Creation of an Electrical Engineering course: Design and simulation of high capacity fiber optic systems utilizing VPI-Photonics

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ABSTRACT

In recent years, the importance of training skillful fiber optic engineers capable of designing and analyzing fiber optic links to deliver the enormous capacity needed for the next generation of mobile phones (5G) has been proven in industry. A comprehensive curriculum for such courses should undoubtedly comprise both theoretical and hands-on skills to better prepare the engineers before entering industry. The hands-on skills can be established through experimenting with real fiber optic links. However, having access to an equipped fiber optic laboratory imposes a significant cost to the academic institutions. Therefore, similar hands-on experiences can be delivered by software simulation of the physical signal generation and propagation. Thus, identifying an efficient yet powerful tool in simulating fiber optics components and devices is of utmost importance toward successfully rendering an understanding of the physical phenomena to the graduates. This paper aims to analyze the necessity of incorporating hands-on experience through software simulation and then it suggests the course topics and the learning outcomes expected to be achieved from this course. In addition, it investigates the feedbacks obtained from graduate engineering students throughout an actual course offered on fiber optic communication and demonstrates the assessment of the strength and weaknesses of the method. Finally, it introduces a powerful software package capable of simulating a variety of optical systems and devices frequently used in a typical fiber optic link and presents the performance analysis of this software package in addressing primitive and complex problems arising in fiber optics.

Keywords: Optical fiber, VPI-Photonics, Software simulation, Course curriculum.

1. INTRODUCTION

This paper describes the application of VPI-Photonics software package in designing fiber optic links and systems. The procedure can be utilized in a laboratory course that is offered concurrently with a lecture course in optical fiber communications. The combined laboratory and lecture courses can be either a senior or first year graduate level course in communication or computer engineering concentrations within an electrical and/or computer engineering program. Ideally, the lecture should be a 3-hour credit course, while the laboratory part is a 1-hour credit course taken concurrently. The combination of the lecture and laboratory provides a totally integrated delivery system for teaching a wide spectrum of topics ranging from optical fiber transmission/reception concepts and applications to performance analysis of fiber optic systems and networks. The laboratory is easily implemented by constructing a PC-based computer network supporting the VPI simulation tool [1]. The topics covered in the laboratory can be divided into three categories: optical fiber devices, links, and systems.

The paper discusses the need for such a course, course topics, student leaning outcomes, and the process for the course assessment. Overall, the course portfolio, which includes syllabus, assessment results, survey results and other documentations are discussed. The discussions in this paper are mostly focused on the laboratory part of this course.

2. NEED FOR CREATION OF FIBER OPTIC SIMULATION LABORATORY

The tremendous growth in the field of information technology in the recent decades has imposed improvement in telecommunications system capacity, performance, and flexibility. Progress in broadband wireless services along with advances in fiber optic technologies have contributed to the largest part of these improvements. With the continuous increase in the use of mobile broadband services and of cellular users, capacity issues in the congested frequency spectrum

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and signal degradation have been problematic for the service providers. The dilemma of signal degradation and bandwidth limitation become more evidence for cases that deal with the indoor reception. At the same time, while fiber-optic technology can provide tremendous bandwidth (capacity) [2],[3] low signal attenuation and high security, it does not support mobility. Thus, the combined use of fiber optics for point-to-point communications and radio frequency (RF) waves for short-range wireless communications can provide high capacity along with mobility [4],[5],[6],[7],[8].

