Influence of the nonlinear effects on the high bit rate fiber-optics communication system

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Abstract. Fiber-optic telecommunication systems provide high information capacity, defined as the product of bit rate and transmission distance. To achieve high information capacity, it is necessary to take into account all the effects that affect symbol pulses in optical fiber. Experimental investigation has shown that control of the symbol pulse spectrum allows us to identify the effects of their self-action and achieve maximum information capacity of the telecommunication system.

Влияние нелинейных эффектов на высокоскоростную-волоконно-оптическую систему связи

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Аннотация. Волоконно-оптические телекоммуникационные системы обеспечивают высокую информационную емкость, определяемую как произведение скорости передачи данных на дальность передачи. Для достижения высокой информационной емкости необходимо учитывать все эффекты, которые влияют на символьные импульсы в оптоволокне. Экспериментальное исследование показало, что управление спектром символьных импульсов позволяет выявить эффекты их самовоздействия и достичь максимальной информационной емкости телекоммуникационной системы.

Introduction

Long-haul fiber-optic distance data transmission involves the use of high-power symbol optical pulses. Given the small size of the mode spot in single-mode optical fiber, nonlinear effects have an impact. Nonlinearity results in a change in the spectrum of the optical signal, and this can be easily controlled using optical spectral analysis.

The change in the shape of the envelope occurs later and these changes are difficult to register. It is necessary to know the effect of nonlinearity for each case. In general, this depends not only on the optical fiber parameters and the input power, but also on the specific laser and its chirp. In dense wavelength division multiplexing (DWDM) systems, the quality of data transmission is affected by linear (loss, dispersion) effects and nonlinear effects (Carrier-Induced Phase modulation, CIP, Four-Wave Mixing, FWM, Stimulated Raman Scattering, SRS, Stimulated Brillouin Scattering, SBR, and others) [1−5].

Some nonlinear effects appear when the pulse power exceeds the threshold level or when there are the large number of spectral channels. The CIP-effect is present not only in DWDM systems, but in single channel system also. So we investigated CIP effect in the high bitrate fiber-optic communication system.

Experimental Results and Discussion

Nonlinear properties of optical fibers are most clearly manifested in the region of anomalous (negative) dispersion. In the region of negative values of group velocities, compensation of dispersion broadening of the pulse by nonlinear effects and formation of a soliton is possible. The joint effect of group velocity dispersion (GVD) and self-phase modulation (SPM) on the process of propagation of an optical pulse is of key importance.

In the presence of nonlinear phase self-modulation, the phenomenon of modulation instability occurs. In many nonlinear systems, the stationary wave state turns out to be unstable. The combined action of nonlinear and dispersion effects can be studied by solving the basic propagation equation.

The propagation equation in the case where losses can be neglected is

$$i \frac{\partial A}{\partial z} = \frac{1}{2} \beta_2 \frac{\partial^2 A}{\partial t^2} - \gamma |A|^2 A$$

is the nonlinear Schrӥdinger equation, where $A(z,t)$ is the amplitude of the wave packet envelope, β_2 is the value of the group velocity dispersion, γ is the nonlinearity parameter for phase self-modulation. In the case of continuous radiation, the amplitude A at the beginning of the optical fiber ($z = 0$) does not depend on t.

In the region of negative dispersion ($\beta_2 < 0$), the solution of the nonlinear Schrӥdinger equation becomes unstable, since spontaneous modulation of the steady state occurs. Nonlinear effects lead to the broadening of the signal spectrum in the optical fiber. The maximum gain of the nonlinear signal occurs at the frequencies that are separated from the signal frequency by the value Δf [1, 2]:

$$\Delta f = \pm \frac{1}{2\pi} \sqrt{\frac{2\gamma P_o}{|\beta_2|}},$$

where P_o is the input optical pulse power. This results in the appearance of two side spectral maxima. In the used Non-Zero Dispersion-Shifted fiber (NZDSF) these parameters are: the group velocity dispersion $\beta_2 = -2.5$ ps²/km, nonlinear coefficient $\gamma = 2.5$ W⁻¹ km⁻¹ at the wavelength $\lambda = 1.55$ μm.

Even when only one pump radiation propagates in the fiber, CIP can lead to spontaneous decay of the stationary harmonic wave into the periodic train of pulses. Spontaneously emitted or thermal photons act as the optical signal, amplified by modulation instability. Therefore, direct evidence of CIP can be the presence of two additional spectral components located symmetrically relative to the central frequency f_o with a spectral detuning $f = f_o \pm \Delta f$.

