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Experimental study of data transmission in a long-haul passive span fiber-optic line with high information capacity

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Abstract. In the course of an experimental study, the possibility of building a line with an information capacity of 1 Tbit/s km using standard components for DWDM systems with non-linear dispersion compensation was shown. The calculation of the optimal parameters of the system has been carried out. It is shown that for given values of range L, chromatic dispersion D, transmission rate B, it is possible to choose the optimal input power of bit pulses P_0, which provides the best signal-to-noise ratio at the reception.

Keywords: fiber optic cable, optical fiber, dispersion, optical soliton, optical communication channel, laser radiation

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Экспериментальное исследование передачи данных в пассивной однопролетной ВОЛС с высокой информационной емкостью

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Аннотация. В ходе экспериментального исследования была показана возможность построения линии с информационной емкостью 1 Тбит/с км с использованием стандартных компонентов систем DWDM с компенсацией дисперсии эффектом фазовой самомодуляции. Проведен расчет оптимальных параметров системы. Показано, что при заданных значениях дальности L, хроматической дисперсии D, скорости передачи B можно подобрать оптимальную входную мощность битовых импульсов P_0, обеспечивающую наилучшее отношение сигнал/шум на выходе линии. Получено хорошее подтверждение экспериментальными данными аналитического описания эволюции символьных оптических импульсов в волоконном световоде и результатов компьютерного моделирования.

Ключевые слова: волоконно-оптический кабель, оптическое волокно, дисперсия, оптический солитон, оптический канал связи, лазерное излучение

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Introduction

To increase in information flows transmitted in fiber-optic communication systems it necessitates an increase in the information capacity of the system: the bit rate over single channel, on the one hand, and the increase the distance between amplifiers, on the other hand.

Fiber optics transmission systems with large distances between amplifiers (long-haul systems) have more advantages. Span lengths of 100 ... 150 km are used, as a rule, on single-span sections.

The task of implementing the long-haul high-speed fiber-optic transport system remains relevant. Of particular interest is the system built on standardized DWDM-system components.

In high-speed data transmission systems over distances of the order of hundreds of kilometers, nonlinear fiber effects cannot be ignored. Moreover, they can be used to increase the information capacity of fiber optics transmission systems. For example, the effect of self-phase modulation (SPM) of the ultrashort optical pulses, which can be used to realize the optical soliton in fiber. The operation of high-speed communication lines is usually limited by the effect of group velocity dispersion [1–5]. The pulse is broadened, losing energy in the bit interval. Since solitons can maintain their shape due to the balance between nonlinear and dispersive effects in the region of anomalous dispersion of fibers, their use could improve the performance of such communication systems [1–3]. At the bit rate near 10 Gbit/s, the power required to form the optical soliton in the standard single mode optical fiber (SSMF) is not very big. The use of the self-phase modulation effect makes it possible to compensate for dispersion broadening by the effect of nonlinear self-compression of pulses in the region of negative fiber dispersion. This increases not only the speed of information transfer, but also its reliability.

Optical solitons occur as the balance between linear effects (which would spread a localized wave packet of small amplitude) and nonlinear effects in the optical fibers. Indeed, the potential for solitons as optical bits for optical fiber transmission systems was recognized immediately. But in real optical fibers, there are losses that can upset the balance between non-linear effects and chromatic dispersion. If the propagation distance of soliton pulses is greater than the characteristic loss length, the so-called pass average soliton can be existed [1–23].

The purpose of this work was to study the possibility of creating a single-span soliton data transmission system with a high information capacity. For this, an analytical study and computer simulation, was carried out. The experimental study showed the possibility of creating the soliton system on standard components of DWDM systems.

