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# Improvement of bit rate transmission using higher order Soliton pulse

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**Abstract:** In this paper, I present the methodology to increase the bit rate transmission from 10 Gb/sec to 40 Gb/sec using higher order soliton pulse in place of conventional pulse. Here I use the PMD fiber to reduce the effect of polarization mode dispersion on data transmission. I use Optsim simulator to simulate the system and for analyze the performance. I analyze the system performance using eye diagram, instantaneous optical power and electrical spectrum.

**Keywords**: Soliton, SPM, GVD, Eye diagram, Instantaneous optical power.

## I. INTRODUCTION

The word “soliton” is meant to describe the particle like behavior of the optical pulses propagating through a medium. The pulses envelope for soliton not only propagates undistorted but also survives collisions just as particles do. The soliton are very narrow, high intensity optical pulses that retain their shape through the interaction of balancing pulse dispersion with the nonlinear properties of an optical filter. If the relative effect of SPM and GVD are controlled just right, and appropriate pulse shape is chosen, the pulse compression resulting from SPM can exactly offset the pulse broadening effect of GVD. Depending upon the particular pulse shape chosen , the pulse either does not change its shape as it propagates, or it undergoes periodically repeating change in shape. The pulses that do not change in shape are called fundamental solitons , and those that undergo periodic shape changes are called higher-order solitons .

As discussed earlier, when a high-intensity pulses is coupled to fiber , the optical power modulates the refractive index seen by the optical excitation. This induces phase fluctuations in the propagating wave, thereby inducing a chirping effect in the pulse. When such a pulse traverses a medium with a positive GVD for the constituent frequency, the leading part of the pulse is shifted towards a longer wavelength, so that the speed in that portion increases. Conversely, in the trailing half , the frequency rises so the speed decreases. This causes the trailing edge to be further delayed. Consequently , in addition to a spectral change with distance, the energy in the center of the pulse is dispersed to either side, and the eventually take a rectangular shape.

On the other hand, when a narrow high-intensity pulse traverses a medium with negative GVD for the constituents frequency, GVD counteracts the chirp produced by SPM. Now, GVD retards the low frequency in the front end of the pulse and advances the high frequencies at the back. The result is that is the high-intensity sharply peaked soliton pulses change neither its shape nor its spectrum as it travel along the fiber. Provided the pulse energy is sufficiently strong, this pulse shape is maintained as it travels along the fiber. In a standard optical fiber, there is a zero dispersion point around 1320 nm [1]. For wavelength shorter than 1320nm, $\beta_2$ is positive and it is negative for longer wavelengths. Thus soliton operation is limited to the region greater than 1320nm.

More specifically, a chirped pulse can be compressed during the early stage of propagation whenever the GVD parameter $\beta_2$ and chirp parameter ‘C’ have opposite sign so that $\beta_2 C$ is negative. The nonlinear phenomenon of SPM imposes chirp on the optical pulse such that $C > 0$. Since $\beta_2 < 0$ in the 1550 nm wavelength region ,the condition $\beta_2 C < 0$ is readily satisfied. Moreover, as the SPM- induced chirp is power dependent, it is not difficult to imagine that under certain condition. SPM and GVD may cooperate in such a way that the SPM-induced chirp is just right to cancel the GVD-induced broadening of the pulses. The optical pulses would then propagate undistorted in the form of soliton.

### A. EVOLUTION OF SOLITON PULSE

To derive the evolution of the pulse shape required for the soliton transmission, one needs to consider the NLS equation in the presence of GVD and SPM. This equation can be written as [2]

$$\frac{\partial A}{\partial z} + \frac{j\beta_2}{2}\frac{\partial^2 A}{\partial t^2} - \frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3} = j\gamma|A|^2 A - \frac{\alpha}{2}A \qquad (1)$$

