

SPECTROPHOTOMETER FOR STUDY OF ATMOSPHERIC OZONE

Garo Mardirossian, Stiliyan Stoyanov

*Space Research Institute – Bulgarian Academy of Sciences
e-mail: mardirossian@space.bas.bg*

Abstract

A paper is presented for the design of a spectrophotometer intended to study the total content of atmospheric ozone based on the absorption principle. The device is designated to operate in the near ultraviolet part of the optic spectrum, where the Hartley–Huggins absorption bands are located and it also provides information from observations in the visible part of the optic spectrum with the Chappuis absorption band. The basic diffracting element of the designed spectrophotometer is the diffraction grating. A photometric channel is provided which reads surface albedo and sun protuberance.

In [1–5], the requirements for rational selection of scanning radiometers and spectrophotometers' parameters are specified and the method developed to calculate the optimal parameters of the optic-electronic tract is presented. This provides to minimize the total error at measuring the brightness of non-homogeneous emission and ensures the specified accuracy for measurement of average brightness during studies of non-homogeneous emissions of arbitrary form, such as the spectral composition of atmosphere.

The contribution aims to develop a method for rational selection and evaluation of the optic-electronic tract's transmission characteristics parameters in a scanning spectrophotometer intended to register dot-source emissions (the Sun, the Moon) which, while passing through the atmosphere, provide to determine the spectral composition of the atmosphere using absorption methods.

The spatial variations of emission brightness are, in their essence, external noise, against the background of which dot-source emissions are registered (atmospheric turbulence, silvery cloudiness etc.).

In practice, usually a spectrophotometer is required to have rectangular view field with uniform sensitivity and to scan along the x line with angular velocity ω_x .

In developing the method, it was assumed that the emission is registered by a receiver with predominant white noise, the optic system is isoplanar, the function has the form of a 2D Gaussoid, the electronic tract describes the product of the transmission characteristics of n pieces of integrating units with one and the same time constant, and external and internal noises at the output of the optic-electronic tract are uncorrelated.

In case of registration of dot-source emissions, it is expedient to determine the parameters of the optic-electronic tract (angular view field along the scanning lines ω_x , accordingly along the y line – ω_y ; time constant of the units of the electronic tract τ ; angular size of the dissipation spot of the optic system ω_a) based on the total measurement error minimization conditions. In the case of registration of a signal originating from a remote dot emitter, the total least square error ε is equal to:

$$(1) \quad \varepsilon^2 = \varepsilon_a^2 + \varepsilon_\tau^2 + \varepsilon_t^2 + \varepsilon_f^2$$

and it includes in itself the systematic errors caused by the part of energy lost while the emission passes through the image analyzer – ε_a , the effect of the time constant and the pulse form at the input of the electronic tract – ε_τ , as well as the random errors – ε_τ , related with the noise's dark component and the background brightness' fluctuation – ε_f .

The constituent signal errors caused by the internal noises of the optic-electronic tract are known and may be determined by the formula:

$$(2) \quad \varepsilon_t = \frac{S_v P_t^2 Q T B_f W_a^2 \alpha \beta}{4\tau},$$

where: S_v – integral sensitivity of the emission receiver;
 P_t – threshold sensitivity in dark regime;
 Q – useful area of the input slit;

T – transmittance capacity of the optic system;
 B_f – average component of background brightness;

$$\alpha = \frac{W_x}{W_a} ;$$

$$\beta = \frac{W_y}{W_a} .$$

The systematic component of signal errors may be determined using the equation for dot-source signal at the output of an ideal receiver which may be derived using the dissipation function:

$$(3) \quad u(t) = S_v F \frac{\beta}{2} \left(\alpha - \frac{2V_x}{W_a} \right) + \left(\alpha + \frac{2V_x}{W_a} \right) ,$$

where F is the emission flow on the image plane of the dot-source (on the back focal plane of the optic system).

