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Investigation of the possibility of creating a broadband measuring source using the nonlinear properties of an optical fiber

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Abstract. A computer simulation and experimental study of a broadband laser source for testing fiber-optic communication systems has been conducted. The study investigated the use of nonlinear optical effects in fiber to expand the spectrum of a laser source. Two types of fiber were compared: standard single-mode fiber (SSMF) and dispersion shifted fiber (DSF), to determine the best parameters for the source.

Keywords: fiber-optic communication system, Wavelength Division Multiplexing, optical fiber, nonlinear effects

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Исследование возможности создания широкополосного измерительного источника с использованием нелинейных свойств оптического волокна

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Аннотация. Проведено компьютерное моделирование и экспериментальное исследование широкополосного измерительного лазерного источника для тестирования спектрально-селективных компонентов волоконно-оптических систем связи с мультиплексированием по длине волны. Показано, что за счет использования нелинейных эффектов в оптоволокне можно добиться многократного расширения спектра лазерного источника. Проведено сравнение параметров таких источников в случае использования стандартного одномодового волокна (SSMF) и волокна со смещенной дисперсией (DSF).

Ключевые слова: ВОЛС, мультиплексирование по длине волны, WDM, волоконный световод, нелинейные эффекты, спектр

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Introduction

The development of fiber-optic communication systems with wavelength division multiplexing has led to the development and implementation of a wide class of passive spectral-selective devices for such systems [1-5]. Measurement sources such as ASE are traditionally used to measure the spectral bandwidth of spectrally selective passive elements of fiber-optics communication system. They provide a wide spectral band at a relatively high power of optical radiation. Broadband sources, complete with spectrally selective meters, such as an optical spectrum analyzer (OSA), allow you to visualize the results of measuring the bandwidth of the device under test. Narrow-band lasers, complete with broadband measuring power (OPM, Optical Power Meter) are used for accurate measurements of device operating parameters. In this case, the optical power meter must have either a smooth spectral sensitivity characteristic, or the possibility of considering its non-uniformity using calibration coefficients in each spectral range.

The aim of this work is to study the possibility of creating a broadband measuring source using a semiconductor laser and the nonlinear properties of an optical fiber.

Theory

Semiconductor lasers make it possible to obtain the high optical power pulses in the single-mode optical fiber; the Kerr nonlinearity effect makes it possible to achieve the significant broadening of their spectrum. Depending on the initial laser energy pulse parameters, the characteristics and length of the optical fiber, the broadband spectrum source can be obtained. Analytical description of nonlinear effects is possible only in some special cases. In this regard, of particular importance is the possibility of computer simulation of the effect of nonlinear broadening of the laser radiation spectrum in an optical fiber, considering optical power losses and group velocity dispersion.

The propagation equation in the case where losses can be neglected has the form of [1–2]

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

is the nonlinear Schrödinger equation, where $A\,(z, t)$ is the amplitude of the wave packet envelope, z, t are the spatial and time coordinates, β_2 is the value of the dispersion of group velocities, γ is the nonlinearity parameter in the case of self-phase modulation.

If the propagation distance $L \ll L_D$, but $L \gtrsim L_{NL}$, then in this case the effect of self-phase modulation determines the evolution of the pulse in the optical fiber, leading to spectral broadening of the pulse. The mode in which the nonlinearity dominates always takes place when

$$\frac{L_{NL}}{L_D}=\frac{\left|\beta_2\right|}{\gamma P_0 T_0^2}\ll 1, \tag{2}$$

In the approximation of the absence of group velocity dispersion ($\beta_2 = 0$) and optical power loss ($\alpha = 0$) for a pulse with a Gaussian envelope profile

$$A(0,t)=e^{\frac{t^2}{2\tau_0^2}}.$$

For a Gaussian pulse, the broadening of the spectrum caused by the self-phase modulation effect, $\delta\omega_{NL}$ is equal to

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$$\delta\omega_{NL} = \sqrt{\frac{2}{e}\frac{z}{L_{NL}}}\Delta\omega_0 .$$

The broadening coefficient of the pulse spectrum K can be determined by the approximate expression

$$K = \sqrt{\frac{2}{e}\frac{z}{L_{NL}}} .$$

Computer simulation

The computer simulation of the effect of nonlinear broadening of the laser spectrum in the optical fiber was made with considering optical power losses and group velocity dispersion. The optical simulation block diagram (Fig. 1) contains of the picosecond pulses source (*1*), optical preamplifier (booster) (*2*), standard single mode optical fiber (SSMF) or dispersion shifted fiber (DSF) (*3*), demultiplexer (*4*) (with $\Delta f = 100$ GHz, for example) and optical spectrum analyzer (5).

