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Fiber Optic Telecommunications Technology and Systems – A Two-Course Sequence for a Telecommunications Engineering Technology MS Program

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Introduction

The continuing growth of telecommunication networks is currently dominated by two technologies: fiber optics (or optical networking) and wireless. The Telecommunications Engineering Technology program at RIT, as part of its continuous improvement program, has been developing and updating courses in these important areas. This paper describes a two-course sequence in fiber optic telecommunication technology and systems. The first course in the sequence was introduced in the spring of 2001 as an advanced undergraduate elective. It has proven to be a popular course and has run at least once per year since then. The second course has just been completed and will be offered this spring (2005).

The paper begins with a brief overview of fiber optic telecommunication, including some recent forecasts of the future of optical networking. The next two sections describe each of the two courses and the last section is a short summary.

Fiber Optics and Telecommunication

Optical communication dates back at least to the ancient Greeks, who used fire signals in the eighth century BC. In 1880 Alexander Graham Bell patented the "photophone", an optical telephone system. Although telephone traffic was carried primarily by wire through most of the twentieth century, investigation of optical communication continued. By 1960 optical fibers were being used in medical imaging, but their attenuation was much too high for long distance communication. Around 1970, however, researchers at Corning developed optical fiber with attenuation of less than 20 dB/km and Bell Laboratories demonstrated a point-to-point fiber optic telecommunication system in 1975. Thanks to further improvements of optical fiber as well as in laser diodes and photodiodes, the performance of fiber optic telecommunication systems has continued to improve. Currently available optical fibers offer attenuation less than 0.2 dB/km. The introduction of optical amplifiers and wavelength-division multiplexing in the 1990's expanded the capacity and reach of fiber optic telecommunication systems dramatically. For example, Lucent Technologies' Lambda Xtreme transport system can operate at 2.56 Tb/s (2.56 trillion bits per second) over a distance of 1000 km or 1.28 Tb/s over a distance of 4000 km.

Although sales of such "extreme" systems slowed at the turn of the century, the fundamental driving forces that led to their development are still present. In the post-bubble years 2000-2004, worldwide Internet usage has grown more than 125%[1]. As of October 2003, more than 35% of U.S. households with Internet access had a high-speed (DSL or Cable Modem) connection to the Internet[2]. Although the rate of growth of bandwidth demand has slowed since 2000, the forecast of 30% growth in 2005[3] is still well into the double digits. Moreover, whereas fiber has played only a minor roll in the local access (loop) network up to now, the market for optical networking equipment, cable and apparatus for the local access network is forecast to reach $3.2B by 2009, which equates to an annual growth rate of 54% during the period 2003-2009[3].

In short, optical fiber has become the guided medium of choice in telecommunications and fiber optic and associated opto-electronic technologies have become important basic components of a telecommunications curriculum. This is why the College of Applied Sciences and Technology at RIT has developed fiber optic courses for its Telecommunications Engineering Technology program as well as opto-electronics courses for its Electrical Engineering Technology program.

Fiber Optic Telecommunication Technology

As the title implies, the first course focuses on the technologies behind fiber optic telecommunications systems. These technologies include the optical medium (i.e., optical fiber itself), optical transmitters and receivers, optical amplifiers and passive optical components. Students must understand these basic components and the associated engineering models in order to evaluate and design systems. In particular, they must understand component characteristics that limit the capacity and reach of fiber optic systems in order to determine such things as maximum span length, maximum bit rate and system margin.

The objectives of the course are formally documented (in accordance with ABET requirements) as Intended Learning Outcomes (ILOs). The ILOs are:

- Explain how light propagates through an optical fiber
- Calculate attenuation and dispersion of a pulse of light as it propagates trough an optical fiber
- Explain qualitatively the operation of light-emitting diodes, laser diodes, photo-detectors, optical amplifiers and selected other components of fiber optic telecommunication systems
- Calculate the maximum transmission distance and data transmission rates for fiber optic telecommunication systems
- Use specifications for optical fiber and optical components to obtain data needed for attenuation, dispersion and selected other engineering calculations

The course was originally designed for advanced undergraduate engineering technology students but has been expanded to include graduate students as well. The prerequisites, which are normally met by students at this level, are

- Basic optics, including geometric, wave and quantum optics, at the level covered in a general physics course. This material is reviewed during the first week of the course.
- Electronics – students should have some familiarity with semiconductors and p-n junctions.
- Calculus – students need calculus to understand the derivation of some of the engineering formulas and to work with dynamic device models.

