

# **AC 2008-2226: USING SIMULATION-BASED HYBRID AND MULTILEVEL VIRTUAL LABS FOR FIBER OPTICS, PHOTONICS AND TELECOM EDUCATION**

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# Using Simulation-based Hybrid and Multilevel Virtual Labs for Fiber Optics, Photonics, and Telecom Education

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## **Abstract**

A rapidly growing number of distance learning programs in science, engineering, and technology demands interactive online activities that are at least partially capable of replacing traditional hands-on practice and experimentation. To address these needs a series of multistage virtual laboratories on fiber optics and wireless communications have been developed. These labs are designed to enhance the understanding of technical concepts and fundamental principles by facilitating virtual but realistic experimentation. The virtual labs can be linked with related hands-on labs to form hybrid laboratories.

Virtual labs contain expandable sets of virtual experiments, learning resources, and assessment activities. An easy-to-use tool that enables instructors with no programming experience to produce appealing and pedagogically sound interactive virtual activities is available as well.

This paper presents a set of interactive simulations and virtual experiments and discusses their applications for Fiber Optics, Photonics, and Telecom education courses, for onsite, online, and hybrid (blended onsite and online) delivery modes.

## **I. Introduction**

Phenomenal growth in a wide spectrum of new and emerging technologies has led to increased demand for engineering and engineering technology graduates who deeply understand the fundamental principles behind contemporary state-of-the-art technologies, but also exhibit analytical, problem solving, and expert thinking skills. To address these industry needs, it is imperative that new technological tools and teaching methodologies be incorporated into curricula so that students can acquire digital-age literacy for becoming life-long learners. However, incorporation and implementation of state-of-the-art technological tools requires considerable investment of time and financial resources. Keeping curricula and lab resources current with respect to the fast pace of technological advances in the field is another challenge for faculty.

College and university professors can address some of these challenges by using simulation and virtual experiments. With the wide availability of broadband technologies, which offer high data rate connections, simulation-based e-learning is rapidly becoming a significant and effective element of the teaching and learning process. The use of virtual systems enables distance learning students to master practical skills at any time and any place.

## **II. Interactive Online Resources**

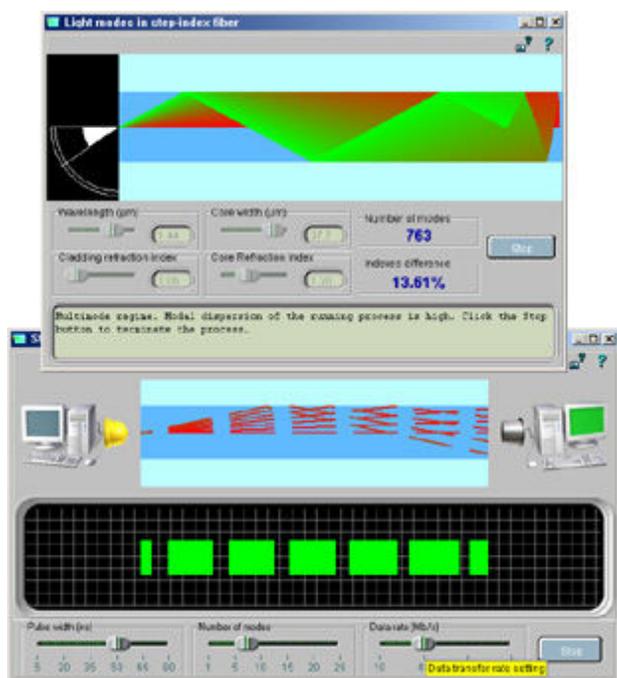
To address the pedagogical and laboratory needs of students, advanced simulation-based e-learning software has been developed. The software uses real-life processes and objects related to fiber optics, photonics, and wireless and wired communications as the context for science and

technology investigations. This enables students to learn the relationship between scientific theory and its practical applications in technology, visualize the processes occurring in the system, and better understand system limitations and bottlenecks.

The core components of all virtual labs discussed in this paper are highly interactive complex Java and Adobe Flash simulations with associated HTML/XML parts and scripts. State-of-the-art graphical interfaces and realistic models of the simulations provide an "insight" view of the process and help users become familiar with the internal structure and operation of complex telecommunication systems and devices. Many of the virtual labs and experiments may be linked to hands-on labs to provide a hybrid lab environment. Many faculties believe that hybrid labs combine the best of both worlds, providing the student with a learning environment and specific scenarios that facilitate the kind of "deep learning" elements introduced earlier in this paper.

The virtual laboratories implement technologies that can provide instructional opportunities in many ways, whether at a campus or school (traditional teaching), at home (warm-ups, post-class tasks, or self-learning), in a corporate setting, or through distance learning. ATeL's realistic simulations (enable learners to:

- (1) Observe the physical processes insightfully at different levels of detail
- (2) Analyze constraints between relevant parameters
- (3) Push these parameters beyond normal allowed values to simulate infrequent operating conditions or casualty situations
- (4) Run "what if" scenarios
- (5) Acquire data from virtual experiments for detailed analysis and comparison to actual operating conditions in a theory-to-practice approach.



**Figure 1.** The simulation *Light modes in a step-index fiber* (top) enables a students to investigate how the quantity of traveling light modes in a step-index fiber depends on wavelength, core diameter, and core/cladding indexes.

The *Step-index fiber-optical link* simulation (bottom) helps to understand how a modal dispersion affects data-transfer rate in the fiber-optical link.

At this point we want to clarify the difference between a simulation, virtual experiment, and virtual laboratory.

A simulation is task and learner neutral, i.e., it models a process, an object/system construction and operation, or a learning situation. Within simulation functionality there are no restrictions on the student's actions.

In contrast with a simulation, a virtual experiment is focused on a particular task. In addition to the simulation, the virtual experiment includes specific learning objectives, scenario/assignment, worksheet, assessment, and, most importantly, step-by-step instructions for students. Virtual experiments may also include optional auxiliary simulations, prerequisites, excerpts from interactive lessons and technical manuals, quizzes, and online reference resources. The student is expected to follow a thorough step-by-step instruction to accomplish a particular educational assignment. Figure 2 shows the virtual experiment designed to explore signal dispersion.