For high capacity transmissions, use of broadband fiber optic communication systems such as wavelength division multiplexing (WDM) systems are continuously advancing due to the spread of technologies that support it [6],[7]. Hybridization of various techniques, such as radio-over-fiber along with new modulation techniques, increases the capacity of fiber optic networks to fulfill the capacity requirements of the next generation of mobile communication (5G). The new fiber optic systems demands highly trained personnel to solve the new challenges. The need for communication engineers capable of new ideas and implementing systems that are feasible to maintain and operate is more relevant than ever. This is particularly important for engineers who are involved with fiber optic systems. Often, electrical engineering curricula offer students one or two theoretical fiber optic communication courses; however, this is not enough to train communications engineers in the proper background of the newer technologies. The traditional courses are focused on the foundations of fiber optic communications theory. The equipment needed to implement laboratories with the newest technologies is expensive and changes constantly. This makes it difficult to continuously upgrade such laboratories. Optical spectrum analysis is required for measuring and monitoring the various characteristics of any optical fiber communication system. Currently, machine learning is used for performance enhancement of optical spectrum analysis technique [9]. It is impractical to design various optical communication systems in a laboratory. However, it is possible to make such system in VPI and collect data to implement machine learning algorithm for research and improvement of the system. Consequently, employing a computer-based laboratory with different software packages dedicated for fiber optic applications can be a good approach to overcome all of the aforementioned drawbacks.

3. COURSE TOPICS

The following represents the list of topics that are covered in the laboratory. The topics are well aligned with the topics that are covered during the lectures. Each 3-hour indicates three hours of laboratory assignment per week.

1. Familiarization with VPI components (3 hours)
2. Optical modulation/detection schemes (6 hours)
3. Component designs (optical amplifiers, modulators, filters, etc.) (6 hours)
4. Single wavelength optical fiber link design (6 hours)
5. Multi-wavelength high capacity optical fiber link design (6 hours)
6. Optical access technologies (3 hours)
7. Integrated photonics (6 hours)

4. STUDENT LEARNING OUTCOMES

This course is a 1-hour credit laboratory that is taken concurrently with a 3-hour credit lecture. The laboratory session is conducted in a PC laboratory for about 2-3 hours per week. The combination of lecture and laboratory provides a leaning environment which supports hands-on approach. The course represents an in-depth study of dispersion and attenuation in optical fibers, non-linear propagation effects, optical amplifiers, sources and detectors, wavelength division multiplexing, coherent systems, performance evaluation of fiber optic systems, and system design considerations. Upon successful completion of this course students will be able to

1. Understand the propagation of light in optical waveguides and optical fibers using ray and wave theories.
2. Understand the operation of fiber optic transmitters.
3. Understand the operation of fiber optic receivers.
4. Perform fiber optic link power budget analysis.
5. Design fiber optic link

5. OUTCOME ASSESSMENT

The combined laboratory and lecture course has been offered once per year for the last five years as a senior level course in the Department of Electrical and Computer Engineering. The learning outcome assessment tools consist of pre-requisite test, quizzes, homework, exams, laboratory reports, design project and an end of semester survey. During the first day of the class, students are typically given a basic 20-question test to measure their knowledge of the required background for the course. The required background for this course is basic knowledge of electronic devices and fundamentals of electromagnetism and communication theory. Figure 1 shows the results of such pre-requisite test for fall 2017. As can be seen, only 13% of students knew the concept of logarithmic measurements (question 12), and how to convert the wavelength linewidth to the frequency bandwidth (question 13). Also, majority of students had problem calculating the required bandwidth for transmitting different multiplexed signals (question 15). Based on the pre-requisite test results, the instructor should dedicate one or two hours of class time to reviewing of the subjects that students demonstrate weak understanding.

