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A MODEL FOR OPTIMIZATION OF SOLITON BASED COMMUNICATION SYSTEMS IN THE VIEW OF RENEWABLE ENERGY RESEARCH

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Abstract- If optical amplifiers remove the fiber losses acceptably in long distance, total transmission length of soliton communication system is primarily definite by amplitude and frequency shifting. The amplitude and frequency shifting effects create by both Gordon-Haus Jitter and soliton-soliton interaction were analyzed in this study. As a result of analyzation these two effects were balanced each other. Thus, data transmission rate was rising and repeater distance has been satisfied. In order to get mentioned situation above, soliton communication system maximum shifting has been calculated firstly for the zero phase difference between the soliton pulses. Mathematical modeling of the optimum phase difference for the minimum shifting has been calculated. According to this model, a simulation program has been built up. Program simulates both the frequency shifting and amplitude changing effects caused by soliton-soliton interaction and Gordon-Haus Jitter effects. In order to minimizing the jitter effects of soliton trains acceptably critical phase difference calculated by simulation program. This results were analyzed in view of renewable energy research perspective. Outcomes are going to be new perspective for renewable energy research in lightning technology.

Keywords: Fiber Nonlinear Optics, Optical Fiber Applications, Optical Solitons, Timing Jitter.

I. INTRODUCTION

Optical soliton was theoretically introduced by Hasegawa and Tapper [1] and Mollenauer was the first person to show it experimentally [2]. Non-linear transmission made by soliton pulses is an effective method in solving the problem of chromatic dispersion which restricts the performances of higher bit rate, long range optical communication systems Soliton is a solution for Non-linear Schrödinger Equation (NLS) which describes non-dispersive propagation of an optical pulse in a dispersive medium. The solution is a balance, between the Group Velocity Dispersion (GVD) and shelf-Phase modulation (SPM) [2, 3].

Although silica fibers provide a perfect medium for transmission of IR signals, there are losses due to absorption and scattering effects. This causes dispersive effects on the optical signal. Therefore, to prevent neighboring soliton interaction with each other, the signals need to be amplified. Optical amplifiers can effectively provide a lossless transmission system by compensating optical attenuation.

Removing the attenuation effects on the fiber based communication system; the total transmission length of the soliton communication systems is determined by the timing jitter. As stated above, in soliton systems factors causing time jitter is Gordon-Haus effect and soliton interaction. These two effects generally cause a frequency shift between the signal soliton. This shift at the frequency causes small changes at the average carrier frequency of soliton system and, due to chromatic dispersion, shift at the velocity of the group also occur. This is also responsible for shifts at the receiver side. Thus, the timing jitter effect appears as amplitude shift which in turn causes detection errors [3, 5, 11, 12].

Sections II and III describes the mathematical model used in our simulations, while section IV is an evaluation of the simulation results, and final section for conclusion of this study.

II. MATHEMATICAL BACKGROUND and MODELING

NLS which characterizes the pulse propagation in optical fiber is:

$$\frac{\partial u}{\partial z}=-\alpha u+\frac{J\beta_2}{2}.\frac{\partial^2 u}{\partial t^2}+\frac{\beta_3}{6}.\frac{\partial^3 u}{\partial t^3}-J\gamma' \left|u\right|^2 u \tag{1}$$

Equation (1) is the starting point for analytical solution. The optical pulse is at the form of:

$$u(z,t)=\exp(J\omega_0 t-\beta_0 t) \tag{2}$$

where, ω_0 is the centre frequency of the carrier signal and $u(z,t)$ corresponds to slowly varying wave envelope amplitude. The first term on the right hand side of Equation (1) represents the attenuation effect at the fiber (i.e. α is attenuation coefficient), the second and third terms are dispersion effects (i.e. β_2 is fiber's dispersion parameter, β_3 is dispersion) and finally the last term represents non-linear effect of fiber's light intensity (i.e. $\gamma^{\imath}$ is nonlinearity coefficient).