The reduction of the signal amplitude at the output of the optoelectronic tract as a result of the energy lost during the emission's passing through the image analyzer may be determined by the formula:

$$(4) \quad \Delta u_a = S_v F (1 - \alpha \beta) .$$

The average square error is equal to:

$$(5) \quad \varepsilon_a^2 = S_v^2 F^2 \left(\frac{1 - e^{-\beta^2}}{\beta \sqrt{\pi}} \right)^2 \frac{e^{-2\alpha^2}}{\pi \alpha^2} .$$

In accordance with the performed calculations and with [6], the spectrum of the signal's power G_w at the output of the electronic tract of a scanning spectrophotometer will be:

$$(6) \quad G_w = S_v^2 T^2 Q^2 W_x^2 W_y^2 \frac{G_B}{V_x} ,$$

where the power spectrum of the spatial variations of background brightness $\frac{G_B}{V_x}$, determined by Fourier transformation is equal to:

$$(7) \quad \frac{G_B}{V_x} = \frac{2\sqrt{2W_f}}{V_x \left(1 + 2\frac{W_f^2}{V_x^2} \right)},$$

and the signal dispersion at the output of the optic-electronic tract caused by the spatial variations of background brightness within the bandwidth of the electronic tract is equal to:

$$\varepsilon_f^2 = \frac{1}{\pi} \int_0^\tau G(w) dw$$

or

$$(8) \quad \varepsilon_f^2 = \frac{2\sqrt{2}}{\pi} S_v^2 T^2 Q^2 W_a^4 \alpha^2 \beta^2 \left[\frac{1}{\sqrt{2}} \operatorname{arctg} \left(\frac{\sqrt{2} \frac{W_f}{V_x}}{\tau} \right) \left(1 + \frac{\alpha^2 \frac{W_a}{V_x}}{\tau \frac{W_a}{W_x}} \right) \right].$$

Therefore, if there are no background brightness fluctuations, the measurement errors are reduced by augmenting the view field along the scanning line, while with increasing background dispersion, the function takes the form of a minimum, corresponding to the optimal parameters of the preliminary characteristics of the spectrophotometer's optic-electronic tract.

In Fig. 1, the emission source 1 is shown, providing signal in the ultraviolet, visible and infrared part of the optic spectrum, as well as spectrophotometer 2, intended to study the spectral composition of atmosphere, and the registration module 3 of the equipment complex.

The results obtained from the evaluation analysis of the transmission characteristics of a spectrophotometer intended to study the spectral composition of atmosphere at dot-source emission registration provide to make the following conclusions:

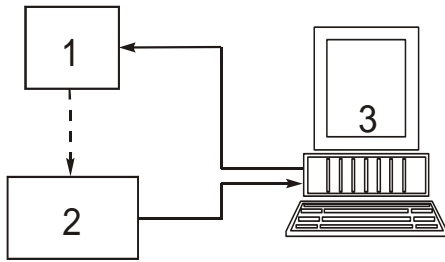


Fig. 1

1. When measuring emission originating from uniform background source, the increase of noise components as a result of the view field's augmentation along the scanning line may be compensated by reduction of the electronic tract's bandwidth at increasing measurement accuracy, whereas the rational selection of the optic-electronic tract's transmission characteristics parameters is substantiated primarily by the device's structural features according to the conditions of the experiment.

2. In the presence of spatial background variations, the developed method allows for a compromise between the influence of the systematic error ε_a at small α and the random error ε_f at increase of α , providing to minimize the total ε for the conducted measurements.

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СПЕКТРОФОТОМЕТЪР ЗА ИЗЛЕДВАНЕ НА АТМОСФЕРНИЯ ОЗОН

Г. Мардиросян, С. Стоянов

Резюме

Представено е изследване за разработване на спектрофотометър, който на базата на абсорбционния принцип да осигурява изследване на общото съдържание на атмосферния озон. Апаратурата е предназначена за работа в близката ултравиолетова част от оптичния спектър, където са разположени ивиците на абсорбция на Хартли – Хюйгенс и предоставя информация и от наблюдения във видимата област с ивица на абсорбция на Шапои. Като основен дифрагиращ елемент с разработвания спектрофотометър е използвана дифракционна решетка. Предвиден е фотометричен канал, отчитащ влиянието на албедото на подстилящата повърхност и протуберанса на Слънцето.