NSF-Supported Instrumentation: Erbium Doped Fiber Amplifiers and Distributed Feedback Lasers for Technicians in Training

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Abstract

Under an NSF ILI grant we are developing experiments and laboratory writeups related to erbium-doped fiber amplifiers (EDFA's) and distributed feedback (DFB) lasers suitable for student technicians in an AAS degree program in Laser and Fiber Optics Technology. Emphasis is on characterizing the devices using standard test equipment. Densely-packed wavelength division multiplexing is demonstrated using a pair of temperature-tuned DFB lasers with a simulated demultiplexer based on a splitter and monochromaters equipped with InGaAs detectors. Laser spectral width is measured with nonconfocal scanning interferometers. EDFA linearity is checked using levelled sinewave generators and high speed digitizing oscilloscopes. Digital capability is investigated using bit-error-rate test sets producing FDDI and SONET test patterns.

Practical realization of all-optical amplifiers is having a major impact on the world of fiber optic telecommunications. A recent study by ElectroniCast Corporation forecasts, "Consumption of optical amplifiers worldwide is expected to expand to $575 million by 1999 from a 1994 figure of $255 million . . . After the turn of this century demand should continue to grow at a rate of 15.6% per year [through] 2004.'" Knowledge about and experience with these systems and the sources used to feed them is of great practical importance to technical personnel in the fiber optics area. The Department of Physics at Queensborough Community College, one of the 22 units of the City University of New York, supervises a TAC/ABET accredited A.A.S. degree program in Laser and Fiber Optics Technology with roughly 125 enrolled students. A very recently completed NSF-ILI grant (number: DUE 9351683) has allowed us to develop laboratory experiments designed to introduce these student technicians to distributed feedback (DFB) lasers and erbium-doped fiber amplifiers (EDFAs). The concept behind the project is to teach the students not only how the devices work and how to operate them, but also how to characterize and test them. Thus, we had to deal with an array of test instruments as well as the devices themselves.

The Equipment

EDFA

Most mature of the optical amplifiers is the erbium-doped fiber amplifier (EDFA). A practical EDFA system has several parts in addition to the doped fiber itself. [See Figure 1] A pump laser producing radiation with 980 nm wavelength works well for erbium-doped fiber. The laser is most conveniently handled if it is put in an appropriate diode laser mount. The pump laser needs to be cooled, and electrical power must be supplied. We use a thermoelectric cooler (TEC), for which appropriate electric power must also be provialed. To combine the 980 nm pump radiation with the incoming signal at about 1550 nm, one needs a wavelength division multiplexer (WDM) designed for these two specific wavelengths. After the dual-wavelength, combined radiation passes through the erbium-doped fiber, the portion of the 980 nm radiation which was not absorbed by the doped fiber must be must be stripped from the (amplified) signal. A second WDM is the preferred device. The 1550 nm output of this WDM is the amplified signal.

DFB Laser

A very narrow linewidth source is needed for several practical applications in fiber optics. The device of choice in telecommunications is the distributed feedback (DFB) laser. For the DFB laser one needs an appropriate mount and electrical power supplied for a thermoelectric cooler and the laser itself.

LED

For a relatively inexpensive source, we also use a 1550 nm light-emitting diode. It is convenient to have a bias-tee available so that a DC bias can be applied to the LED from a simple power supply and a modulating signal added from an appropriate source such as a leveled sine wave generator or bit-error-rate-transmitter.

Test Instrumentation

To measure accurately the (quite narrow) spectral width of a DFB laser, the standard 0.25 m monochromators we use for general laboratory purposes are not adequate. Minimum acceptable resolution is on the order of 0.01 nm, with better resolution a decided plus. We decided to opt for nonconfocal scanning interferometers. For measurement of the peak central wavelength, on the other hand, we decided that our 0.25 m monochromators would be adequate provided that we could equip them with a grating appropriate to the 1300-1550 nm wavelengths we use. This proved feasible.

