The Stability and Dynamics of Optical Waveguides, Lasers, and Amplifiers

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We have completed basic theoretical studies of optical storage loops using solitons and phase-sensitive amplifiers (PSAs) and did detailed modeling of ongoing experiments performed in the Department of Electrical Engineering at Northwestern. The goal was to resolve the technical details associated with making a working storage device. We also performed studies of the dynamics and control of optical solitons in other situations, such as the effect of random birefringence on long-distance propagation and timing jitter in erbium-doped fiber lasers. In the later case, the configuration studied was one in which a mode-locked fiber laser is used as a clock recovery device; we derived theoretical estimates for the timing jitter reduction that can be obtained with this device.

In the area of pulse propagation, we investigated work on polarization-mode dispersion and have examined the use of dispersion management to improve transmission performance. Such techniques have also been demonstrated to be useful in fiber lasers (in that context known as stretched-pulse mode-locking).

In the area of wavelength conversion, we made several trips to the Air Force Research Laboratories in Dayton, OH to discuss issues and research needs with the group there headed by Dr. Ken Schepler. It was determined that key issues that are needed to be supported are numerical and analytical modeling of optical parametric oscillators (OPO) that use quadratic crystals with periodic polling to quasi-phase-match conversion of the pump lasers.
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OBJECTIVES

The original goal of this project was to investigate mathematically methods for controlling optical soliton communication systems and fiber lasers. Such methods of control are important for applications involving the generation and processing of high-speed optical bit streams. Specific devices to be investigated include: optical memory loops using phase-sensitive optical amplifiers; switches, timing regenerators, and nonlinear amplifiers using nonlinear optical loop mirrors. These devices can be thought of loosely as basic optical 'circuit elements' for the next generation of high-speed information processing systems. Another area investigated was a new method for controlling streams of high-speed optical pulses using periodic optical phase conjugation.

Another goal added to this project in response to AF needs was to advance the state of the art of mid-infrared laser technology. The Air Force has a critical need for agile-wavelength infrared laser sources to be used as key components in countermeasures systems, laser-based radars, and remote sensing devices. Optical parametric oscillators employing periodically-poled materials such as lithium niobate are widely regarded as a leading candidate for mid-infrared laser systems satisfying Air Force requirements.

The techniques used to investigate these problems were two-fold: theoretical analyses using singular perturbation methods, and numerical computations. These techniques were used simultaneously and in parallel, so that information obtained with one technique was immediately available to help guide the investigations with the other. In addition to the more practical reasons for investigating these problems, the results to be obtained are also expected to have significant scientific relevance to areas of study concerned with dynamical systems, nonlinear wave propagation, and solitons.

STATUS OF EFFORT

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propagation and timing jitter in erbium-doped fiber lasers. In the later case, the configuration studied was one in which a mode-locked fiber laser is used as a clock recovery device; we derived theoretical estimates for the timing jitter reduction that can be obtained with this device.

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ACCOMPLISHMENTS/NEW FINDINGS

○ We modeled all-optical storage rings using parametric gain to compensate loss and reduce noise. Based upon these studies, experiments were performed at Northwestern demonstrating the feasibility of the technique. Further work has since been done at NTT Optical Network Systems Laboratories in Japan. Researchers there have demonstrated that phase-sensitive amplifiers are effective for suppressing amplitude noise (Elect. Lett., 32 1996 p. 677; Opt. Lett., 22 1997 p.1). They have also demonstrated the phase-locking of a pump light source to an incoming signal using an optical phase-locked loop (Optical Amplifiers and Their Applications Postdeadline Paper 5, August 1997). This development is key to the potential application of such amplifiers.

○ We analyzed the timing jitter reduction achieved by an all-optical clock recovery device. In this situation, an incoming bit stream (with timing jitter) is used to mode-lock a fiber laser. Since the fiber-laser’s response time is much longer than the bit period or the round trip time of the laser, the laser responds only to an average over many input pulses. In this way, the laser locks onto the average repetition rate of the input signal, thus averaging out much of the timing jitter. We derived a theoretical estimate for the efficiency of the timing jitter reduction which agrees quite well with simulations and with experiments.

○ We proposed an advantageous dispersion management scheme for wavelength-division-multiplexed soliton transmission, in which optimal launch points are obtained whose locations are independent of the fibers’ dispersion parameters. Since using such optimal launch points minimizes dispersively shed radiation, it is therefore possible to simultaneously optimize the transmission in several different channels. For the particular case of a two-step dispersion map, we have shown this result can be achieved by properly choosing the fiber lengths. We have also used our models to optimize the placement of the amplifiers in such dispersion maps.

○ Randomly varying birefringence leads to nonlinear polarization-mode dispersion (PMD) in addition to the
well-known linear PMD. We have calculated the variance of the field fluctuations produced by this nonlinear PMD. Knowing the size of these fluctuations is useful for assessing when nonlinear PMD is important and for its proper incorporation in fast numerical algorithms. We also derived the equilibrium probability distributions for the PMD coefficients, and tracked the evolution of the polarization state's probability distribution from its initial delta-function distribution to its steady-state uniform distribution on the Poincare sphere.

We have begun numerical modeling efforts of wavelength conversion and have developed a first version of a simulation code that includes both diffraction and thermal heating due to signal, idler and pump absorption.

PERSONNEL SUPPORTED

* Faculty

William L. Kath, Northwestern University

* Post-Docs

Dr. Tian-Shiang Yang
Dr. Gino Blondini

* Graduate Students

Mr. Michael Mills
Mr. Brian Marks
Mr. Richard Moore

* Other (please list role)

PUBLICATIONS

* SUBMITTED

* Books/Book Chapters

* Journals

* Conferences

* ACCEPTED

* Books/Book Chapters

* Journals


* Conferences

Refereed:


Unrefereed:

Experiments on soliton pulse storage using phase-sensitive amplification, Proceedings of the Optical Society of America 1996 Annual Meeting (with Glenn Bartolini, Darwin K. Serkland, and
INTERACTIONS/TRANSITIONS

* Participation/Presentations At Meetings, Conferences, Seminars, Etc

Invited talks:

"High bit-rate data transmission in nonlinear optical fibers", Workshop on Complex and Nonlinear Systems, University of Chicago, May 1999.


Contributed talks:


"Power enhancement and optimal launching of dispersion-managed solitons" Workshop on Nonlinear Optics, Arizona Center for Mathematical Sciences, University of Arizona, October 1997.


"Dispersion maps with amplifier placement optimized for massive WDM," European Conference on Optical Communication, Nice, France, September 1999.


"Have we exploited glass fully yet?" Northwestern University
Technology Review, McCormick School of Engineering, March, 1999 (with Prem Kumar).

* Consultative And Advisory Functions To Other Laboratories And Agencies

Visitor, July and August, 1999 to University of Maryland Baltimore County, Professor Curtis Menyuk

* Transitions

NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

Patent applied for:
``High-stability soliton source"

Patent applied for:
``Optimizing launch points for dispersion-managed solitons"

HONORS/AWARDS