Proceedings of the BRIMS Workshop on Mathematical Methods in Nonlinear Optics

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HPL-BRIMS-96-21
September, 1996

optical soliton;
second harmonic generation;
nonlinear optics;
communications;
fiber optics

Proceedings of the BRIMS Workshop on Mathematical Methods in Nonlinear Optics

September 2-3, 1996

ORGANIZING COMMITTEE

Yuri Kivshar and Greg Luther

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This document was updated last on September 10, 1996

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Minutes of the workshop

On September 2nd-3rd BRIMS, Hewlett-Packard Laboratories held its second workshop on solitons. This year the emphasis of the workshop was on recent developments in optical communications and $\chi^{(2)}$ or quadratically nonlinear materials. A great deal of activity has taken place in both of these areas over the past year or two. In particular the application of advanced mathematical ideas and techniques by researchers in analytical nonlinear optics has lead to important advances in these technologies.

In $\chi^{(2)}$ materials, three-wave mixing and second harmonic generation takes place. These materials hold great promise in nonlinear guided wave optics. Inspired by recent experimental successes, this field has seen a resurgence of theoretical activity. New predictions about the existence and stability of solitary waves including self-trapped pulses in higher dimensional systems have been made. Technologies for generating integrated short wavelength light sources and for all optical switching rely heavily on the advancement of our understanding of the interaction of light with $\chi^{(2)}$ materials.

In communications numerous techniques for the generation, transmission and processing of optically encoded information are competing. All of them are based on nonlinear optical processes and all of them will continue to require advances in the development and application of modern nonlinear mathematical tools. The most important in this instance being tools and ideas for integrable and near-integrable evolution equations. Over the last year a theory for nonreturn to zero or NRZ pulse transmission that is based on the modulation theory of semi-classical solutions of the near-integrable nonlinear Schrödinger (NLS) and coupled nonlinear Schrödinger (CNLS) equations has made possible a basic understanding of the dynamics of NRZ pulses and predictions of the minimum pulse spacing in NRZ systems with wavelength division multiplexing. The top theoretical advances in both of these areas were represented at this workshop.

The workshop followed the Optical Society of America's Nonlinear Guided Waves Meeting held at St. John's College in Cambridge. Holding the BRIMS workshop just after the OSA meeting permitted several researchers from overseas to participate. The workshop was informal and open discussions were encouraged. The schedule was flexible enough to permit the continuation of discussions where necessary. In fact, several participants used part of their time and some of the discussion period to give short tutorials on important technical issues.

The workshop began in Themes with a brief organizational meeting before breaking for lunch where the participants were able to get acquainted or re-acquainted. The first session was on solitons in second harmonic generation. Kivshar gave a general overview of the state-of-the-art in the theory of parametric solitary waves associated with three-wave mixing in a diffractive quadratic medium. This included solitons that form due to degenerate two-wave mixing (or type II second-harmonic generation). The classification and properties of localized solutions describing bright and dark solitons were presented. This analysis was based on both numerical and analytical (e.g. variational) techniques. An important stability criterion for these soliton solutions has been derived analytically and verified numerically. The stability criterion for two-wave solitons resembles the Vakhitov-Kolokolov criterion for solitons described by the generalized NLS equation, however it becomes more complicated for the three-wave interaction. One of the important areas which needs further study is the problem of quasi-phase matched systems. The basic notion of composing two or more nonlinear maps which have in some sense opposite effects has become a standard paradigm in the design and development of nonlinear optical devices. In quasi-phase matched second harmonic generation, the nonlinear coupling is modulated to optimize the gain of the second harmonic.

David Parker gave the second talk showing how to generate, from the coupled equations for second-harmonic near-resonance, explicit solutions with complex structure. These include bright/dark and dark/dark coupled structures, as well as some previously known bright/bright pulses. They include a family of solutions with shift in the phase across the soliton in the dark mode which is adjustable and is a function of the intensity in the bright mode. His talk was followed by a progress report from his research student Stuart MacIntosh on developing an asymptotic scheme to describe pulse oscillations and radiation. Lively discussion suggested that the formulation requires amendment, but that there is a need for an approach which is independent of those based on inverse scattering, since many applications for coupled systems concern situations far from the integrable cases.