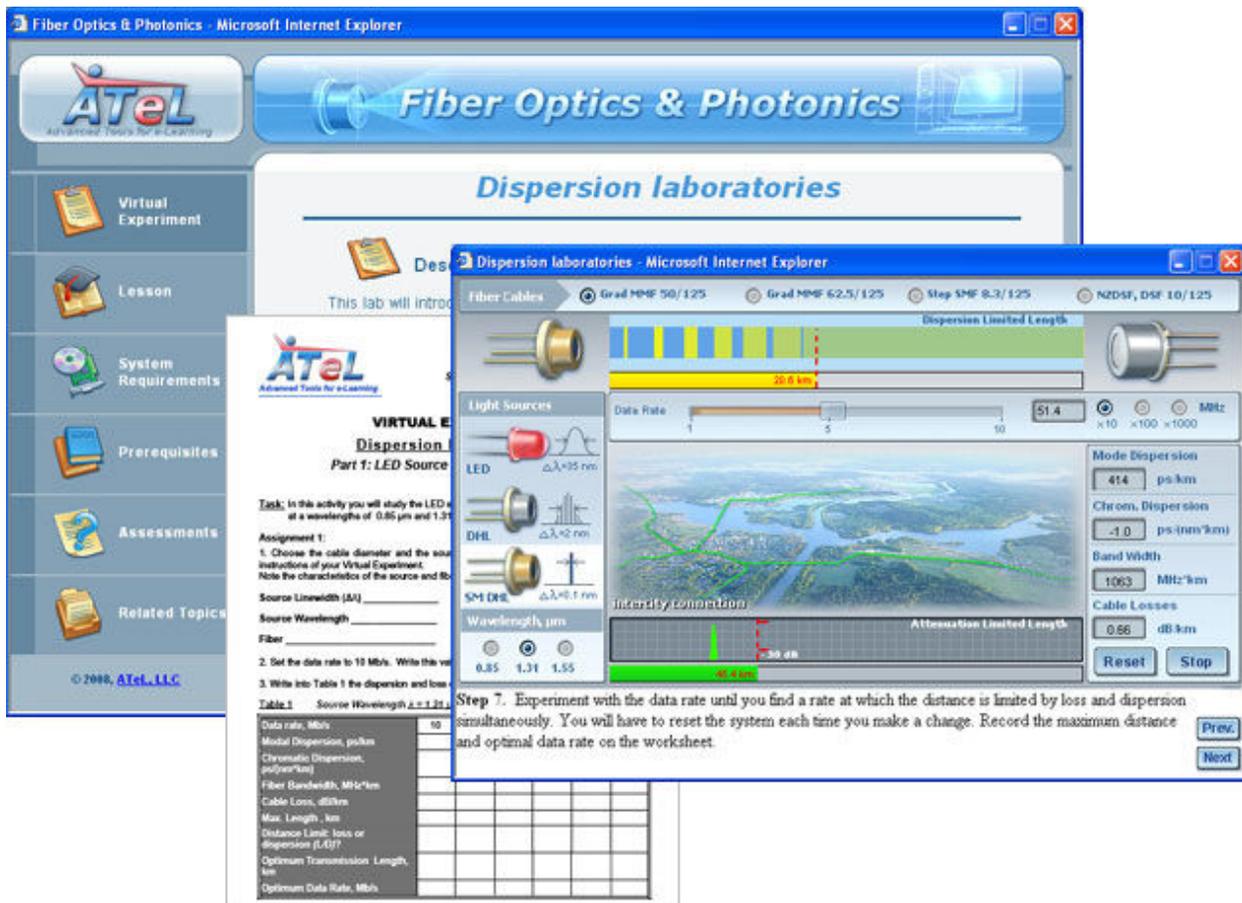


Figure 2. A virtual experiment based on multifunctional simulation.

As shown in Figure2, enables students to explore what is going on with various light signals while they travel in different fiber cables. Students can select different light sources and fibers and vary wavelength, data rate, and network type (local, inter-district, and inter-city). By observing the signal changes and collecting and analyzing virtual data, students learn requirements and limitations of optical networks. An instructional panel beneath the simulation displays step-by-step instructions for the student. An experiment worksheet (shown in the middle) can be opened and printed from within the experiment. The worksheet helps the student conduct the experiment and collect data. An Excel worksheet can be created and linked with the experiment as well.

The main menu of the experiment (shown in the left) provides students with access to embedded resources, assessment and a system diagnostic tool.

When a simulation is used in a lecture-lab environment, learning becomes more efficient because students can watch system response and immediately apply their theoretical knowledge by conducting a virtual experiment. Virtual experiments incorporated into online courses dramatically enhance the quality of distance learning.

The simulations and virtual labs described here facilitate both conventional sequential learning paradigm and just-in-time learning. In the conventional approach, studying the design and operation of telecommunication systems and devices is preceded by learning basic scientific and engineering principles. The just-in-time learning strategy proposes to study underlying fundamental concepts and laws as they are needed in the context of specific applications.