The course is organized into two threads: a system component thread and an engineering calculation thread. The system component thread covers the basic components of fiber optic telecommunications systems, namely

- Optical fiber
    - Optical fiber composition and structure
    - Light propagation in optical fiber
    - Attenuation and dispersion in optical fiber
- Optical sources and transmitters
    - Review of applicable semiconductor theory
    - Light-emitting diodes (including rate equations)
    - Laser diodes (including rate equations)
    - Optical modulators
- Photo-detectors and optical receivers
    - Photo-diodes and basic receiver circuits
    - Noise in optical receivers
- Optical amplifiers
    - Semiconductor optical amplifiers
    - Fiber amplifiers
    - Amplifier noise
- Passive components

This list of topics is fairly standard and most texts[4, 5] cover these topics in one order or another.

The engineering calculation thread develops a repertoire of tools that can be used to analyze and design fiber optic systems. The calculation thread is closely coupled to the component thread in that it relies on mathematical models of the components. The calculation thread includes the following:

- Power budget analysis – system margin and attenuation-limited fiber length
- Dispersion analysis – dispersion-limited fiber length and bit rate
- Bit error rate analysis – calculation of receiver sensitivity

- Long-haul system analysis – calculation of cumulative noise from optical amplifiers

The engineering calculation thread not only provides a useful set of tools that can eventually be applied on the job, but also reinforces students' understanding of the system components and how they affect system performance.

The engineering calculation thread is supported by an ongoing project call the Fiber Optic Telecommunication Spreadsheet or FOTS. Each student is required to develop a spreadsheet-based tool to carry out the engineering calculations. They must develop a series of "releases" of the tool that are due at various times during the course. Each release adds new "features" to support an increasing repertoire of calculations. Release 1.0 is limited to power budget analysis and the final release contains most of the calculations that the students have learned. Student response to this project has been very positive and several students have admitted that they did not really understand the calculations until they had to implement them as spreadsheet formulas. Although FOTS is not graded as a programming project, we usually have an informal contest to determine the "coolest" spreadsheet.

The course is offered in both traditional classroom and online format. A series of studio recorded lectures and demonstrations are available on CD-ROM for the online version of the course.

Early feedback from students indicated a strong desire for associated laboratory exercises that would provide "hands-on" experience with optical fiber and opto-electronic components. Unfortunately, communication grade optical hardware is very expensive and companies in the optical space have not recently been in the position to make substantial contributions. Our solution to this dilemma consisted of two initiatives

- The purchase of relatively inexpensive "educator kits" manufactured by OptoSci Ltd.
- The purchase of OptiSystem simulation software from Optiwave Corp.

The educator kits include the following components:

- A single unit housing an electrical pulse generator, and LED-based transmitter, a laser diode-based transmitter and a PIN photodiode-based receiver. The unit displays transmitter bias current and receiver input power
- Two reels of multi-mode fiber (1 km and 2 km in length) plus a 1 m patch fiber, all with standard connectors
- Electrical cables and connectors

The receiver output (electrical) may be connected to an oscilloscope and the transmitters can be driven by an external pulse generator.

The kits support a number of experiments, including

- Measurement of LED and laser diode characteristics and comparing the measurements with the rate equations covered in lecture
- Measurement of fiber and connector losses
- Measurement of system rise time and calculation of fiber rise time due to modal and chromatic dispersion

OptoSci now offers a pseudo-random bit sequence generator as an add-on for the kits. This add-on allows one to generate an eye diagram (using an attached oscilloscope), which is a standard display of communication system performance. The add-on also includes software to process data generated by the oscilloscope and display histograms of the received signal and noise. I have obtained one unit of this add-on and plan to use it for a demonstration.