The Equation (4) excluding the non-linearity term describes linear pulse propagation of fiber and it is analytically solvable. However, solving the complete equation can only be possible with numerical methods. Since the attenuation and dispersion terms depend on the frequency, their effect on the pulse propagation is on the frequency domain, on the other hand, since the non-linearity term only changes on the time domain, its effect is observable and must be calculated on this domain. For this operation the most widely used method is FFT algorithms using split-step Fourier technique [2, 5, 9, 11].

The non-linear Schrödinger equation, showing two solitons-with a certain distance in between them and under the higher order non-linear effects-move towards individual soliton at varying speeds is represented as [2, 4, 8, 10];

$$u(0,\tau)=\mathrm{sech}(\tau-q_0)+r\,\mathrm{sech}\left[r/\tau+q_0)\right]e^{\imath\theta} \tag{3}$$

where, initial term is relative amplitude, Q is relative phase and q_0 initial pulse separation.

Erbium doped fiber amplifiers (EDFA) are preferred in the commercial market in higher bit rate soliton transmission due to their lower costs [7]. The Gordon-Haus Jitter effect is as a result of Amplitude Spontaneous Emission (ASE) noise and seen at EDFA's. ASE not only reduces the SNR of the system but also, causes frequency shift on signal solitons. The time-shift variation of optical amplifier based soliton transmission system can be expressed as [2, 14, 15];

$$\sigma_t^{\,2}=<\delta_t^{\,2}>\left[\frac{1.763N_{sp}N_2Dh(G-1)L^3}{9T_{FWHM}A_{eff}L_{amp}\theta}\right]^{1/2} \tag{4}$$

where, L_{amp} is the distance between the amplifier N_2 is the non-linear coefficient, N_{sp} is the amplifiers spontaneous emission factor, h is the Planck constant, G is the amplifier gain, L is the transmission distance, and A_{eff} is effective mod area, while TFWHM is the full width at half maximum of the initial soliton pulse, D is fiber dispersion parameter and finally $\beta=\dfrac{\lambda^2}{2\pi c}D$ and $T_{FWHM}=1.763\tau$ values have been used.

The equation which characterizes soliton pulse propagation to obtain the necessary optimization using the critical initial phase in between the soliton pulses is [2, 6];

$$\rho\exp\,(q+iy)\;=\;2\cosh\,(z_0+i\rho Z_a) \tag{5}$$

where, ψ and q corresponds to phase difference and the distance between two deporting pulses respectively and ρ and ζ_0, is the propagation coefficient. Each parameters of Equation (5) corresponding to an amplifier outputs to another amplifiers output is represented as;

$$\rho_{k-1}\exp(Q_k)=2\cosh(\zeta_{k-1}+i\rho_{k-1}z_a) \tag{6}$$

The subscript K represents the kth amplifier. The amount of delay after n identical amplifier is given by;

$$<dq_n^2>=<\delta\dot{q}^2>\sum_{p=1}^{n}(3a_p^2+b_p^2) \tag{7}$$

where, $<\delta\dot{q}^2>$ is the mean square jitter caused by each amplifier and its value given by;

$$<\delta\dot{q}^2>=0.752\pi^2\beta\frac{(G-1)^2hn_2c^2\tau}{G\ln(G)\lambda^4A_{eff}D} \tag{8}$$

where, G is amplifier gain and β is the excessive noise factor.

In the Equation (7) in the absence of soliton interaction, means, taking $\theta=0$ it becomes;

$$<dq_{nGH}{}^2>=<\delta\dot{q}^2>z_a^2\frac{n}{3}(n-\frac{1}{2})(n-1) \tag{9}$$

and this represents the Gordon-Haus shift.

As long as the interaction power is not high, there is an unchanging $\psi_{ZM}(Q)$ value for the ψ_0 input phase (mean soliton interval transmission line output) ψ_{ZM} is a solution for the Equation (9);

$$\cos\left[2Q\cos(\psi_{ZM})\right]+\cosh\left[2Q\sin(\psi_{ZM})\right]-2=0 \tag{10}$$

This equation has been coded using C++ programming language and the minimum total shift values;

$\psi_{ZM}=2.36\,,\quad Q=0.2$

have been calculated as numerically.