We then heard from Stefano Trillo, who discussed the use of Floquet theory for the stability analysis of solitons in quadratic cavities. This talk evoked a great deal of discussion on the use of Floquet theory and lead to comments by John Elgin on the Evans function method.

The last talk of the day was by Boris Malomed, who discussed fully localized or self-trapped solitons which propagate in two- and three- dimensional media. Here an analytical approximation based on the variational approach (VA) was used. It predicts that stable solitons must exist in both 2D and 3D. Results from direct simulations were also presented that gave some indication that these solitary waves are stable.

On Tuesday the workshop continued with talks on applications of ideas and techniques of soliton theory and nonlinear dynamics to optical communications. We started off with a talk from Sergei Truitsyn who described the results of an investigation of the stability of solitons in cascaded transmission systems based on standard monomode fibers with in-line semiconductor optical amplifiers (SOAs), sliding filters and saturable absorbers (SAs). Stabilization of pulses in these systems was achieved for the proper choice of filter and SA parameters. Conditions for stable propagation including a critical sliding rate was determined and the impact of the saturable absorber on the stability of soliton solutions was described.

Though transmission issues tend to get much of the press in this field, there are many key devices and phenomena that require mathematical analysis that involve the generation and processing of optical bit streams. In the second talk, Anne Niculae described analytical and numerical studies of the timing jitter reduction achieved in a fiber ring soliton laser. An input bit-stream is used in this laser to mode-lock the clock pulses. Using ideas from soliton perturbation theory and stochastic processes, the timing jitter suppression was estimated and good agreement with recent experiments was achieved.

Bill Kath followed with a description of a new device developed at Northwestern University that generates a highly-stable soliton pulse train by compressing the sinusoidally modulated output of a dual-frequency short-cavity Er/Yb bulk phosphate-glass laser. In addition to being one member of the most important class of sources for RZ communications, this talk illustrated many of the challenges and advantages for mathematical scientists who are willing to work closely with experimental groups.

In the last talk of the morning, John Elgin started off with a short tutorial of the Evans function method. This was essentially a continuation of the discussion brought out by Trillo's talk on Monday. Alexander Mikhailov added to this by describing a similar technique which avoids the construction of the adjoint problem. Elgin then went on to describe perturbation theory for soliton propagation in birefringent optical fiber. This perturbation theory for the coupled NLS extends work on the NLS using the associated field and expansion in terms of the squared eigenfunctions. These tools were applied to the problem of the generation of solitons 'shadows'.

After breaking for lunch Stefan Wabnitz reviewed the theory of NRZ pulse propagation. His theory, developed with Yuji Kodama, can be described simply in the language of hydrodynamics. The complete theory couples the modulation theory of periodic waves due to McLaughlin, Forest and their colleagues with the theory of semiclassical solutions of the integrable nonlinear evolution equations developed by Lax and Levermore. Wabnitz and Kodama apply these concepts to analyze cross-phase modulation effects and instabilities in NRZ-WDM long distance fiber-optics transmissions. They give a simple analytical prediction for the minimum channel spacing in such systems and achieve excellent agreement with numerical simulations. The simple theory of NRZ propagation and control has already been shown to give the first basic understanding of NRZ pulse dynamics given by experimental evidence.

Alexander Mikhailov continued the session with a discussion on how to optimize the amplitudes of pulses launched in different channels in a WDM communications systems. It was shown that it is necessary to adjust the amplitudes according to the wave-length shift in order to avoid the generation of continuous spectrum from reshaping to form fundamental solitons during propagation. The optimal parameters for input pulses that minimize this reshaping were presented and agreement with numerical simulations was shown. Mikhailov continued his talk by introducing a discussion on the process of radiation shedding based on his recent paper in Physica D. This work shows that the simplest variational estimate of oscillations induced by radiation shedding are wrong and describes a correct estimate.

The final talk on the schedule was by Alan Champneys. Since the introduction of the Townes soliton in the early 60's, Optical scientists have been interested in self-trapped or self-guided waves. These solitary waves are often the first thing people are interested in when studying new nonlinear optical systems. Of course, questions about their stability and dynamics are never far behind. This is certainly in evidence in the recent work on resonant wave interactions in second order media. In the case of non-integrable models there are very few tools at our disposal. Champneys reviewed mechanisms whereby non-integrable soliton equations have solitary wave solutions which consist approximately of two or more copies of a primary pulse (sometimes called bound states). Applications to two different coupled NLS systems and to the 5th-order KdV equation were discussed. He showed that infinitely many pulses can be found in both the case where the primary pulse has oscillatory and monotonicly decaying. In each case specifically designed numerical methods were used to unravel the multiplicity. Additionally, for the 5th-order KdV it was shown that half of the two-pulse solutions are stable.

