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ABSTRACT

One of our objectives in the College of Applied Science and Technology at RIT is to offer our students some kind of "hands-on" experience along with theory. Providing a hands-on experience can be costly, however, especially in the field of optical communication. Although reasonably priced laboratory kits are available, the optical-electronic components in these kits are well below communication grade. Thus if we rely only on hardware, our students can only experiment with low power, low bit rate communication over a few kilometers of fiber.

Computer simulation software offers an affordable alternative "hands-on" experience. With this software, a student can create a model of an optical system, execute the model and view measures of the system's performance. The system components can include DFB laser diodes, high-speed modulators, hundreds of kilometers of fiber, APD receivers and other optical and electrical components. The student can view the optical signals in the time or frequency domain, measure optical power and signal-to-noise ratio and much more. He or she can also view the effects of parameter variations or find the optimal value of a parameter. The software is easy to learn, especially if the student has previous experience with an electronic system simulator.

This paper describes our application of an optical-electronic system simulator in the Telecommunications Engineering Technology program at RIT. We are developing a series of exercises to complement courses in fiber optic. These exercises will allow students to model and test systems that they have designed. We expect computer simulation to enhance our fiber optic courses significantly by adding a reasonably realistic and accessible test bed for student designs.

1. INTRODUCTION

In the winter of 2000, W. Koontz developed an introductory course in fiber-optic telecommunications technology for engineering technology students at RIT. The course was designed for upper-level undergraduates and covered the following topics:

- Basic telecommunications components
    - Medium (optical fiber)
    - Transmitters (LEDs and laser diodes)
    - Receivers (photodiodes)
- Additional telecommunications components
    - Modulators
    - Amplifiers
    - Couplers
    - Multiplexers/demultiplexers
- System engineering
    - Power budget and attenuation-limited fiber length
    - Dispersion and dispersion-limited fiber length
    - Dispersion compensation
    - Receiver sensitivity

The course did not have an associated laboratory course. Students practiced what they learned in class by completing homework problems and the closest they got to "hands-on" experience was to learn to read manufacturers' specifications of optical components.

The course quickly became a popular technical elective for junior and senior students in both telecommunications engineering technology and electrical engineering technology. Student feedback made it very clear, however, that associated laboratory exercises would significantly increase the value of the course.

A number of vendors offer equipment to support laboratory exercises in fiber optic telecommunication. Koontz eventually selected a laboratory kit that supports experiments to observe and measure fiber attenuation and dispersion, LED and laser diode characteristics and a few other items. These kits have been very useful, but they are designed to be affordable and this presents several disadvantages, such as:

- They only provide and support multi-mode fiber
- Both the LED and laser diode transmitters have broad spectral width and their wavelengths are well outside the standard communications bands
- The transmission bit rate is limited to 40 Mb/s
- The fiber length is limited to 3 km

In other words, these kits do not provide telecommunications grade optics. Modern high-speed, long-haul fiber optic systems are generally characterized by

- Non-zero dispersion-shifted single-mode fiber
- Externally modulated DFB laser diodes (or arrays thereof)
- Erbium-doped fiber amplifiers and Raman pump lasers
- Transmission rates of 40 Gb/s or more
- Fiber lengths of thousands of kilometers

To provide this kind of equipment for a laboratory section of twenty students would be prohibitively expensive. Such a predicament naturally leads one to think of simulation.

2. FIBER OPTIC SYSTEM SIMULATION

Although fiber optic telecommunications equipment developers and network providers may have more resources than universities, even they cannot always afford to experiment with actual systems. Thus they have faced the same predicament, if on a different scale. In response to this, a small number of companies have developed and offer fiber optic systems simulation software. This software is similar to software that has been developed for electrical systems (e.g., PSpice). It allows an engineer (or a student) to model an optical system by selecting components from a library and interconnecting them. Once the model has been created, it can be run to simulate the behavior of the modeled system over a specified period of time. Results of the simulation can be recorded in various ways, displayed and analyzed.

Koontz investigated two such software packages: OptSim offered by RSoft [1] and OptiSystem offered by Optiwave [2]. On the basis of a *brief* comparison, he chose OptiSystem primarily because of the following:

- The hardware and system requirements of OptiSystem were a better match to the PCs in the departmental laboratories
- He had a better feel for the OptiSystem component models, many of which are based on the work of Agrawal [3]

It is important to note that the comparison was by no means exhaustive and this paper should not be viewed as advocating any particular software package.

