AUTOMATED MULTIWAVE METER OF SPECTRAL TRANSMISSION OF THE GROUND LAYER OF THE ATMOSPHERE

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A filter automated meter of spectral transmission of the atmosphere which operates along a horizontal path with reflection having a 500–m baseline at 22 discrete points within the wavelength range 0.44–12.2 μm is described in this paper.

The solution of a number of scientific and applied problems calls for the measurements of spectral transmission of the ground atmospheric layer to be carried out in the given region and in a wide wavelength range. To do this, a measuring system is needed which could meet the following requirements: small weight, portability, relatively short baseline, rather simple tuning of optical systems, and convenience in operation.

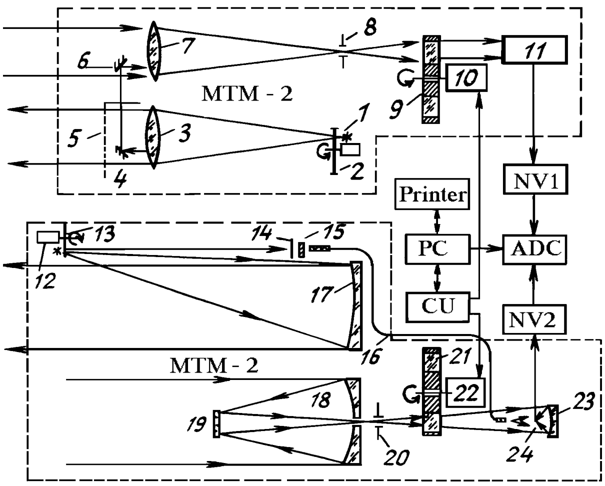

FIG. 1. Block diagram of the multiwave meter of spectral atmospheric transmission: 1) SIRSh 6×100 photometric lamp, 2) modulator of the MTM–1, 3) MTO–1000 transmitting objective, 4 and 6) flat mirrors, 5) switch of the operating and control channels of the MTM–1, 7) MTO–1000 receiving objective, 8) field stop of the MTM–1, 9) turret with interference filters of the MTM–1, 10) motor, 11) FEU–28 photomultiplier, 12) globar, 13) modulator of the MTM–2, 14) blind of the MTM–2 control channel, 15) cutoff filter, 16) lightquide, 17) transmitting off–axis parabolic mirror 250 mm in diameter, 18) receiving spherical mirror 250 mm in diameter, 19) flat mirror, 20) field stop of the MTM–2, 21) turret with interference of the MTM–2, 22) motor, 23) elliptic mirror, and 24) BM6–K1 bolometer.

Such a system for the wavelength range 0.44–12 μm was designed and produced at the Institute of Atmospheric Optics in 1991 and first tested in integrated studies of the atmosphere as part of the SATOR program. It incorporated multiwave transmission meters for the wavelength range 0.44–1.06 μm (MTM–1) and for the wavelength range 1.06–12.0 μm (MTM–2).

In this modification both meters operated according to the scheme with reflection on a 500–m baseline (the total length of the measuring path was 1000 m).

A receiving–transmitting optics in both these meters was spaced but mounted on the same rotating unit. The entire system was installed on a massive table, and the distance between the optical axes of the receivers of the MTM–1 and MTM–2 did not exceed 60–70 cm. Such a compact location of the measuring devices in a heated laboratory room with the exit to the atmosphere through the diaphragms in the window of the room made this system practically all–weather. The scheme of the measuring system is shown in Fig. 1. Its principal elements are listed in the figure caption. It should be noted that the required wavelength in the MTM–1 was selected with interference light filters and in the MTM–2 with both interference (in the range λ = 1.06–2.17 μm) and combined (λ = 3.91–12.2 μm) filters. To suppress the overtones in the bandwidth of the interference filters we used pigmented glasses, and in two cases (λ = 1.06 and 1.22 μm) the 5–mm cells filled with distilled water were additionally used. In both meters the filters were clamped on a turrent.

The turret for the interference filters of the MTM–1 contained 8 filters while the turret of the MTM–2 designed for 16 positions, incorporated 15 filters and a metallic shutter. The shutter was intended for covering of a measuring beam during the signal record in a control channel. Characteristics of the interference filters are listed in Table I.

