a wavelength window of 1520nm to 1590nm. The dispersion was assumed to be dominated by the chromatic dispersion which cannot exceed 1.5ps/nm-km at wavelength of 1550nm. Students selected different materials and doping concentrations for the fiber core and cladding. MATLAB was used to calculate the dispersion factor as a function of wavelength for different core radius as well as for different relative index difference of the core and cladding. Based on the results obtained from MATLAB, the optimal core radius and refractive index were determined for the optical fiber that met the dispersion requirements.

Final Project

The final project of the course was to design a long-haul WDM system. Students were given the detailed system requirements like the span length, the overall system length, the transmission speed, the sensitivity of the receiver, the number of wavelength channels, and the operating power margin. They researched system components from different companies and designed the WDM system that met both the rise-time and power budgets.

Learning Module Assessment

1. Direct assessment: For each lab activity, students were not only required to conduct the activity but also to write reports to demonstrate their understanding of the materials covered. In some labs, questions were asked to further inspire students' thinking. In the

activity: Fiber Handling and Bending Losses, after measuring the crimped loss for different optical fibers, the following questions were asked:

- Is the crimped loss worse for MM fiber or SM fiber?
- Do you think this is a problem in real installation?
- How can it be prevented?

The activity report grades' distribution is depicted in Figure 9 which showed that all students conducted the experiment successfully and understood the materials well.

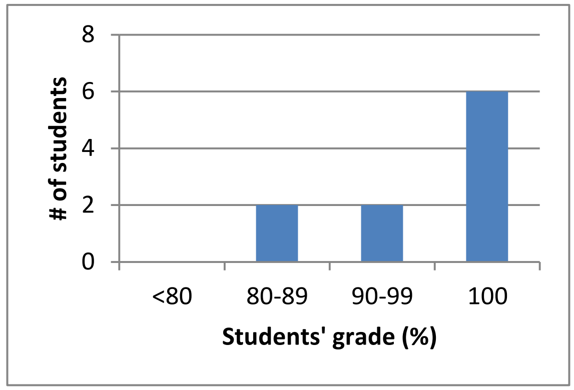

Figure 9 Report grade distribution for activity #1

2. Indirect assessment:
   During the end of term evaluation, 100% students indicated that the course was taught well and they enjoyed taking this course. Some of the comments are:
   - It is effective to have hands on learning activities.
   - Used the "lab" to clarify the material taught in lecture.

Conclusions

Active learning modules were developed and delivered for the senior level elective course of electrical engineering students. The learning modules include eight learning activities, one mid-term project, and one final project. These learning activities covered multiple aspects of fiber optics to expose students to the field of fiber optics. Through these activities, students gained interests and practical knowledge in fiber optics and optical fiber communication systems.

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