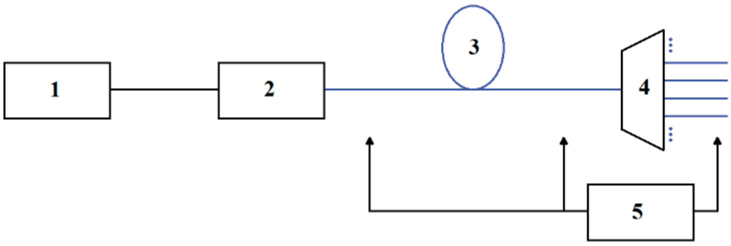

Fig. 1. The optical block diagram of the computer simulation: *1* – laser, *2* – optical amplifier, *3* – optical fiber, *4* – demultiplexer, *5* – optical spectrum analyzer

Picosecond pulses from the laser (*1*) after amplification (*2*) are fed to the input of the SSMF or DSF (*3*). The input power P_0 of the optical pulses was selected to be sufficient for the formation of a high-order soliton (Eq. 2). Such pulse undergoes self-compression with a significant broadening of the spectrum. The simulation was carried out under the condition of a slight change in the envelope of the optical pulse ($z < (L_D L_{NL})^{1/2}$) [2].

The spatial dynamics of the spectrum broadening as it propagates along the optical fiber is shown in Figure 2. The monotonic broadening of the initial spectrum corresponds to the calculations. Envelope of the optical pulse remained the same.

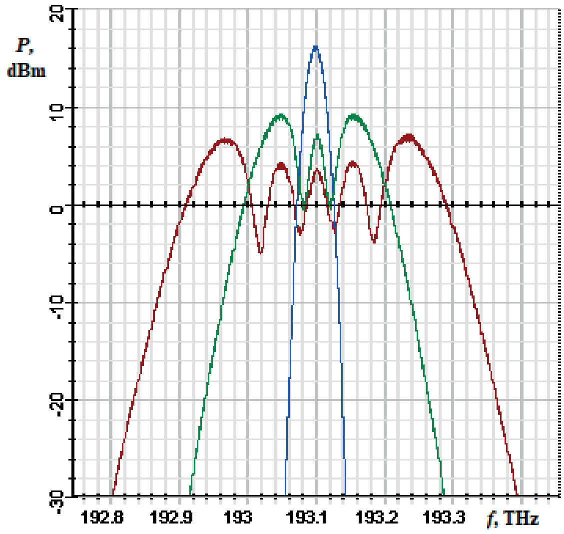

Fig. 2. The spectrum of the pulse at the entrance to the optical fiber (1) and after passing 1.2 km (2) and 2 km (3)

Thus, computer modeling has shown that the numerical estimates for K obtained in the approximation of the absence of dispersion of the second and higher order, as well as other nonlinear effects, can be used to qualitatively describe the broadening of the spectrum in an optical fiber.

Experimental Results and Discussion

The experimental setup included the laser source, the narrow-band filter, Er-amplifier, the standard optical fiber and the optical spectrum analyzer. Operating wavelength of the laser $\lambda = 1546.12$ nm (39th DWDM channel). Fiber optic parameters: dispersion $D = 16.67$ ps/nm/km ($\beta_2 = -20$ ps^2/km), Kerr nonlinearity coefficient $\gamma = 1.2$ W^{-1}km^{-1} loss 0.2 dB/km. The Previal erbium amplifier provided 24 dBm of optical power in the optical fiber. Results are presented at Fig. 3.

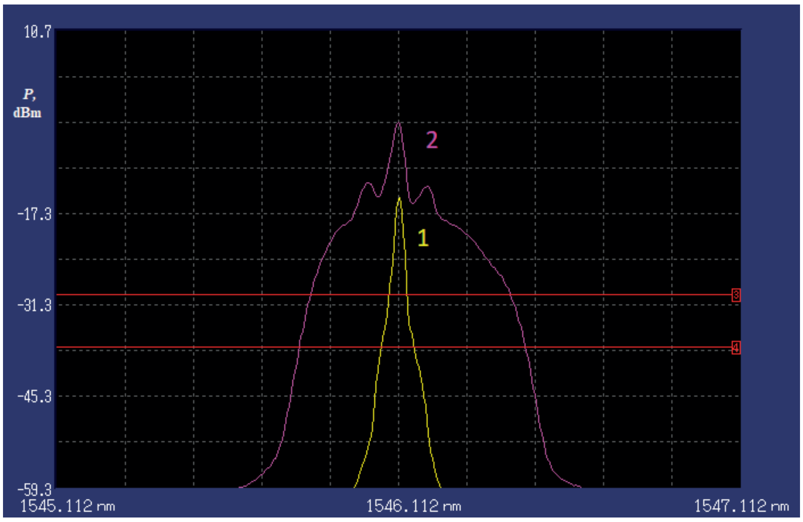

Fig. 3. Optical signal spectrum at the output of the optical fiber without an amplifier (1) and with an amplifier (2)

Studies have shown that to achieve greater spectral width at the output of the optical fiber, it is necessary to use a laser with a narrow spectrum to input radiation. Notch filters can be used to improve efficiency.

Conclusion

Thus, it has been shown that, due to the use of nonlinear effects in an optical fiber, it is possible to achieve a multiple broadening of the spectrum of a laser source.

Computer simulation confirmed the possibility of obtaining a broadband source. Spectrum broadening can be achieved by using a longer optical fiber. With a fixed optical fiber length, a wider spectrum is achieved with more input power. A smoother spectral response is achieved with DSF. With SSMF, a slightly higher optical signal power is required to achieve the same bandwidth as with DSF.

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