For measurements of amplification and signal distortion, we decided that at the technician level a highly visual approach is more useful than a much more abstract mathematically-oriented approach. Consistent with this concept, we decided to generate analog test signals with leveled sine-wave generators, and digital test signals with high speed bit-error-rate testers and examine the optical signals, either without amplification or after amplification by the EDFA, directly on a digitizing storage oscilloscope. This approach allows direct visual comparison between input electrical signal and output optical signal.

For two of our four EDFA's, we chose Newport Corporation's Fiber Amplifier Kit (FA 100-01) and for the other two Newport's "basic" model of the same kit (FA 1OO-B) with additional items from other vendors. The full kit comes with everything necessary to make an EDFA except for an optical isolator. While complete EDFA's are now commercially available, the various components are integrated into a package which makes it difficult for students to analyze the roles of each element separately. The downside of the kit approach is that quite a few optical connections between singlemode fibers must be made. The finger splices supplied with the kit are nontrivial to use. We ended up purchasing a semiautomatic fiber optic cleaver (JDS Fitel/Furukawa) to get reliable cleaves. In some instances we are using fusion splices. We already owned a singlemode fusion splicer. We have also spliced cables with FC/PC connectors to some segments of the system. DFB lasers are available from a variety of vendors. We selected standard 1300 nm and 1550 nm DFB lasers from North American Philips Key Modules.

There are also several suppliers of 1550 nm LED's. We are using those supplied by MRV Corporation. To modulate these while maintaining a DC bias, we used bias tees from Mini-Circuit Inc. For optical isolators we selected those from ISOWAVE. There are several other vendors for these also. One of our 980 nm pump lasers is manufactured by EG&G Canada and the other three are from Lasertron, Inc. The controllers and mounts for the pump lasers are catalog items from ILX Corporation. The WDM'S are from Gould Inc. and couplers are from Gould and Amphenol.

For our leveled sinewave generators we selected the Model SG 5030 from Tektronix Corporation. This module is in a TM 5003 power supply. We already owned Tektronix model CSA 907 bit-error-rate testers and Tektronix model TRS 540 oscilloscopes. We also already owned four Jarrell Ash MonoSpec 25 monochromators equipped with gratings designed for visible light. For our scanning interferometers we selected Burleigh Instruments, Inc. HiFase with mirror sets for the 1310 nm region and the 1550 nm region. We also purchased fiber optic adapters and Burleigh's True View software and hardware computer interfacing package.

Although most of the equipment purchased was, more or less, "off the shelf," a few custom items were needed. The DFB lasers from NA Philips are in a "butterfly" package. Unfortunately, the lead height (height of the butterfly leads above the bottom of the package) is incompatible with standard commercially available laser diode mounts. Light Control Instruments, Inc. (independent at the time, but now a division of Newport Corporation) customized mounts to accommodate the package.

To use our monochromators for infrared radiation coming from an optical fiber, we had to arrange for modifications. Since the monochromators already had a holder for a second grating, it was relatively simple to add a grating for IR work. Scientific Measurements Corporation did this work as well as designing and building a connectorized fiber optic input and an adjustable mount for a detector at the output. The output mount was designed to handle a custom package from Germanium Power Devices which has a 1 mm diameter InGaAs detector with an integrated preamplifier. The mount is designed so that the detector can be moved around to "catch" the output radiation. (This is necessary because the light from the very small diameter fiber at the monochromator input out is not spread evenly over the output slit.)

The Experiments

The simplest experiment uses a 1550 nm LED as a signal source for amplification by the EDFA. A 90:10 (10 dB) directional coupler after the light source allows measurement of the source output before amplification. The signal passes through the EDFA where it is amplified. In the setup we are using, the pump laser temperature is constantly monitored and kept at a preset figure. Students learn to set the maximum allowed temperature, operating temperature, maximum laser current, and operating current on the laser diode controller. If the LED is unmodulated, a fiber optic meter can be used to measure output power. Students can vary the current to the LED and the current to the pump laser to see how the amplification varies. An actual student graph appears as Figure 2.