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mHere, A (z ,t) is the pulse envelop function and 'z' is the propagation distance along the fiber. To discuss the soliton solutions of this equation as simply as possible, we first set $\alpha = 0$ and $\beta_3 = 0$, it is useful to write this equation in a normalized form by introducing $\tau = t / To$, $\zeta = z / L_D$ and $U = A / \sqrt{Po}$, where To is a measure of the pulse width, Po is the peak power of the pulse and $L_D = To^2 / |\beta_2|$ is the dispersion length above equation take the form :

$$-j\frac{\partial U}{\partial z} = -\frac{s}{2}\frac{\partial^2 U}{\partial t^2} + N^2|U|^2 U - j\frac{\alpha}{2}U$$

(2)

Where s = ± 1, depending on whether $\beta_2$ is positive ( normal GVD) or negative (anomalous GVD). The parameter N is defined as

$$N^2 = \gamma P_0 L_D = \gamma P_0 T_0^2 / |\beta_2|$$

(3)

It represent a dimensionless combination of the pulse and fiber parameter. For the three right-hand term in equation (3):

1. The first term represent GVD effect of the fiber. Acting by itself, dispersion tends to broaden pulses in time.
2. The second nonlinear term denotes the fact that the refractive index of the fiber depends on the light intensity. Through the self modulation process, this physical phenomenon broadens the frequency spectrum of a pulse .
3. The third term represents the effect of energy loss or gain; for example, due to fiber attenuation or optical amplification, respectively.

Solving NLS equation analytically yield a pulse envelope that is either independent of 'z' ( N=1) or that is periodic in 'z'( for higher-order soliton with $N \geq 2$). The NLS equation is wel known in the soliton literature because it belong to a specific class of nonlinear partial differential equation that can be solved exactly with a mathematically technique known as the inverse scattering method [3-4]. Although the NLS equation supports soliton for both normal and anomalous GVD, pulse-like soliton are found only in the case of anomalous dispersion[8]. In our studies, we focus only the pulse-like soliton, where GVD is anomalous. In this case s = -1in equation (2). It is common to introduce u = NU as a renormalized amplitude and write the NLS equation in its canonical form with no free parameter as

$$j\frac{\partial u}{\partial \zeta} + \frac{1}{2}\frac{\partial^2 u}{\partial \tau^2} + |u|^2 u = 0$$

(4)

This equation can be solved by the inverse scattering method . Detail of this method are available in several books devoted to soliton[9-11]. The result obtained from the soliton may be summarized as follows:

- When an input pulse having an initial amplitude $u(0,\tau) = N \operatorname{sech}(\tau)$ is launched into the fiber, its shape remains unchanged during propagation when N = 1. for integer values of N > 1, it follows a periodic pattern such that the input shape is recovered at $\zeta = m\pi / 2$, where 'm' is an integer.
- An optical pulse whose parameters satisfied the condition N=1, is called the fundamental soliton. Pulses corresponding to other integer values of N are called higher order solitons. The parameter N represents the order of the soliton. The soliton period '$z_0$'and soliton order N play an important role in the theory of optical soliton.

## II INFORMATION TRANSMISSION WITH SOLITONS

The NRZ format is commonly used because it uses about 50% bandwidth as compared to the RZ format. However, the NRZ format cannot be used when soliton are used as information bits. The reason is easily understood by noting that the pulse width must be a small fraction of the bit slot to ensure that the neighboring soliton are well separated. It remains approximately valid for a train of solitons only when individual soliton are well isolated. This requirement can be used to relate the soliton width 'To' to the bit rate 'B' as $B = 1 / T_B = 1 / 2q_0T_0$, where '$T_B$' is the duration of the bit slot and $2q_0 = T_B / To$ is the separation between neighboring solitons in normalized units. Typically, the spacing between solitons exceeds four times their full width at half maximum ( FWHM).