Theoretical Description

The equation of pulse propagation in an optical fiber in the case of taking into account dispersion, nonlinearity, and losses is [1, 3]:

$$i\frac{\partial q}{\partial Z}+\frac{1}{2}\beta_2\ \frac{\partial^2 \mathrm{q}}{\partial \mathrm{T}^2}q=-i\Gamma q,$$

nonlinear Schrödinger equation, where $q(z, t)$ is the pulse amplitude, β_2 is the group velocity v_g dispersion related to the fiber dispersion parameter D by the relation: $\beta_2 = -\lambda^2 D/(2\pi c)$, λ is the wavelength, c is the light velocity,

$$\Gamma=\frac{\pi c\alpha T_0^2}{\lambda^2 D}=\alpha L_D,$$

where α is the optical loss, L_D is the dispersion length:

$$L_D=\frac{T_0^2}{\beta_2},$$

where the value of T_0 is related to the pulse full width at half maximum T_{FWHM} by:

$$T_{FWHM} = \frac{2T_0}{\cosh\left(\sqrt{2}\right)} = 1,76T_0,$$

In the case of Γ > 1, a soliton solution of the Schrцdinger equation can be obtained under the condition [2–3]

$$P_0 = a_0^2 \frac{\beta_2}{\gamma T_0^2},$$

P_0 is the initial soliton pulse power, γ is the non-linear parameter, and

$$a_0 = \sqrt{\frac{2\alpha L}{1-\exp(-2\alpha L)}}.$$

As can be seen from the above relations, the soliton like propagation of the symbol pulses is possible with special choice of the optical fiber parameters (dispersion, nonlinear coefficient, loss) and the pulse parameters (power, width).

For SSMF (standard single mode fiber) typically $\beta_2 = 20$ ps²/km, $\gamma = 1.2$ W⁻¹km⁻¹, $\alpha = 0.023$ km⁻¹. For transmission length L = 100 km the initial soliton pulse power must be P_0 = 20 dBm.

To realize pass-average soliton it was carried out the computer simulation and the experimental investigation.

Computer Simulation

Computer simulation allows to identify the mechanisms that determine the performance characteristics of the system. It is shown that the greatest contribution is made by such a nonlinear effect as self-phase modulation (SPM). The use of this effect makes it possible to increase the output optical signal-to-noise ratio (OSNR), which ensures high communication quality, in the absence of the need to turn on the dispersion compensator.

Block diagram of the modeling information transmission system is presented in Fig. 1. Symbol pulses from semiconductor laser with direct modulation (wavelength $\lambda = 1536$ nm) with the bit rate $B = 10$ Gbit/s were propagated throw SSMF ($L = 100$ km). Initial pulse power P_0 was from 1 up to 25 dBm.

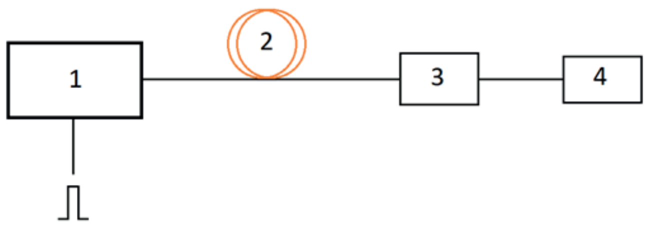

Fig. 1. Block diagram of the modeling information transmission system: 1 – semiconductor laser with direct modulation (wavelength λ = 1536 nm), 2 – optical fiber, 3 – photodetector, 4 – BER-analyzer

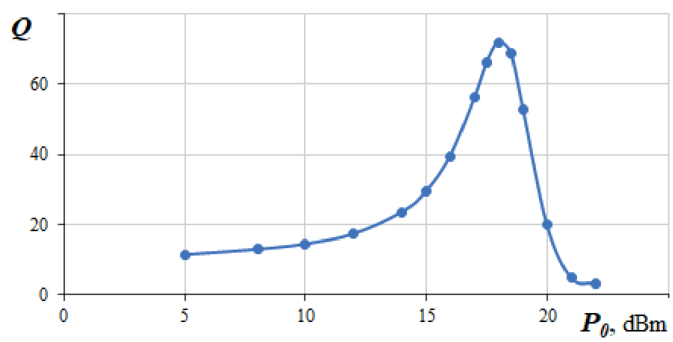

Fig. 2. Dependence of Q-parameter on the pulse input peak power P_0. Results of computer simulation

Results of computer modeling in OptiSystem program is presented in Fig. 2, where $Q \sim$ OSNR^2. The optimal initial pulse power is 18 dBm, which is in good agreement with the calculated value.