2.1 OptiSystem Overview

This section provides an overview of how to create and run an OptiSystem model and analyze the results of the simulation. For a more complete description, see the OptiSystem documentation [4].

2.1.1 Creating a Model

Creating an OptiSystem model is very straightforward, especially for those familiar with electronic circuit simulators such as PSpice. OptiSystem provides a hierarchically organized library of electrical components. A small subset of the library is listed here to provide an idea of the type and level of components and how they are organized:

- Transmitters
    - Pulse generators
    - Optical sources
        - CW laser
        - Directly-modulated laser
- Optical fibers
    - Nonlinear dispersive fiber
- Receivers
    - Photodetectors
        - PIN photodetector
- Amplifiers
    - Optical
        - EDFA
- Visualizers
    - Optical
        - Optical spectrum analyzer
    - Electrical

There are many more categories and components available than are listed above.

The last category of devices, *visualizers*, includes components that provide numeric and graphical displays of the results of the simulation.

Components are added to the model using the familiar drag-and-drop technique. OptiSystem has an auto-wire facility that usually makes the right connection, at least for straightforward models. Auto-wire can be turned off and wrong connections are easy to repair.

There are three types of connections: optical, electrical and logical. All of the connections represent some kind of signal channel and do not necessarily represent a physical object such as a wire. The port types of the connecting components determine the connection type. Of course, these port types must match. For example, the connection between a pseudo-random bit sequence generator and an electronic pulse generator is logical; the connection between an electronic pulse generator and the modulating signal input of a Mach-Zehnder modulator is electrical.

Each component has a set of parameters that can be set to a constant value, swept through a range of values, determined by a script, read from a file (look-up table) or optimized. There are also global parameters (e.g., transmission bit rate), some of which may be user-defined. A few parameters are either/or. For example, for a laser diode one may specify either the operating frequency or the operating wavelength. Fortunately, all parameters have reasonable default values. Moreover, OptiSystem is delivered with a generous supply of examples and often the best way to create a model is to start with an example that is close and modify it.

Figure 1 is a sample model and Figure 2 is a partial list of the parameters of the optical fiber component in Figure 1.
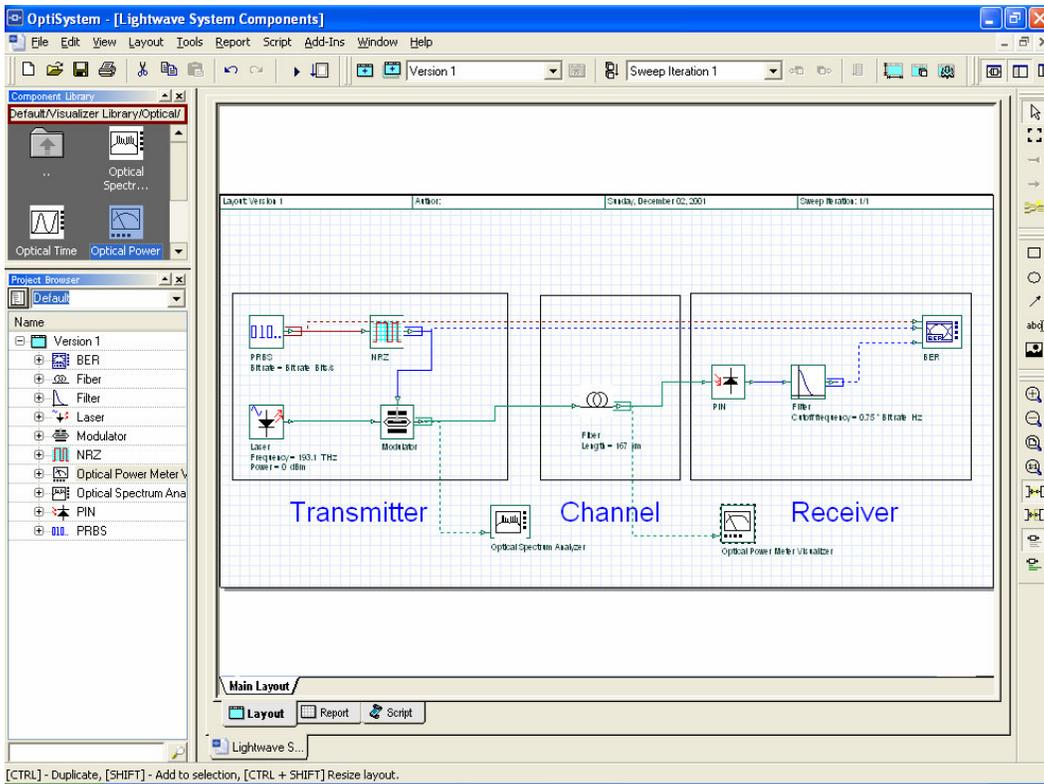
Fig. 1. Sample OptiSystem layout

