Review of Gaussian and Soliton Systems for Long Haul Communication

Er. Charu Vashisht, Mtech student, LR group of institutes, Solan ,H.P
Er. Shikha Verma Assistant professor, LR group of institutes, Solan ,H.P
Er. Ruchi Sharma, Student, CGC Landran, Mohali

Abstract— — ***Soliton is a special kind of wave packet that travels distortion less over long distances. It is based on pulse spreading due to Self –phase modulation (SPM) which is a non-linear effect based on refractive index variation and Group Velocity Dispersion (GVD) which is a linear effect. The dispersion due to GVD puts severe limitation on information carrying capacity of optical communication systems. Suitable stable light pulse known as soliton pulses are generated when effect of GVD is well-adjusted by SPM. The solitons retain their shape over long distances and are appropriate for long range communication.***

Keywords—GVD,SPM,Solitons, gaussian,EDFA.

I. INTRODUCTION

Interest in optical solitons has grown steadily in recent years. The field has considerable potential for technologi-cal applications, and it presents many exciting researchproblems both from a fundamental and an applied pointof view. New optical devices are in various stages of de-velopment; soliton information processing looms on thehorizon. At the same time, basic research in nonlinearoptical phenomena maintains its vitality. The methods of communication have changed rapidly in the last few decades and still the pace is set to further improve the current technology in leaps and bounds. Ever since the user base has increased a hundred fold the bandwidth requirement by the industry has grown exponentially. The data transmission rate is limited by the Shanon limit which in turn is dependent on the bandwidth of channel. Soliton transmission makes use of GVD and SPM balancing so that the received signal is exact replica of transmitted signal. Using Solitons the effective transmission length increases manifold. This paper focusses on review of the soliton history and its evolution.

II. HISTORY OF SOLITONS

Solitons were first observed by J. Scott Russell in 1834, whilst riding on horseback beside the narrow Union canal near Edinburg, Scotland. There are a number of discussions in the literature describing Russell's observations. Subsequently, Russel did extensive experiments in a laboratory scale wave tank in order to study this phenomenon more carefully. Included amongst Russell's results are the following: (i) he observed solitary waves, which are long, shallow, water waves of permanent form, hence he deduced that they exist; this is his most significant result; (ii) the speed of propagation, v, if a solitary wave in a channel of uniform depth h_d is given by $v = g(h_d + a_m)$, where a_m is the amplitude of the wave and g is the force due to gravity.

Further, investigations were undertaken by Airy, Stokes, Boussinesq and Rayleigh in an attempt to understand this phenomenon. Boussinesq and Rayleigh independently obtained approximate descriptions of the solitary wave; Boussinesq derived a one dimensional nonlinear evolution equation, which now bears his name. These investigations provoked much lively discussion and controversy as to whether the in viscid equations of water waves would possess such solitary wave solutions. The issue was finally resolved by Korteweg and de Vries in the year 1895. They derived a nonlinear evolution equation governing one dimensional with lowest-order of dispersion and nonlinearity. When the equation was numerically solved in a periodic boundary condition by Zabusky and Kruskal in 1965, a set of solitary waves was found to emerge and stably pass each other. They named these solitary waves solitons because of their stability. The term "soliton" was justified when the KdV equation was solved analytically by means of inverse scattering transform (IST) and the solution was described by a set of solitons. Solitons are regarded as a fundamental unit of mode in nonlinear dispersive medium and play a role similar to the Fourier mode in a linear medium. In particular, a soliton being identified as an eigenvalue in IST supports its particle concept.

III. REVIEW OF EXISTING RESEARCH

The transmission distance of any fiber-optic communication system is eventually limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using optoelectronic repeaters in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive. An alternative approach to loss management makes use of optical amplifiers, which amplify the optical signal directly without requiring its conversion to the electric domain. Several kinds of optical amplifiers were developed during the 1980s, and the use of optical amplifiers for long-haul Light wave systems became widespread during the 1990s. By 1996, optical amplifiers were a part of the fiber-optic cables laid across the Atlantic and Pacific oceans.

