# LIGHTWAVE COMMUNICATIONS
# LABORATORY EXPANSION

## FINAL REPORT

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## Abstract

The progress made in developing the Lightwave Communications instructional laboratory under the grant from the National Science Foundation is detailed. A comparison between the original and present state of the laboratory is made to demonstrate the specific points of improvement. New experiments which were developed as both direct and indirect consequences of the NSF grant are described.

## I. Introduction

The project entitled "Lightwave Communications Laboratory Expansion" was funded by the National Science Foundation in September, 1981. This work was directed towards upgrading the existing laboratory facilities within the School of Electrical Engineering at the Georgia Institute of Technology to allow for students to gain an exposure to a set of relatively sophisticated fiber optic experiments. Included in the plan was equipment purchases, and also the introduction of new experimental procedures.

This report details the progress made in restructuring and upgrading the Lightwave Communications laboratory at Georgia Tech under the NSF grant. The presentation has been written to allow a direct comparison between the initial and final states of the lab.

## II. Initial Status of the Laboratory

When the NSF grant was received in September, 1981, six experiments were used in teaching the Lightwave Communications Laboratory. These are listed in Table 1, which also provides the experiment titles and a short description of the concepts covered. Typically, one week was devoted to individual student projects which used the resources of the lab.

The laboratory was originally built using internal funds. Owing to the expense involved in purchasing optical components, much of the development centered around optoelectronic concepts which could be taught using the existing equipment in the Electronics laboratory of the School of Electrical Engineering.

Donations were also solicited from Industrial concerns, with Western Electric, Bell Laboratories and Corning Glass providing many samples of optical fibers, light-emitting diodes,and light detectors.

The optoelectronic circuits used in the experiments were, for the most part, designed, constructed and tested by students. Many of these were conceived by the students themselves during "Independent Study" courses. For example, the Pulse Amplitude Modulation (PAM) decoding scheme introduced in Experiment 3 was built using standard circuit techniques and a handful of parts. This situation was necessitated by the fact that the commercial units which were secured did not allow for the internal circuitry to be studied. Consequently, a large portion of the work centered around comparing the student designs with the properties of commercially-available units.

Experiment 6, "Spectral Transmission Properties of Optical Fibers", was the only original experiment which allowed students a "hands-on" introduction to typical fiber optic measurements. In this experiment, the students measured the transmission properties of a silca fiber as a function of the lightwave frequency. This serves a multitude of purposes. First, the students are exposed to the correlation between theory and experiment. This is most prevalent in that the OH-radical absorption lines of the silica molecule are easily observed in the data. Second, practical problems such as optical system alignment are illustrated by requiring the students to construct the system from parts. Third, the problem of light coupling in and out of the fiber with the associated concept of the Numerical Aperature becomes more realistic in the focussing of the light beam. Fourth, the sensitivity of optical systems to mechanical vibrations is an every day problem, as the optical table is not isolated from the building.

The plan for expanding the Lightwave Communications Laboratory developed for two reasons. First, it was felt that some of the experiments were too elementary for an Electrical Engineering cirriculum, in that the limited equipment did not allow for overly sophisticated systems to be constructed. The second factor was the desire to include more basic optical techniques in the laboratory to balance out the optoelectronics. The formal course offerings in the Optical Engineering program at Georgia Tech tend to center around the properties of the otpical fields. In its initial state, the Lightwave laboratory did not meet the goal of providing experience which correlated with the lectures in the classroom. This deficiency was a major drawback of the lab.

Emphasis was thus directed towards the creation of a new set of experiments which would better illustrate the field of Optical Engineering to the students. A list of basic laboratory procedures was developed and set as the minimum desired content of the new experiments. This effort resulted in the submission of the proposal to NSF which was later funded under the Instructional Laboratory Grant program.

## III. Current Status of the Laboratory

The list of experiments now included in the Lightwave Communications laboratory is shown in Table 2. Experiments 2, 3, 5, and

10 were developed from the previously existing set shown in Table 1. The remaining experiments in the list are direct and indirect consequences of the work allowed by the NSF grant. These are detailed below.