The next step up in complexity is to modulate the LED with either a sine wave or a bit pattern from a bit-error-rate tester (BERT) transmitter. The amplified signal can be observed on an oscilloscope, or the BER can be measured after suitable attenuation with a BERT receiver.

Very similar measurements can be done using a DFB laser as the source. The variety of settings for this experiment are somewhat more elaborate than those for the LED. For this experiment, the current supplied to the DFB laser must be set and its temperature kept constant. This requires a setup similar to that for the pump laser. In addition, because the DFB laser can produce several milliwatts of optical power exiting the fiber pigtail, attenuation before the EDFA may be desirable. Students can see the difference between large signal amplification and that of small signals. The DFB lasers we purchased have built-in thermoelectric coolers, optical isolators, and bias tees circuits, so very little needs to be added to make them fully functional.

In the next experiment we have prepared, students measure the spectral band-width (difference between the points with energy of half the peak energy) of the DFB laser. To do this, the students must learn to operate the Burleigh HiFase. Students-learn to align the device manually, perform mode matching, view output on an oscilloscope, and calculate spectral width. We also have Burleigh's True View software/hardware package for computerization of most functions. After students succeed in the manual operation, they learn how to use the computerized version.

A "Poor Person's" Densely-Packed Wavelength Division Multiplexer.

One of the projected uses for distributed feedback lasers is as transmitter sources for wavelength division multiplexing, a technique for maximizing total data transmission rates in fiber optic telecommunications. Because of their highly-stable, temperature controllable wavelength and very narrow (< 0.1 nm typically) spectral width, DFB lasers can serve as carrier sources for signals with wavelengths less than a nanometer apart. These characteristics are necessary if one wishes to keep as close as possible to the wavelength for the minimums of dispersion and/or attenuation and within the gain bandwidth of an appropriately-doped fiber amplifier. (Erbium is the appropriate dopant for 1550 nm transmission. Praesodymium is the current choice for 1300 rim.) In a commercial setup, several DFB laser transmitters operating at closely-spaced wavelengths, would have their signals combined using a wavelength division multiplexer (WDM), which is generally based on a diffraction grating. The combined signal travels through the fiber-optic cable system and is demultiplexed by a similar (probably identical) device. From a pedagogic perspective, commercial WDM'S leave much to be desired. They are a "black box" to the students. There are two or more fibers on one side and one on the other, but it is impossible to see what goes on inside. Furthermore, commercial WDM'S are quite expensive, particularly if the wavelengths to be combined and separated are close to each other. In addition, commercial WDM'S are not useful for other purposes. Because we have plenty of optical power to spare, we have been able to produce a student-friendly version of a "densely packed" (i.e. closely spaced in wavelength) WDM without using commercial WDM devices. Instead, we use a 3 dB (1: 1) optical directional coupler as the combining element and a combination of a 3 dB coupler with two monochromators as the demultiplexer.

For demonstration purposes, we decided that a two-wavelength system would be adequate. We use two DWB lasers tuned thermally to wavelengths less than 2 nm apart as the transmitters. [See Figure 3]. Their signals go into the two "output" ports of a 3 dB optical coupler. The "input" port is connected to the optical fiber cable plant. If desired, this can include a doped-fiber amplifier. At the receiving end, the combined signal is split equally by another 3 dB coupler. Each signal goes to a different monochromator set for one of the transmitted wavelengths. The optical signal from the monochromator is detected by an InGaAs detector. The electrical signal from the detector can be displayed on an oscilloscope or analyzed by the receiver of a bit-error-rate tester when appropriate. Although the system wastes a considerable amount of optical power, its advantage is that 3 dB couplers are relatively cheap and common and monochromators are standard "workhorse" general optical instruments, which can be found in most reasonably-advanced optics laboratories. Equally important, students can see how the demultiplexing process works.

