# Photo detection process and power spectrum estimation of optical radiation by the multichannel resonant spectrum analyzer

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**Abstract** The problem of receiving of an energy spectrum estimation of optical radiations in the new analyzer of optical signals is considered. It is the parallel resonant optical spectrum analyzer (SPECTRUM ANALYZER). Its resolving system is a set of narrow–band optical resonators in the form of interference filters. Each optical resonator is equivalent to a system with lumped parameters. This allows us to consider only oscillations of an optical field in the form of a scalar functions and adopt as a model of analyzed signal harmonized scalar random process. The photodetector operation and average of photocurrent using an integrator and integrating circuit is considered too. On the basis of the application prolate entire spheroidal wave function theory energy spectrum estimation by the integral of photocurrent is obtained. This energy spectrum estimation is consistent and asymptotically unbiased.

## 1. Introduction

The measurement of the optical signals spectrum is the one of the most important types of optical measurements and an energy spectrum estimation of a stationary random process is the one of the most important problem in the theory of statistical measurements.

There are several methods of receiving of energy spectrum estimation: using predefined the correlation function estimation; on the basis of processing of the instantaneous frequency spectrum; using the filtration method. This work is devoted to the implementation of the filtration method by the multichannel optical SPECTRUM ANALYZER which is considered as the multi-channel narrow-band system [1].

## 2. The multichannel optical specrum analyzer

The block diagram of the multichannel optical spectrum analyzer which allows to receive an energy spectrum estimation is shown in figure 1.

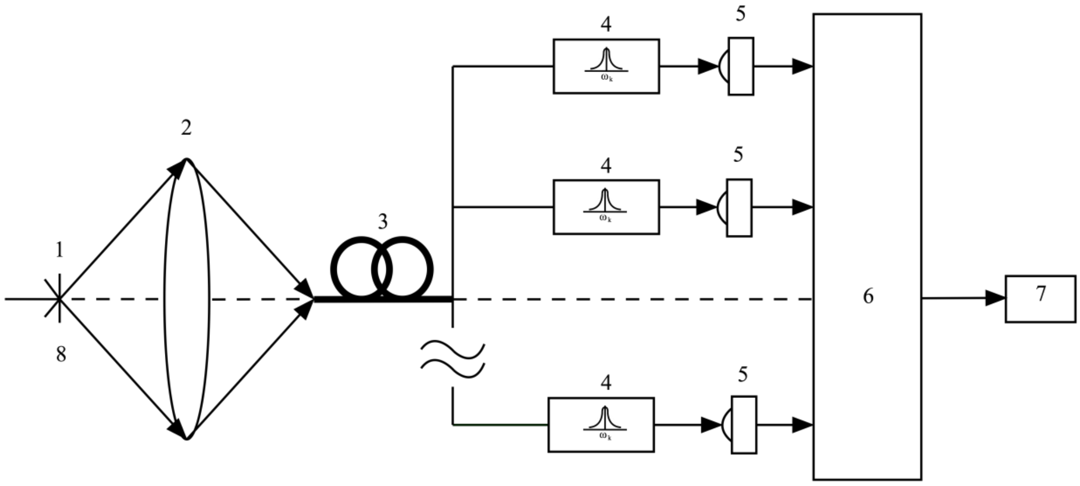


**Figure 1.** The block diagram of the multichannel optical spectrum analyzer

Where 1, the following notation is introduced: 1 – a source of optical radiation; 2 – forming optics; 3 – fiber optic harness; 4 – resonator units; 5 – photo detectors; 6 – spectroscopic information processing unit; 7 – recorder.

The process of optical filtering in one channel of spectrum analyzer is shown in figure 2.

