

Investigation of optical pulse propagation in optical fiber

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Abstract. The optical analog of dispersion-time method of measurement of radio spectrum is offered. The ratio between the duration of the input pulse and the differential delay group of dispersion system is established for satisfaction spectrum analyzes of optical pulses. Determining spectral measurements errors method is offered.

1. Introduction

Spectrum analysis is one of the most important field in optical measurements. In compare, with radiofrequency measurements it is impossible oscilloscopic observation of optical signals. Only one way exists to research dynamic signal optical frequency – it's spectrum analysis. Therefore, the most urgent goals at present time and future is improving of known methods and apparatus spectrum analysis. Offered researches allow building the basis of another new optical spectrum analyzer.

In this paper the possibility of new optical spectra measurement like as propagation of optical pulses in a dispersive system (optical fiber) is considered. Such spectrum analyser creating is based on a well-known in a radio range dispersion-time method of measuring radio spectrum [1].

2. Complex spectrum spread function of spectrum analyzer

The functional diagram of the optical spectral device is shown in figure 1.

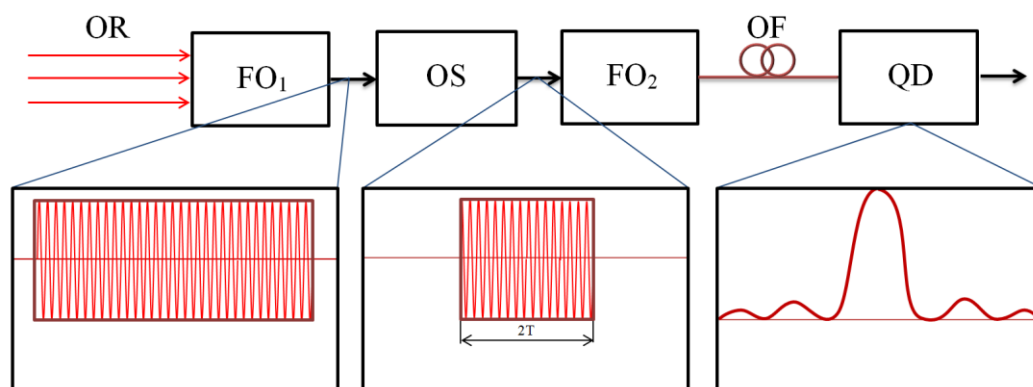


Figure 1. Functional diagram of definition complex spectrum spread functions dispersion-time spectrum analyser, where OR – optical radiation, FO₁,FO₂ - forming optics, OS - optical shutter, OF – optical fiber and QD - quadratic detector.

A well-known theory of dispersion-time analysis of radio spectrum is based on inequality $\Delta T \gg 2T$, where ΔT – is length of the analyzed radio pulse; $2T$ – is differential delay. In the frame theory of spectral measurements the problem of ratio $\Delta T/2T$ is not detected. The goal of this paper is researching of transformation optical pulse in dispersive medium, for example in an optical fiber for determining the minimum allowable ratio $\Delta T/2T$.

The result of measuring the complex spectrum $S_a(\omega)$ dynamic signal $s(t)$:

$$S_a(\omega) = \int_{-\infty}^{\infty} K(\omega, \omega') S_0(\omega') d\omega', \quad (1)$$

where $S_0(\omega)$ – mathematic spectrum of analyzed signal $s(t)$, $K(\omega, \omega')$ – complex spectrum spread function of spectrum device.

In the case of “real spectral device in perfect performance” witch making is Fourier transform of its complex spectrum spread function have form:

$$K(\omega, \omega') = \frac{\sin(\omega, \omega')T}{\omega - \omega'}, \quad (2)$$

where $2T$ – time of analyzing.

The complex spectrum spread function of optical spectral devices is defined as a reaction to the homogeneous plane monochromatic wave. When using optical fiber as resolving system of a spectral device, it is only required to study propagation in an optical fiber of a single optical pulse $e_0(t)$ shaped as monochromatic oscillation with duration $2T$ (figure 1).