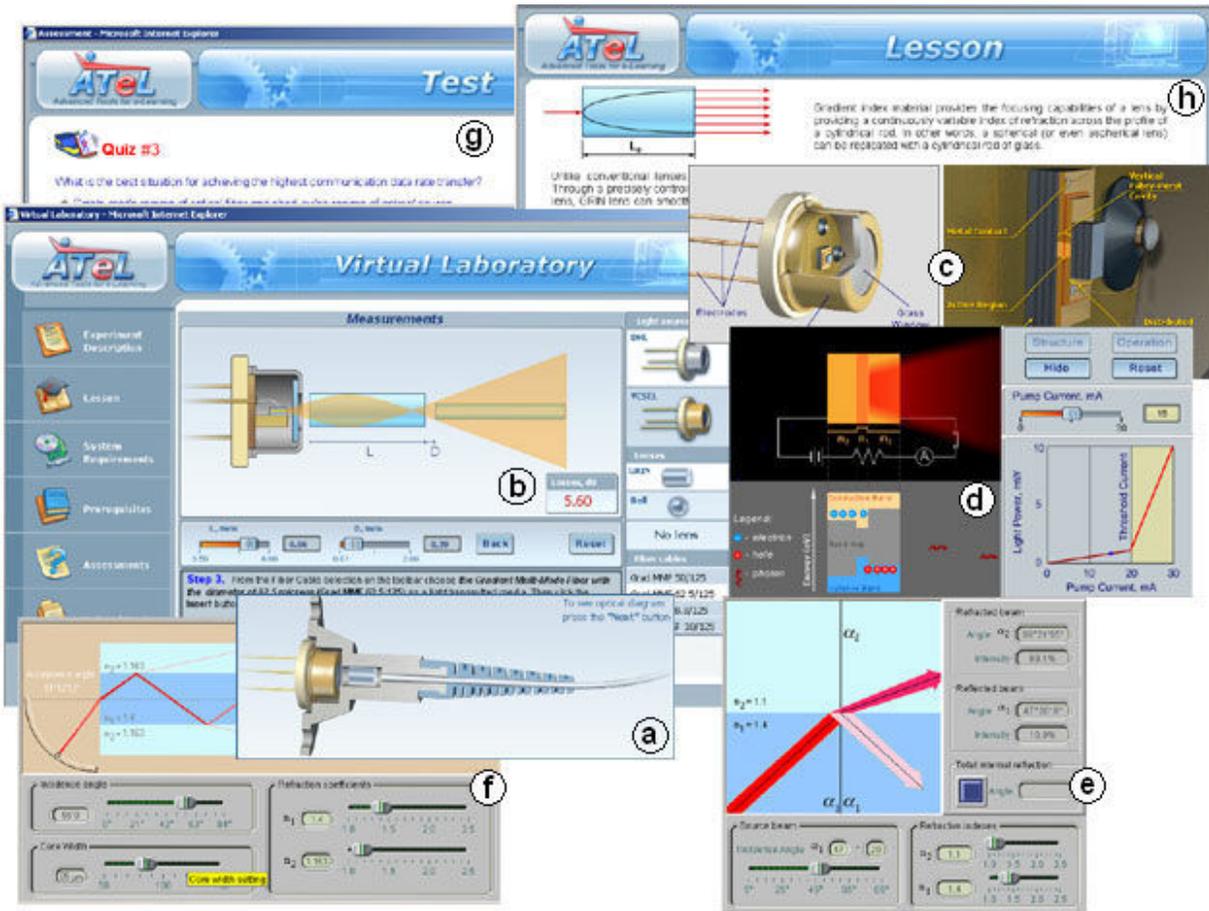


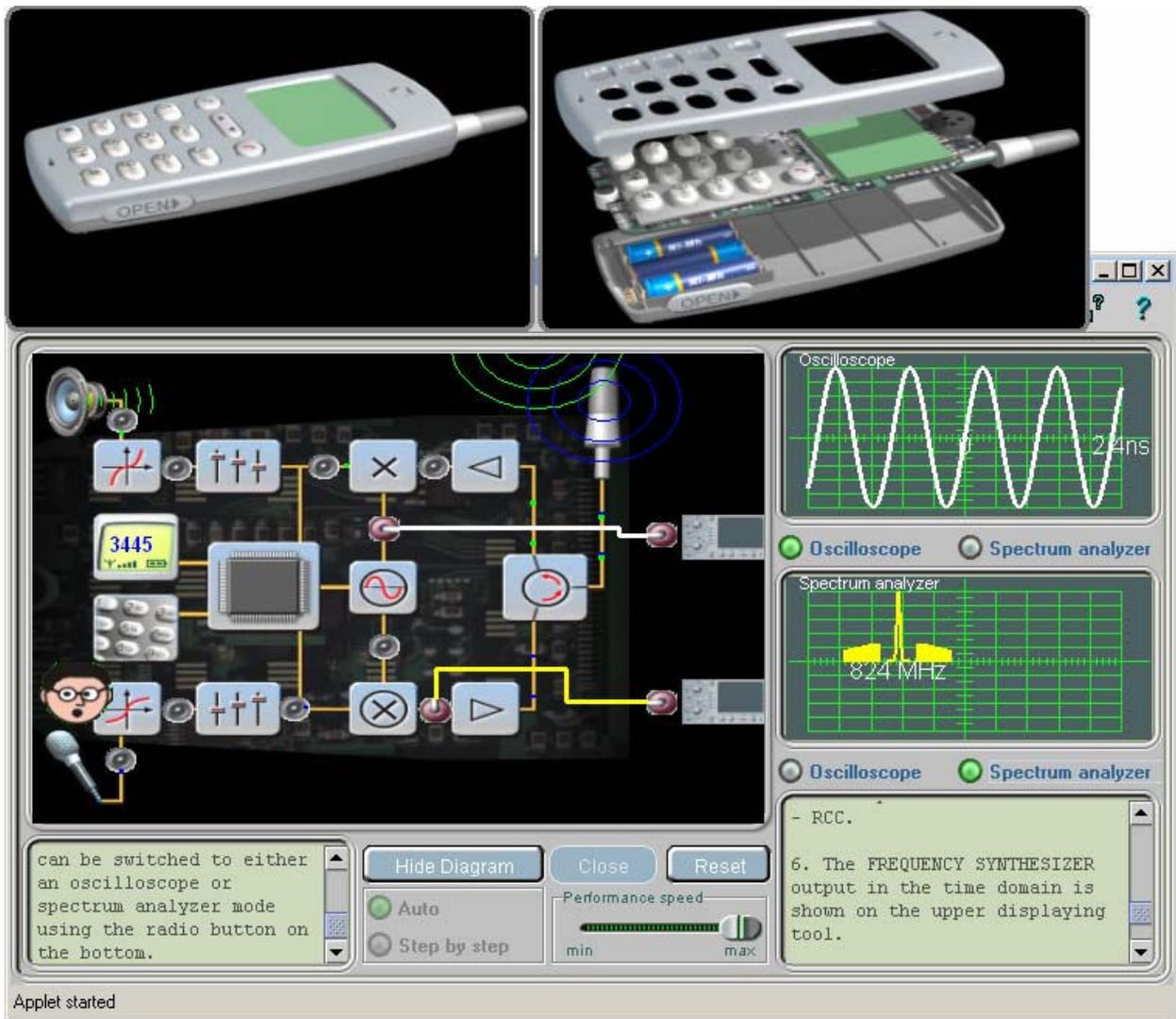
Figure 3. Screenshots of the virtual lab “Pigtail”.

The lab presented in Figure 3 that enables students to do the following:

- ◆ Assemble a Laser Diode to Fiber Coupling (a) using different types of diodes, lenses, and fibers
- ◆ Study the impact of various parameters on the coupling losses and collect virtual data (b)
- ◆ Explore the design and operation of the system components (c, d)
- ◆ Learn underlying fundamental principles (e, f).

An online assessment (g) and a brief relevant interactive lesson (h) can be incorporated into the laboratory as well.

The example in Figure 4 illustrates how students can explore system design and operation and then investigate system components and underlying scientific principles using interconnected simulations and other resources integrated into the virtual lab.