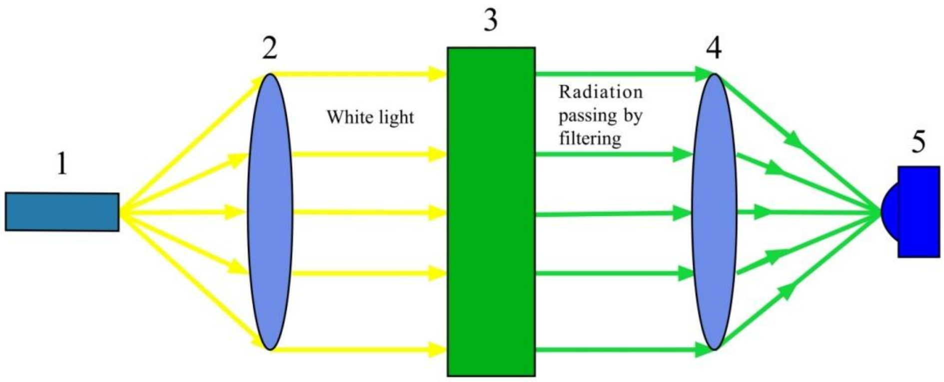


**Figure 2.** The process of optical filtering in one channel of spectrum analyzer

1 – is output of optical fiber, 2 - is first collimating lenses, 3 – is optical filter, 4 – is second collimating lens, 5 – is photodiode

The spectral characteristic of the optical filter is shown in figure 3.

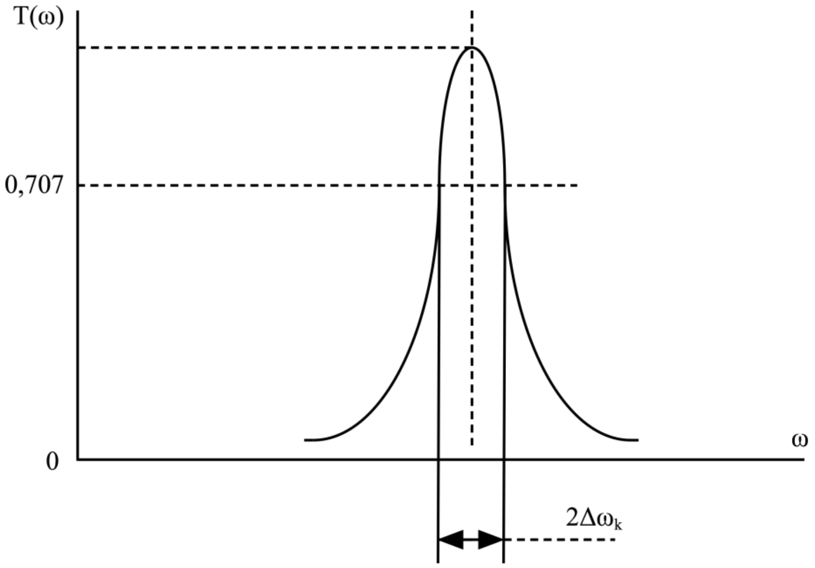


**Figure 3.** The spectral characteristic of the optical filter

The algorithm of receiving of an energy spectrum estimation of an optical signal is implemented by the following sequence of operations: a narrow-band filtration of an optical radiation – square-law photo detection – temporal integration. The functional diagram of receiving of an energy spectrum estimation of an optical signal is shown in figure 4.

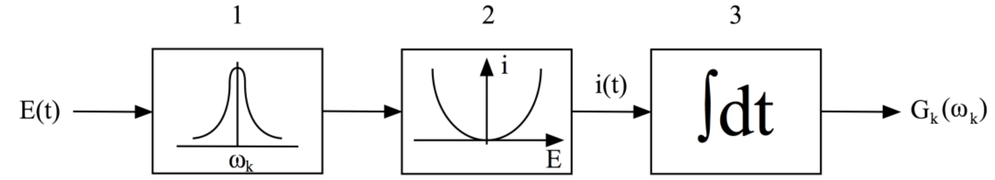


**Figure 4.** The functional diagram of receiving of an energy spectrum estimation of an optical signal

1 – resonator, 2 – quadratic detector, 3 – integrator, $G_k(\omega_k)$ – evaluation of the energy spectrum of the optical signal at the output $k$ –th channel of multichannel spectrometer.