This chapter summarizes the literature that was surveyed and reviewed for this dissertation work to optimize the transmission network using different optical amplifiers. Several papers have been referred for this study. They review and highlight the various aspects related to reducing critical distortions in optical communication systems and furthermore provide a description, implementation and evaluation of the various simulation techniques to enhance the network performance.

Masataka Nakazawa et al. 2000[1], presented the simulation analysis of 640 Gbps WDM soliton transmission over 1000km using Dispersion Managed (DM) single mode fiber. It is observed that the capacity of a single channel is improved using DM soliton WDM systems. It is emphasized in the paper that the DM soliton is the best way to achieve high speed over long distance.

Akira Hasegawa 2001[2], introduces problems in the use of ideal solitons as information carriers and provided the solutions to overcome these problems. Further, it is also shown that only RZ pulse is used for a trans-oceanic transmission of 10 Gbps per channel or beyond in optical fibers and NRZ format of transmission has been discarded due to its intolerance to nonlinear effects of fibers.

Avner Peleg et al. 2003[3], proposed a perturbation theory with two small parameters: the third order dispersion coefficient d3, and the reciprocal of the interchannel frequency difference, 1/b. They found that amplitude of the leading contribution to radiation emitted during the collision is proportional to d3 /b2. The source term for this radiation is of the form that would be generated by a variation in the second order dispersion coefficient. They have also shown that the intrachannel interaction effect, induced by many interchannel collisions, is identical to the radiation mediated intrachannel interaction effect observed for solitons propagating under the influence of disorder in the second order dispersion coefficient.

Seinchei et al. 2004[4], has given the theoretical model for the transmission of ultra-short soliton pulse trains. The model has been used for study of non-reciprocal characteristics of energy amplification and evolution of pulse train in erbium doped fiber amplifier.

L.F. Mollenauer et al. 2006[5], investigated the spatial dependence properties of the gain offered by long erbium-doped amplifiers in a soliton transmission system and proved the possibility of reaching a prefixed value of gain with a variety of different configurations. The effect on the shape of propagating soliton has also discussed.

R. Ganapathy et al. 2008[6], studied the concept of soliton dispersion management pertaining to the effect of varying dispersion with external harmonic oscillator potential for chirped solitons with emphasis on the various aspects of soliton dispersion management namely: 1) dispersion management of solitons 2) soliton energy control 3) soliton pulse width management 4) soliton amplification management due to Raman gain.

Dan Grahelj 2010[7], presented the general properties of solitons as solutions of certain nonlinear partial differential equations and found that the canceling of dispersive broadening of pulses makes temporal solitons suitable for ultra-long haul high bit rate optical communication and the particle-like behavior in interactions, makes possible the use of solitons for ultra-fast optical logical devices.

Y Kodama et al. 2011[8], derived a soliton resulting from the combined effect of higher-order dispersion and nonlinearity in an optical fiber with a non-vanishing boundary condition for the generalized nonlinear Schrodinger equation (NLSE). It was reported that in the normal dispersion regime, dark solitons exist; however, in the anomalous dispersion regime, bright solitons exist superimposed on the continuous wave background.

Sergei K. Turitsyn et al. 2012[9], presented an overview of dispersion managed soliton theory focused on the fibre-optic and laser applications and discussed the results that are relevant to many other fields of science. They have introduced a general framework for the analysis of such breather-like solutions in nonlinear systems with periodic variation of parameters.

N J Smith et al. 2012[10], investigated the propagation of ultra-short pulses along the slow group velocity fiber. A more generalized NLSE as the superposition of monochromatic waves was derived and the propagations of 2.5-fs fundamental and 5-fs second-order solitons were numerically studied. It was found that, for a slow group velocity fiber, the magnitude of time shift is related with the group velocity and the more generalized NLSE is more suitable than the conventional NLSE.