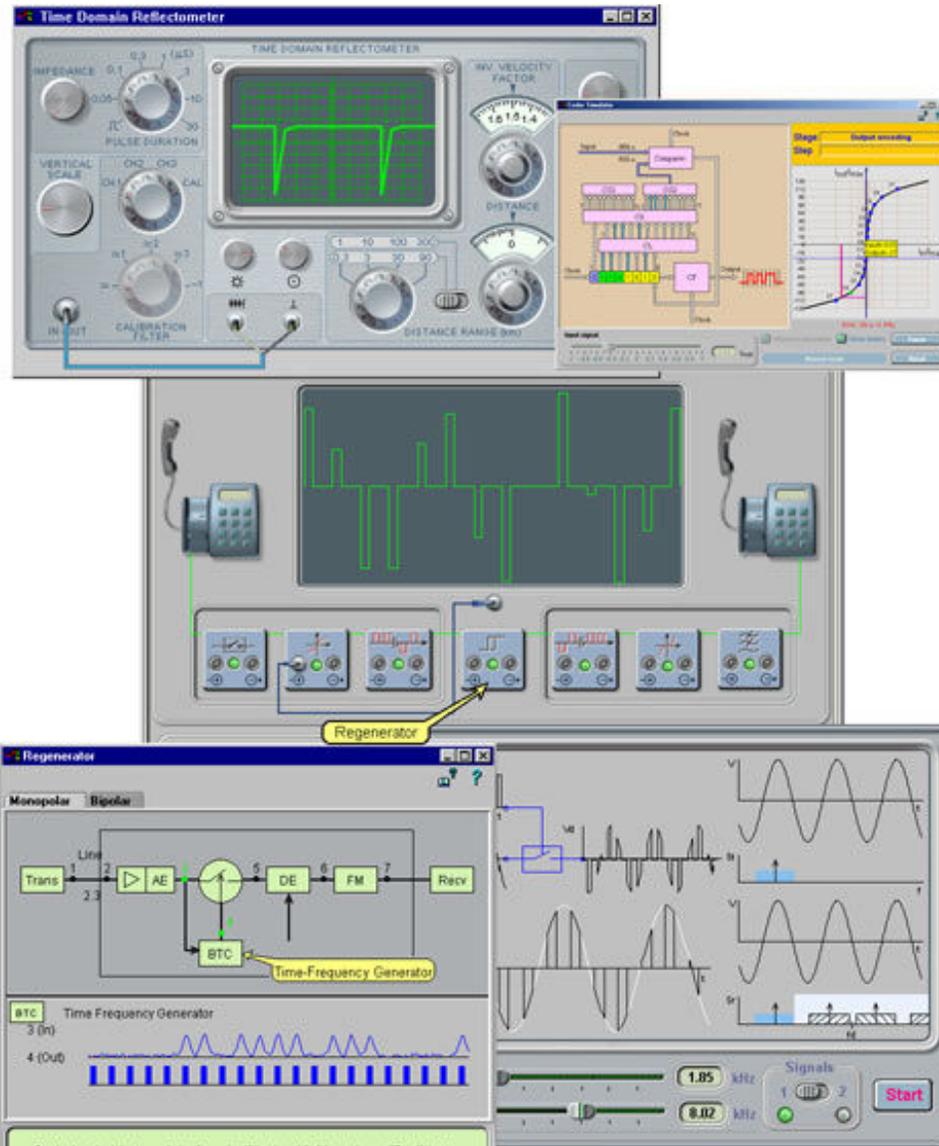


**Figure 4.** The “*Mobile Phone*” simulation introduces learners to the concept of cell phone design and functionality of major cell phone components.

In the simulation shown in Figure 4, a learner can open the unit and see its structure (top right). The diagram enables him/her to explore major phone components and their interaction. The input and output of each component can be connected with either an oscilloscope or spectrum analyzer to investigate the signal in each stage of its transformation. The right-bottom panel displays the current process status and gives a brief description. The left-bottom panel provides instructions for how to manipulate the simulation.

Control devices and testing equipment used in the telecommunications industry enable technicians to measure and define correlations between virtually all internal and external

parameters that describe a process or object's properties. The majority of technical college students and corporate maintenance/service staff are more empirical than abstract learners.<sup>1-3</sup>



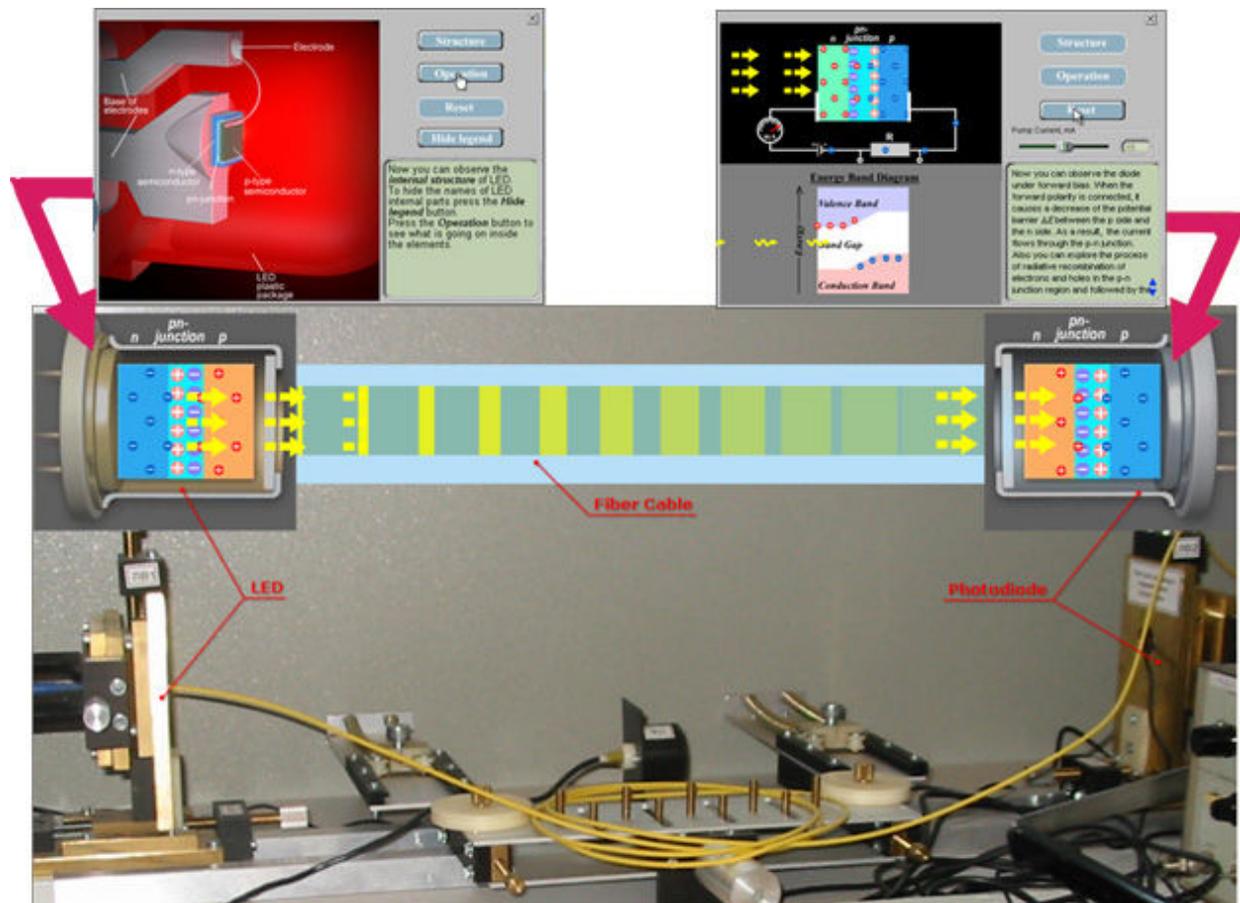
**Figure 5.** The simulations on the right are designed to assist learners in exploring the architecture and operational principles of a wired telephone system and its parts. The middle simulation presents all major devices that form a communication track as well as input and output signals for each device. A click on a device icon launches the second level program that simulates the design and operation of the chosen device (Regenerator- bottom left and Non-linear decoder – top right). It enables the learner to fully explore the device functionality and structure. The embedded tool enables the student to digitize graphs and convert them into tabular data. The bottom right simulation visualizes all sequences of the processes occurring during the voice transmission from one subscriber to

another. The student is able to trigger the simulation screen into a display of a virtual oscilloscope and examine signals in detail. The virtual Time Domain Reflectometer (top left) allows a student to analyze signals and master the use of the apparatus for tasks in the field.