## III .WAVE THEORY

Wave theory of light, based on Maxwell.s equations, provides a comprehensive and rigorous approach to understanding light propagation in optical fibers [5-7]. These equations represent the relations between various optical wave fields in terms of electric and magnetic fields associated with them. The fields vary with space and time. The time variation is considered harmonic so that the fields vary as:

$$\mathrm{E}(r,\phi,z,t) = \mathrm{E}(r,\phi,z)\exp(j\omega t)$$
$$\mathrm{H}(r,\phi,z,t) = \mathrm{H}(r,\phi,z)\exp(j\omega t)$$

(5)

This results in dealing with complex valued fields with amplitude and phase. Taking the advantage of cylindrical symmetry of the fiber, following general vector wave equation for the optical fields can be derived from Maxwell.s equations [8].

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$$\frac{\partial^2 E_z}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial E_z}{\partial \rho} + \frac{1}{\rho^2}\frac{\partial^2 E_z}{\partial \phi^2} + \frac{\partial^2 E_z}{\partial z^2} + n^2 k_0^2 E_z = 0 \quad (6)$$

where for a step index fiber of core radius .a., the refractive index .n. is of the form:

$$n = \begin{cases} n_1 ; & \rho \le a , \\ n_2 ; & \rho > a , \end{cases} \quad (7)$$

Equation (6) is written for the axial component Ez of the electric field vector. Similar equations can be written for other five components of E and H. However, it is not necessary to solve all six equations since only two components out of six are independent. It is customary to choose Ez and Hz as the independent components and obtain E , E , H and H in terms of these independent components. It may be noted that in general various field components are coupled, alongwith the explicit inclusion of refractive index variations into the wave equations.

## IV DISPERSION IN SINGLE MODE FIBERS

Intermodal dispersion in multimode fibers leads to considerable broadening of short optical pulses. It is because of the different mode indices (or group velocities) associated with different modes. The main advantage of SM fibers is that intermodal dispersion is absent. However, pulse broadening does not disappear altogether. The group velocity associated with the fundamental mode is frequency dependent because of chromatic dispersion. As a result, different spectral components of the pulse travel at slightly different group velocities. This phenomenon is referred to as group velocity dispersion (GVD), or intramodal dispersion. It has two contributions; material dispersion and waveguide dispersion. In this section we discuss how GVD limits the performance of lightwave systems employing SM fibers.

### A. GROUP VELOCITY DISPERSION

Consider an SM fiber of length .L.. A specific spectral component at the frequency . . would arrive at the output end of the fiber after a time delay / g , T L v where .vg.is the group velocity, defined as [9]

$$v_g = (d\beta / d\omega)^{-1} \quad (8)$$

The frequency dependence of the group velocity leads to pulse broadening because different spectral components of the pulse disperse during propagation and do not arrive simultaneously at the output. If is the spectral width of the pulse, the extent of pulse broadening is governed by

$$\Delta T = \frac{dT}{d\omega}\Delta\omega = \frac{d}{d\omega}\left(\frac{L}{v_g}\right)\Delta\omega = L\frac{d^2\beta}{d\omega^2}\Delta\omega = L\beta_2\Delta\omega \quad (9)$$

The parameter $\beta_2 = d^2\beta / d\omega^2$ is known as the GVD parameter. It determines how much an optical pulse would broaden on propagation inside the fiber. The frequency spread may also be determined by the wavelength range emitted by the optical source. Using, equation

$$\int_0^{L_A} g(z)\,dz = \alpha L_A \quad (10)$$

can be written as:

$$\Delta T = \frac{d}{d\lambda}\left(\frac{L}{v_g}\right)\Delta\lambda = DL\Delta\lambda \text{ where } D = \frac{d}{d\lambda}\left(\frac{1}{v_g}\right) = -\frac{2\pi c}{\lambda^2}\beta_2 \quad (11)$$

.D. is called the dispersion parameter and is expressed in units of ps / (km-nm). The effect of dispersion on the bit rate .B. can be estimated by using the criterion $B\Delta T < 1.$
Using T from equation (11), this condition becomes

$$BL|D|\Delta\lambda < 1 \quad (12)$$

The dispersion parameter .D. can vary considerably with the operating wavelength. The wavelength dependence of .D. in equation (11), can also be written in the form of frequency dependence of mode index n as [6]

$$D = -\frac{2\pi c}{\lambda^2}\frac{d}{d\omega}\left(\frac{1}{v_g}\right) = \frac{2\pi}{\lambda^2}\left(2\frac{d\bar{n}}{d\omega} + \omega\frac{d^2\bar{n}}{d\omega^2}\right) \quad (13)$$