3. Mathematic modeling of evolution optical pulse in dispersive media.

To determine the degree of closeness function describing the response of the optical fiber impulse $e_0(t)$ to the complex spectrum spread function (2) corresponding mathematical modeling was performed at the following approximation of the transfer function of the optical fiber:

$$K = \begin{cases} K \exp \left\{ -i \left[\frac{(\omega - \omega_0)^2}{2\nu} + (\omega - \omega_0)t_0 \right] \right\} & \text{if } \omega_0 - \frac{\Delta\omega_0}{2} \leq \omega \leq \omega_0 + \frac{\Delta\omega_0}{2} \\ 0 & \text{if } \omega < \omega_0 - \frac{\Delta\omega_0}{2}, \omega > \omega_0 + \frac{\Delta\omega_0}{2}, \end{cases} \quad (3)$$

where, ω_0 – average frequency bandwidth;

t_0 – constant delay;

ν – the slope of the linear group delay characteristics;

$\Delta\omega_0$ – bandwidth.

One of the most important characteristics of the dispersive medium which using the transfer function (3) is the differential delay ΔT .

Mathematical modeling of evolution $e_0(t)$ in optical fiber with different ΔT was performed with corresponding with formula:

$$I(y) = \frac{I_0}{2} \left[\left(C(\xi_2) - C(\xi_1) \right)^2 + \left(S(\xi_2) - S(\xi_1) \right)^2 \right], \quad (4)$$

where, $I(y)$ – oscillation intensity at the output of optical fiber; $C(\xi) = \int_0^\xi \cos(\frac{\pi t^2}{2}) dt$,

$S(\xi) = \int_0^\xi \sin(\frac{\pi t^2}{2}) dt$ – Fresnel integrals.

The results of mathematical modeling of the optical pulse evolution in the form of truncated monochromatic oscillation are presented at the following diagrams:

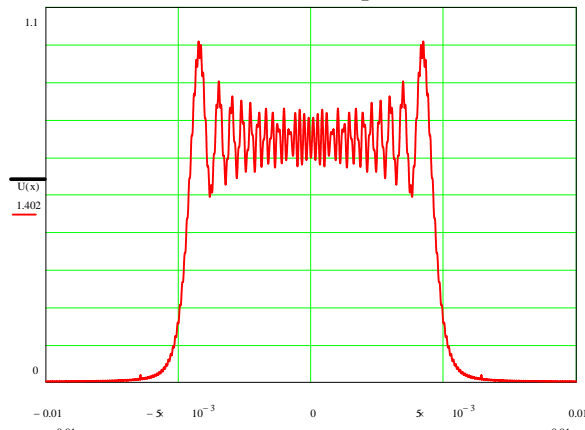


Figure 2.

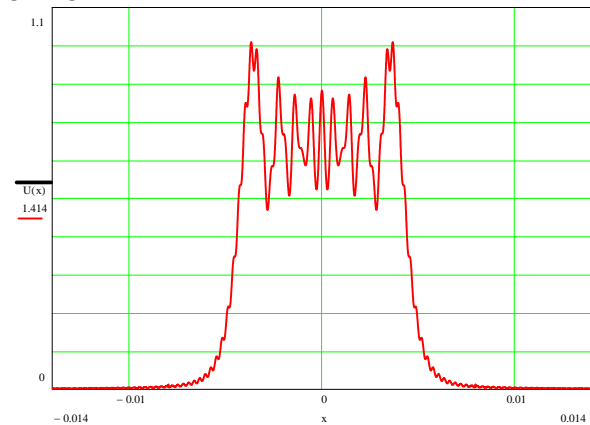


Figure 3.

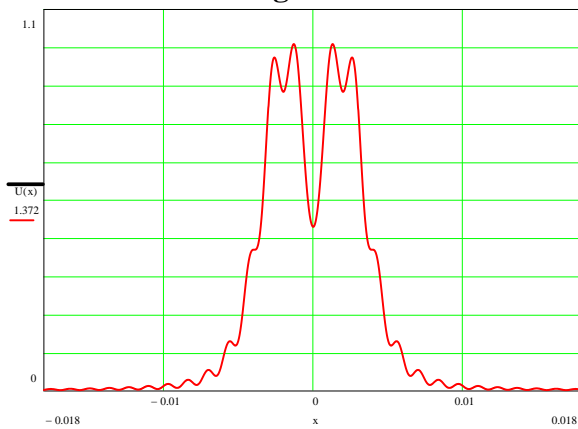


Figure 4.