The final talk of the workshop was given by Boris Malomed who agreed to give an impromptu report of the proceedings of a meeting recently held in Osaka, Japan by the group of A. Hasegawa. Apparently they have been working a great deal on dispersion allocated systems. A talk by Mamyshev of AT&T described how four-wave mixing effects in very high bit-rate systems is suppressed by dispersion varying fibers. A major break through in this technology was simply in the quick measurement of the variation of dispersion in the fibers. This technique uses four-wave mixing and measures the variation in period of Rayleigh scattering at the four-wave mixing line. In attempts to remove filters from soliton communications systems, new progress has been made for systems with only amplification and dispersion management. Malomed also described his recent work on the dynamics of a pulse propagating through three fibers of different dispersion. His work is based on a variational principle approach. The workshop closed with a short discussion on the limitations of variational and adiabatic perturbation theories.

Remarks and Summary

We feel that the meeting was very successful. The attendees participated actively in discussions about several important technical issues. Probably all of the participants learned something that will affect their future work in a nontrivial way. Having had this meeting many of the important open problems seem to be defined more clearly. It was clear that analytical nonlinear optics will continue to require the development and application of modern techniques for the analysis of nonlinear partial differential equations.

In the area of resonant wave mixing there are very few tools for the construction and analysis of solutions. Ideas about radiation modes, which are difficult but clear for integrable systems seem a bit more hazy for nonintegrable systems. People in analytical optics have been slow to adopt techniques for identifying self-similar solutions based on Lie algebraic ideas and in using tools for the estimation of the number of degrees of freedom of the dynamics. There are many more specific problems of interest in SHG. Random and quasi-phase matched systems have yet to be studied. New solutions in vector systems should be obtained in more systematic ways. Open problems exist related to the extension of early work on patterns in the Raman laser for resonant-wave processes in cavities.

In the area of communications there are new problems introduced by the technology of dispersion maps and dispersion allocation while more basic problems related to interactions of integrable and especially near-integrable solutions remain. Distinguishing the solutions of nonintegrable systems like the complex Ginsberg-Landau equation from solutions that are continuous deformations of the integrable systems like NLS is an important current topic in applied mathematics that is of particular relevance in the analysis of near-integrable systems. The analysis of stochastic perturbations in soliton and NRZ systems is clearly a very important aspect for the analysis of these systems. The analysis of systems where there is no guiding center averaging or where segments of the system are inhomogeneous is remains a difficult and important problem. Work on systems with parameters that vary with propagation are also important.

Analysis of periodic systems using and extending the well developed analysis may well be of importance. Here the coupled NLS is the vector system. Perturbation theory and even the construction of solutions in this system are important areas. Application of modulation theory and semi-classical theory to NLS and CNLS are important areas for NRZ analysis. Much of the basic theory there is still open. As Mikhailov pointed out, even some simple issues about the interaction of radiation with soliton objects and the application of these ideas to WDM systems are useful areas of investigation. Finally, the basic problem of control of nonlinear systems using the composition of two or more vector fields as maps has not been systematically developed despite its central importance in nonlinear optics.

BRIMS Workshop on Mathematical Methods in Nonlinear Optics

September 2-3, 1996

ORGANIZING COMMITTEE

Yuri Kivshar and Greg Luther

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This document was updated last on September 11, 1996

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DESCRPTION:

The goals of the workshop are to help advance the theoretical and mathematical understanding of Nonlinear Optics and to identify mathematical problems of interest suggested by this field. The workshop will be held at BRIMS, Hewlett-Packard Labs on September 2 and 3, 1996 following the Nonlinear Guided Waves Meeting in Cambridge.

The emphasis will be on areas where the theory of solitons and nonlinear waves is essential to both basic and applied advances. The meeting will focus on recent developments in the areas of optical communications and second harmonic generation. The workshop will include review material and discussions as well as descriptions of recent results. We hope that the discussions will bring to light problems where either new mathematical tools are needed or where existing tools could lead to new results.