For standard SM fibers, material dispersion .DM. is negative at lower wavelengths and positive at higher wavelengths. The wavelength at which slope of the group index is zero is referred to as zero-dispersion wavelength '$\lambda_{ZD}$'. . ZD On the other hand, waveguide dispersion '$D_W$' . is small but negative for all wavelengths. The main effect of waveguide dispersion is to shift ZD to slightly higher wavelength, a typical value being 1310 nm. Since the waveguide dispersion depends upon fiber parameters such as core radius and index difference, it is possible to design the fiber such that ZD can be shifted to the vicinity of 1550 nm [10-11]. Such fibers are called dispersion shifted fibers. It is also possible to tailor the waveguide dispersion such that the total dispersion is relatively small over a wide

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wavelength range extending from 1300 . 1600 nm [12-14]. Such fibers are called dispersion flattened fibers. Waveguide dispersion can also be used to produce dispersion decreasing fibers (in which dispersion decreases along the fiber length because of axial variations in core radius) and dispersion compensating fibers (in which dispersion is normal and has relatively large magnitude).

## V HIGHER ORDER DISPERSION

From the previous discussion it may appear that the BL product of an SM fiber can be increased indefinitely by operating at ZD . The dispersive effects, however, do not disappear completely at this wavelength. Optical pulses still experience broadening because of higher-order dispersive effects, which are governed by the dispersion slope [8]. This feature can be understood by noting that .D. cannot be made zero at all wavelengths contained within the pulse spectrum centered at . ZD Clearly, the wavelength dependence of .D. will play its role in pulse broadening. The dispersion slope S dD/ d , is also called differential-dispersion parameter. From equation (7) it can be written as

$$S = (2\pi c/\lambda^2)^2 \beta_3 + (4\pi c/\lambda^3)\beta_2 \tag{14}$$

$\beta_3 = d\beta_2 / d\omega \equiv d^3\beta / d\omega^3$ is the third-order dispersion (TOD) parameter.

At $\lambda = \lambda_{ZD}$, $\beta_2 = 0$ and '$S$' is proportional to $\beta_3$.

The numerical value of the dispersion slope .S. plays an important role in the design of modern WDM systems. Since S > 0 for most fibers, different channels have slightly different GVD values. This feature makes it difficult to compensate dispersion for all channels simultaneously. To solve this problem new kinds of fibers have been developed for which .S. is either small (reduced-slope fibers) or negative (reverse-dispersion fibers).

## VI POLARIZATION MODE DISPERSION

A potential source of pulse broadening is related to fiber birefringence because of small departures from perfect cylindrical symmetry. If the input pulse excites both polarization components, it becomes broader as the two components disperse along the fiber because of their different group velocities. This phenomenon is called polarization mode dispersion (PMD). In PM fibers, having constant birefringence, pulse broadening can be estimated from the time delay . T. between the two polarization components during propagation of the pulse. For a fiber length L, T is given by:

$$\Delta T = \left| \frac{L}{v_{gx}} - \frac{L}{v_{gy}} \right| = L\left|\beta_{1x} - \beta_{1y}\right| = L(\Delta\beta_1) \tag{15}$$

where .x. and .y. identify the two orthogonally polarized modes and 1 is related to the difference in group velocities along the two principle states of polarization [15]. T/L is large (~ 1 ns/km) when the two components are equally excited at the fiber input but can be reduced to zero by launching light along one of the two principle axes.

