INFORMATION METROLOGY OF ACOUSTO-OPTIC TUNABLE FILTERS

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Abstract

As acousto-optic tunable filters (AOTF) are intended for information processing and transmission, so their parameters have to be measured proceeding from this fact. However, the existing methods of AOTF metrology do not take into consideration the amount of information that has to be processed by AOTF. This amount, in its turn, is limited by level of noise and dynamic range of the device (which can also be described by amount of recognizable grayscale levels in output data). Here we propose how to include these factors into consideration. The connection has been established between the AOTF measured physical characteristics and amount of the processed data via the admissible probability of one data bit failure. The experimental installation for the proposed method realization has been elaborated and tested. Its principle of operation can be explained from the point of view of information transmission optimization. The installation measures both signal and noise which is calculated of the signal value standard deviation.

Introduction

Different kinds of AOTF can be divided from the point of view of the processed information into two kinds: spectrometric AOTF [1] and imaging AOTF [2,3]. Spectrometric AOTF provides processing and transmission of data on spectral composition of input light beam whereas imaging AOTF additionally processes and transmits spatial data describing the image to be processed. Hence, generally, imaging AOTF usually transmit larger amounts of information than the spectrometric.

Information transmission in AOTF is organized by another way than that in the other kinds of acousto-optic devices. AOTF is the only device among other acousto-optic structures in which useful information is introduced together with input light beam (fig.1).

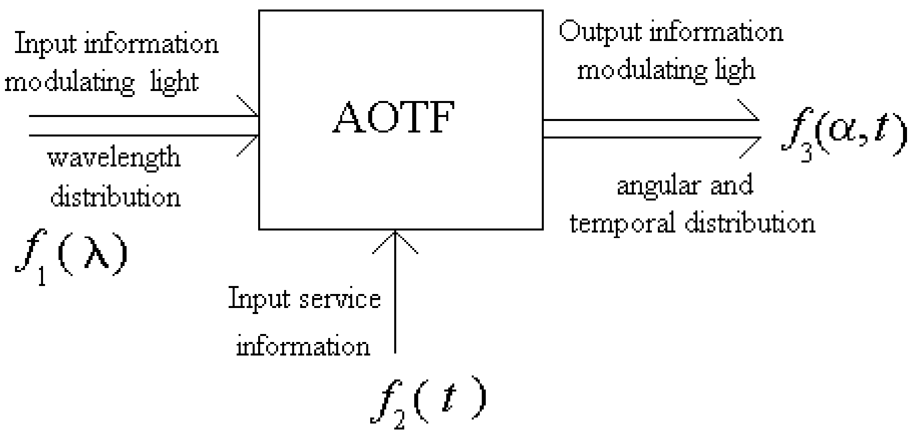

Fig.1. Distribution of information flows in AOTF [4]

Besides information that has to be processed and transmitted, AOTF operates with service information which is introduced into the device in electric signal form through the piezoelectric transducer. Hence, total amount of information contained in the device simultaneously, is bigger than the amount of useful information; this circumstance limits the AOTF information possibilities.

Below we will consider the basic information characteristics of AOTF for both kinds of the devices.

AOTF information characteristics and their interconnection with AOTF physical parameters

The basic information characteristics of AOTF, as of many other information transmission devices, are information capacity and information transmission capability [5]. The first describes the device ability to process large amount of data simultaneously, and the second - its information productivity. Let us consider these parameters for spectrometric AOTF. Information capacity for acousto-optic devices can be expressed as

$$I = N \log_2(m + 1), \tag{1}$$

where N is number of resolvable spatial positions of diffracted light, and m is amount of gray scale levels which can be recognized in each position. But all the spectral components in AOTF are diffracted to the same direction by the input signal frequency variation. Moreover, single element detectors can be used in spectrometric AOTF. Hence, $N = 1$, and in this case only number of gray scale levels defines the AOTF information capacity.

Number of resolved spectral intervals N' can be defined as

$$N' = (\lambda_2 - \lambda_1) / \Delta\lambda, \tag{2}$$

Where $\lambda_2 - \lambda_1$ is the total width of processed spectrum, and $\Delta\lambda$ represents the device selectivity.

The selectivity definition is connected with the criterion of resolving power by wavelength. It can be found from the selectivity physical nature consideration.