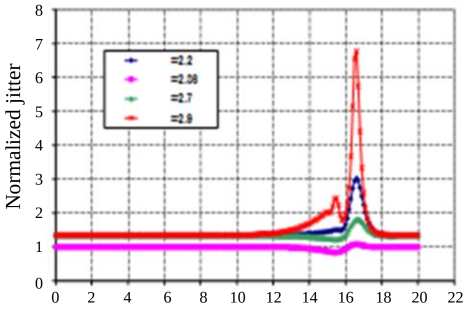


Figure 1. Normalized Shift Graphs as a function of initial pulse intervals of $\psi_{ZM}=2.2$, $\psi_{ZM}=2.36$, $\psi_{ZM}=2.7$ and $\psi_{ZM}=2.9$

As it may be observed from the Figure 1 the large fluctuation on the normalized jitter in the case of zero phase difference between soliton pulses, becomes lower jitter windows when the phase difference is reduced to minimum (i.e. optimized). This optimized value was used as input in MATLAB simulation program.

III. CALCULATION OF PULSE WIDTH WITH INPUT PHASE OF MINIMUM COMBINED EFFECTS OF SOLITON INTERACTION AND GORDON-HAUS JITTER EFFECT

Generally, we want to send pulses with zero phase difference, because generating of pulses with different phase for high repetition rate of soliton pulses is difficult. If we allow a phase difference between pulses, in this case the jitter is calculated versus q_0 with considering $\psi_0=\psi_{ZM}$. Refer to (8), to calculate the variation we need to know the initial conditions.

For soliton pulses of equal amplitude and equal velocity, but with phase difference of $\psi_0 = \psi_{ZM}$, the condition of equation (8) becomes;

$$Q_0 = q_0 + i\psi_{ZM} \quad , \quad \rho_0 = 0 \tag{11}$$

Using Equation (8) into the Equations (11) and (5),

$$\rho = 2\exp\left[-(q_0 + i\psi_{ZM})\right] = \rho_1 + i\rho_2 \quad , \quad \zeta_0 = 0 \tag{12}$$

Normalizing the this equation to Gordon-Haus Jitter, the total jitter can be expressed as,

$$\frac{(<\delta q_n^2>)^{1/2}}{(<\delta q_{nGH}^2>)^{1/2}} = \left(\frac{3\sum_{p=1}^{n}(b_p)^2}{z_a^2(n)(n-1/2)(n-1)}\right)^{1/2} \tag{13}$$

This equation gives the variation of total normalized jitter versus pulse separation q_0, for the value of system length, Z, amplifier spacing, Z_a, number of amplifier n. Real parameters of fiber are shown in 3-D figure panels.

IV. SIMULATION AND ANALYSIS OF RESULTS

The NLS equation has been solved in MATLAB using numerical methods. The input pulses used in the simulation are ideal soliton pulses and can be expressed using [2]:

$$u(0,t) = A\,\mathrm{sech}\left(\frac{t}{\tau}\right) \tag{14}$$

where, A is the peak amplitude (i.e. $A = \sqrt{P_o}$, P_o is the peak power of the pals), τ is the pulse width (i.e. $t_{FWHM} = 1.763\tau$ is the full width at the half maximum power [11]). In the simulations, for a standard single mode fiber (S-SMF) of 50 km has been taken into account and the input soliton pulses are at the length of 10 ps (i.e. $\tau_{FWHM} = 17.63ps$) which means that with the $5\tau_{FWHM}$ pulse interval a 10 Gbit/s speed is obtained.

