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Optical Solitonic Communication: Next Generation Communication

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Abstract

Photon is the youngest one in the field of communication science and technology. There lies a huge advantages of optical digital signal based systems, not only in communication and data processing operations but also in 2-D or 3-D holographic processing, 2-D Fourier transform, convolution, correlation, optical pattern recognition, memory system, image edge detection, multiplexing – demultiplexing operation, neural networking, artificial intelligence, channel based and channel free operations, fyzzy logic operations etc. In optical communication system, optical soliton pulse (OSP) are well accepted rather than ordinary optical pulse as OSP offers some special and very crucial advantages over ordinary pulse. Due to the high potentiality of the OSP, it may be used for ultra high speed (UHS), very long distance optical communication systems without use of any repeaters. The photonic age in optical communication system may touch the highest point of turning when optical soliton pulse will be used very successfully and massively in optical communication systems.

Keywords: Soliton pulse, non-linearity, optical communication

1 Introduction

Many scientists around the world are very much actively involved in the research of photonic communication. They believe that if the optical signal can be replaced successfully in communication systems instead of electrons, then the horizon of the world of communication will be enhanced automatically. Due to this replacement, not only the high speed communication will be achieved but also many other operational activities like three dimensional image and data processing, neural networking, real time operations, memory storage capacity of the computer, data carrying capacity, computer computer interaction and interfacing, channel base and channel free operation, local to wide area networking etc. will be implemented very successfully. In the common electronic communication systems the operation speed is limited by the speed of electron. In these systems several improvements have been noticed by reducing the size of the electronic components to very small micron size scale and only a few gigabits per second data processing can be achieved. To enhance the speed of operation the system should be switch over the traditional electronic systems all optical one where photon is the basic carrier of information.[4]. One of the keys to the success of the ensuing photonic revolution is the use of optical soliton pulse in fiber optic communication systems.[9]. Soliton appear in almost all branches of Physics, such as plasma Physics, acoustics, bio Physics, astro Physics, nuclear Physics, particle Physics, condensed matter Physics, low temperature Physics, hydrodynamics, non-linear Physics etc.[1-3,5,11]. In this present communication we are very much interested about the soliton in nonlinear Physics specifically the optical soliton in nonlinear optical fiber. Here we discuss about optical soliton, different types of soliton, past work of soliton pulse, the possible applications of soliton pulse in a very compact form.

2 What is optical soliton?

The term soliton was introduced in the 1960's, but the scientific research of soliton has started in the 19th century when John Scott Russell observes large solitary waves in a canal near Edinberg. In the days of Scott Russell, there was much debate concerning the very existence of this kind of solitary waves. Many model equations of non-linear phenom-

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ena are known to possess soliton solutions. Solitons are very much stable solitary waves in a solution of those equations as the term Soliton suggests, these solitary waves like particles. When they are located mutually far apart, each of them is approximately a traveling wave with constant shape and velocity. As two such solitary waves get closer, they gradually deform and finally merge into a single wave packet, this wave packet, however, soon split into two solitary waves with the same shape and velocity before collisions.

An optical soliton pulse is a pulse that can travel through an optical fiber without any distortion due to dispersion or other effect. Therefore, it is a compressed optical pulse that can propagate over a long distance without any distortion, attenuation and chirping. In a word, we can say that soliton is such type of pulse which broaden neither in time domain nor in the frequency domain. When an optical pulse travels through the optical fibre, the higher intensity portion of the pulse encounter a higher refractive index of the fiber compare with the lower intensity region. This intensity dependent refractive index leads to the phenomenon known as self phase modulation (SPM). The primary effect of SPM is to broaden the spectrum of the pulse while keeping the temporal shape unaltered. This spectral broadening of the pulse without a corresponding increase in temporal width leads to a frequency chirping of the pulse. This broadening of the pulse spectrum generates new frequencies in the pulse & will ultimately lead to an increased broadening through the phenomenon of dispersion. Therefore if we inject too many short pulses into a fibre, then the pulses will overlap after propagating over some distance and the information, therefore, will have been lost after propagating over some distance.

Fortunately there is an another counter effect which can shorten the pulse width. This effect is termed as non-linear effect. In right situation, the chirping effect due to SPM and non-linearity cancel each other, then we have a pulse that remain unaltered both in time domain and frequency domain. These steady pulses are called optical fiber soliton.[6,7]. To achieve the balancing condition between SPM and non-linearity a Laser pulse of finite shape of high intensity is required. Thus soliton are very narrow laser pulses, each of width near about second with high peak power more than 100 mw.[10].

After solving the so-called non-linear Schordinger equation (NLSE), we obtained the envelop function of an optical soliton pulse as,

$$f(z,t) = E_0 Sech[\nu(t - z/v)]e^{igz} \qquad (1)$$

where, $g = \frac{1}{2}\Gamma E_0^2$ and $\Gamma = \frac{1}{2}\omega_o \epsilon_o n_0 n_2$. n_0 and n_2 are the r.i. of the material in the absence of external electric field and the nonlinear term respectively.

