Stable Soliton Propagation Over the Fiber-optic System with Losses

B. Stojanović[1], D. Milović[2] , M. Stefanović[3] and N. Spasojević[4]

***Abstract* – This paper investigates the stable soliton propagation over the realistic fiber-optic system when fiber losses are taken into the consideration. The motivation for this paper is a fact that the fiber losses can be compensated by suitable amplification scheme. Periodically amplified signal yields stable pulse propagation over a long-haul distances.**

***Keywords* – Fiber-optic transmission, soliton, amplification scheme.**

I. INTRODUCTION

In a fiber-optic communication system information is transmitted over a fiber by using a coded sequence of optical pulses whose width is determined by the system bit rate R. The drawback of the fiber-optic transmission is a fiber loss. The fiber exhibits a minimum loss of about 0.2 dB/km near 1550 nm which has to be compensated.

There are several factors that contribute to the loss spectrum; material absorption and dominantly contributed Rayleigh scattering. The loss is considerably higher at shorter wavelengths [1].

The development of erbium-doped-amplifier (EDFA) has eliminated loss as a fundamental limit to achievable fiber optic transmission distance. This has rapidly led to the construction of all-optical long-haul communication systems. Before invention of optical amplifiers, optical transmission systems typically consisted of a digital transmitter and receiver separated by spans of transmission optical fiber interspersed with optoelectronic regenerators.

The application of optical amplifiers eliminated the problem of signal attenuation over the link, but the effect of fiber dispersion is still rising. Fiber dispersion is serious problem particularly in systems with large bandwidths and long distance lengths. Consequently, the extensive research on compensating techniques is present, including the soliton technique which eliminates the fiber dispersion effects by utilizing nonlinear fiber effects, namely, by balancing them for a sufficiently high levels of transmitted signal. Soliton technique is quite complex but very powerfull as it was implemented and utilized in many system designs.

[1]Bratislav D. Stojanović is with the Faculty of Electronic Engineering, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: batas@ni.ac.yu

[2]Daniela M. Milović is with the Faculty of Electronic Engineering, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: dacha@elfak.ni.ac.yu

[3]Mihajlo Č. Stefanović is with the Faculty of Electronic Engineering, Beogradska 14, 18000 Niš, Serbia and Montenegro, E-mail: misha@elfak.ni.ac.yu

[4]Nebojša D. Spasojević is with the NIS Jugopetrol, Milentija Popovića 1, 11000 Belgrade, Serbia and Montenegro, E-mail: nebojsa.spasojevic@jugopetrol.co.yu

II. OPTICAL LOSSES VS EDFA'S GAIN

A very important fiber parameter that should be taken into consideration is a measure of power loss during transmission of optical signals inside the fiber. If P_0 is the power launched at the input of a fiber of length L, the transmitted power P_T is given by [1]

$$P_T = P_0 e^{-\alpha L} \tag{1}$$

where α is attenuation constant, commonly referred to as the fiber loss.

The fiber attenuation is mainly caused by absorption and scattering. Absorption arises from impurities and atomic effects in the fiber glass. Scattering is mainly due to intrinsic refractive index variations of fiber glass with distance (Rayleigh scattering) and imperfections of the cylindrical symmetry of the fiber. The Rayleigh-scattering loss varies as λ^{-4} and is dominant at short wavelengths. Since this loss is intrinsic to the fiber, it sets the ultimate limit on the fiber loss. The loss level can reach values below 0.2 dB/km at around 1550 nm.

As a result of the power loss, the pulse width of the soliton also increases with propagation. To overcome the effect of fiber loss, solitons needs to be reshaped and amplified periodically to recover their original width and pick power. In a simple scheme, an optical amplifier boosts the soliton energy to it's input level. The soliton then readjusts its width to it's input value. However, it also sheds a part of its energy as a dispersive wave during the contraction phase.

The EDFA is an optical amplifier that amplifies signal purely in the optical domain. EDFAs can be used as a power amplifiers to boost transmitter power, as repeaters or in-line amplifiers to increase system reach, or as preamplifiers to enhance receiver sensitivity. The most far-reaching impact of EDFAs has resulted from their use as repeaters in place of conventional optoelectronic regenerators to compensate the transmission loss and extend the span between digital terminals. EDFAs amplifies light at wide range of wavelengths. In addition, optical amplifiers support the use of wavelength division multiplexing (WDM), whereby signals of different wavelengths are combined and transmitted together at the same transmission fiber.

Range of wavelengths when EDFA's gain is around 30 dB is 20-30 nm. With this kind of optical amplifiers, the overall gain is decreasing with the level of the output power and reaches 10 dB at +20 dBm of output power.

