Laboratory Emphasis in Optical Signal Transmission

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Abstract

The facilities of an undergraduate optics teaching laboratory that was developed with NSF support have been incorporated in an established course in optical signal transmission. Students with majors in physics and engineering have learned professional optics techniques for evaluating the characteristics of optical fibers and obtained hands-on experience with optical communications.

Introduction

The primary objective of the National Science Foundation (NSF) optics education project at North Dakota State University has been the development of an undergraduate optics laboratory to serve the needs of a general optics course (Physics/ECE 411/611) that is the joint responsibility of the Departments of Physics and Electrical and Computer Engineering. This course includes ten experiments in a lab that was established with the support of NSF and adapted from work done at New Jersey Institute of Technology [1]. Most recently the lab has been employed to revitalize an optical signal transmission course (ECE 457/657) that has been in existence at NDSU for over 15 years. The lecture portion is based on Gerd Keiser's *Optical Fiber Communications* [2] and includes topics such as basic electromagnetics, propagation of light in cylindrical dielectric structures, solid-state sources, and photodetectors. It culminates

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with a study of digital signal transmission over optical fibers. It serves seniors or beginning graduate students in electrical engineering, computer engineering, and physics.

Implementation

During the spring semester of 2003, students in ECE 457/657 made use of the general optics lab, which has four large optical tables that easily accommodate two students each. Five experiments that utilize the facilities of the lab were adapted from the Newport fiber optics kit [3] with emphasis on the use of professional optics components for optical fiber studies. The course benefited from faculty and student experience in the 411/611 course [4]. The general optics course included three experiments involving optical fibers: measurement of numerical aperture, use of the cutback method to measure optical fiber attenuation, and observation of linearly polarized (LP) modes in a four-mode fiber. These experiments also are adapted from the set of experiments developed by Newport Corporation. The Newport fiber optics kit was purchased for the general optics laboratory. The lab is outfitted with enough components so that all four laboratory stations have sufficient material to allow the four student groups to do their experiments independently. The students in 457/657 were organized into three sections to accommodate approximately 20 students. The first experiment was measurement of the optical fiber numerical aperture. Each student group measured the power collection capability of the input face of the fiber by using a helium-neon laser, the input face of a fiber mounted on a rotation stage, and a photodetector with its power meter to measure the output power. Students also optimized the power collected at the input face and observed the visible light cone at the output face. This is a very pleasing visual experiment that gives the student a firsthand understanding of numerical aperture. The second experiment dealt with optical fiber attenuation by using the cutback method. Red light from the laser was transmitted through about 500 meters of fiber with the use of suitable fiber holders and positioners, a mode scrambler, and the photodetector with associated power meter. After the measurement, all but a short length of fiber at the input end (about two meters) was removed, and the power was measured again. If the input conditions are undisturbed, this gives a good measure of the attenuation in dB of the optical fiber.

A third experiment used a true single-mode fiber. In the general optics course the student does a related experiment to study modes in a four-mode fiber. Both experiments use light at 633 nm. The four-mode experiment used a fiber with a core diameter that was twice as large as that required for true single-mode operation and thus allowed four LP modes to propagate. With the true single-mode fiber, the student observed the LP_{01} mode and measured the transverse profile of the light intensity of the single-mode beam at the output face of the fiber.

For the fourth experiment each student group studied two basic optical communication links. For both links students used a Newport laser driver to interface an audio signal to each of two infrared sources. One source was a light-emitting diode (LED) and the other was a laser diode. For each source the students used a short length of fiber that they had prepared to transmit an audio signal. An audio signal injected through the laser driver modulated the light source. Positioned using fiber positioners and optical translation stages, the fiber captured the signal and transmitted it to a photodetector connected to an audio amplifier and speaker. Operated in the infrared region, this invisible light gave the students a new experience with sources and detectors beyond that obtained with earlier experiments with the helium-neon laser. Students reduced the received signal intensity by inserting a translucent card between the fiber output face and the photodetector.