Often these learners struggle to understand processes at a qualitative level and prefer to learn through "hands-on" activities. The vast majority of experiments in real photonics laboratories look like sets of boxes linked with wires; this provides only an “external” view of the process, phenomena, or operation of a device without visual exposure to what is going on inside and how that is related to fundamental laws and principles. This approach fails to excite students’ imagination or visual perception. Our simulations and virtual experiments provide both “inside” and “outside” views of the process. The simulations shown in the Figures 1 and 3 reveal the

processes taking place inside the fiber optic devices and components and links parameter changes with quantum mechanical concepts and with internal device design and structures.

All computer simulations described in this paper are based on scientific-mathematical models, which contain certain assumptions and neglect some phenomena. Depending on the topic under study, the purpose of simulations, and available recourses, the model can be more or less sophisticated and thereby describe the original phenomena for better or worse. For prospective engineers, it is crucially important to understand the accuracy of simulated results and the limits of their applicability. Our simulations enable students to export virtual data to MS Excel or other data acquisition software. The ability to compare data acquired from student hands-on experiments with data generated by a simulation based on various models (from simple to more sophisticated ones) provides a unique opportunity for the professor to discuss with students the discrepancies between real-world processes and theoretical schemes, as well as the accepted assumptions, limitations, and applicability of science models.



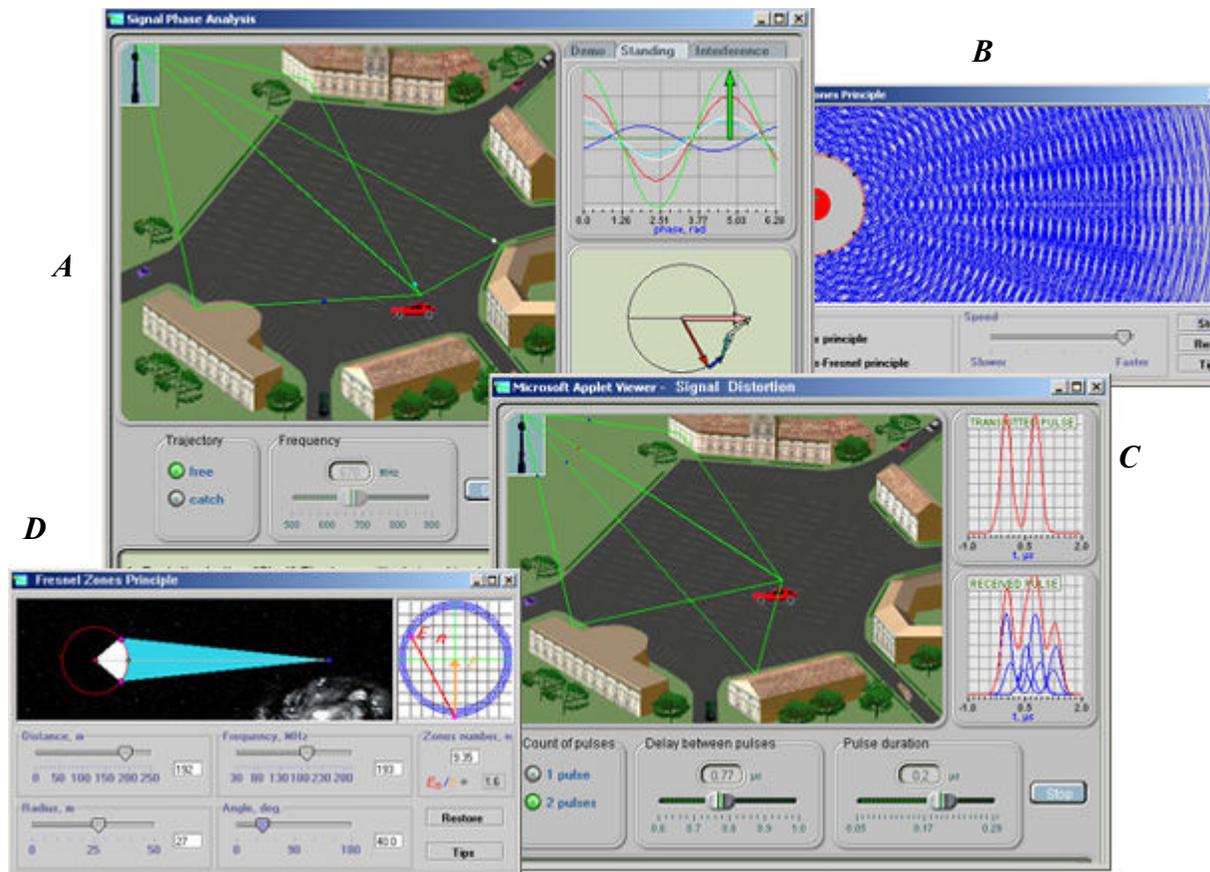
**Figure 6** The hybrid lab combining an in-lab physical test setup that examines the transmission of light from an LED source through a fiber optic cable to a detector photodiode at the receiving end with a virtual experiment that simulates the same process.

Figure 6 depicts the hybrid lab approach in which a virtual lab experiment is combined with an actual hands-on lab to provide a richer learning experience for the student, in this case on photonics principles and fiber optic transmission of light. The student is able to physically connect and perform

the experiment while at the same time is able to see a simulation of the underlying physics of the process.

A virtual experiment provides an opportunity to separate the particular impacts of each of several parameters that affect the outcomes of measurements. Using simulations the student is able to isolate and analyze the contribution of a specific process and by this means to recognize and evaluate errors in actual measurements made in laboratory experiments.

Realistically looking simulations can help students conceptualize the physical principles underlying the operation of a real device.