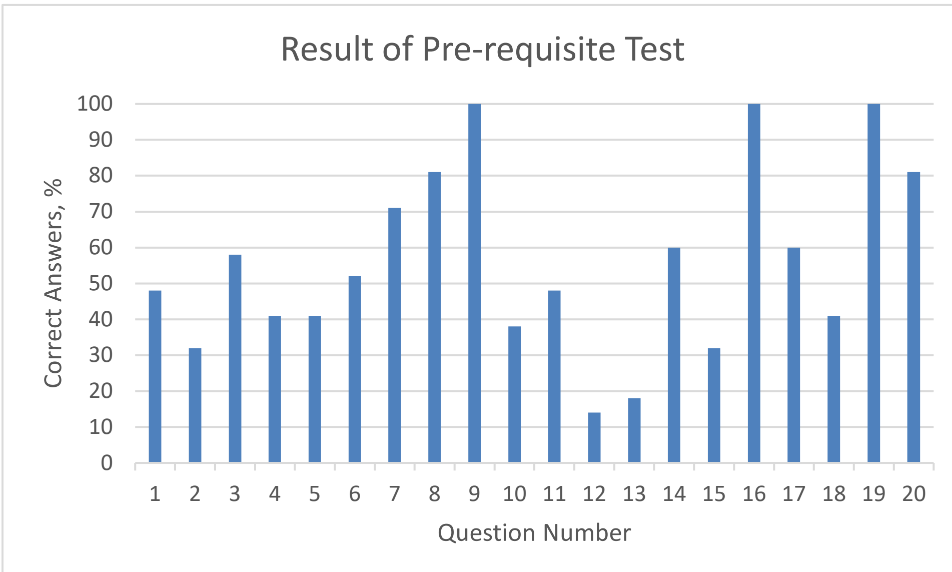

Figure 1. The Pre-requisite Test Results

The following shows an example of a laboratory assignment for designing a high capacity optical fiber link:

You are asked to design a 10 Gb/s, 60 km, fiber optic link. You are required to keep the BER below 10^{-6}. Use VPI software package to select the link's components. Use an attenuator in the link to count for a 6 dB safety margin. You should use a laser transmitter that operates in the C-band along with a single-mode fiber and a PIN photo detector. You are also allowed to use up to 20dB (AmpSysOpt) amplifier as needed.

a) Obtain the BER for different values of laser linewidths, and specify the maximum allowable linewidth. For this study keep the overall fiber attenuation at 0.3 dB/km, this counts for losses caused by the fiber, connectors and other misalignments.
b) For part (a), obtain the eye diagram for the BER of the maximum allowable linewidth.
c) Obtain the BER values when the total link attenuation varies from 0.0 dB/km to 0.5 dB/km, and specify the maximum allowable loss. For this study keep the laser linewidth at the maximum allowable value you obtained in part (a).
d) Write a comprehensive report. Justify all the components and parameters you have used for this design. Your report should include an abstract, an introduction, a design procedure, simulation results, a summary and a conclusion. The total number of pages can be between 5 to 10 pages. All figures, tables, etc. should have

corresponding captions. Your report should be typed single space, using Times New Roman font with point 12 size.

The setup in fig. 2 was implemented by a student that had taken this course. The simulation results in fig. 3 to fig. 5 show the performance of the links and were included in the assignment report.