Regina Gumenyuk et al. 2013[11], studied the effect of the gain medium dispersion on stability of soliton groups in fiber laser. An attractive force produced by bi-temporal saturable absorber is used to enhance the soliton interaction and results in a firm bound state formation. It was found that active media supporting soliton formation causes irregular bunching in the fiber cavity, while the gain media with normal non-soliton dispersion demonstrates stationary bound state soliton generation. The results provide guidelines for the synthesis of an optimal dispersion map for soliton fiber.

Manoj Kumar et al. 2015[12], demonstrated the performance evaluation of path-averaged soliton transmission link for various performance measures viz. OSNR, optical power, extinction ratio, bit error rate (BER) and Q factor at different levels of noise figure and values of pulse width(FWHM) has been carried out without including dispersion medium.

IV SOLITON BASED TRANSMISSION

Soliton refers to the special kind of waves that can propagate undistorted over long distances and stay unaffected after collisions with one another.

- Generally when one pulse is assigned to represent '1' bit, the format is called RZ (Return to Zero).
- If two (or more) pulses are joined when a sequence of '1' appears, the format is called NRZ (Not Return to Zero).
- Also, if the '1' pulse is permitted to have two type of pulses with opposite phases; then this format is called duo-binary.
- Soliton format principally utilizes one soliton to represent '1' bit.

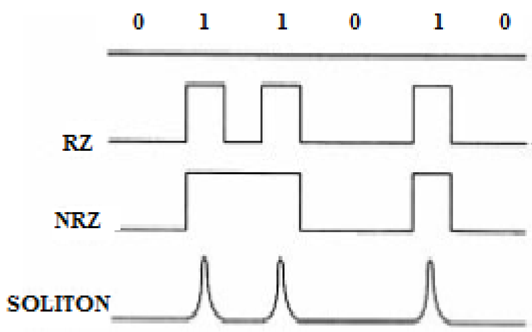

Fig-1: Various formats for information transfer in fiber

(*a*) *Transmission of information*

The soliton is utilized as a part of every bit slot representing 1 in a bit stream as indicated in Fig-3.2. The adjacent solitons in this scheme ought to be very much isolated and thus the spacing between two solitons surpasses their FWHM (Full Width at Half Maximum) [10]. This can be guaranteed by keeping soliton width a little fraction of the bit slot. For this RZ format is used as demonstrated as a part of Fig. 1

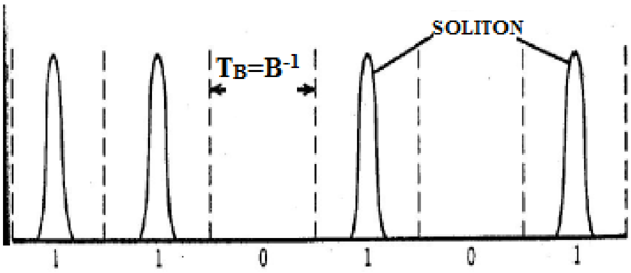

Fig-2: Soliton bit stream in RZ format

The bit rate and the soliton width is related as

$$B= 1/T_B = 1/2q_0T_0$$

where *TB* is the Bit slot duration and $2q_0= T_B/T_0$ is the normalized partition between adjacent solitons. The soliton communication system needs an optical source equipped for creating chirp free Pico-second pulses at a high redundancy rate. The source should operate in the wavelength region ~ 1550 nm.

(*b*) *Soliton in Optical Fiber*

The presence of solitons in optical fibers is the result of a balance between the variations induced by fiber dispersion characterized by GVD coefficient β_2 and fiber nonlinearity characterized by SPM coefficient ω. Analytically soliton is a answer of nonlinear Schrodinger equation depicting pulse spreading in optical fiber [5].