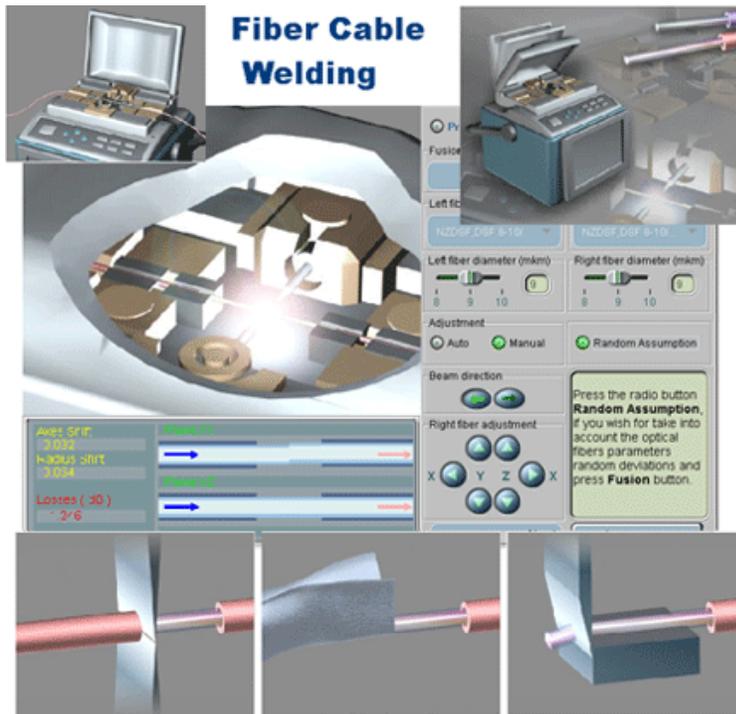


**Figure 7** Simulations designed for virtual exploration of signal reflection and distortion effects.

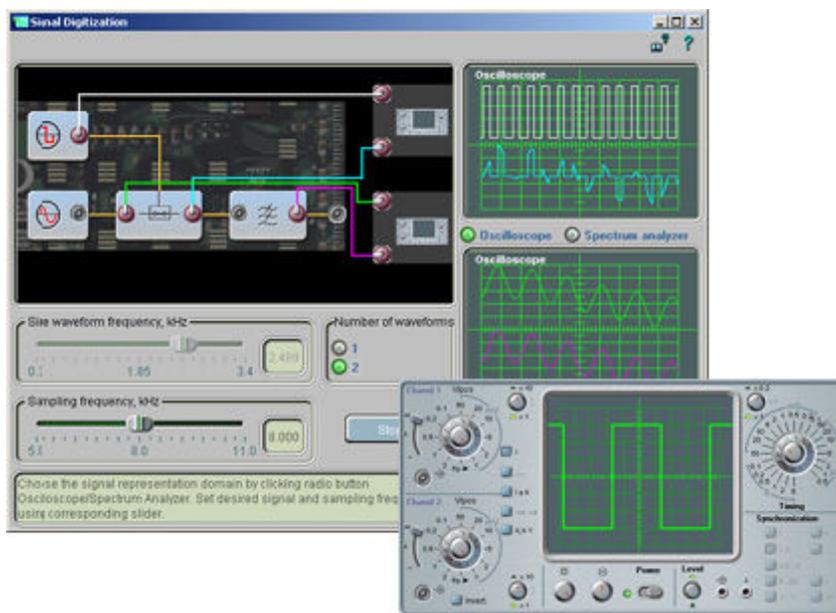
Using the drag and drop option on simulations *A* and *C* in Figure 7, a student is able to move the car around a parking lot and see how the different reflections from surrounding buildings affect the signal shape, phases, and amplitudes. S/he can choose between one or two pulse signals and vary signal frequency, pulse duration, and delay between pulses. Simulations *B* and *D* help the student understand the Huggens-Fresnel principle and the impact of various parameters on the structure of Fresnel’s zones, as well as what sources of secondary waves should be taken into account during the calculations.

Many hands-on labs require unique and expensive equipment, complicated multi-step actions, or require specific training. In contrast, simulations and virtual experiments allow students to perform realistic hands-on labs efficiently online. For example, the “*Fiber Cable Fusion*” and

“Signal digitization” virtual experiments shown in Figures 8 and 9 can be used to guide students virtually through all the steps of the splicing/welding process before they have mastered real splicing/welding techniques. Such warm-up preparation will increase the effectiveness of hands-on labs, making students’ learning more proactive, and thus reducing the time to understand the functionality of unique equipment. Distance learners can use virtual experiments on a regular basis from a college Website while occasionally performing a hands-on laboratory session at the college.



**Figure 8.** The virtual experiment **Fiber Cable Welding** is designed to introduce to students, in detail, all steps of a welding process, welding equipment, and factors which affect the quality of welded cable and signal losses. The learner is able to explore all stages of the preparation phase, select the cables for welding either from a list of standard industrial products or set up customer cable parameters. In the Fusion phase, he/she can launch an automatic Fusion Splicing or adjust the cables manually and measure the losses if the adjustment was not perfect.