Experiment 1 deals with laser safety and general introduction to the optical equipment employed in the laboratory. The NSF Instructional Equipment grant made possible the purchase of a high power laser and sophisticated measurement equipment, such as the light chopper and lock-in amplifier. The general operation of each important item is illustrated by examples. This then provides a basis for the remaining experiments. Since both HeNe and GaAs semiconductor injection lasers are employed in the experiments, the safety procedures are stressed in this experiment, with continuous reminders throughout the lab.

The problems of "Large-Scale Fiber Optic Transmission Systems" are discussed in Experiment 4. This was not one of the originally proposed experiments, but was developed as a direct consequence of the NSF grant. It was found possible to purchase an inexpensive desk-top computer system with a built-in RS-232 output. Combined with the donation of a digital fiber optic link from Western Electric /Bell Laboratories, it was sufficient to create a realistic envi-roment to study the attenuation of lightwave signals in a long-haul link, EMI immunity and distribution of signals. The light-chopper and lock-in amplifier are used in conjunction with this experiment.

"Optical Fiber Splicing" is just the subject of Experiment 6, and constitutes one of the experiments described in the original NSF proposal. The scheme for this is illustrated in Figure 1. The procedure used in practice is essentially the same as that originally set forth.

The measurement of fiber splicing losses proceeds by the students first choosing a sample of fiber from a large assortment. Most of the samples are multi-mode graded-index fibers, although a few single-mode structures are available. Each group of two students is given 2 samples approximately 1 meter in length. One sample is used for the reference, as shown in Figure 1. The other sample is scored with a sapphire blade, then mechanically stressed to induce a break. After visual examination of the broken ends under a stereo microscope, the splice is made by sanding, polishing, and using an index-matched epoxy compound. The spliced fiber is then measured for its transmission properties, which illustrates the excitation of the radiation and leaky wave modes created by the splice.

This experiment provides for experience in light beam alignment, and also introduces the students to a realistic practical problem. If time permits, the students are urged to study two variations on this problem. The first deals with purposely creating a bad splice to measure the increased lightwave amplitude losses. The second is more involved, and is concerned with measuring the angular splice properties and also the concept of a fiber numerical aperature.

Experiment 7 presents a technique to study the "Experimental Determination of Fiber Index Profiles". It is also one of the originally proposed experiments, and proceeds using the basic arrangement illustrated in Figure 2. The implementation of this procedure has proven quite difficult for two reasons. First, the alignment is complicated, and has taken students as long as an hour to perform the fine-adjustments. This situation has led to an initial setup time problem, which has not yet been solved. Second, detection of the near-field pattern is limited by the resolution allowed by the detector array. Since the array is micrometer-driven, it is quite sensitive to the reading of the Vernier scale. This has led to many discrepencies in comparing the measured to known results.

The procedure requires students to first review the light-chopper and lock-in amplifier properties. After this is completed, they then examine the PIN photodiode array/amplifier and test the detection system using a low power infrared LED source. Finally, the actual experiment is performed in which the near-field patterns are measured.

To alleviate some of the problems encountered in implementing this experiment, additional steps have been taken. These were not in the original proposal, but tend to help the students in their work. An example of the modifications currently being used is a micro-manipulator system in which the motion of the detector array can be controlled by typing in the appropriate binary code. Although this is still in the developmental phaseses, it appears a good candidate for apermanent inclusion in the system.

Experiment 8 introduces the student to a technique for optical computing. This experiment was not in the originally proposed set, but employs the optical bench and the 15 mW HeNe laser secured from the NSF grant. It requires students to investigate a basic technique for performing optical binary logic by passing the laser beam through a series of glass masks. A pinhole approach is also included to demonstrate diffraction principles int his methodology. The work is correlated with ongoing research in the School of Electrical Engineering.

"Introduction to Integrated Optics" is the subject covered in Experiment 7. Although this was conceived some time ago, it was not a feasible experiment until the NSF grant allowed for the purchase of an isolated optical bench. Consequently, it is considered an indirect consequence of receiving NSF funds. This experiment employs some crude waveguides fabricated in the Solid State laboratory. The students are allowed to study the properties of lightwave guiding in planar structures, and also various input/output coupling techniques.

As can be seen from the brief descriptions above the NSF grant has allowed many advances to be made in the Lightwave Laboratory. Figure 4 provides the alloted space layout for the optical bench, while Figure 5 shows the floorplan of the Lightwave Laboratory.