The nonlinear Schrödinger equation (NLSE) is a suitable equation for describing the propagation of light in optical fibers. Using standardization parameters for example, the normalized time T_0, the dispersion length L_D and peak power of the pulse P_0 the nonlinear Schrödinger equation in terms of normalized coordinates can be written as

$$i\left(\frac{\partial u}{\partial z}\right) - \frac{s}{2}\left(\frac{\partial^2 u}{\partial t^2}\right) + N^2|u|^2u + i\left(\frac{\alpha}{2}\right)u = 0 \qquad (1)$$

where $u(z, t)$ is pulse envelope function, z is propagation distance propagated along the fiber, N is an integer assigning the order of soliton and α is the coefficient of energy gain per unit length, the negative values represents energy loss. The value of s is −1 for negative β_2 and +1 for positive β_2 as shown in figure 2 and 3. The optical pulse compares to N=1 is called fundamental soliton. Pulses with N>1 are called higher-order solitons [8]. Soliton order parameter N depends on the balance between dispersion and nonlinearity characteristics and is defined as

$$N^2 = \frac{\gamma P_0}{|\beta_2|}T_0^2 \qquad (2)$$

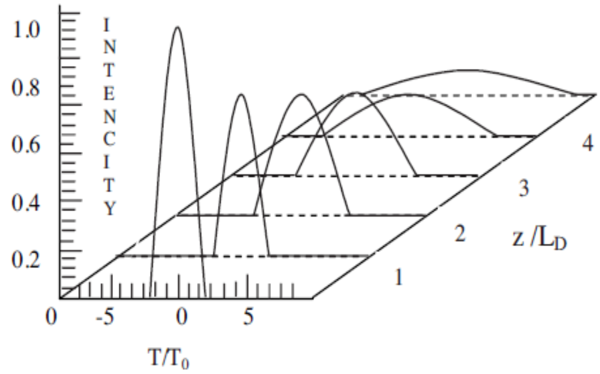

Fig-3: Evolution of soliton in normal dispersion regime

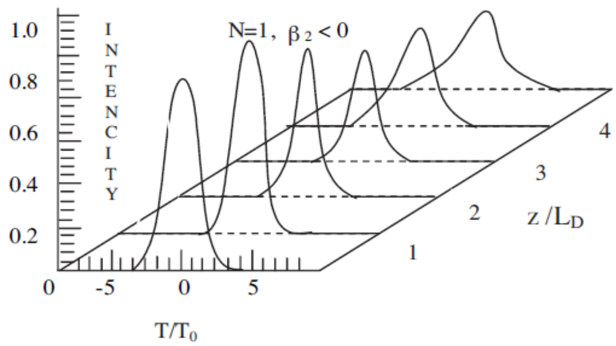

Fig-4: Evolution of soliton in anomalous dispersion regime

It is obvious that SPM dominates for $N > 1$ while for $N < 1$ dispersion effect dominates. For $N \approx 1$ both SPM and GVD cooperate in such a way that the SPM-induced chirp is just right to cancel the GVD-induced broadening of the pulse. The optical pulse would then propagate undistorted in the form of a soliton [5].
By integrating the NLSE, the solution for fundamental soliton ($N = 1$) can be written as

$$u(z,t) = \text{sech}(t) \, . \exp(\frac{iz}{2}) \qquad (3)$$

where sech (t) is hyperbolic secant function. Since the phase term exp ($iz/2$) has no influence on the shape of the pulse, the soliton is independent of z and hence is non-dispersive in time domain. It is this property of a fundamental soliton that makes it an ideal candidate for optical communications. Optical solitons are very stable against perturbations; therefore, they can be created even when the pulse shape and peak power deviates from ideal conditions (values corresponding to $N = 1$).

CONCLUSION

Optical solitons have established themselves as a central presence in the study of physical phenomena. The field is still evolving at a very rapid pace, and we will not try to predict the next developments. Whatever directions the field will take, however, we are confident that it will continue to offer exciting topics from both a mathematical and from a physical point of view, as well as providing problems which have direct relevance for concrete technological applications.

REFERENCES

[1] G.P.Aggarwal, Nonlinear Fiber Optics, Academic Press, San Diego, CA, 2001.

[2] Sein chei, Chir-Weei Chang, Senfar Wen, “Ultrashort soliton pulse train propagation in erbium doped fiber amplifiers,” Elsevier optics communication, vol.111, pp. 132-136, Sept. 1994.