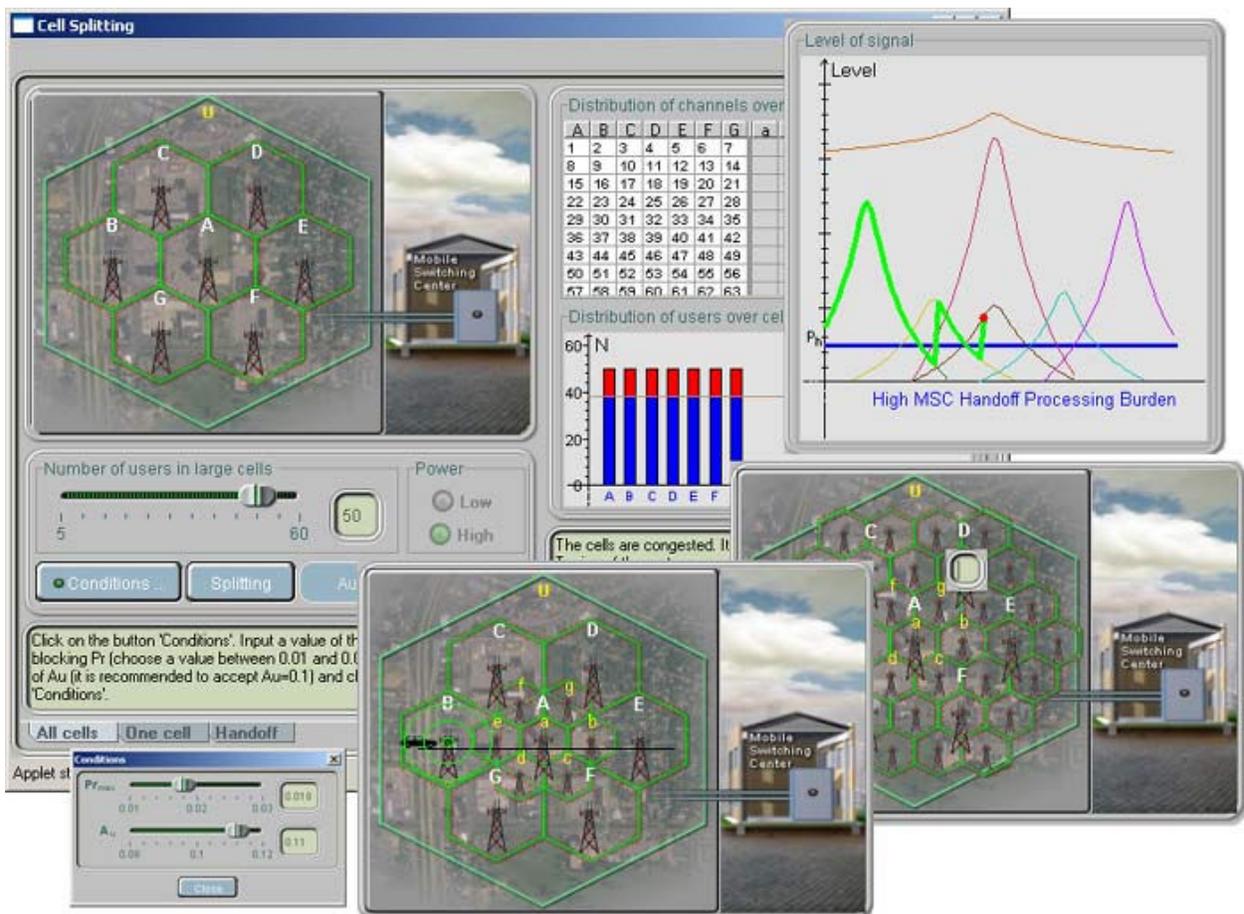


**Figure 9.** The virtual experiment **Signal Digitization** is designed to explore in detail what is going on in the course of signal transmission between subscribers. Such issues as waveform sampling, impact of various frequencies interference due to incorrect sampling frequencies and others are studied.

Input and out of each component can be connected with either built-in oscilloscope or spectrum analyzer to investigate signal on each stage of its transformation. For detailed exploration fully functional virtual oscilloscope can be used.

In a lecture-lab environment, learning can be made more efficient because students can immediately apply their theoretical knowledge by conducting a virtual experiment. Virtual experiments incorporated in online courses are capable of dramatically enhancing the quality of distance learning.

Initially, our software was intended for problem-based learning and “learning-by-doing.”<sup>4-7</sup> However, it can facilitate more traditional learning and teaching strategies as well. The interactive exercises and virtual experiments are designed to challenge learners to develop effective problem-solving and critical and expert thinking skills. This enables the learner to discover the connections between theoretical concepts of the technology and their practical applications in the real world.



**Figure 10.** A simulation enabling a student to explore situations when cell splitting is appropriate and various strategies of cell splitting.

In the simulation of Figure 10, learners can explore how the maximum number of users in a system increases as cells are split. The procedure of switching or handing off a mobile phone from one cell to another as it moves across cell boundaries in a system of different sized cells can be explored as well. The student is able to change values of the probability of blocking, traffic intensity  $A$ , and the number of users in initial cells.

All simulations, virtual experiments and virtual laboratories can be run from any of the following:

- ◆ A Website
- ◆ A server via a local school or corporate network
- ◆ A CD or hard drive of a stand-alone computer.

The software and its components are compliant with SCORM and compatible with major learning and content management systems.

### **III. Incorporation of ATeL software into Telecommunication courses at DeVry University**

A number of simulation and virtual experiments based on ATel software have been incorporated for the Hybrid delivery of Wireless and Fiber optics course at DeVry University, Addison, IL. A sample hybrid experiment titled “Fiber Attenuation Measurements” is presented in the appendix. In the hybrid mode a combination of hands-on lab component coupled with virtual simulation help students develop a very strong conceptual knowledge-base.

### **IV. Conclusion**

The use of interactive simulations and virtual experiments in Fiber Optics and Wireless Communications courses delivered via online, onsite and hybrid delivery modes enables students to acquire digital-age literacy by developing complex and expert thinking skills.



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## APPENDIX

### Hybrid Experiment: FIBER ATTENUATION MEASUREMENTS [8]

#### I. Hands-on Experience

##### Materials Required

##### Equipment

Dual trace oscilloscope  
Function generator  
Digital multi meter  
DC power supply  
Optical power meter  
Optical fiber connector/adapters

##### Components

Four meter 1000 micron core plastic fiber (DuPont OE1040 or Eska SH4001)  
1 Infrared LED MFOE71  
1 Photo transistor  
1 150 ohm ( $\frac{1}{2}$  watt) resistor  
1 100 ohm ( $\frac{1}{2}$  watt) resistor

##### Lab Text

Fiber Optic Communication: An Applied Approach by Ahmed S. Khan (Pearson, ISBN 0-536-67051-X).

For all circuit diagrams refer to pages 176-188 of Lab text.

##### Objective

To study various types of fiber attenuation mechanisms and to measure cable loss, and cable bending loss.

##### Introduction

The attenuation or transmission loss of an optical fiber is one of the important factors in the design of the system as it dictates (i) the spacing between the repeaters, and (ii) the type of optical modulator and demodulator to be used.

As an optical signal propagates through an optical fiber, it undergoes attenuation. A number of mechanisms contribute to the signal attenuation within the optical fiber. These mechanisms are influenced by the material composition, the manufacturing technique and the waveguide structure. Fiber attenuation is expressed in terms of db/km. The following loss mechanisms contribute to overall fiber attenuation in fiber:

1. Absorption loss
2. Scattering loss
3. Bending loss
4. Mode coupling loss
5. Leaky mode loss

In a fiber optic system, there are also losses at connectors and splices. Figure 1 illustrates various losses in a fiber optic system. For a fiber optic system to be viable, the system power margin must be equal to or greater than the sum of total channel losses and the safety margin. This experiment deals with measuring the cable loss and cable bending loss.

## **Procedure**

### **Part-I: Cable loss**

1. Assemble and connect the components according to Figure 2-a.
2. Adjust the power supply voltage so that  $I_t$ , the current through the IDLED, is 100 mA.
3. Measure  $I_d$ , the current through the detector.
4. Keeping  $I_t = 100$  mA, replace the photodetector MFOD72 with a power meter (Figure 2-b), and measure the power level that is incident on the photodetector.
5. Now remove the fiber and connect the IDLED MFOE71 directly to power meter (with appropriate connector or a short piece of fiber, Figure 2-c) and, by keeping  $I_t = 100$  mA, measure the optical power (this represents the magnitude of optical power being launched into optical fiber by the IDLED).