## IV. Conclusions and Projected Future of the Laboratory

Receiving the grant for the project "Lightwave Communications Laboratory Expansion" from the National Science Foundation has allowed a significant amount of progress to be made. New experiments have been developed, and the funds have provided for a much more detailed presentation of the basic properties of fiber optics and optical engineering. This has been complimented in the lecture courses, since it is possible to correlate much of the theory with experimental measurements. Student interest remains high, and the School is now in the process of evaluating the success of the project by means of questionnaires. Although the final results are not yet completed, it is obvious that the laboratory is providing a firm foundation for students entering Graduate studies.

It is felt that the laboratory will always be in a state of change. This is necessary to provide state-of-the-art experience for the students. In addition, new faculty members within the School of Electrical Engineering have continuously contributed to the development of new approaches to presenting the experiments. Since the faculty numbers are increasing, this type of interaction will undoubtedly increase in the future.

The response from industrial concerns has also been very good. For example, the Atlanta branch of the Bell Laboratory system is primarily concerned with fiber optic transmission problems. Georgia Tech is very fortunate to have excellent working relations which allows the students to see research and to meet with leaders in the field. As an example of the tie between Bell Laboratories and

Georgia Tech, it should be noted that a textbook in fiber optics was authored by a member of the Bell Labs Technical Staff in conjunction with teaching the course on campus.

In conclusion, it has been demonstrated that the Instruction Equipment Laboratory grant from the National Science Foundation has had a significant impact on the education provided to Georgia Tech students. The ramifications of the grant will continue to improve the status of the laboratory for many years to come.

## Appendix

| Experiment Number | Title and Description |
|---|---|
| 1. | "Optical Sources". Various light sources and their properties are examined through measurements which relate to theoretical predictions. Devices include a low power HeNe laser, infrared light emitting diodes, and a quartz-halogen lamp. Spectral emission curves and angular radiation patterns are emphasized. |
| 2. | "Optical Detectors". PIN photodiodes and phototransistors are studied from both the theoretical and experimental viewpoints. Spectral response, sensitivity and noise figures are measured. Practical design of solid state source and detector circuits are presented. |
| 3. | "Digital Optical Communications". The students are introduced to digital modulation techniques for optical communications including PAM, PPM and PWM. Demodulation schemes are presented. Both discrete source-detector systems and commerical fiber optic units are evaluated in terms of optical and electrical performance. |
| 4. | "Analog Fiber Optic Systems". This is an in-depth study of analog signal transmission using optical fibers. The optoelectronic portions of an analog optical communication system are examined, with emphasis placed on the structure of the lightwave signal. Free space transmission is compared to fiber guidance. Excitation and coupling techniques for optical fibers are studied, as are the properties of various grades and typed of lightguides. |
| 5. | "Spectral Transmission Properties of Optical Fibers". In this experiment, the students measure the power transmission of an optical fiber as a function of wavelength. A quartz-halogen lamp serves as the source, with frequency selectivity accomplished by a grating monochrometer. Experimental results are compared with theoretical predictions and known transmission curves. The OH-radical absorption lines are studied. |
| 6. | "Independent Project". The students are allowed to design and perform an optical communications experiment of their own choosing. Both individual and group efforts are permitted. Examples of systems which have been built by past (Independent Study Course) students in this regard include a fiber-based microprocessor system, multiplexed three-channel analog fiber link, and fiber optic video transmission system. |

Table 1

Summary of Original Experiments

| Experiment Number | Title and Description |
|---|---|
| 1. | "Lightwave Laboratory Orientation". A basic introduction to laser safety and optical equipment. |
| 2. | "Optical Sources and Detectors". Various light sources and detectors are studied for optical properties in fiber optic systems. Both gaseous and solid state devices are included. Practical design of basic optoelectronic circuits in included. |
| 3. | "Digital Lightwave Communication Techniques". Digital modulation techniques suchas PAM, PPM and PWM are presented in the context of fiber propagation channels. Students construct a basic system, and then compare the resulting performance with a commercial unit. Coupling problems and numerical aperature concepts are included in an introductory manner. |
| 4. | "Large Scale Fiber Optic Transmission System". Introduction to characteristics and design of long-haul and local-distributed fiber optic digital systems. Couplers and distribution techniques are illustrated for a serial RS-232 encoding scheme. EMI immunity is examined. |
| 5. | "Spectral Transmission Properties of Optical Fibers". the students measure the power transmission of an optical fiber as a function of wavelength. Experimental results are compared to the measurements, with OH absorption line studies and 1.3 micron source requirements. |
| 6. | "Optical Fiber Splicing". Basic Splicing techniques are introduced, and each student must perform an epoxy splice. The splice losses are then measured by comparing the transmission of the spliced fiber with one which is left intact. Geometrical optic radition calculations are used, and the experiment is related to the fiber propagation modes. |
| 7. | "Experimental Determination of Fiber Index Profiles". Near-field measurements are used to extrapolate the model patterns from basic output field intensities. These are then used to estimate the index profile of the fiber under measurement. The results are then compared with the known profile. |