One catopter with a basic mirror 500 mm in diameter and 1500 mm in focal length located at the end of the measuring path (it is not shown in the figure) serves as a radiation reflector for both devices. The catopter allowed us to avoid noise induction in the optical systems thereby improving the accuracy of the atmospheric transmission measurement. The reflector was enclosed in a metallic protective tube and was equipped with a heating system for the mirror to be protected against sweating in any season. Since the catopter possesses an autocollimation property, the reflected light beam returns to the radiation source. The diameter of the reflected beam in the source plane for an ideal optical system of the catopter is determined from the relation

$$D = 2D_1 - D_2 ,$$

where D_1 is the diameter of the reflector and D_2 is the diameter of the source objective. Hence it follows that for the MTM–1 the equibright beam should be 900 mm in diameter while for the MTM–2 it should be 750 mm in diameter which are quite sufficient for arrangement of the receiving optics.

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TABLE I. Characteristics of the employed interference filters.

MTM–1		MTM–2			
λ, μm	Δλ, μm	λ, μm	Δλ, μm	λ, μm	Δλ, μm
0.44	0.009	1.06	0.015	9.12	0.25
0.48	0.006	1.22	0.02	9.55	0.24
0.55	0.010	1.60	0.02	10.34	0.24
0.63	0.004	2.17	0.02	10.66	0.22
0.69	0.008	3.91	0.10	11.21	0.29
0.87	0.015	4.69	0.18	11.76	0.32
0.94	0.015	8.18	0.25	12.19	0.38
1.06	0.015	8.66	0.28	–	–

The optical scheme and the principle of operation of the meter are fairly simple and can be understood from the given block diagram.

Operation of the MTM–1. Radiation of the lamp *1* is modulated at a frequency of 450 Hz and collimated with the objective *3*, and a diverging beam is transmitted to the atmospheric path at the end point of which there is the catopter. The catopter intercepts about 1/20 part of the reflected beam and directs it to the receiving objective *7* which, in its turn, intercepts only a small part of the incident beam. The incident radiation is focused in the plane of the field stop *8*, passes through the interference filter *9*, and then enters the FEU–28 photomultiplier *11*.

Operation of the MTM–2. The radiation of the globar *12* is modulated at a frequency of 12 Hz, collimated with the mirror *17* and transmitted to the atmospheric path. After reflection from the same catopter placed at the end point of the path, the IR radiation flux returns. A part of the incident radiation is intercepted with the specular system *18* and *19* (the Newton telescope) and focused onto the field stop *20*. It passes through the interference filter *21*, and, after reflection from the elliptic mirror *23*, enters the receiving area of the bolometer *24*. To improve the measurement accuracy both meters have means for control of the radiation source stability and of the photodetector sensitivity.

In the TMT–1 a control channel is formed by rigidly held flat mirrors *4* and *6*. The operating and control channels are switched with an automatically controlled blind of special configuration. The measurements in the operating and control channels are made successively at every wavelength.

An analogous channel in MTM–2 is basically intended for control of the globar temperature at the wavelength λ = 1.06 μm (the filter *15*). Using the lightquide *16* the radiation of the globar, passing by the interference filters, is directed to the elliptic mirror *23* and then to a BM6–K1 bolometer. The control and operating channels are switched with the blind *14* connected with an electromagnetic actuator. The control is accomplished at the start of each measurement cycle and, if necessary, the temperature of the globar is controlled. The filter *15* is chosen so that the signal in the control channel lies within the same dynamic range as in the course of measurements along the path.

In addition to the control channel, in the MTM–2 the possibility is envisaged of occasional control of the state of the mirrors *17*, *18*, and *19* and the constancy of the globar emissivity. Such a control is accomplished using a special specular attachment consisting of two flat mirrors (it is not shown in the figure) which is positioned in front of the receiving–transmitting optics of the MTM–2.

The measurements with these two devices are performed simultaneously. The signals from the outputs of the photomultiplier and bolometer, amplified with the selective nanovoltmeters (NV1 and NV2) are applied at a two–channel 12–bit automated ADC. The analog signals are converted into digital ones and enter a computer where they are accumulated and averaged over a period of 20 s. The measured signals are recorded on a digital printing device. It should be noted that the use of modulated light fluxes and selective amplifiers in the meter enabled us to significantly improve the signal–to–noise ratio of the meter in the daytime.

The motors of the turrets with interference filters (*10* and *22*) are controlled by a control block (CB) and the pairs of the corresponding bilateral optoelectronic transducers and switches with hermetically sealed contacts positioned on the turrets. In addition to the aforementioned functions, the computer controls completely the operation of the entire system in the automated mode.