The mathematical description of acousto-optic interaction in Bragg mode is identical to that of volume holograms reconstruction. This process can be formalized by using theory of coupled waves developed by Kogelnik [6]. Namely, the division of this theory regarding volume phase transmission holograms is exactly related to the problem of acousto-optic selectivity.

As it follows from Kogelnik's theory, diffraction efficiency can attain 100% only in the case if light incidence angle is exactly equal to Bragg angle. Kogelnik has introduced parameters $\xi = \delta\beta T \sin\theta_0$ and $\nu = \pi n_1 T/(\lambda\cos\theta_0)$, where δ - incident light angle deviation from Bragg angle, $\beta = 2\pi n/\lambda$, T is acoustic beam width, if Kogelnik's theory is applied to the case of AOTF operation, θ_0 is Bragg angle value, n and n_1 are active medium refractive index average value and modulation amplitude. Calculations followed from Kogelnik's theory give curves shown in figure 2.

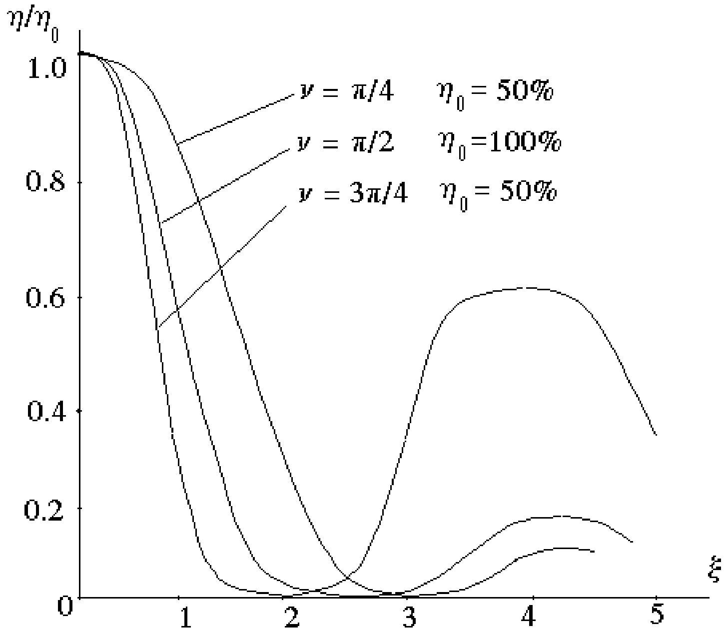

Figure 2. Dependence of relative diffraction efficiency of AOTF on Kogelnik's parameters ξ and η

Using the curves presented in figure 2 it is possible to determine the character of diffraction efficiency variation if the wavelength of incident light deviates from the value meeting Bragg condition. This condition can be written as

$$2n\Lambda\sin\theta_0 = \lambda. \tag{3}$$

If this condition is met, the value of diffraction efficiency corresponds to its maximum. If the incident light wavelength is $\lambda + \Delta\lambda$, so diffraction efficiency becomes less. Angle θ_0 will differ from new Bragg angle value by $-\delta$, and parameter $\xi = -\delta\beta T \sin\theta_0$ is negative. As diffraction efficiency is quadratic relatively to diffracted light amplitude, so the curves in figure 2 becomes symmetric regarding zero of ξ, and it becomes possible to calculate the efficiency deterioration. Value of δ can be expressed by substitution of new Bragg parameters $\theta_0 + \delta$ and $\lambda + \Delta\lambda$. If $\sin\delta$ is supposed to be close to δ, and $\cos\delta$ - to 1, so [7]

$$\delta = (\Delta\lambda/\lambda)\mathrm{tg}\theta_0 \quad (4)$$

and

$$\xi = -(\Delta\lambda/\lambda)\mathrm{tg}\theta_0(2\pi n/\lambda)T\sin\theta_0. \quad (5)$$

According to Raleigh criterion two points are resolvable if principal maximum of one coincides with 1st minimum of another. Hence, two resolvable points must be shifted apart at angular distance corresponding to value $\Delta\lambda$ for which diffraction efficiency falls down to zero. Finding ξ from figure 2, and knowing the other components of expression (5), it is possible to define $\Delta\lambda$. The calculations for TeO_2 at 0.63 μm give $\Delta\lambda$ of the order of 10 nm.

However, Raleigh criterion does not reflect information possibilities of the device. Really, the spectral lines located more closely, can be resolved in the case of low noise. From the other hand, if spectrometric measurements require to recognize some gray scales in the spectrum pattern, so for the spectral lines resolution they must be moved apart [4, 5].