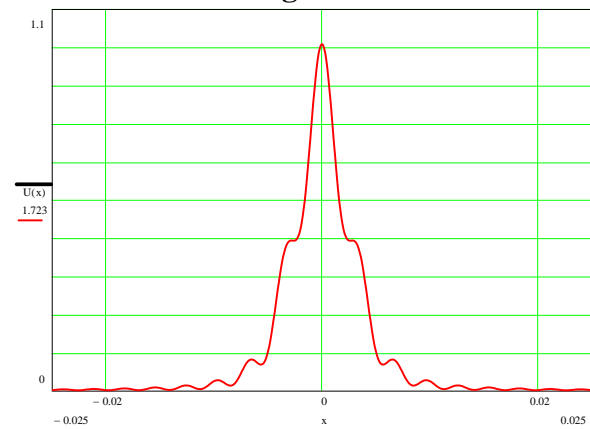


Figure 5.

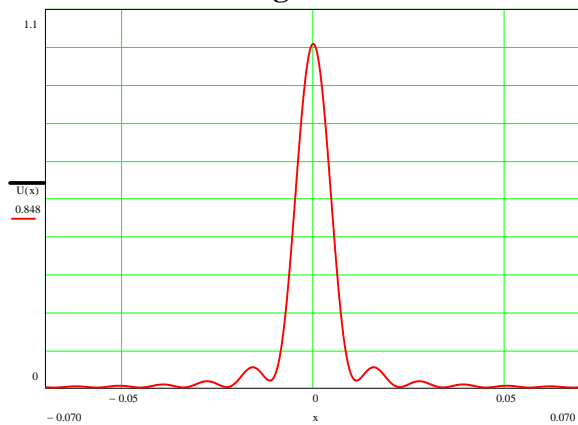


Figure 6.

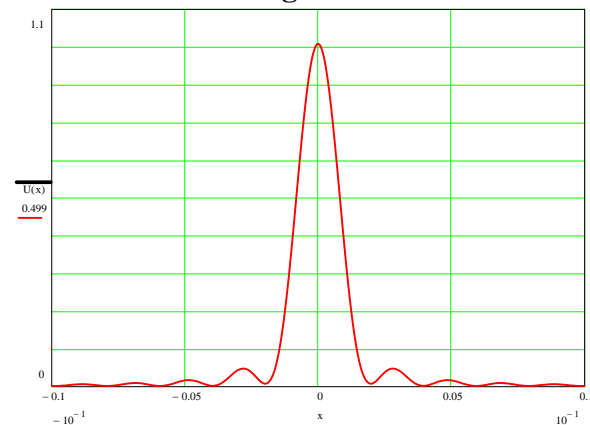


Figure 7.

From these figures, it follows that a good approximation to the required complex spectrum spread function (2) is obtained when $\Delta T/2T = 50$ (Figure 7).

4. Errors of the spectral measurements.

In the ratio (1) the complex spectrum spread function is a reproducible kernel for spectral function which is described by entire functions of exponential type of degree T . For this reason, the kernel (1) is complex spectrum spread function of "real spectral device in perfect performance"

In real spectrum measurements with help of optical fiber the complex spectrum spread function as shown by figure 7 is described by relation which differs from (2). It leads to spectral measurement errors because the results of spectrum analyzing is described in the form (1), where $K(\omega, \omega') \neq \sin(\omega - \omega')/(\omega - \omega')$.

The error of spectral measurements ΔS have form:

$$\Delta S = \int_{-\infty}^{\infty} d\omega \left[\int_{-\infty}^{\infty} S_0(\omega') \frac{\sin(\omega - \omega')T}{\omega - \omega'} d\omega' - \int_{-\infty}^{\infty} S_0(\omega') K(\omega, \omega') d\omega' \right]^2, \quad (5)$$

this function can be simplified to:

$$\Delta S = \int_{-\infty}^{\infty} d\omega \left[\int_{-\infty}^{\infty} S_0(\omega') \Delta K(\omega, \omega') d\omega' \right]^2, \quad \text{where } \Delta K(\omega, \omega') = \frac{\sin(\omega - \omega')}{\omega - \omega'} - K(\omega, \omega'). \quad (6)$$

The equation (6) allows to raise the question of such complex spectrum function $S_0(\omega)$ which is maximum distorted at given complex spectrum spread function $K(\omega, \omega')$. This problem can be solved by methods of calculus of variation.

5. Conclusion

In this paper method of measuring optical spectrum which based on dispersion properties of optical fiber is offered. The ratio between the length of the analyzed signal and differential delay dispersion system is detected. This ratio allows to say about the satisfactory performance of the analysis of the spectrum of the optical pulse signal. The method of determining the spectral measurement errors is offered. This method can be used for spectral measurements in any spectral instruments.

6. Reference

- [1] V I Tverskoy 1974, *Dispersion-time measurement methods of radio spectrum* (Moscow: Soviet radio)