The device is compact and convenient in operation. A Ge–Ne laser positioned between the MTM–1 and MTM–2 is used for rapid and highly accurate beam directing. For operation of both meters in an automated mode it is sufficient to key onto a keyboard and to display the input information and to run the program which provides an entire sequence of required operations. A single cycle of measurements at all wavelengths takes 10 min.

The technique for determining spectral transmittance of the atmosphere. The technique for measuring the atmospheric transmission (T) preassumes the derivation of the absolute values of $T(\lambda)$ in the first channel (MTM–1) and the relative ones in the second channel (MTM–2).

The atmospheric transmission on a given path of length L_1 in general for the MTM–1 can be represented in the form

$$T_{L_1}(\lambda) = K(\lambda)U(\lambda)/U^c(\lambda) , \quad (1)$$

where $U(\lambda)$ is the signal at the wavelength λ obtained on the measuring path using the catopter, $U^c(\lambda)$ is the signal in the control channel, and $K(\lambda)$ is the proportionality factor taking into account the beam divergence and the radiation source intensity.

To find $K(\lambda)$ for the entire wavelength range of the MTM–1 it is sufficient, alongside with the measurements of the signals $U(\lambda)$ reflected from the catopter, to measure the atmospheric transmission using either a point source or a portable flat mirror. Let us now consider, in particular, the technique for determination $K(\lambda)$ using the portable mirror. In this case a supplemental calibration path L_2 is chosen so as it is much shorter than L_1 but longer than a zone of forming the beam of the MTM–1 radiation source. When these conditions hold, the atmospheric transmission in the layer $L_1 - L_2$ can be determined from the relation

$$T_{L_1 - L_2}(\lambda) = \frac{U^*_{L_1}(\ )U^{c2}(\ )L_1^2}{U^*_{L_2}(\ )U^{c1}(\ )L_2^2} , \quad (2)$$

where $U^*_{L_1}$ and $U^*_{L_2}$ are the signals reflected from the flat mirror positioned at the distances L_1 and L_2, and U^{c1} and U^{c2} are the corresponding controlling signals.

Assuming that the Bouguer law is valid in the atmospheric transparency windows for the spectral resolution Δλ indicated in Table I, T_{L_1} can be considered to be related to $T_{L_1-L_2}$ via the relation $T_{L_1} = (T_{L_1-L_2})^{L_1/(L_1-L_2)}$. Then the value of $K(\lambda)$ in Eq. (1) can be given by the formula

$$K(\lambda) = \frac{U^c(\lambda)}{U(\lambda)} \, (T_{L_1 - L_2})^{L_1/(L_1 - L_2)} \, . \qquad (3)$$

The technique for measuring the atmospheric transmission in the IR spectral region using the MTM–2 is based on obtaining the relative spectra of transmission with their subsequent referencing to the absolute values at a wavelength of 1.06 μm derived from the MTM–1 data.

In this case the algorithm for calculating the transmission $T^{\rm IR}_{L_1 - L_2}(\lambda)$, for a difference path $L_1 - L_2$ has the form

$$T^{\rm IR}_{L_1 - L_2}(\lambda) = T_{L_1 - L_2}(1.06) \, \frac{V_{L_1}(\lambda) V_{L_2}(1.06)}{V_{L_2}(\lambda) V_{L_1}(1.06)} \, , \qquad (4)$$

where $T_{L_1 - L_2}(1.06)$ is the absolute transmission at the wavelength $\lambda = 1.06$ μm on the difference path derived from the MTM–1 data; $V_{L_1}(\lambda)$ and $V_{L_1}(1.06)$ are the signals measured on the path L_1 using the catopter and derived from the MTM–2 data. The values $V_{L_2}(\lambda)$ and $V_{L_2}(1.06)$ are found from the relation

$$V_{L_2}(\lambda) = \frac{V_{L_1}(\;) V^*_{L_2}(\;)}{V^*_{L_1}(\;)} \, ,$$

where $V^*_{L_1}$ and $V^*_{L_2}$ are the signals reflected from the flat reference mirror located at distances L_1 and L_2.

The values of $V_{L_2}(\lambda)$, in their physical meaning, correspond to the calculated signals reflected from the catopter positioned at the distance L_2. The transformation to the transmission along the path L_1 is accomplished using formulas (3) and (1).

The coefficients of total attenuation for both channels are calculated by the well–known formula

$$\varepsilon(\lambda) = - \ln[T(\lambda)]/L_1 \, .$$

The estimate of the errors made using the standard techniques gives a random error in determining the extinction coefficient of 0.02–0.03 and a systematic error of 0.03 km^{-1}.

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