Table 2
Summary of Current Experiments

8. "Introduction to Optical Computing". A laser beam is used to perform basic binary functions with masks. Diffraction is studied on both a theoretical and experimental basis.

9. "Introduction to Integrated Optics". A basic planar waveguide is studied for mode propagational behavior. Active detectors are examined, with projections for future integrated structures. Coupling in and out of of the waveguide to sources, detectors, and fibers is included.

10. "Independent Project". Students are allowed to investigate a particular problem of their choice using the resources of the laboratory.

Table 2
Summary of Current Experiments

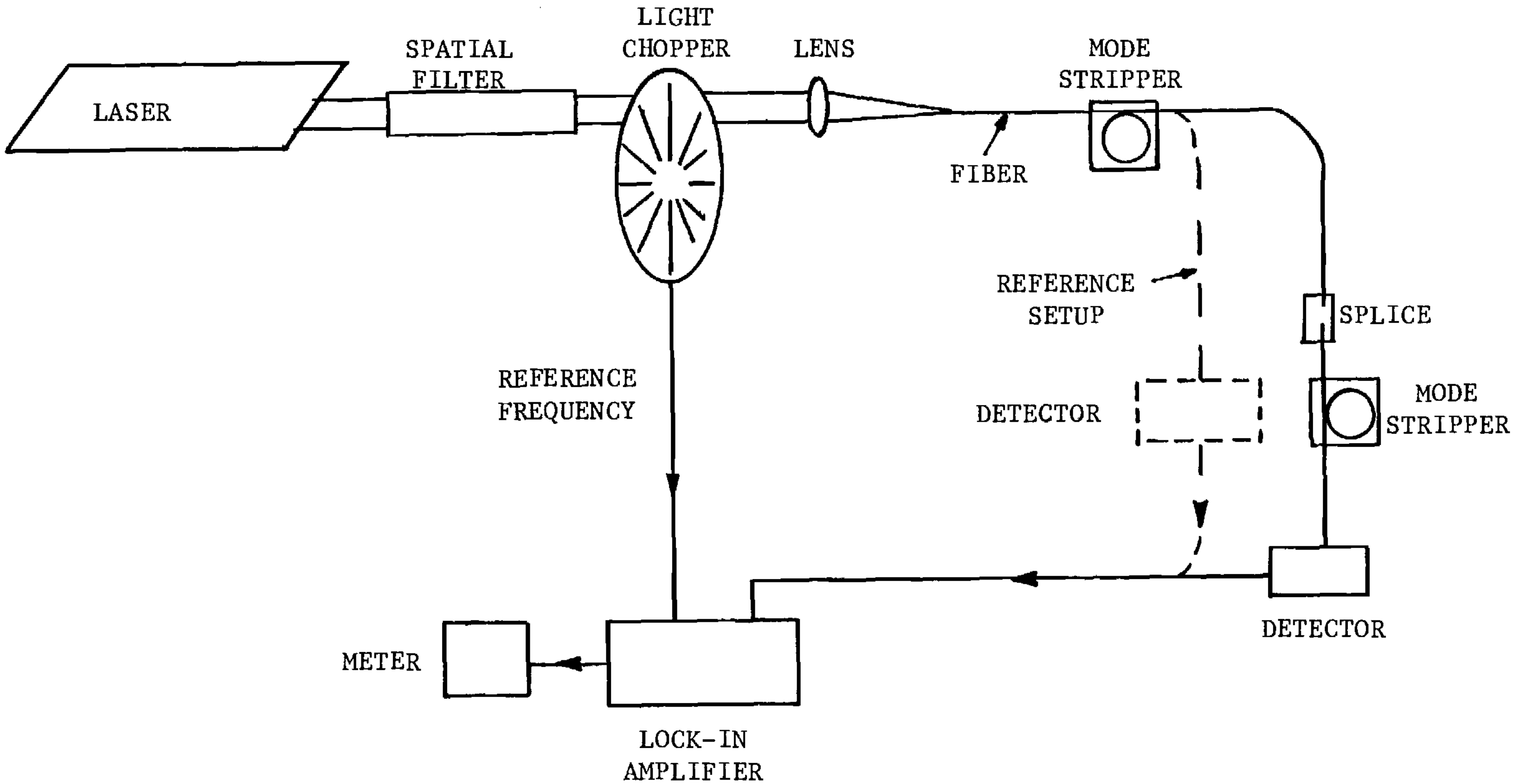



Figure 1 - Block Diagram for Splicing Loss Experiment

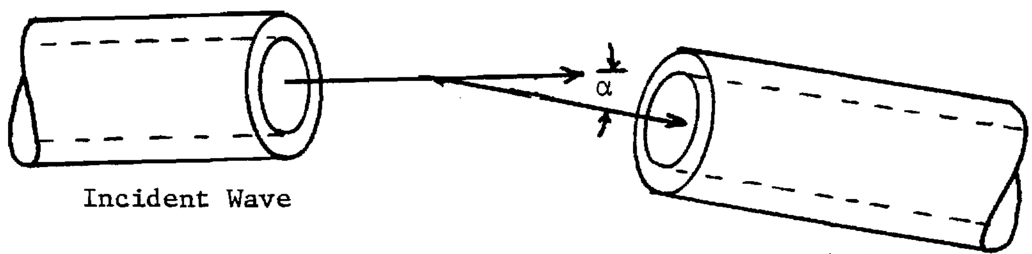



Figure 2

Experiment for Angular Splicing Losses

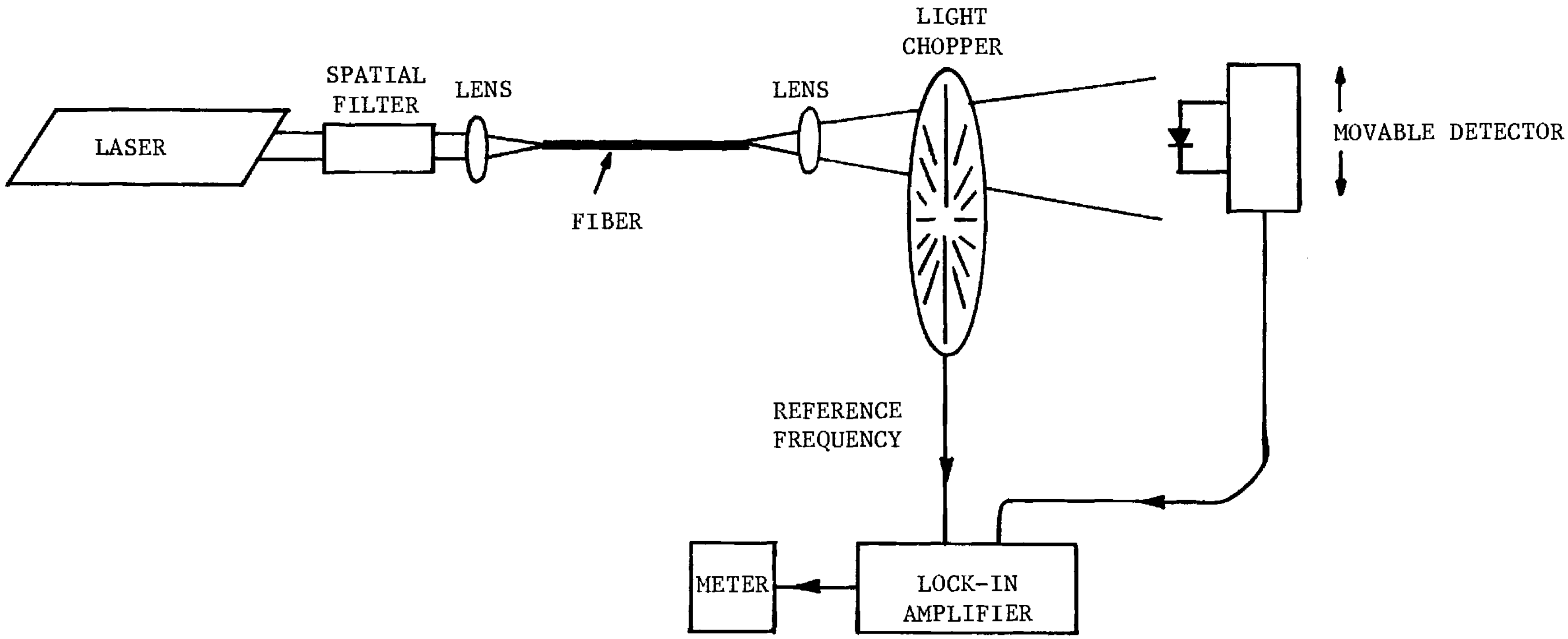