Results and Conclusions

The project offers considerable flexibility for teaching purposes. A group of student technicians working as assistants under an NSF AMPS grant have been able to assemble the system from all its individual pieces, testing at each stage. They have learned an immense amount (as well as being a great help). Because there are so many parts to assemble, settings to adjust, and alignments to perform, experiments can be devised at all levels of difficulty and for almost any time period, depending on how many of the tasks are left for the students.

Although there is no really inexpensive way to acquire this apparatus (since the doped fiber itself is several thousand dollars), schools with personnel who are willing to expend time rather than money can reduce expenses substantially by, for example, buying DFB lasers without TEC'S, isolators and other refinements, and adding their own. The elegant TRS 540 oscilloscopes can be replaced (at least for relatively low data rates and frequencies) with much simpler, lower bandwidth analog scopes. Leveled sinewave generators can be replaced (though with obvious loss of accuracy) by much simpler signal sources. Although the scanning nonconfocal interferometer is exquisitely accurate, any monochromator can establish an upper limit on the spectral width. In view of the increasing significance of optical amplifiers and the requisite sources for densely-packed WDM, a substantial investment in making this technology available for students would seem warranted.

Although we have not yet tried out the experiments on large numbers of students, preliminary reaction has been uniformly enthusiastic among student technicians. Students who choose a technical field have a strong desire to work with the most current equipment at a level related to what they expect to deal with in their careers. There is no gainsaying the fact that developing and putting experiments like these in place is difficult and time intensive. But student enthusiasm is very strongly in favor.

Special thanks are in order to ILX Corporation for a no-strings equipment grant of $10,000, and to Tektronix, Newport, Burleigh, Elvex, Lasertron, Philips, Isowave, and Scientific Measurements for their contributions. New York State and the Research Foundation of CUNY also contributed matching funds. My student assistants, Eric Rabarijaona, Luis Chamorro, Rodolfo Rodriguez, and Kevin Thomas deserve special mention.

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Figure 1 — Components of an erbium-doped-fiber amplifier system.

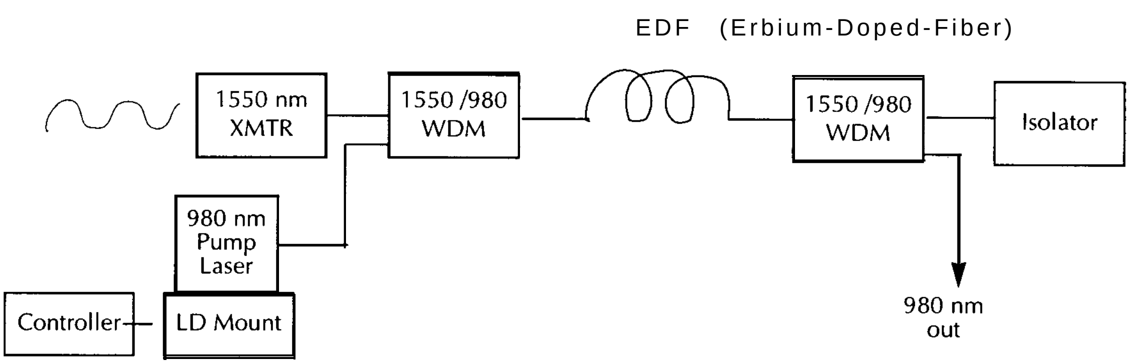


Figure 2— Student-generated graph of 980 nm pump laser input current vs. EDFA output for three different 1550 nm LED input currents.