3 History of optical soliton

In the mid sixties at Princeton University, two mathematical Physicists, Zabuski and Kruskal, had discovered the existence of a special type of localized wave exhibit partical like behavior. They show that the waves keep their identities intact even when they interact with each other. They named these stable waves as soliton. But actually the soliton phenomenon was first noticed by a Scottish Engineer, John Scott Russell, after observing a solitary waves on the bank of the Edinburg-Glasgow canal in Scotland. In 1849, Stokes had shown that the permanent wave as reported by Russel is just a combination of periodic waves containing non-linear terms which modified the shape and the speed of the waves. Untill 1870's, the permanent wave shape as reported by Russel nearly fourty years beforehand, could be explained. Boussinesq and Rayliegh had independently derived expressions for the shape and the speed of such special waves. In mid 1960's the soundness of Russel's early ideas began to be appreciated when applied scientists began to use modern digital computers to study non-linear wave propagation. In 1964 Zabusky and Kruskal simulated the collision of two soitary waves. The solitonic behaviour in a media was at first demonstrated by Zabusky and Kruskal in 1965. In1973 Hasegawa and Tapert proposed that the soliton could exist in optical fiber and it could be used in optical communication systems. the soliton industry has grown steadily ever since that time. In the mid 1980's it was proposed that by sending in an additional pumpwave along the fiber, the dispersion of a soliton could be halted through a process known as Raman Scattering. In 1987, Emplit, Hamaide, Raynaud, Froehly and Barthelemy from the Universityof Brussels and Limoges, made the first experimental observation of the propagation of the dark soliton in an optical fiber. In 1988, Mollenauer and his group had shown that this could be done by propagating a soliton pulse over 6000 kilometer without any repeaters. In 1989, Drazin and Johnson describe soliton as a solution of non-linear differential equation. AT and Bell labs research team transmitted soliton pulse of error free 2.5 gigabits over more than 14,000 kilometer using erbium optical fiber amplifiers. In 1998, T. Georges and his team at France Telecom R and D center, combining optical solitons of different wavelengths (wavelength division multiplexing) demonstrated a data transmission of 1 terabit per second. In 2001, the practical use of soliton becomes a reality when Algety Telecom deployed submarine telecommunications equipment in Europe carrying real traffic using John Scott Russell's solitary wave.

4 Possible application of optical soliton pulse

The interesting concept of solitons finds a lot of application in many fields. Out of those, the important application of optical soliton are the all-soliton optical communication link, optical pulse compression, optical soliton switching, optical soliton logic operation, optical computation, soliton laser etc.. Though optical soliton have been studied in many fields but the most promising and also challenging applications of the optical soliton are in the field of optical communication. But here we discuss about the applications of optical soliton in the above all cases.

a) Pulse compression: The very important application of optical soliton pulse is in pulse compression. The production of ultra short pulse (USP) is very much important in communication systems. Optical soliton pulses are used massively to generate USP. When a symmetric shape of the pulse input in a fiber in the absence of higher order effect, then the soliton generate and propagate with an identical speed. Due to this, phase interference occurs among the solitons and at a particular distance during the transmission, the pulse width is compressed. Using this technique pulse compression by a factor of 1000 to 3000 has been achieved experimentally. In another experiment the initial 90ps pulse was compressed to 18ps (consisting of only four optical cycles).

b) Soliton laser: By injecting a mode-locked laser pulse with appropriate amplitude one can produce an optical soliton. By employing the fiber as part of the feed back system in the cavity of the laser oscillator, we can produce a soliton of arbitrary width. By adopting this mechanism, Mollenauer et al invented soltion laser. It succeeded in producing a sub-Pico second pulse at infrared wavelength for the first time. Soliton laser provided the finest quality lasers available for health and rejuvenation. Soliton lasers are especially effective for pain relief, facial rejuvenation, laser acupuncture, immune enhancement, weight loss, stress reduction, migraines, chronic fatigue syndrome, anti aging etc.

c) Soliton in optical communication: Recognizing the potential of soliotn communication, many research groups around the world are currently conducting soliton transmission experiment, attempting to push the transmission capacity to higher limits.[12]. In optical communication systems, optical solitons are used as it can travel millions of kilometer without significant distortion. In 1973, Hasegawa and Tappert first proposed that optical soliton can exist optical fiber and it can be used optical communication systems. In 1988 Mollenauer and his group shown that an optical soliton can travel over 6000 km without use of any repeaters. Soliton can multiplex at several wavelengths without the interaction between channels suffered by non-return to zero (NRZ) systems. Mollenaur at AT and T Lab. in USA has demonstrated an optical soliton systems using seven channels at 10 Gbit per second where as the current systems operated at 5 G bit per second and do not connect easily with land based networks which have standard data rates 2.5 to 10 Gbit per second. M.Suzuki and his colleagues at KDD laboratories, Japan have shown that a system with a data rate of 20 Gbit per second workover 10,000 km , even without components for controlling jitter. The optical time domain multiplexing (OTDM) or optical time domain demultiplexing (OTDD) techniques at upto 40 Gbit per second can be implemented only by active use of optical soliton.

d) Soliton in all-optical logic operation: All optical logic operations are very much expected in ultra high speed long distance communication systems, where all the logical operations are implemented using optical signals. Optical soliton signals may be used for this purpose very successfully. There are several approaches to construct all optical logic using soliton pulse.[14,15]. Umeton et-al has proposed all optical logic operations by incoherent interaction of multiple spatial solitons with non-linear interface. M. Peccianti et-al, reported that all optical switching and logic gating may be implemented in a liquid crystal using spatial soliton. Similarly there are a lot of proposals to perform all optical logic operations in medium, where the interaction properties of the soliton pulses are used actively.

5 Conclusion

Solitons may have their greatest impact on the development of photonic computers. Soliton switches and various logic operations have been demonstrated experimentally using solitons in conjunction with other non-linear optical phenomena like cross phase modulation,wave mixing etc. These are all necessary components for the development of the photonic computer. Though many scientists already reported a large number of interesting theoretical and experimental work in the field of solitonic systems under external forces, noises, impurities, perturbation etc. but there are required further investigation about soliton and their character in the field of application level.

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