[3] L.F. Mollenauer, J.P. Gordon, M.N. Islam, “Soliton propagation in long fibers with periodically compensated loss,” IEEE Journal of Quantum Electron, vol.22, pp. 157–173, 1986.

[4] N.J. Smith, K.J. Blow, I. Andonovic, “Sideband generation through perturbations to the average soliton model,” IEEE Journal of Lightwave Technology, vol.10, pp. 1329–133, 1992.

[5] A. Hasegawa, Y. kodama, “Guiding centre-soliton in optical fibers,” Phys. Rev. Letter, vol.66, pp. 161-164, 1991.

[6] Manoj Kumar, Ajay K. Sharma, T.S.Kamal, “Performance evaluation of path-averaged soliton pulses in loss-managed 10-Gbps soliton transmission link over a long haul,” International Journal for Light and Electron Optics, vol. 121, issue 1, pp. 68-76, Jan. 2010.

[7] Akira Hasegawa, “Solitons Based Ultra High Speed Optical Communication,” PRAMANA, Journal of Physics, vol. 57, pp. 1097-1127, Dec. 2001.

[8] Regina Gumenyuk, Oleg G. Okhotnikov, “Impact of Gain Medium Dispersion on Stability of Soliton Bound States in Fiber Laser,” IEEE Photonic Technology Letters, vol. 25, no. 02, Jan.15, 2013.

[9] Amarpal Singh, AjayK.Sharma, T.S.Kamal, ManjuSharma, “Simulative investigations of power penalty for DWDM link in the presence of FWM,” International Journal for Light and Electron Optics, vol. 120, pp. 579-584, 2009.

[10] Simranjit Singh, Amanpreet Singh, R.S. Kaler, “Performance evaluation of EDFA, RAMAN and SOA optical amplifier for WDM systems,” International Journal for Light and Electron Optics, vol. 124, pp. 95-101, 2013.

[11] F. Chiaraluce, E. Gambi, P.Pierleoni, “Soliton propagation in long erbium doped fiber amplifiersth nonuniform gain,” Optics communication, vol. 105, pp. 47-51, July 1994.

[12] P.Shum, H.Ghafouri-Shiraz, “Analysis of bit error rate in an optical soliton communication system,” Optics and Laser Technology, vol. 28, no.7, pp. 535-547, 1996.

[13] Linn F. Mollenauer, Stephen G. Evangelides, Hermann A. Haus, “Long-distance soliton propagation using lumped amplifiers and dispersion shifted fiber,” J. Light Wave Technology, vol. 9, pp. 194–197, Feb. 1992.

[14] S.M.J. Kelly, Characteristic side band instability of periodically amplified average soliton, Electron. Lett., vol.28, pp. 806–807, 1992.

[15] N.S. Bergano, F.W. Kerfoot, C.R. Davidson, Margin measurements in optical amplifier systems, IEEE Photon. Technol. Letter, vol. 5, pp.304–306, 1993.

[16] E.Gambi, F. Chiaraluce, 2004 “Soliton propagation in long erbium-doped fiber with non-uniform gain” Science Direct, vol.105.

[17] C.H Lange , G.I. Stegeman, E. Ultanis, 2004“Dissipative spatial solitons in active semiconductor optical amplifiers”, Proceedings of IEEE conference on transparent optical networks , vol. 1

[18] O.G Lopez, A. Bruckmann, P. Urquhart, 2007 “optical amplifiers for telecommunications”, Proceedings of IEEE conference on intelligent signal processing.

[19] Ganapathy R., Porsezian K., Hasegawa A.,2008 “Soliton interaction under Soliton Dispersion management,” IEEE Journal of Quantum electronics, Vol.44, No. 04.

[20] M.F. HASSAN, M.H. Aly, 2009 “Non adiabatic amplification of train of solitons in EDFA”, Proceedings of IEEE conference on high capacity optical networks and enabling technologies.

[21] Grahelj Dan 2010 “Solitons In Optics” Progress in Electromagnetic Research, (PIER) 74.