Experimental Results and Discussion

An experimental study was carried with the DWDM fiber optics equipment. The experimental stand included transponder, multiplexor, Er-doped amplifier, optical fiber (100 km), demultiplexor and testing systems equipment (Optical Spectrum Analyzer, OSA, BER - analyzer, optical power meter). The pulse coded sequence of the optical pulses with clock frequency 10 GHz was generated by the semiconductor distributed feedback laser (DFB laser) with external modulation. The signal from the laser was fed to the input of the multiplexer and then to the input of Er-doped optical amplifier. The optical pulse parameters were controlled using OSA.

The study was conducted at wavelength $\lambda = 1536$ nm. SSMF was used as the transmission path. The used transponder provided bit rate $B = 10$ Gbit/s, $L = 100$ km. Losses in the multiplexer did not exceed 6 dB and were compensated by an optical Er-amplifier. Block diagram of the experimental study is presented in Fig. 3.

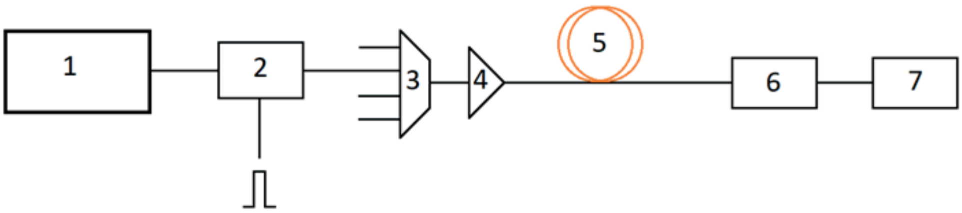

Fig. 3. Block diagram of the experimental study: 1 – optical pulse source, 2 – modulator, 3 – multiplexer, 4 – optical amplifier, 5 – optical cable, 6 – photodetector, 7 – BER-analyzer

The results of OSNR measurements by OSA versus the initial power P_0 are shown in Fig. 4. The best OSNR was obtained at $P_0 = 18$ dBm, which is in good agreement with computer simulations.

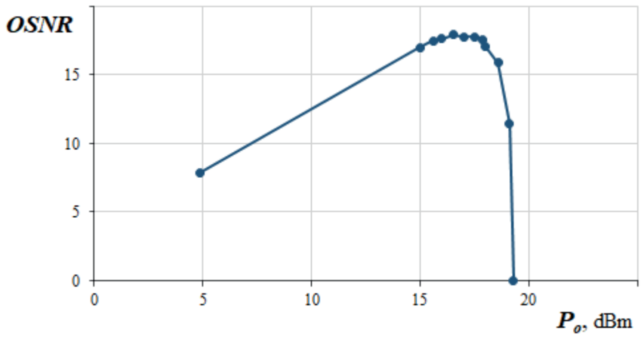

Fig. 4. Dependence of OSNR on the input pulse peak power P_0. Results of the pilot study

Conclusion

During the computer modulation and experimental study, it was shown that the effect of self-phase modulation can be effectively used to compensate for the dispersion broadening of pulses – information carriers and the creation of optical solitons. The optimal parameters of the pulse and optical fiber are selected to obtain high information capacity (1 (Tbit/s)·km) system: span – 100 km at high speed – 10 Gbit/s. The possibility of constructing the soliton long-haul fiber optics system using standard for DWDM systems components was successfully demonstrated.

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