Information transmission capability of spectrometric AOTF can be represented as its information capacity related to the minimum time for information processing

$$I' = (1/\tau)\log_2(m + 1), \quad (6)$$

where τ is minimum processing time. It corresponds to time necessary for acoustic wave to walk through the light beam aperture and is often known as temporal aperture. Hence, in comparison with such acousto-optic devices as, for example, acousto-optic spectrum analyzers [8], information characteristics of spectrometric AOTF are much lower.

Let us consider the situation taking place in AOTF providing multispectral imaging [9,10].These devices transmit not only spectral but also spatial information. For high quality data transmission it is necessary that all pixels of input images would be transmitted into 1st diffraction order without distortions.

Information capacity of such AOTF can be described as

$$I = N_x N_y \log_2(m + 1), \quad (7)$$

where N_x and N_y are numbers of pixels in the processed image for coordinates x and y, which could be resolved, correspondingly.

In practice, anisotropic acousto-optic diffraction causes some variations in the stated calculations.

Means for information measurements of AOTF

Measurements of AOTF parameters proceeding from the stated approach can be performed using the special installation shown schematically in figure 3. Its principle of operation is close to that of installation proposed for information measurements of the other kinds of acousto-optic devices [8]. Let us consider that we measure parameters of imaging AOTF. Hence, we have to take into consideration both spatial and wavelength information.

Light source illuminates the transparency with the image to be processed. Then light beam modulated by this image comes to AOTF. Light diffracted into 1st diffraction order comes to the screen plane where the image is focused. The moving spit of photomultiplier records the light distribution in this plane, and measurements of spatial resolution are performed by the same way as it was proposed earlier [8]. The procedure includes also measurements of the signal-to-noise ratio. Exactly the same procedure is performed also for wavelength resolving power but all the measurements are performed not in space but in time. Special software for both kinds of measurements has been designed.

Using of this principle of measurement allows to avoid estimation of both kinds of resolving power according to Raleigh criterion, and two spatial points (or wavelength intervals) are considered resolved if probability of their false recognition is less than certain value given beforehand, proceedings from the demands of the problem.

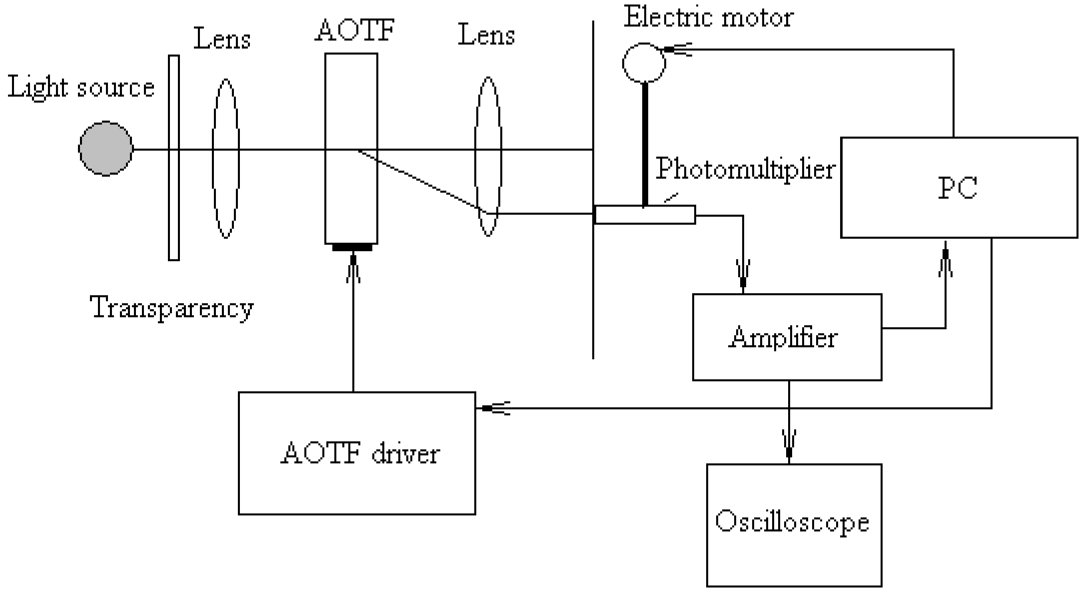

Figure 3. Schematic representation of installation for information measurements of AOTF parameters

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