OPTICAL PROPERTIES OF TEST BENCHES WITH FRESNEL ATTENUATORS FOR REPRODUCTION OF THE DIFFERENCE IN RADIANCE AND DIFFERENCE IN RADIATION TEMPERATURE

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Different variants of optical systems and analytic models of these systems are proposed for the purpose of developing test benches to support measurement of the limiting values of the sensitivity of high-precision optoelectronic scanning devices determined from the difference values of radiance and radiation temperature.

General physico-mathematical models of the optical systems of calibration test benches intended for the reproduction and experimental computational normalization of the difference in radiance \( \Delta L_e, \text{ W/(sr\cdot m^2)} \) and difference in radiation temperatures \( \Delta T_M, \text{ K} \) were presented in [1]. They are given as follows:

\[
\Delta L_e = \tau_2 [e_1 (L_01 - L_0a) - e_2 (L_02 - L_0a)],
\]

\[
\Delta T_M = \left[ \tau_2 e_1 (T_1^4 - T_a^4) + T_a^4 \right]^{1/4} - \left[ \tau_2 e_2 (T_2^4 - T_a^4) + T_a^4 \right]^{1/4},
\]

where \( L_01 \) and \( T_1, L_02 \) and \( T_2, L_0a \) and \( T_a \) are the radiances and thermodynamic temperatures of black body models, respectively, BBM-1 and BBM-2, and the inner walls of the calibration test benches (background); \( e_1 \) and \( e_2 \) are the radiation coefficients of the active cavities of BBM-1 and BBM-2, respectively; \( \tau_2 \) is the total transmission coefficient of the optical system of the calibration test benches along the path from the black body model to the inlet diaphragm of the device which is being calibrated, determined by means of the expression

\[
\tau_2 = \tau_f \tau_e \tau_a,
\]

where \( \tau_f \) is the transmission coefficient of the additional optical attenuator; \( \tau_e \) is the total transmission coefficient of the optical elements of the calibration test benches; and \( \tau_a \) is the transmission coefficient of the atmosphere along the path from the black body model to the inlet diaphragm of the calibration device.

Reproduction of the values \( \Delta L_e \leq 1 \pm 0.2 \text{ mW/(sr\cdot m^2)} \) and \( \Delta T_M \leq 0.5 \pm 0.1 \text{ mK} \) necessary for direct measurements of the minimally resolvable levels of the above quantities through the use of optoelectronic spatial scanning devices is technologically impossible to achieve, given the angular resolutions of these devices, and instead requires purely optical methods. Thus, introduction into the optical system of an additional attenuator of the “difference” radiation behind a target with \( \tau_f = 0.001 \) makes it possible to achieve the required levels of the difference in radiance and difference in radiation temperature. Measurement of the transmission coefficients of attenuators even with \( \tau_f \leq 0.01 \) does not, however, guarantee the degree of precision and reliability required for the measurements. It would be useful to select optical materials for the additional attenuators and determine their transmission coefficients on the basis of experimentally verified theoretical assumptions, among which may be included...
the Fresnel formulas. The latter formulas provide a quantitative description of the law of reflection and transmission of optical radiation at the smooth interface between two media, characterized by the index of refraction \( n \) and index of absorption \( k \) of the two media [2]. The materials that prove to be the most preferable for use as optical materials in attenuators turn out to be dielectrics and semiconductors that are transparent in the operating spectral region and for which the values of \( n \) have been reliably determined and standardized [3], and which exhibit values of \( k \) that are so low \( (k \ll (n - 1)) \) as to have practically no effect on the reflection coefficients of the interface.

Optical System with Discrete Attenuators. One possible optical scheme for creating calibration test benches with mirror-image targets and with discrete optical attenuators is presented in Fig. 1. Radiation from BBM-1 and BBM-2 is incident on the mirror faces of target 2 mounted at the focus of collimator 4-5. An attenuating system consisting of two mirror-image plane surfaces 6 and 7 is situated in a parallel flow of radiation. The plane surfaces 6 and 7 are mounted in such a way that the flow of radiation that horizontally exits the collimator is incident on collimator 6 at a 45° angle to its surface in the vertical direction along the axis 6-7. This flow is then incident on the plane 7 also at a 45° angle and is reflected by it in the horizontal direction with respect to the axis 7-8 perpendicular to the projection of optical axis 4-6 (in Fig. 1, the axis 7-8 and elements 7-11 are provisionally rotated 90° about the axis 6-7). Next, an image of the target is created at “infinity” by means of a detachable telescope objective 8-9 the exit diaphragm of which 10 must be of the same diameter as the inlet aperture of the device which is being calibrated.

A previous study [4] presented a calculation of the transmission \( \tau \) of an optical attenuator consisting of two plates, each of which reflects by means of a single external surface. This calculation demonstrated that a nonpolarized radiation flow incident on the inlet to the attenuator will again be nonpolarized at the exit from the attenuator and will be greatly attenuated. (The inner surfaces of the reflectors must be inclined relative to the active outer surfaces at an angle such that the images of the target 2 created through the reflectors would fall outside the field of vision of the device which is being calibrated.) The transmission coefficient of such an attenuator \( \tau = \rho_r \rho_p \), where \( \rho_p \) and \( \rho_r \) are the reflection coefficients of the components of the total flow polarized, correspondingly, in the plane of incidence and in the plane perpendicular to the plane of incidence. Also recalling that, by the Fresnel formulas, the equality \( \rho_s = \rho_p^2 \) (consequently, \( \tau_f = \rho_p^2 \)) holds independently of the values of \( n \) and \( k \) for angles of incidence of 45°. After simple algebra we find, in view of (3),

\[
\tau = \tau_r \tau_p \left[ \frac{n^2 - (2n^2 - 1)^{1/2}}{n^2 + (2n^2 - 1)^{1/2}} \right] \left[ \frac{n^2 + (2n^2 - 1)^{1/2}}{n^2 - (2n^2 - 1)^{1/2}} \right]^{3/2},
\]

where the expression enclosed in the braces corresponds to \( \tau_f \).

For example, for the 8–12 μm spectral region we find, using barium fluoride \( (n = 1.4) \), \( \rho_p = 0.0685 \) and \( \tau_r = 3.21 \times 10^{-4} \), while for the optical ceramic PO-4 \( (n = 2.4) \), we have \( \rho_p = 0.28 \) and \( \tau_r = 2.18 \times 10^{-2} \). Substituting the values for \( \tau_r \) into (4) with \( \tau_r = 0.9 \) and