The simulation software provides a kind of virtual hands-on experience. OptiSystem allows students (and practitioners) to model and simulate optical systems that would be prohibitively expensive to acquire in hardware. OptiSystem uses sophisticated mathematical models of fiber and opto-electronic components. In spite of its sophistication, however, OptiSystem is easy to learn and use, especially by students who are already familiar with electrical system simulators such as PSpice. It offers the same (or very similar) interface to create a system model, set component parameters and run the simulation. A graduate student an I developed a series of laboratory exercises using OptiSystem[6], including

- Attenuation- and dispersion-limited fiber length
- Gaussian pulse propagation
- Receiver sensitivity calculation
- Long-haul systems with optical amplifiers

All of these exercises include a pre-lab calculation based on theory, modeling and simulation and comparing simulation results with the pre-lab calculation.

Fiber Optic Telecommunications Systems

This is a newer course and is currently only offered at the graduate level. The course focuses on telecommunication networks and systems that use fiber optic technology and the standards that apply to these systems. It also includes some technology not covered in the first course, such as components used to implement wavelength division multiplexing and passive optical networks.

The ILOs for this course are:

- Know the common names and functions of optical networking elements and the basic configuration of optical networks
- Understand in-depth the SONET and SDH standards, including frame format, multiplexing hierarchy and pointer processing
- Be familiar with protection schemes and fault-tolerant optical networks

- Understand technology for wavelength-division multiplexing and the standards for WDM systems
- Understand technology for passive optical networks

SONET (Synchronous Optical NETwork) and SDH (Synchronous Digital Hierarchy) continue to be key standards for fiber optic transport and these standards are covered in detail in the course. Inclusion of both the North American standard (SONET) and the standard used in most of the rest of the world (SDH) gives the course a global flavor that is important for telecommunications students.

The SONET/SDH topic is also the vehicle to introduce the elements of optical transport networks such as regenerators, multiplexers and switches. Students learn the functions of network elements and how they are interconnected in linear, ring and mesh networks. Students also learn how these elements provide reliable transport through various protection switching mechanisms.

The Telecommunications Engineering Technology program at RIT includes a telecommunication system laboratory containing a variety of equipment including some fiber-optic transport systems, namely

- Two Nortel S/DMS OC-3 transport nodes (terminal multiplexers)
- Two Cisco ONS 15454 metro optical transport platforms

The ONS systems have just been purchased and some graduate students and I are currently setting them up in a ring configuration. The students are contributing to the effort as a project associated with the course. Our near term goal is to establish a unidirectional path switched ring and transport DS1 traffic between the two sides of the laboratory with protection. So far it has been an excellent learning experience for all of us: dealing with incompatible connectors, resolving unexplained power losses, etc. The ONS systems promise to be a valuable asset for the course.

Wavelength division multiplexing (WDM), which increases the capacity of fiber optic systems enormously, is another major topic. Students learn about the technology for optical multiplexing and de-multiplexing and the applicable global standards for WDM. The course also includes an overview of nonlinear effects in optical fiber, which are significant factors in the design of WDM systems.

The third and currently last major topic is passive optical networks (PON). PON technology is the most attractive alternative for bringing optical fiber into the local access network. Telecommunications service providers as well as equipment providers have been talking about fiber to the home (FTTH or FTTP), fiber to the business (FTTB), fiber to the curb (FTTC) and other locations in the last mile of the network (FTTx or FITL*) at least since the mid 1990s.

* Fiber In The Loop

Recently, major service providers have taken serious steps toward deploying FTTx on a wide scale and the industry views this as an opportunity for renewed growth in the fiber optic business.

The topics in this course are less mature and more dynamic than the basic topics in the first course. The technology, standards and business conditions are all changing rapidly. For this reason, the course includes a research project leading to a written report and a presentation. Since the duration of the course is only a single ten-week quarter, the scope of the research is modest and students are encouraged to work in small teams.

Summary

Telecommunications engineers are faced with a host of technologies including legacy systems based on twisted copper wire pairs, coaxial cable and microwave as well as the newer wireless and fiber optic technologies. The goal of RIT's Telecommunications Engineering Technology program is to prepare people to work with these technologies as well as learn about future technologies. The fiber optic curriculum described in this paper addresses this goal by

- Describing the basic technologies
- Providing a set of tools for analysis and design
- Describing optical network elements and networks
- Referring to applicable global standards
- Providing research experience

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Biographical Information

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