The experimental study was carried out with the measuring stand included the telecommunication DWDM equipment (Fig. 1). The experimental setup included: the laser source ($\lambda = 1550$ nm), optical Er-doped amplifier; optical fiber; attenuator; optical spectrum analyzer. Initial pulse power changes from a 1 dBm to 24 dBm in the optical fiber.
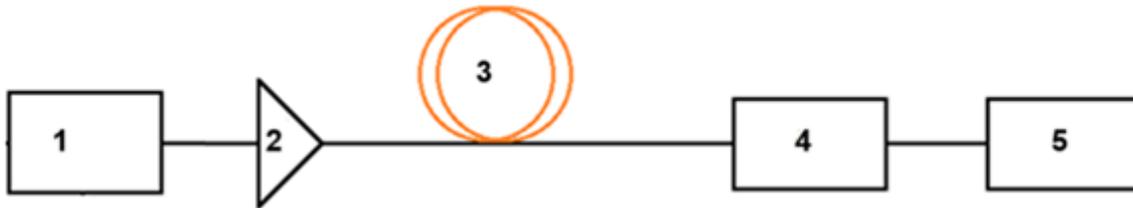

Fig. 1. Structural block diagram of the measuring stand:
laser source ($\lambda = 1550$ nm) *1*, optical Er-doped amplifier *2*, optical fiber *3*,
attenuator *4*, optical spectrum analyzer Yokogawa AQ6370C *5*

The results of the experimental investigation are presented in the Fig. 2. Change of the optical signal spectrum at $\lambda = 1550$ nm is the result of CIP-effect.
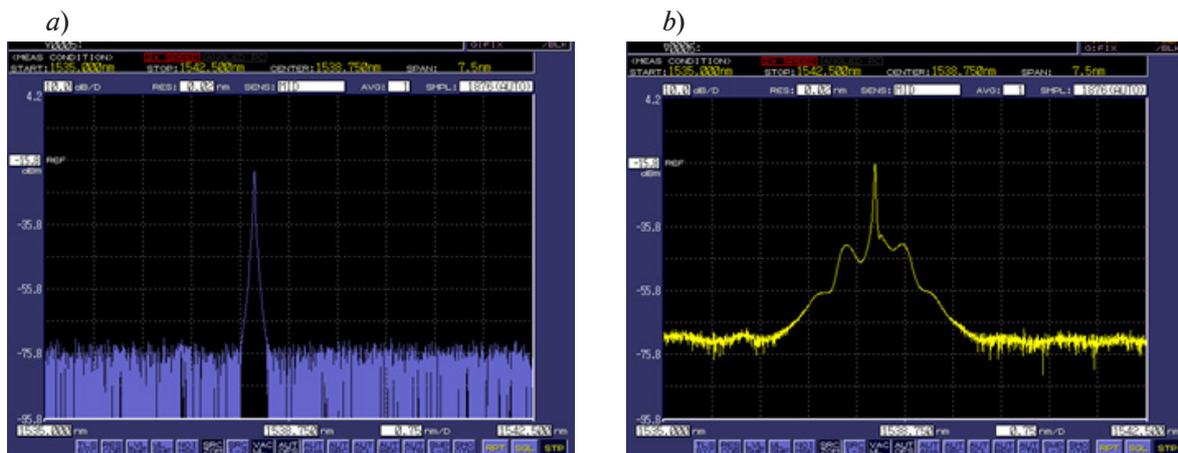
a)

b)

Fig. 2. Optical signal spectrum at the input (*a*) and output (*b*) of the optical fiber

Nonlinearity leads to the change in the spectrum optical signal and this is easy to control by optical spectrum analyzer (Fig. 3)

Experimental investigation has shown that nonlinear effect imposes limitations on the initial optical pulse power in high bit rate DWDM telecommunication system.
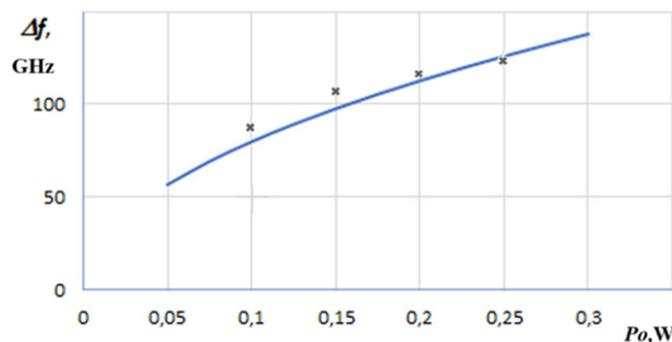

Fig. 3. Dependence of Δf on the input optical signal power P_o
The points *x* mark the measurement results

Conclusion

Thus, nonlinear effects have the significant impact on the parameters of symbol pulses when transmitting an optical signal over a single-mode fiber optic cable. With increasing bit rate, the initial pulse power and the communication transmission length, the influence of nonlinear effects increases.

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