TRAVEL TO BRISTOL:

From London: Trains on the Great Western line leave from Paddington Station, London, and take you to Parkway Station near HP Labs or to Temple Meads near Bristol City Center and the hotel. These trains are roughly hourly.

From Cambridge: Take the train to London Paddington from Cambridge. At Paddington the Great Western line will take you to Parkway Station near HP Labs. If you are not traveling on Monday morning September 2 or if you are planning to go to your hotel first, you will want to take the train to Temple Meads Station, which is nearer to Bristol City Center and the Hotel.

If you are planning to travel Monday morning September 2 and go directly to HP Labs, you will want to catch one of the trains indicated below.

Dep. Cambridge	Arr. Kingscross	Dep. Paddington	Arr. Bristol Parkway
07.15	08.21	09.00	10.20 (supersaver valid)
08.07	09.25	10.00	11.22 (supersaver valid)

From Leeds:

Dep. Leeds	Arr. Birmingham	Dep. Birmingham	Arr. Bristol Parkway
06.05	08.24	08.28	9.54

ACCOMMODATION:

A set of rooms have been reserved for participants in the Rodney Hotel near the Bristol City Center in Clifton. We will take care of these arrangements, but for you information the address follows.

Rodney hotel
4 Rodney Place
Clifton
Bristol
BS8 4HY
0117 973 5422
FAX: 0117 946 7092

VENUE:

Talks and discussions will be held at Hewlett-Packard Labs, Bristol. When you arrive at the gate you need to mention the meeting at BRIMS and proceed to "reception two" where a receptionist will give you a visitor's badge. One of us will pick you up there. The talks and discussions will be held in the Thames conference room. If you have luggage with you when you arrive, the receptionist will store it for you in a secure room in the reception area.

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W. Forysiak, Aston University
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D.D. Holm, CNLS, Los Alamos National Laboratory
W. Kath, Northwestern University
Y.S. Kivshar, Australian National University
G.G. Luther, BRIMS, Hewlett-Packard Research Labs
S. MacIntosh, University of Edinburgh
B. Malomed, Tel Aviv University

A.V. Mikhailov, University of Leeds
A. Niculae, Northwestern University
D.F. Parker, University of Edinburgh
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N.J. Smith, Aston University
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SCHEDULE: September 2-3, 1996

Monday September 2

7:15 Train leaves Cambridge (arrive Kingscross 08:21)

8:07 Train leaves Cambridge (arrive Kingscross 09:25)

9:00 Train leaves Paddington (arrive Bristol Parkway 10:20)

10:00 Train leaves Paddington (arrive Bristol Parkway 11:22)

11:45 Gather at BRIMS, Hewlett-Packard Labs

12:00 Lunch at Hewlett-Packard

Session I: Solitons and SHG

1:00 **Y.S. Kivshar**
"Solitons in chi-2 materials: Overview of Theory"

2:00 **D.F. Parker**
"Bright-dark solitary waves for second-harmonic generation"

2:30 **S. MacIntosh**
"A matched asymptotic description for soliton evolution"

3:00 **Coffee and Discussion**

3:30 **S. Trillo**
"Modulational instability and solitons in quadratic cavities"

4:30 P. Drummond, Hao He, **B. Malomed**, D. Anderson, A. Berntson and M. Lisak
"Spatiotemporal parametric solitons in multidimensional optical media,"

5:45 **Shuttle to Hotel**

8:00 **Workshop Dinner (Meet around 7:30 at Bouboulina's 9 Portland Street, Clifton Village)**

Tuesday September 3

8:00 **Shuttle to HP**

Session II: Optical Communications

8:30 **S.K. Turitsyn**
"Soliton stability in optical transmission lines using semiconductor amplifiers and fast saturable absorbers"

9:30 **Coffee and Discussion**

10:00 **A. Niculae** and W. L. Kath
"Timing jitter reduction in a fiber laser mode-locked by an input"

10:30 D. K. Serkland, G. D. Bartolini, **W. L. Kath** P. Kumar, D. W. Anthon and D. L. Sipes
"A highly-stable 60 GHz soliton source at 1550 nm"

11:00 **J. Elgin**
"The generation of shadows in birefringent fibres"

12:30 **Lunch**

Session III: Optical Communications

1:30 **S. Wabnitz**, S.Y. Kodama and A. Maruta
"Theory of cross-phase-modulation induced instabilities in dispersion-managed NRZ transmissions"