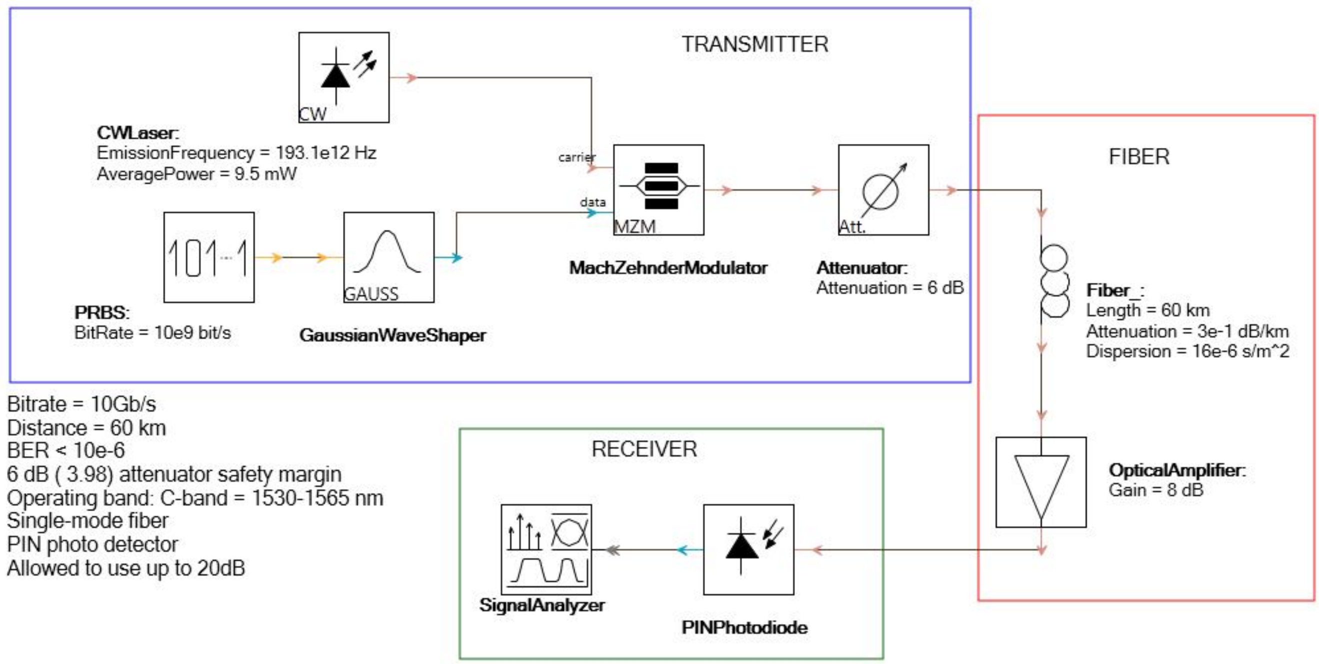

Figure 2. VPI Schematic diagram

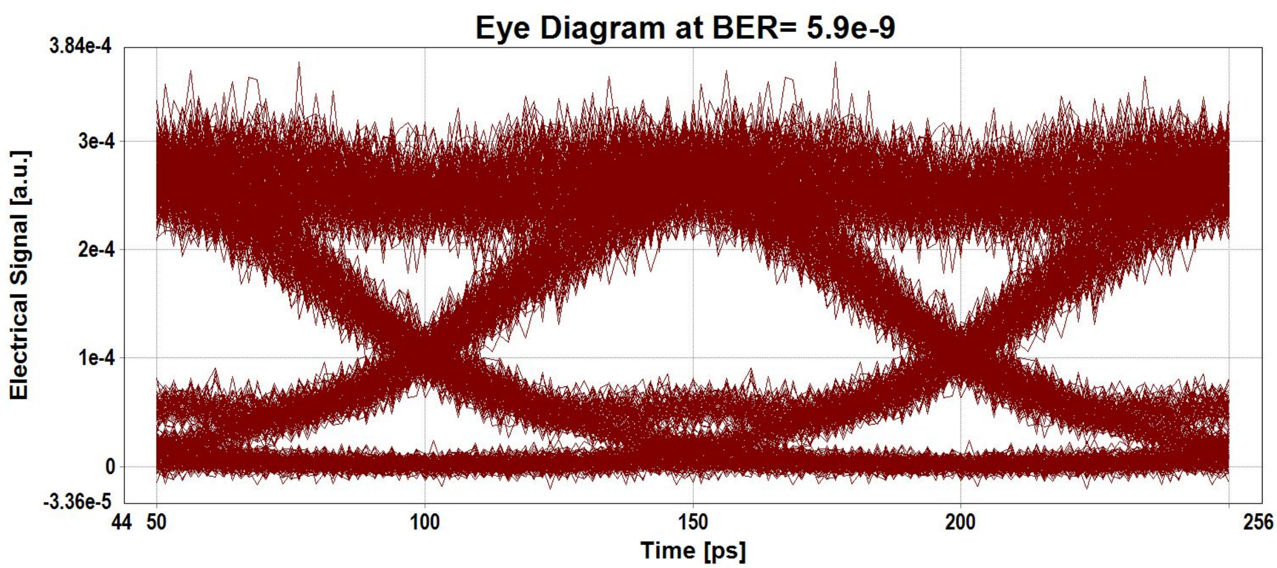

Figure 3. Eye diagram

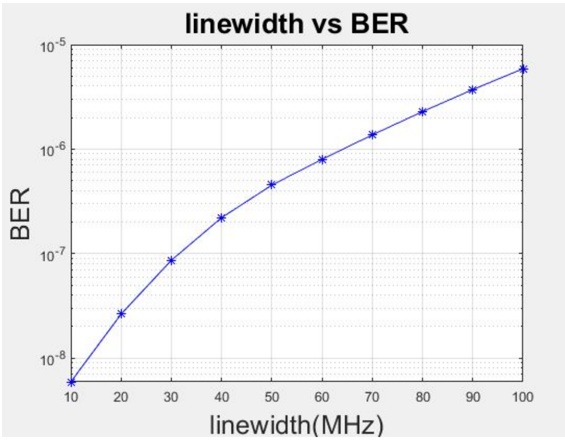

Figure 4. Linewidth vs BER

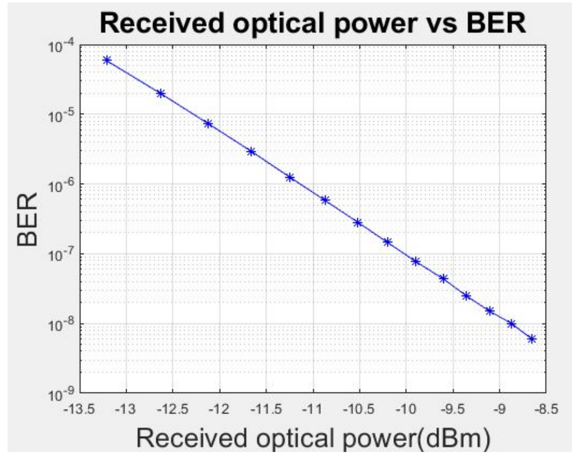

Figure 5. Received optical power vs BER

At the end of each semester, a student survey is administered to assess the students' perception of their knowledge of the course learning outcomes. Students are given 15 questions that measure the five learning objectives that were mentioned previously. Table 1 shows the results of such survey. As can be seen, a compelling majority of students have indicated that they either agree or strongly agree that they have learned different subjects that satisfy the criteria for the course learning outcomes.

Table I. End of Semester Survey Results

Survey Result					
Question	Strongly Agree (%)	Agree (%)	No Opinion (%)	Disagree (%)	Strongly Disagree (%)
1	46	54	0	0	0
2	46	54	0	0	0
3	38	62	0	0	0
4	46	54	0	0	0
5	46	46	8	0	0
6	46	46	8	0	0
7	77	23	0	0	0
8	23	77	0	0	0
9	15	77	8	0	0
10	15	77	8	0	0
11	46	54	0	0	0
12	23	69	8	0	0
13	46	54	0	0	0
14	8	77	0	15	0
15	100	0	0	0	0

6. CONCLUSION

Demands for high capacity communication systems with mobility have been described. Application of fiber-optic technology in the backbone network, along with wireless techniques at the end user site, can provide tremendous bandwidth (capacity) low signal attenuation, high security and mobility. The electrical engineering programs are compelled to train students, who are in the communication engineering concentration, in practical aspects of fiber optic communication. A computer simulation laboratory for experimenting and designing fiber optic systems is an alternative approach to establishing a real laboratory. Such a laboratory has a significant advantage over a real laboratory because the capability to upgrade and update software packages to emulate the real one is much easier and cheaper than replacing the equipment found in a real laboratory.

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