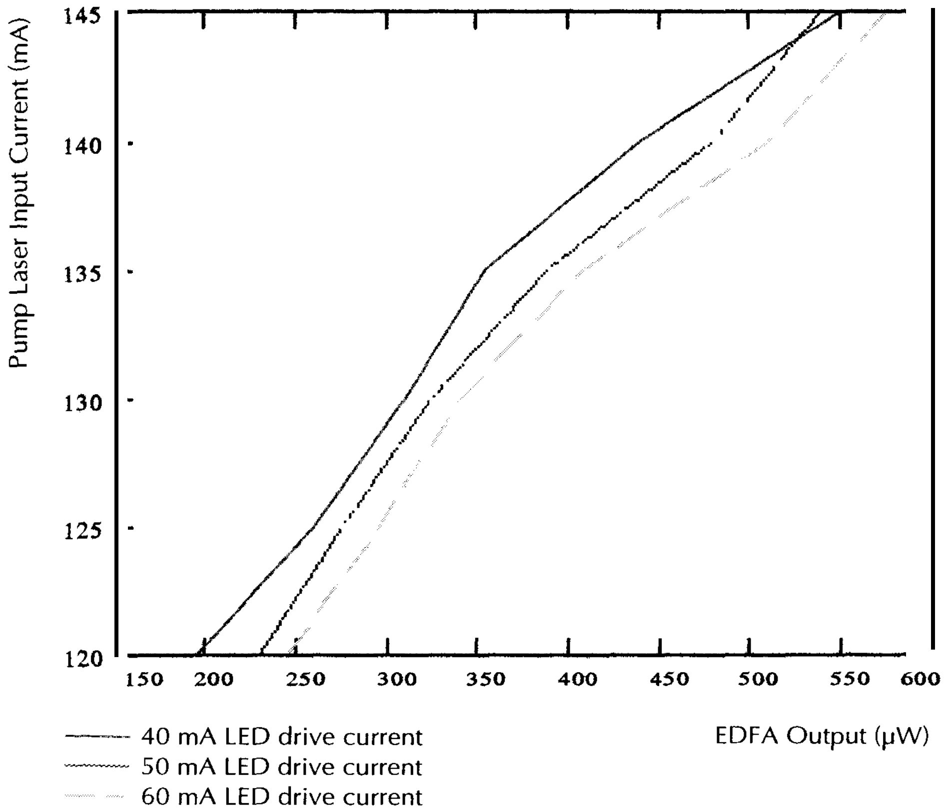
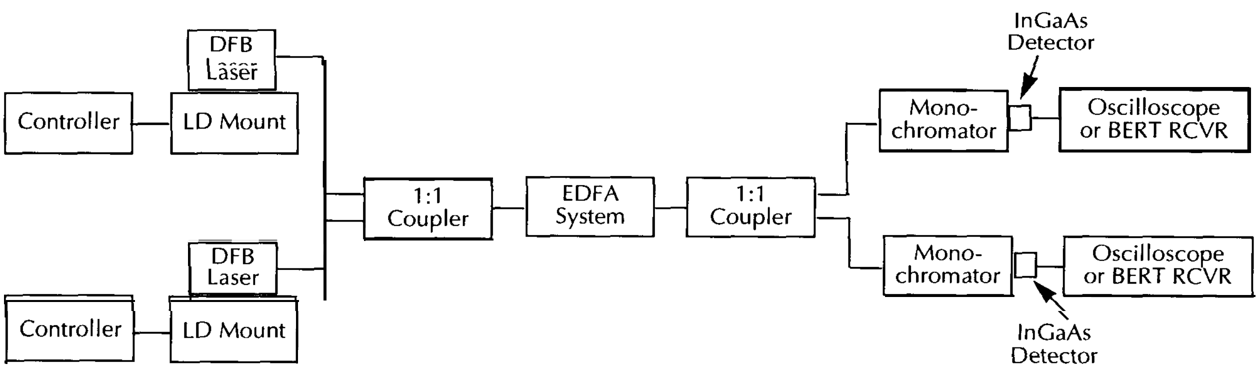


Figure 3— "Poor person's" densely-packed wavelenth-division multiplexer (WDM) system.



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