2:30 **A.V. Mikhailov**
"Optimisation of soliton shape for WDM"

3:30 **Coffee and Discussions**

4:30 **A. Champneys**
"On multi-pulse solutions of non-integrable soliton equations"

5:00 **B. Malomed**
"Summary of A. Hasegawa's workshop in Osaka"

5:30 Summary Discussion, G.G. Luther and Y.S. Kivshar

5:45 **Shuttle to Hotel**

ABSTRACTS:

On multi-pulse solutions of non-integrable soliton equations

A. Champneys
Applied Nonlinear Mathematics Group, Department of Engineering Mathematics, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR, UK

This talk will review mechanisms whereby non-integrable soliton equations can have solitary wave solutions which consist approximately of two or more copies of a primary pulse (sometimes called bound states). Applications will be discussed to two different coupled NLS systems and the 5th-order KdV equation. Infinitely many can be found in both the case where the primary pulse has oscillatory and monotonic decay. In each case specifically designed numerical methods will be used to unravel the multiplicity. Additionally, the 5th-order KdV it will be shown that half te two-pulse solutions are stable.

The generation of shadows in birefringent fibres

J. Elgin
Department of Mathematics, Imperial College, London SW7 2BZ

A perturbation theory pertinent to soliton propagation down a birefringent optical fibre will be described. This will then be applied to the problem of the generation of soliton 'shadows', and results will be compared with those from complementary studies published elsewhere.

A highly-stable 60 GHz soliton source at 1550 nm

D. K. Serkland, G. D. Bartolini, W. L. Kath and P. Kumar
McCormick School of Engineering and Applied Science Northwestern University, 2145 Sheridan Road, Evanston, IL 60208-3125

D. W. Anthon and D. L. Sipes
ATx Telecom Systems, Inc., 1251 Frontenac Road, Naperville, IL 60563

A highly-stable soliton source is demonstrated by compressing the sinusoidally modulated output of a dual-frequency short-cavity Er/Yb bulk phosphate-glass laser. The short-term stability of the repetition rate is shown to be 10 kHz.

Solitons in chi-2 Materials: Overview of Theory

Y.S. Kivshar
Optical Sciences Centre Australian National University, Canberra

A general overview of the state-of-the-art in the theory of parametric solitary waves associated with three-wave mixing in a diffractive quadratic medium will be presented. This includes also solitons due to the degenerated two-wave mixing (or type II second-harmonic generation). Classification and properties of localized solutions describing bright and dark solitons will be presented on the basis of numerical and analytical (e.g. variational) techniques. The most important issue to be discussed will be a stability criterion for these solitons which have been derived analytically and also verified numerically. The stability criterion for two-wave solitons resembles the Vakhitov-Kolokolov criterion for the solitons described bz the generalized NLS equation, however it becomes more complicated for three-wave interaction. It is also planned to present a summary of unsolved problems in the theory of solitons due to parametric wave mixing.

A matched asymptotic description for soliton evolution

S. MacIntosh
Department of Mathematics and Statistics, The King's Buildings, University of Edinburgh, Mayfield Rd, Edinburgh, EH9 3JZ UK

We consider a perturbed soliton (beam) solution to the standard NLS equation using a 'pulse co-ordinate' with standard and stretched axial length scales for the inner solution. The resulting solution with growing terms in both amplitude and phase at orders lower than O(1) is matched to positive and negative region outer solutions with decaying amplitude as the transverse co-ordinate tends to plus or minus infinity respectively.

Spatiotemporal parametric solitons in multidimensional optical media

Peter Drummond and Hao He
Dept. of Physics, University of Queensland, St. Lucia, Australia

Boris Malomed
Dept. of Interdisciplinary Studies, Faculty of Engineering, Tel Aviv University, Tel Aviv, Israel

Dan Anderson, Anders Berntson, and Mietek Lisak
Institute for Electromagnetic Field Theory, Chalmers University of Technology, Gothenburg, Sweden

We extend the second-harmonic-generation equations, which have recently attracted a lot of attention in nonlinear optics, to description of fully localized moving solitons ("light bullets") in two- and three- dimensional (2D and 3D) media. The dispersion at the fundamental harmonic is assumed to be anomalous, while at the second harmonic it is allowed to be either anomalous or normal, which corresponds to physically realistic situations. An analytical approximation based on the variational approach (VA) is developed, which predicts that the stable solitons must exist in both 2D and 3D. Direct simulations are performed for the 2D model (in the 3D model, the simulations are underway), demonstrating that the stable solitons exist indeed. The agreement between VA and the numerical results is somewhat worse than in similar problems in 1D, but still acceptable, so that VA remains a useful tool to guide search for numerical solutions. It is found that (similar to the recently investigated properties of the 1D parametric solitons) the 2D solitons can support long-lived internal vibrations.