### **Part-II: Bending Loss**

6. Assemble and connect components according to Figure 3-a.
7. Adjust the power supply voltage so that current through the LED equals 100 ma, and measure the power level with the optical power meter.
8. Now, by bending the fiber, introduce a loop with a radius of approximately 25 cm, and measure the power level (Figure 3-b).
9. Decrease the loop radius with a decrement of 1 cm, from 25 cm to 0.2 cm (Figure 4) and measure the optical power level at the detector for each value of the bending radius.

## **Data Presentation and Interpretation**

### **Part-I**

1. Using the data sheet for MFOE71, determine the value optical power (in micro-watts) being launched into the fiber for an  $I_t$  value of 100 mA.
2. Using the responsivity of MFOD72 from the data sheet, calculate the optical power received for the value of  $I_t$  measured in step-3 of procedure.
3. Calculate the cable loss by using power values obtained in step 1 and 2.  
Cable loss =  $10 \log (\text{power launched} / \text{power received})$
4. Determine the cable loss (measured) using the power levels obtained in steps 4 & 5 of procedure.
5. Is there agreement between the calculated and measured values of cable loss? What factors are responsible for any difference in two values?

6. Does the measured cable loss value represent the true cable loss or is any other type of loss included in it?

## **Part-II**

7. What causes bending loss in fiber?
8. Plot bending radius vs. power.
9. Beyond what radius value does the power loss increase significantly?
10. What factors does the minimum bend radius depend on?
11. Define the follow units:
  - a. db
  - b. dbm
  - c. dbw

## **Hybrid Experiment: FIBER ATTENUATION MEASUREMENTS**

### **II. Virtual Simulation Experience**

#### **Study of loss mechanisms in optical fiber: Part 1**

##### Objectives

- ◆ To demonstrate the types of loss mechanisms that occur in optical fiber.
- ◆ To determine the ways in which loss varies with the composition of the fiber.
- ◆ To determine the way in which loss varies with wavelength in optical fiber.

##### Experiment Description

The primary components of signal attenuation in fiber are scattering and absorption within the fiber material. The level of dominant Rayleigh light scattering depends on wavelength as  $1/\lambda^4$ . Absorption by pure silica increases for wavelengths longer than about 1.6  $\mu\text{m}$ . Residual impurities absorb light at some wavelengths between 0.7 and 1.55  $\mu\text{m}$ . The most strongly absorbing impurities are heavy metal atoms such as copper and iron. The chemical-vapor method of production of fused silica allows one to almost completely remove these impurities. But there is still residual absorption from water molecules in the fiber.

This simulation enables you to learn what types of losses are present in silica fibers and how their values depend on wavelengths of light. So, it allows us to find out the wavelength preferable for long-distance communication links.

##### Procedure

Using Internet web browser go to the Active Learning Suite website (<http://atellearning.com>) and click on fiber optic virtual experiments and from the menu select “Study of loss mechanisms in optical fiber: Part 1” and perform the following steps

**Step 1** (of 4). Push the **Rayleigh scattering** button. Note how rapidly the loss declines with increasing  $\lambda$ . The Rayleigh scattering losses are proportional to  $1/\lambda^4$ .

**Step 2** (of 4). Push the button **Infrared absorption of silica**. You can see that these losses become of importance at wavelengths longer than  $1.6 \mu\text{m}$  ( $\lambda > 1.6 \mu\text{m}$ ). Both Rayleigh scattering and Infrared absorption losses are fundamental and irremovable.

**Step 3** (of 4). Now press the button **Impurity absorption**. You can see that impurity losses prevail in insufficiently purified fibers. Next, press buttons of purity from **min** to **max** and watch as a curve of the Impurity losses moves down closer to curves of fundamental losses. The button of the highest purity (**max**) corresponds to the most widespread modern fibers.

**Step 4** (of 4). The remaining peaks of absorption are mostly due to remainders of water in silica. The latest sophisticated technologies of purification make it possible to get rid of residual water in fiber. Push the button **Total removal of water impurities** and you will see a very smooth curve of loss in such fiber. But this technology is still rather expensive and therefore such **dry fibers** are not yet in common use.

## Study of loss mechanisms in optical fiber. Part 2

### Objectives

- ◆ To demonstrate the types of losses that occur in optical fiber.
- ◆ To determine the ways in which loss varies with the composition of the fiber.
- ◆ To determine the way in which loss varies with wavelength in optical fiber.

### Experiment Description

The primary components of signal attenuation in fiber are scattering and absorption within the fiber material. The level of dominant Rayleigh light scattering depends on wavelength as  $1/\lambda^4$ . Absorption by pure silica increases for wavelengths longer than about  $1.6 \mu\text{m}$ . Residual impurities absorb light at some wavelengths between  $0.7$  and  $1.55 \mu\text{m}$ . The most strongly absorbing impurities are heavy metal atoms such as copper and iron. The chemical-vapor method of production of fused silica allows one to almost completely remove these impurities. But there is still residual absorption from water molecules in the fiber.

This simulation enables you to learn what types of losses are present in silica fibers and how their values depend on wavelengths of light. So, it allows us to find out the wavelength preferable for long-distance communication links.

### Procedure

Using Internet web browser go to the Active Learning Suite website (<http://atellearning.com>) and click on fiber optic virtual experiments and from the menu select “Study of loss mechanisms in optical fiber: Part 2” and perform the following steps

**Step 1** (of 6). Set the loss curve corresponding to **max** at the panel **Purity**.

**Step 2** (of 6). Find out the loss level at  $\lambda=0.85 \mu\text{m}$ . The GaAlAs/GaAs laser emits at this wavelength. This laser was used in early fiber communication lines and is still used nowadays in short-distance communications. Move a mouse cursor to a loss curve and read out the exact values of loss and wavelength. Accurately shift the cursor to desired  $\lambda$ .

**Step 3** (of 6). Figure out the longest possible communication distance ( $L_{\text{max}}$ ) at this wavelength (without repeaters and amplifiers) if the admissible signal attenuation level  $A_{\text{max}}$  is 20 dB. In

order to find this distance, divide  $A_{\max}$  by the loss level in units of dB/km :  $L_{\max} = A_{\max} /(\text{loss [dB/km]})$ .

**Step 4** (of 6). Find the exact wavelengths of the loss minima in the vicinity  $\lambda = 1.25\text{-}1.35 \mu\text{m}$  and  $\lambda = 1.5\text{-}1.6 \mu\text{m}$ .

**Step 5** (of 6). Repeat Steps 2 and 3 for these  $\lambda$ . Note that at  $\lambda = 1.31 \mu\text{m}$  most of short and medium-distance optical fiber communication lines are still operating, especially those deployed 10 to 15 years ago.  $\lambda = 1.55 \mu\text{m}$  is now standard for medium and long-distance communication lines.

**Step 6** (of 6). Repeat Steps 2 and 3 for any desired  $\lambda$ . For example, at the loss maximum.