The gain of EDFA is varying with the distance from the location of pump signal, hence the gain is represented as follows [2]

$$G = \exp\left[\int_0^2 [\Gamma g(z) - a_i] dz\right] \quad (2)$$

where Γ represent limitation factor of propagating field, $g(z)$ is an inline amplification of a doped fiber that is changing over the axis of a propagating, pump wave, a_i is a total inline attenuation through the amplifying zone in doped fiber. Inline amplification can be represented as [2]

$$g(z) = \frac{g_0}{1 + I_{pro}(z)/ I_{sat}} \quad (3)$$

where g_0 is a small signal gain, $I_{pro}(z)$ is the intensity of propagating signal and I_{sat} is the intensity at the saturation level.

III. Simulation results

A single-channel transmission system is investigated, where timing jitter effects are negligible. Pulses are propagated with a bit rate of 40 Gbit/s. The transmission link consists mainly of SSMF with a nominal dispersion of 0.2 ps/nm·km and fiber losses of 0.2 dB/km. The RZ pulses are launched with peak power of 6 mW and FWHM duration of 12.5 ps. No extra phase modulation is applied. It should be noted that the pulse energy do not correspond with the solution of the fundamental soliton; it was significantly increased to provide the stable soliton propagation [3].

A single RZ signal stream is transmitted over 2,500 km, applying optical inline amplifiers and a periodic spacing of 50 km. Figure 1. shows the power profile and a portion of first three amplified spans (out of 50 spans) of fiber link. It is clearly noticable that the pulse power is rapidly decreasing but after each amplifier the soliton regains it's original peak.

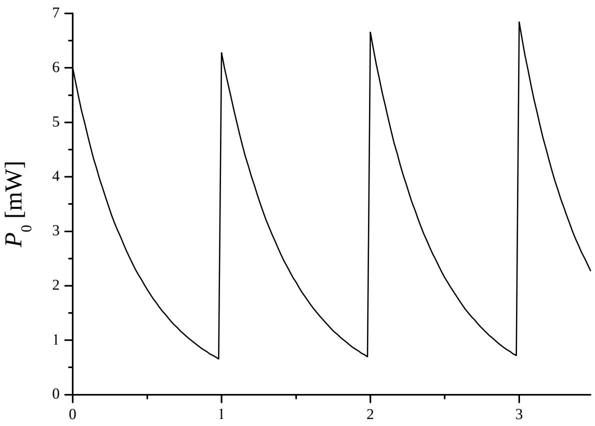

Fig. 1 Portion of power profile with first three spans

In this simulation, the doped fiber length was 30 m. Amplifiers gain was calculated to be the exact amount of the fiber loss in a single span.

Fig. 2 represents the evolution picture of stable soliton propagation over the 2500 km long fiber link with 50 amplified spans.

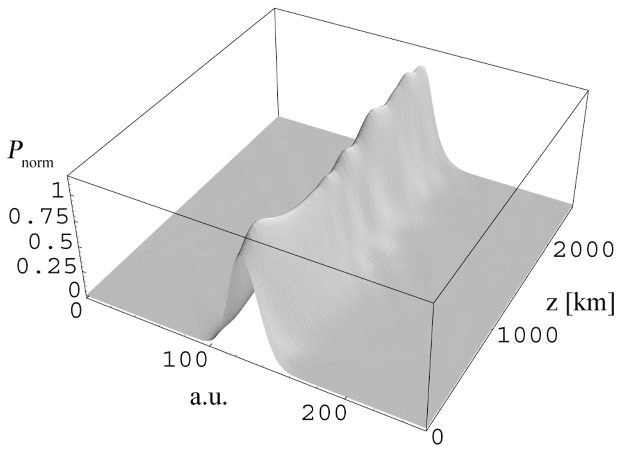

Fig. 2. Stable soliton propagation over periodically amplified fiber link

Fig. 2 is very descriptive as it shows soliton propagation that is slightly changing it's power and width. The figure encounters only the snap shots after each erbium doped amplifier (50 km), so it should be noted that the pulse is rapidly changing its peak power (nonlinear effect) and width (dispersive fiber effect) over one amplification span but readjusts itself after the amplifier. That should be taken into account in order to reduce the possible ISI effect when designing the real system.

IV. Conclusion

With the invention of Erbium-doped fiber amplifiers, the development of fiber-optic communication systems accelerated rapidly. Electro-optic repeaters could be replaced by the more robust, flexible and cost-efficient EDFAs, allowing all-optic links over transoceanic distances. The goal of this paper was to verify the necessity of the fiber amplifiers in the long distance link. In this simple simulation, it is shown that with the suitable amplification scheme fiber losses can be totally compensated. It should be also noted that the main drawback of the EDFA amplification is the induced ASE noise that should be considered at the receiver input.

References

[1] Govind P. Agrawal, *Nonlinear Fiber Optics*, The Instityt of Optics, University of Rochester, Rochester, New York.

[2] A. Marinčić, *Optičke telekomunikacije*, Univercity of Belgrade, Belgrade, 1997.

[3] W. Xue, G. Zhou, Z. Li, and S. Guo, “Stable Propagation of Solitons in Strongly Dispersion-Managed Unequal-Lenght Optical Fiber Link with Loss,” *Journal of Lightwave Technology*, vol. 18, pp. 926-932, No. 7, July 2000.