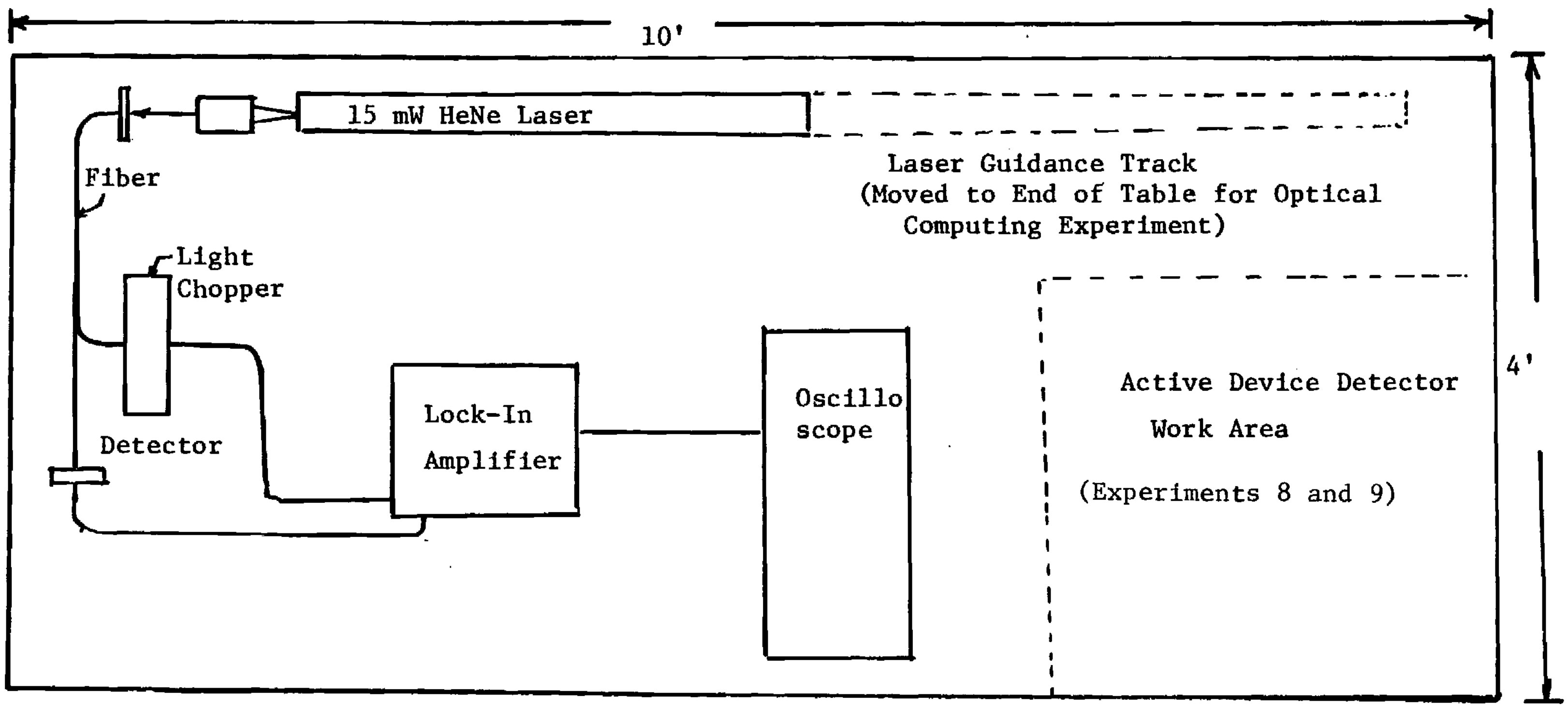
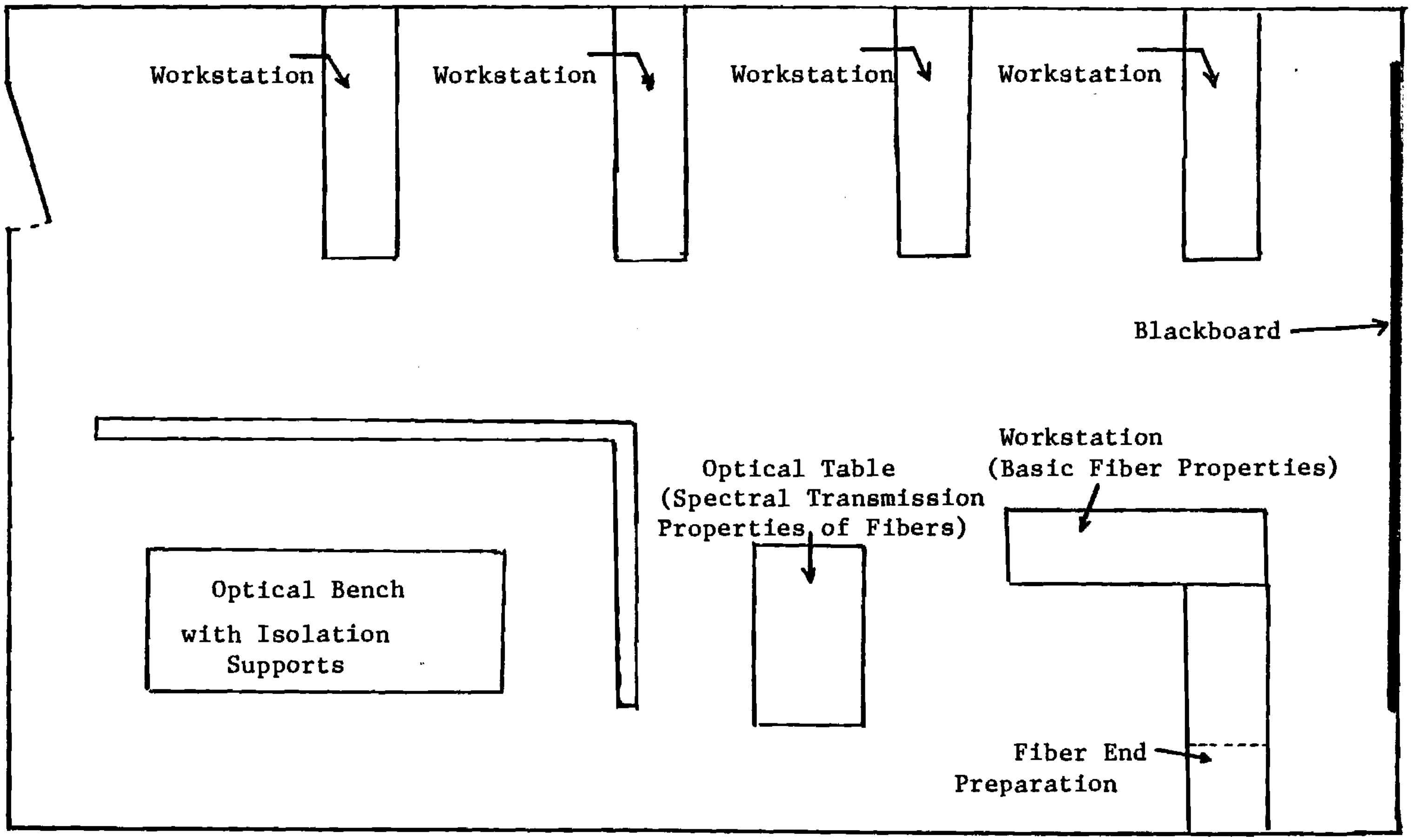



Figure 3 - Block Diagram for Index Profiling Experiment




Basic Layout of Workspace Allottment
on Isolated Optical Bench

Figure 4




Floorplan of Lightwave Communications
Laboratory with Expansions

Figure 5