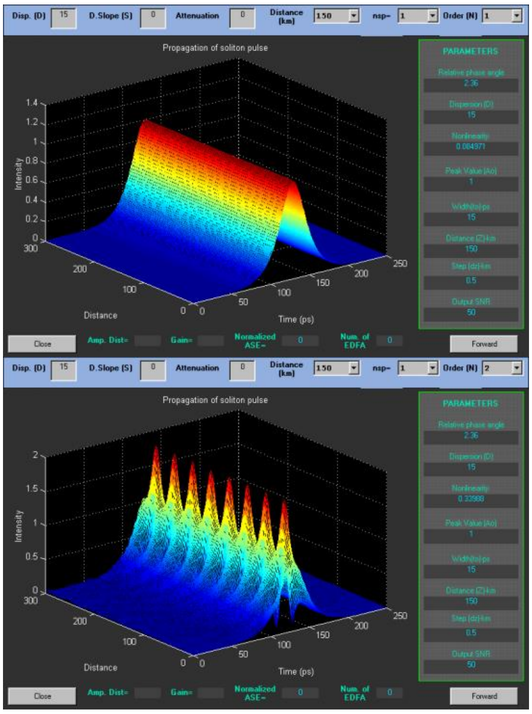
In the simulation program the iteration steps Δ_z is depending on the transmission distance are determined. The non-linearity coefficient $(\gamma^{\prime})$ which could provide soliton pulse propagation is calculated using the formula;

$$N^2 = \frac{\gamma P_0 Z_0{}^2}{|\beta_2|} \tag{15}$$

where, N is the order of soliton and is a positive number, N=1 is known as base soliton and in the cases of N=2, N=3 the move soliton pulse becomes more complicated [4, 10].

In the solutions, the pulse shape of the soliton in the transmission fiber, with varying levels of attenuation, dispersion on non-linearity effects for the first and second order solitons (N = 1, N = 2) are numerically calculated and simulated as illustrated in Figure 2.

The calculation performed in the simulation process to this point is also present in many studies including [2, 3, 11, 13] and the obtained results are parallel with the results found in these references. However, since we adopt a numerical approach unlike analytical approaches used in these studies, our results differ from them from this point.



Disp. (D) 15 D.Slope (S) 0 Attenuation 0 Distance (km) 150 nsp= 1 Order (N) 1

PARAMETERS
Relative phase angle 2.36
Dispersion (D) 15
Nonlinearity 0.084971
Peak Value (Ao) 1
Width(to) ps 15
Distance (Z) km 150
Step (dz) km 0.5
Output SNR 50

Amp. Dist= Gain= Normalized ASE= 0 Num. of EDFA 0

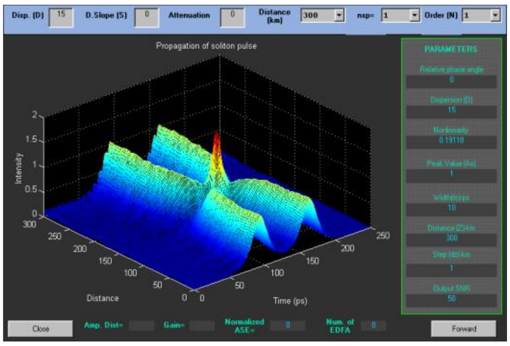
Disp. (D) 15 D.Slope (S) 0 Attenuation 0 Distance (km) 150 nsp= 1 Order (N) 2

PARAMETERS
Relative phase angle 2.36
Dispersion (D) 15
Nonlinearity 0.33988
Peak Value (Ao) 1
Width(to) ps 15
Distance (Z) km 150
Step (dz) km 0.5
Output SNR 50

Amp. Dist= Gain= Normalized ASE= 0 Num. of EDFA 0

Figure 2. The soliton pulse dispersion effect removed by the effect on non-linearity for N = 1 and N = 2

To see the soliton interaction two soliton pulses have bean applied to the input of the simulation system and the results illustrated in Figure 3 are obtained. In the soliton communication systems the desire is sending higher bit rate pulses. If these pulses are so close to each other, they start to interact with each other conform the soliton propagation equation. This situation, results an increase at the speed of trailing soliton group while reducing the group speed of soliton in front. The speed changes in the group, causes time and amplitude shifts at the receiver side. As Figure 3 illustrates this interaction between two soliton either causes a periodical separation or collusion.