Fig. 2. Component parameters – nonlinear dispersive fiber

2.1.2 Running the Simulation and Viewing the Results

This is the easiest step: click the run button on the toolbar and then click the "yes, I really want to run" button on the run window. Actually, second button is necessary when one wants to use advanced features such as parameter optimization.

Without sweep iterations or optimizations, the simulation usually completes within a time period on the order of seconds or tens of seconds on a current generation PC. Of course the run time gets longer (minutes or more) when one introduces sweep iterations (repeated sub-runs with varying values of a chosen parameter) or optimization (seeking a minimum, maximum or target value for one or more measured values with respect to one or more parameters.

Visualizers, such as oscilloscopes, spectrum analyzers and optical power meters, are the key to viewing results of the simulation. Figures 3 and 4 are the displays of the optical spectrum analyzer and the optical power meter in Figure 1.
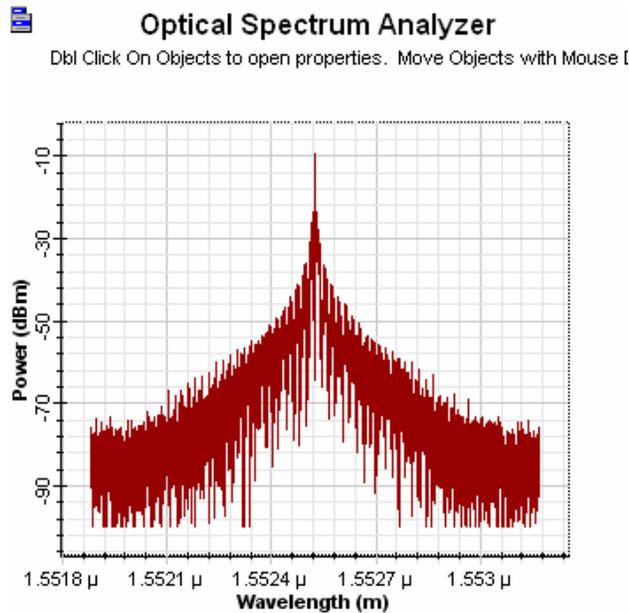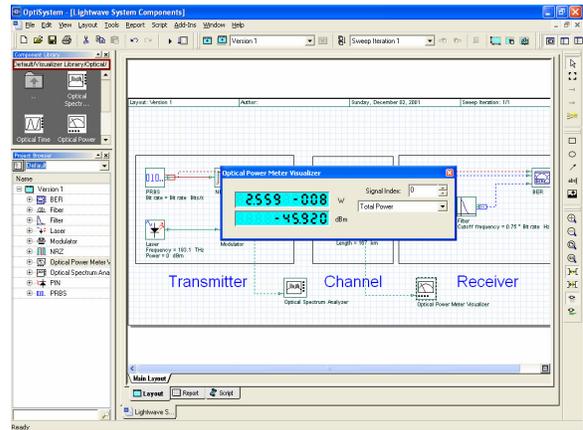

Fig. 4. Optical power meter display

Fig. 3. Optical spectrum analyzer display

OptiSystem also provides a plotting facility in conjunction with sweep iterations. Figure 5 shows a plot of maximum Q factor vs. fiber length for the model in Figure 1.