The output current of the photo detector

$$i = \gamma \cdot P = \gamma \cdot \iint_{\Delta S} \left|\vec{\Pi}\right| \cdot ds = \frac{c \cdot \gamma}{4\pi} \cdot \sqrt{\frac{\varepsilon}{\mu}} \cdot \iint_{\Delta S} E^2 ds. \tag{8}$$

Fluctuations of the electric field strength in the plane of the photo detector are defined as:

$$\overline{E_k} = \overline{E_k}(t) = \frac{\overline{e_1}}{2\pi} \cdot \left( \int_{-\omega_k - \Delta\omega}^{-\omega_k + \Delta\omega} S(\omega) \cdot K_k(\omega) \cdot B_k(\omega) \cdot e^{i\omega t} d\omega + \right. \\ \left. + \frac{\overline{e_1}}{2\pi} \int_{\omega_k - \Delta\omega}^{\omega_k + \Delta\omega} S(\omega) \cdot K_k(\omega) \cdot B_k(\omega) \cdot e^{i\omega t} d\omega \right). \tag{9}$$

Substitution of expression (11) in (6) gives the Pointing vector:

$$\overline{\Pi} = \frac{c}{4\pi^2} \cdot \sqrt{\frac{\varepsilon}{\mu}} \cdot \bar{e} \cdot$$
$$\cdot \int_{\omega_k - \Delta\omega}^{\omega_k + \Delta\omega} S(\omega) \cdot K_k(\omega) \cdot B_k(\omega) \cdot e^{i\omega t} d\omega \cdot \tag{10}$$
$$\cdot \int_{\omega_k - \Delta\omega}^{\omega_k + \Delta\omega} S^*(\omega') \cdot K_k^*(\omega') \cdot B_k^*(\omega') \cdot e^{-i\omega' t} d\omega'.$$

Using the integrator in scheme is very important because the result of estimation is defined by the accumulated energy. This means the necessity of integration of the Pointing vector in time:

$$\int_{-T}^{T} \overline{\Pi}(t) dt = \int_{-\mathrm{T}}^{\mathrm{T}} \mathrm{dt} \int_{\omega_k - \Delta\omega}^{\omega_k + \Delta\omega} S(\omega) \cdot K_k(\omega) \cdot B_k(\omega) \cdot e^{i\omega t} d\omega \cdot$$
$$\cdot \int_{\omega_k - \Delta\omega}^{\omega_k + \Delta\omega} S^*(\omega') \cdot K_k^*(\omega') \cdot B_k^*(\omega') \cdot e^{-i\omega' t} d\omega'. \tag{11}$$

Application of the theory of prolate spheroidal wave functions to the expression (14) gives[2]:

$$G_k(\omega) = (\Delta\omega_k)^2 \cdot P_k(\omega_k) \cdot$$
$$\cdot \int_{-\Delta\omega_k}^{\Delta\omega_k} |K_{kk}(\omega_k, \omega')|^2 \cdot |B_{kk}(\omega')|^2 \cdot |S_0(\omega')|^2 d\omega'. \tag{12}$$
$$\cdot \int_{-\Delta\omega_k}^{\Delta\omega_k} |K_{kk}(\omega_k, \omega')|^2 \cdot |B_{kk}(\omega')|^2 \cdot |S_0(\omega')|^2 d\omega'.$$

This expression determines the energy density accumulated in the estimating process of the energy spectrum of optical radiation.

The accumulated energy during this process is expressed by:

$$W_k = \iint_{\Delta S} G(\omega) ds \tag{13}$$

This expression determines an energy spectrum estimation of optical radiation as a stationary random process.

Previously it was assumed that the process of integration is performed perfectly. However it is necesspectrum analyzerry to consider using integrating circuit instead of the integrator. It is described by the expression.

If the time constant of the integrating circuit is more than the processing time, then the process is close to a perfect integration. If this condition doesn't perform, the energy spectrum estimation is distorted.

## 3. Conclusion

The performed analysis has demonstrated that the properties of energy spectrum estimation depend on the characteristics of the transfer function of the narrow-band filter and the time of perfect integration. Distortions of energy spectrum estimation can be defined on basis of the transfer function.

Using a simple integrator as an integrating circuit allows to implement perfect integrating and defining distortions during long period of observation.

Given energy spectrum estimation of optical radiation is a consistent and asymptotically nondisplacement [3].

## 4. Reference

[1] Moskaletz, O.D., Vaganov, M.A., Kulakov, S.V., Preslenev, L.N., Arkhipov, I.N., Kotlikov, E.N. and Prokashev, V.N. Parallel spectrum analyzer of signals of optical range. Patent of Russian Federation № 86734 (2009).
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[3] Bendat J.S., Piersol A.G. Measurement and analysis of random data. John Wiley & Sons, Inc. New York-London-Sydney. 1967.

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