Optimisation of soliton shape for WDM

A.V. Mikhailov
Department of Applied Mathematics, University of Leeds, Leeds, LS2 9JT

Amplitudes of launching pulses for different channels of WDM soliton systems have to be adjusted to the wave-length shift in order to avoid a reshaping and generation of continuous spectrum during the propagation. Optimal parameters for input pulses, that minimize the reshaping are suggested. Our simple analytical result perfectly fits numerical simulations.

Timing jitter reduction in a fiber laser mode-locked by an input bit stream

A. Niculae and W. L. Kath
Engineering Sciences and Applied Mathematics Department McCormick School of Engineering and Applied Science Northwestern University, 2145 Sheridan Rd., Evanston, IL 60208–3125

We present analytical and numerical studies of the timing jitter reduction achieved when an input bit-stream is used to mode-lock clock pulses in a fiber ring soliton laser.

Bright-dark solitary waves for second-harmonic generation

D.F. Parker
Department of Mathematics and Statistics, The King's Buildings, University of Edinburgh, Mayfield Rd, Edinburgh, EH9 3JZ UK

Current interest in cascaded nonlinearity and SHG suggests new possibilities for both temporal and spatial coherent structures. Although some explicit solutions for both bright-bright and bright-dark coupled solitary waves have been reported in the quadratic nonlinearity literature, it appears that under appropriate circumstances, explicit solutions with more complex structure may be found. We shall outline a procedure which determines some additional explicit solutions, including a family of solutions with shift in the phase across the soliton in the dark mode which is adjustable and is a function of the intensity in the bright mode. Possibilities for dark-dark coupled solitons are also derived.

Modulational instability and solitons in quadratic cavities

Stefano Trillo
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We review recent advances in the theory of modulational instabilities (MIs) in media with quadratic nonlinearity (e.g., second-harmonic generation). The concept of MI in travelling-wave two-mode systems such as second-harmonic generation can be generalized to pump waves which are dynamically evolving upon propagation. Using Floquet theory for periodic system we show that MI is a quite general phenomenon which is enhanced for near separatrix pump evolutions. Then MI in driven-damped dissipative systems such as optical cavities (optical parametric oscillators) is considered. In this system MI is an instability occurring on a fast time-scale which competes with other instabilities such bistability and Hopf bifurcation

induced chaotic self-pulsing. MI is shown to prevail and lead to the formation of stable trains of solitary-like pulses.

Soliton stability in optical transmission lines using semiconductor amplifiers and fast saturable absorbers

S.K. Turitsyn
Institute fuer Theoretische Physik I, Henrich Heine Universitat Duesseldorf, Universitatsstrasse 1, 40225 Duesseldorf Germany

Soliton stability has been examined in the cascaded transmission system based on the standard monomode fibers with in-line semiconductor optical amplifiers (SOAs), sliding filters and saturable absorbers (SAs). Stabilization of the pulse propagation in such a system can be achieved under a proper choice of the filter and SA parameters. Conditions of the stable propagation including a critical sliding rate are determined. Impact of the saturable absorber on the soliton stability has been investigated.

Theory of cross-phase-modulation induced instabilities in dispersion-managed NRZ transmissions

S. Wabnitz
Universite de Bourgogne, Dijon, France (from sept. 1st, 96), Lab de Physique, Faculte des Sciences Mirande, Av. A. Savary, 21004 Dijon Cedex, France

S.Y. Kodama and A. Maruta
Department of Electronics and Information Systems, Osaka University, 2-1 Yamade-Oke, Suita Osaka 565, Japan

A new hydrodynamic treatment was applied to analyse XPM effects and instabilities in NRZ-WDM long distance fiber-optics transmissions. A simple analytical prediction for the minimum channel spacing is derived. The theory is confirmed by numerical simulations.

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