The most useful visualizer for telecommunications systems is the bit error rate (BER) analyzer. The BER analyzer is actually both a visualizer and a receiver component in that it simulates the conversion of electrical pulses into logical 1s and 0s and displays quantities such as Q factor and BER as well as an eye diagram. Figure 6 shows the eye diagram displayed by the BER analyzer.

Max. Q Factor (Length (km))

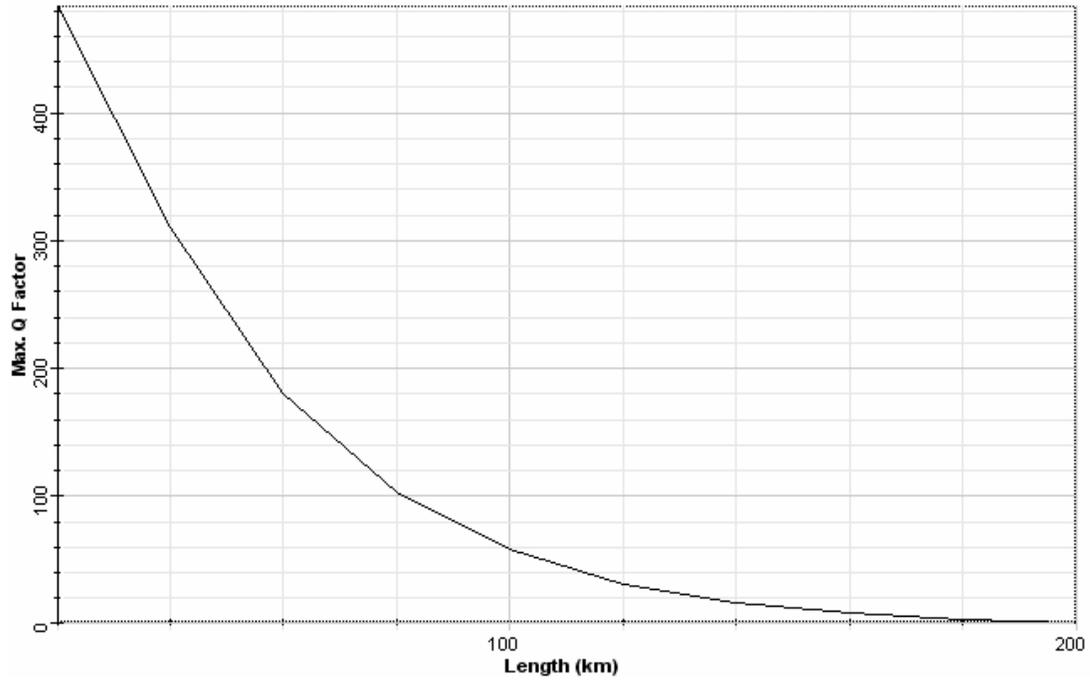Dbl Click On Objects to open properties. Move Objects with Mouse Drag

Fig. 5. Maximum Q factor vs. length for the system in Fig. 1

BER

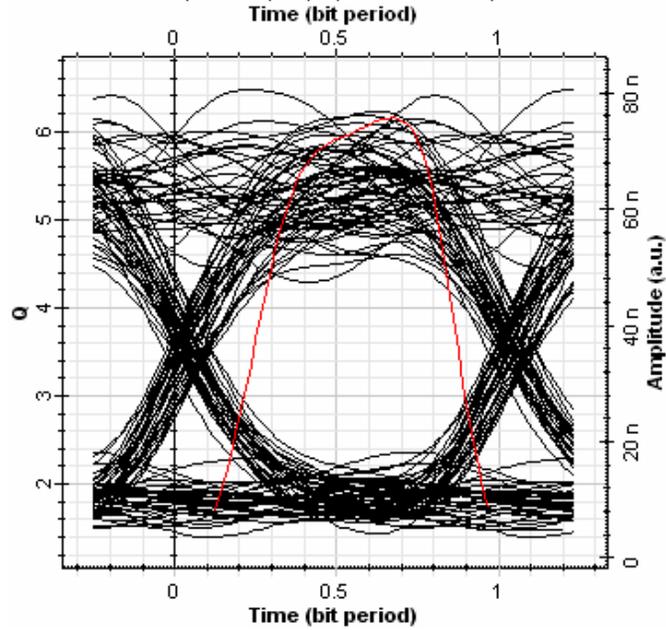Dbl Click On Objects to open properties. Move Objects with Mouse Dr

Fig. 6. Eye diagram for system in Figure 1 with fiber length = 160 km

3. LABORATORY EXERCISES

This section lists and summarizes the laboratory exercises that the authors have completed to date.