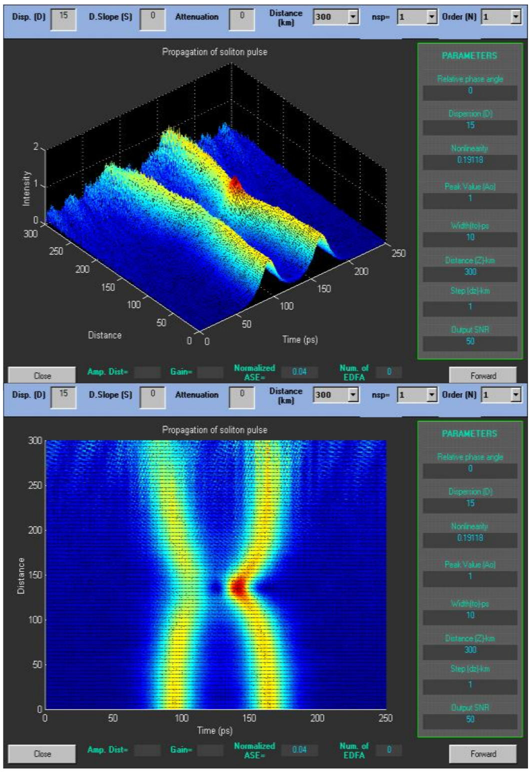
Disp. (D) 15 D.Slope (S) 0 Attenuation 0 Distance (km) 300 nsp= 1 Order (N) 1

PARAMETERS
Relative phase angle 0
Dispersion (D) 15
Nonlinearity 0.19118
Peak Value (Ao) 1
Width(to) ps 10
Distance (Z) km 300
Step (dz) km 1
Output SNR 50

Amp. Dist= Gain= Normalized ASE= 0 Num. of EDFA 0

Figure 3. Soliton-Soliton interaction with the dispersion effect removed by non-linear effect

At the next step, the combined effect of soliton interaction with Gordon-Haus Jitter effect on a communication fiber has been examined. As well known, the Gordon-Haus Jitter effect is a result of ASE distortion occurring on EDFA's. This effect not only reduces the SNR, it also causes frequency shifts on signal soliton as illustrated in Figure 4.

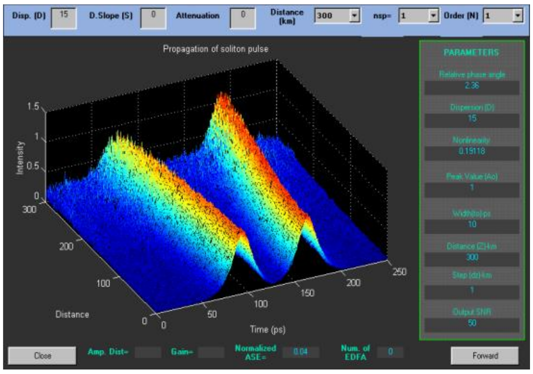

Disp. (D) 15
D.Slope (S) 0
Attenuation 0
Distance (km) 300
nsp= 1
Order (N) 1

PARAMETERS
Relative phase angle 0
Dispersion (D) 15
Nonlinearity 0.19118
Peak Value (Ao) 1
Width(to)-ps 10
Distance (Z)-km 300
Step (dz)-km 1
Output SNR 50

Amp. Dist=
Gain=
Normalized ASE= 0.04
Num. of EDFA 0

Figure 4. The combined dispersion effect of soliton-soliton interaction with Gordon-Haus Jitter effects removed by non-linear effect; Perspective and top view

The critical values of phase difference occurring between the soliton pulses have been calculated using equation 16 and the results are used to form figure 1. The frequency shift caused by these combined effects are optimized with the critical phase angle mentioned earlier resulted an improvement on phase shift shown in Figure 5.

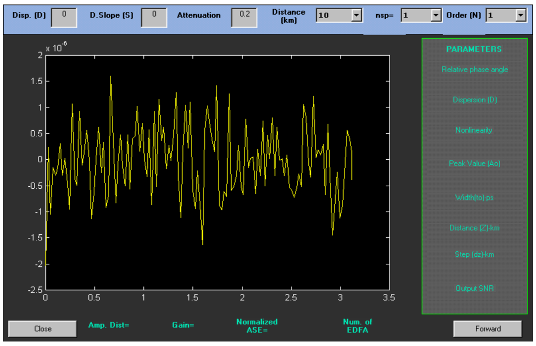

Disp. (D) 15
D.Slope (S) 0
Attenuation 0
Distance (km) 300
nsp= 1
Order (N) 1

PARAMETERS
Relative phase angle 2.36
Dispersion (D) 15
Nonlinearity 0.19118
Peak Value (Ao) 1
Width(to)-ps 10
Distance (Z)-km 300
Step (dz)-km 1
Output SNR 50