The situation is somewhat different for standard fibers. Here birefringence varies along the fiber length in a random fashion. In the case of optical pulses, the polarization states will also be different for different spectral components of the pulse. The final polarization state is not of concern for most of the systems, as photo detectors are insensitive to the state of polarization. What affects such systems is the pulse broadening induced by random changes in the birefringence. This is referred to as PMD induced pulse broadening. The analytical treatment of PMD is quite complex in general because of its statistical nature. A simple model divides the fiber into a large number of segments. Both the degree of birefringence and the orientation of the principle axes remain constant in each section but change randomly from section to section. In effect, each fiber section can be treated as a phase plate using Jones matrix [15]. Propagation of each frequency component associated with an optical pulse through the entire fiber length is then governed by a composite Jones matrix by multiplying individual Jones matrices for each fiber section. The composite Jones matrix shows that two principle states of polarization exist for any fiber. When a pulse is polarized along them, the polarization state at the fiber output is frequency independent to first order, in spite of random changes in fiber birefringence. These states are analogous to the slow and fast axes associated with PM fibers. It has been analyzed through numerical simulations that soliton splits into two pulses if large value of PMD and other higher order effects coexist. The same phenomenon has been experimentally demonstrated in a figure of eight mode locked fiber laser by introducing birefringence into the cavity through a gradual twist in the fiber [16]

## VII RESULT

The results of the simulation trials are in the form of eye diagrams from which Q-value, jitter, BER, and eye opening has been measured and instantaneous power at 40Gb/sec bit rate transmission using fiber length of 1000 km.

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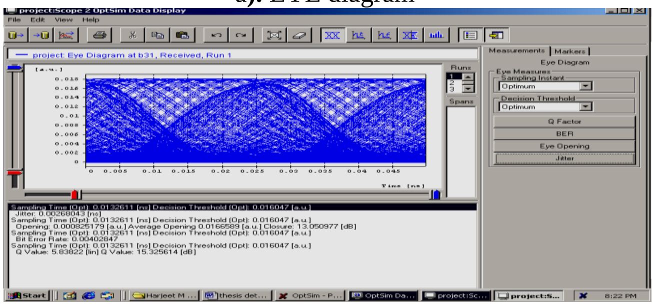
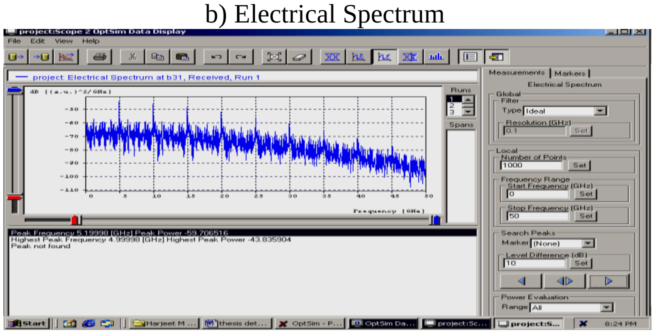
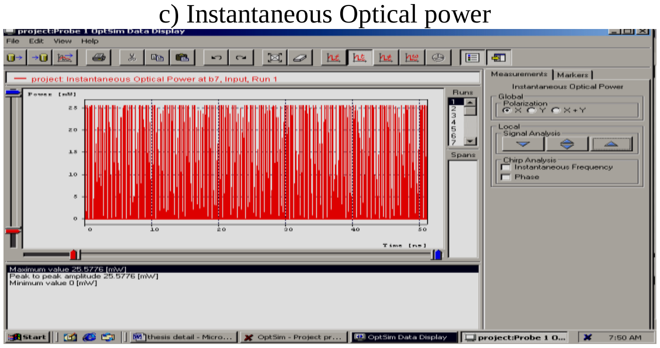
a**).** EYE diagram



b) Electrical Spectrum



c) Instantaneous Optical power



## VIII CONCLUSION

Here, I conclude that the using soliton pulse in place of convention pulse bit rate increases to 40 Gb/sec. As we know that as the PMD increases the BER increases and the output electrical power decreases but I observe after simulation for conventional pulse that sometimes the BER decreases and the electrical power increases, this is due to the effect of the dispersion on the PMD. Then I simulate the system for soliton pulse and observe that the Q factor of the system improve and decrease the BER to 0.0227501 ( 40 Gb/sec),also improve electrical spectrum and Instantaneous Optical power.

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