The first four experiments dealt with relatively straightforward concepts that were directly related to the lecture portion of the course. A fifth experiment was more challenging since it dealt with a polarization-preserving fiber. Experimentally much was learned from this setup. It also is an experiment that would fit quite nicely in a nonlinear optics course. Operationally it is quite similar to the single-mode fiber experiment. However, a microscope is used to observe the longitudinal variation of light intensity.

The success of the experiments was significantly aided by the contributions of students in 457/657 who had already taken 411/611. They exercised leadership in the lab groups, demonstrated lab techniques, helped with the setup of the labs, and, in some cases, worked in advance with the instructor to check the experiments. A few exceptionally well-motivated students registered for a parallel independent study course in fiber optics lab techniques. Physics/ECE 411/611 is not a prerequisite for 457/657. In 411/611 there are two lectures on fiber optics. In 457/657 the study of optics itself is confined to what is necessary for comprehending optical communication.

Faculty Reaction

The experiments went very well and the availability of the undergraduate optics lab significantly improved 457/657. In the past in 457/657 there were a few simple demonstrations and student experiments, but this was the first time students had a comprehensive exposure to professional fiber optics measurements with all experiments performed by the students. This truly improved student competency in professional optics techniques as applied to optical communication.

In the lecture course the topics included basic optics and electromagnetics, fiber mode theory, characteristics of fibers with different transverse index profiles, optical sources and detectors, and optical digital system design. Computer simulations, cooperative learning exercises, and a lecture-discussion format were used outside of the lab. The lab experiments brought the students and instructor together in a realistic working environment involving the use of teams of two students and peer help from more experienced students.

The lectures were more meaningful when related to the experimental or "hands-on" work by each student. The numerical aperture experiment really helped the student understand the light-gathering capability of a fiber. Attenuation measurements clearly showed the impact of a loss of several dB of optical power. The single-mode fiber experiment allowed the student to become familiar with a technology that is in common use in telecommunications. Audio transmission can be done at a pre-college level, but it certainly can be approached from a more comprehensive senior or graduate perspective in 457/657. The polarization-preserving fiber experiment made use of techniques that are useful in building optical communication lab skills.

Student Reaction

Students were surprised by the mechanical skill necessary in these experiments. The lab involves mechanical and spatial reasoning along with patience and diligence in getting things to work. Very satisfying results are possible with these experiments, but they do require tenacity in pursuing the objectives of the experiments through to successful outcomes that includes a careful interpretation of the results. Here it is worth noting that the students didn't use connectorized fibers, but had to measure, cut, and cleave an appropriate length of fiber for each experiment. Initially this was a challenge.

North Dakota Governor's School of Science and Mathematics

We also used the audio transmission experiment in the summer North Dakota Governor's School of Science and Mathematics, which is devoted to outstanding high school students. Each summer the lab accepts about 20 students in two sections which each last for four hours.

The students begin by doing some basic experimental work to study reflection and refraction of light. They then prepare a fiber to do the audio transmission experiment. The lab goes quite well if the students are given appropriate guidance in the setup of the equipment and components.

Conclusions and Future Work

The use of the undergraduate optics lab for the optical signal transmission course significantly improved student learning. It breathed new life into a course that was already well established in the curriculum. Future possibilities for new experiments include, for example, the use of wavelength-division multiplexing and study of optical fibers with different index of refraction profiles.

The NSF-funded lab for undergraduate optics education gives students a chance to develop a professional competency in optical techniques for optical communications. The faculty involved have found this to be a rewarding experience, and it has received favorable comments from university administrators. They especially appreciate the direct faculty involvement in the labs.

The use of the undergraduate optics lab in ECE 457/657 is a model for what will happen in the future as other optics-related courses make use of the lab. A new course in laser theory already uses the lab quite extensively, and the lab will be used in the nonlinear optics course that is scheduled for the spring of 2004. We also expect the experiments used in 457/657 will be improved and expanded. Optics courses offered at NDSU will have significant laboratory content as a distinguishing feature.

References

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