Amp. Dist=
Gain=
Normalized ASE= 0.04
Num. of EDFA 0

Figure 5. The effect of applying optimized initial phase difference between the successive soliton pulses for a 300 km transmission line

The varying parameters of simulation program can be seen on the figure panels. The number of EDFA's which have been used, varies depending on the dispersion effect, distance, soliton order, and attenuation. The ASE values appearing on the graphical screen shown in Figure 6 are appropriate overall values providing transmission without losing the characteristics of the soliton.


Disp. (D) 0
D.Slope (S) 0
Attenuation 0.2
Distance (km) 10
nsp= 1
Order (N) 1

PARAMETERS
Relative phase angle
Dispersion (D)
Nonlinearity
Peak Value (Ao)
Width(to)-ps
Distance (Z)-km
Step (dz)-km
Output SNR

Amp. Dist=
Gain=
Normalized ASE=
Num. of EDFA

Figure 6. The spectrum of ASE noise function at the input of EDFA

V. SOLAR ENERGY TRANSMISSION WITH OPTICAL FIBERS IN THE VIEW OF RENEWABLE ENERGY PERSPECTIVE

Solar energy transmission with the help of optical fibers idea was realized in 1980. Because of the difficulty of usage of high quality optical fibers and their high cost design, up to now, this project was analyzed only theoretical. Today effectiveness of fiber optic techniques, the solar energy could be transmitted with optical fibers which are high core diameter and large numerical aperture [16].

With some flexible options such as solar pumped lasers solar energy and lighting, power generation could be transmitted by with the help of optical fibers. The image of sun could be satisfied by a paraboloid concentrator and high density radiation on its focal point. To transfer the solar energy completely and efficiently, bundle components and the concentrator have to integrate properly. The dish parameters and image size on the focal point have a relationship. Aperture diameter, rim angle, focal length, diameter and location of fiber optic bundle, are critically important to optimize [17].

As a further study, it is going to be optimizing the low cost balance paraboloid dish. This is focus direct solar radiation with two axes follow up component, and the fiber optic bunch. By the way the solar energy could be transmitted. Optical importance and level of transferring energy with soliton based nonlinear optical systems will mathematically modelled for a non-symmetrical, low cost and high reflective balance paraboloid dish, transformed from a simple satellite antenna.

VI. CONCLUSIONS

The timing jitter may significantly limit the transmission distance in soliton based communication systems. In this study, the negative effects of the Gordon-Haus Jitter and soliton interaction mutually have been examined. The combined frequency shift caused by these two effects have been calculated and simulated. Generally, these two effects cause frequency shifts on the signal solitons. The combined jitter effects occurring between the neighboring soliton pulses which start either with or without phase shifts have been calculated and illustrated in the figures. The critical phase angle between the neighboring soliton have been calculated and normalized as Ψ_{ZM}=2.36, θ=0.2.

We have seen that when the phase difference between pulses was zero, there was a large fluctuation in normalized jitter. By allowing a phase difference between sequences of optical solitons, the low jitter window was obtained. The important result in this study is that mutually Gordon-Haus jitter and soliton interaction deal with the phase of optical pulses. This result is important for long haul communication systems and also lightning technology which is going to use in renewable energy research and application.

Next study will focus on mathematical modeling for ASE effect and direct relation and application of renewable energy research on lightning technology. The plastic, glass or liquid type of the optical fibers, could be chosen for this study. As known, glass optical fibers have less attenuation characteristic than the plastic ones. On the other hand, plastic optical fibers are more flexible and have higher core diameter. With these properties, they prefer for solar lighting. However, the solar power generation techniques are required high temperatures. Also, they are more appropriate to use with glass optical fibers. Optical fibers' holes margin should be reduced as much as possible to minimize the losses during the bundling process and timing jitter effect.

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BIOGRAPHIES

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