Exercise 1 – Introduction to OptiSystem – Create and execute a simple OptiSystem model. This exercise is provided by Optiwave Corp. in the OptiSystem documentation [4]. It gives the student detailed instruction on how to access components in the library, create a system layout, run a simulation and view the results.

Exercise 2 – Power budget and attenuation-limited fiber length – Calculate power budget and attenuation-limited fiber length based on theory, then create and execute an appropriate OptiSystem model and compare calculation with simulation. One difficulty with this exercise is that receiver sensitivity cannot be input directly, but is determined by a combination of factors in the model. Therefore, receiver sensitivity is provided in the exercise and the determination of receiver sensitivity is deferred to a later exercise.

Exercise 3 – Dispersion budget and dispersion-limited fiber length – Calculate dispersion budget and dispersion-limited fiber length based on theory, then create and execute an appropriate OptiSystem model and compare calculation with simulation. Measure the amount of pulse spread due to dispersion and compare with the calculated value.

Exercise 4 – Dispersion compensation – Design a fiber optic link consisting of a length of transmission fiber followed by a length of dispersion-compensating fiber. Set the fiber lengths such that, according to theory, both attenuation and dispersion constraints are met. Create and execute an OptiSystem model of the design and evaluate the results of the simulation.

Exercise 5 – Comparing direct and external modulation – The spectral width of an optical transmitter using a directly modulated single-mode laser diode is primarily due to chirp, whereas the spectral width of an externally modulated laser diode is primarily due to the modulating signal. The formulas for pulse spread are different for the two types of modulation. Use the theoretical formulas to determine pulse spread for both types of modulation and then create and execute an OptiSystem model and compare the results with the calculations.

Exercise 6 – Receiver sensitivity – Use the optimization feature of OptiSystem to determine the minimum received power required to achieve a specified Q factor. Compare the result with the value obtained from a theoretical formula.

Exercise 7 – Dispersion of Gaussian pulses – Measure the spread of a chirped Gaussian pulse propagated through a length of optical fiber. Compare the measured value with the value predicted by a simple Gaussian transfer function model of the optical fiber.

Exercise 8 – Long-haul transmission with optical amplifiers – Measure the performance of a long-haul fiber optic system of a given length as a function of the number of evenly-spaced inline optical amplifiers and compare with a theoretical calculation. This exercise is set up so that the primary limitation is amplified spontaneous emission (ASE) noise. It makes use of the loop component provided by OptiSystem.

The other two exercises for the ten-week course involve the hardware kits mentioned earlier.

4. EXPERIENCE OR THE LACK THEREOF

The OptiSystem experiments have been developed over a period of about one year and the laboratory component of the course has not been offered yet. However, earlier versions of most of the experiments have been run in the lecture session as demonstrations. These demonstrations have been very useful for illustrating concepts and comparing engineering calculations with simulation results. Although there has so far been no formal evaluation of the impact of simulation, several students have made favorable comments about the demonstrations in their course evaluation forms.

One of the first benefits we observed from the demonstrations follows from the fact that topics in the course are presented sequentially, starting with optical fiber. Students are introduced to fiber attenuation and attenuation-limited fiber length at a point where most of them are not familiar with the concept of receiver sensitivity. By observing the demonstration and the eye diagram, however, they can quickly appreciate the fact that receiver performance degrades as the received power decreases, even if they do not yet know exactly why this happens.

5. SUMMARY AND CONCLUSIONS

We have enhanced the existing fiber optic telecommunications technology course significantly through the introduction of computer simulation. To date we have used the software only for demonstrations, but now that we have a twenty-seat license, we will incorporate laboratory exercises into the course and most of the exercises will be simulations.

The laboratory exercises are a response to a request from the students for a laboratory component and for at least something close to a hands-on experience. Simulation allows the students to observe the behavior of systems that would be much to costly to provide in a hardware-based laboratory.

REFERENCES

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