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Optics and photonics — Test methods for telescopic systems —

Part 5: Test methods for transmittance

Optique et photonique — Méthodes d'essai pour systèmes télescopiques —

Partie 5: Méthodes d'essai du facteur de transmission

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 4 *Telescopic systems*.

This second edition cancels and replaces the first edition (ISO 14490-5:2005), which has been technically revised. It also incorporates the ISO 14490-5:2005/Amd 1:2015.

The main changes are as follows:

— the normative references has been updated;

— In 5.8, the wording has been changed to "maximum diameter of the aperture stop";

— Formulae (3) and (4) have been corrected.

A list of all parts in the ISO 14490 series can be found on the ISO website.

Optics and photonics — Test methods for telescopic systems —

Part 5: Test methods for transmittance

1 Scope

This document specifies the test methods for the determination of the transmittance of telescopic systems and observational telescopic instruments.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11664-2, *Colorimetry — Part 2: CIE standard illuminants*

ISO 14132-1, *Optics and photonics — Vocabulary for telescopic systems — Part 1: General terms and alphabetical indexes of terms in ISO 14132*

ISO 14490-1:2005, *Optics and optical instruments — Test methods for telescopic systems — Part 1: Test methods for basic characteristics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14132-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

4 Principle

To determine the spectral transmittance $\tau(\lambda)$, the flux of radiation in a limited bundle of rays will be measured before entering $\Phi_0(\lambda)$ and after passing $\Phi_p(\lambda)$ through the optical system. The transmittance results from Formula (1):

$$\tau(\lambda)=\frac{\Phi_p(\lambda)}{\Phi_0(\lambda)} \quad (1)$$

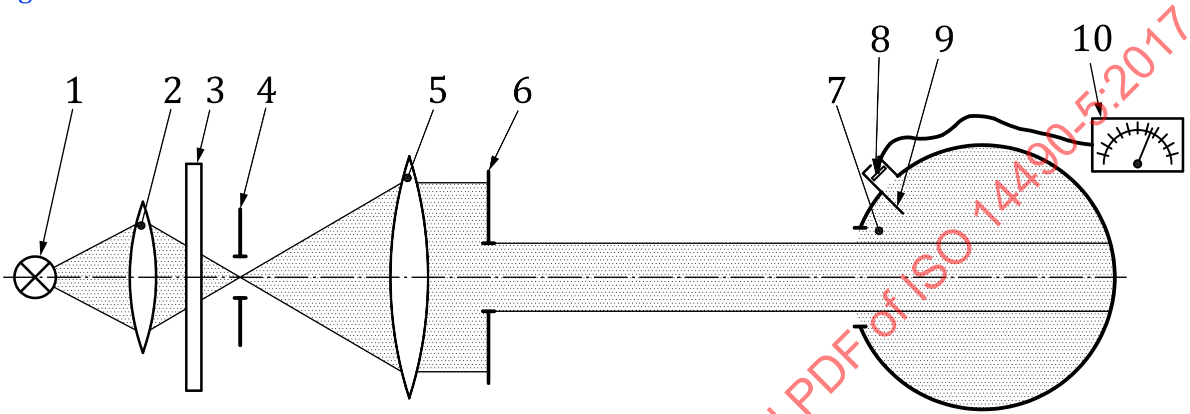
During the spectral measurement, the emergent light of the radiation source will be limited to a small wavelength band by means of a monochromator or a set of filters.

5 Test arrangement

5.1 General

The measuring device consists of radiation source (optionally with a condenser), monochromator or set of filters, collimator lens, aperture stop, specimen mounting, veiling glare stop, integrating sphere, radiation detector and measuring and evaluation unit (signal processing).

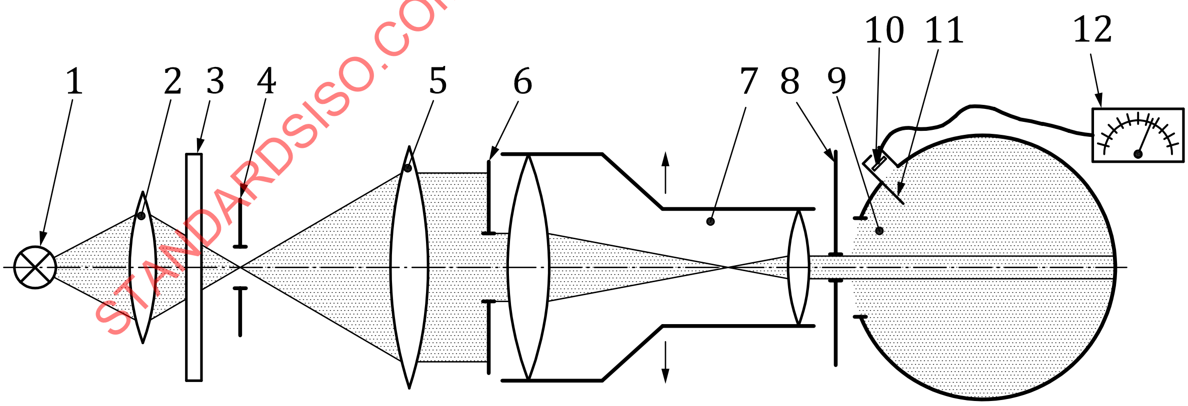
See Figure 1.



Key

1 radiation source
2 condenser
3 monochromator
4 selectable diaphragm as field stop
5 collimator lens
6 aperture stop
7 integrating sphere
8 detector
9 baffle
10 measurement and evaluation unit

Figure 1 — Test arrangement without test specimen (schematic)



Key

1 radiation source
2 condenser
3 monochromator
4 selectable diaphragm as field stop
5 collimator lens
6 aperture stop
7 test specimen
8 veiling glare stop
9 integrating sphere
10 detector
11 baffle
12 measurement and evaluation unit

Figure 2 — Test arrangement with test specimen (schematic)

5.2 Source of radiation and condenser

The radiation source shall emit a continuous flux of radiation in the specified wavelength range. The variation of flux during the measurement of a pair of values shall be less than 1 %. The condenser adapts the radiation source to the optical measurement path.

5.3 Monochromator or set of filters

Grating or prism monochromators can be used to select the wavelength. The smallest adjustable wavelength distance shall be less than 2 % of the dominant wavelength of the respective measurement.

The necessary spectral bandwidth depends on the sample. It shall be ensured that a steep alteration of the transmission curve is detected correctly. Thus, the bandwidth shall be smaller than the distance in the wavelength, at which the transmittance is changed by 4 %. This condition cannot always be satisfied because of measuring and energy reasons or because the time/cost effort is not adequate. In these cases, a maximum bandwidth of 4 % of the wavelength is allowable. A bandwidth of less than 2 % of the wavelength is necessary if the colour rendition indices are to be calculated.

Instead of a monochromator, a set of filters can be used. They are especially useful with flat-shaped transmittance curves. The number of measuring points shall allow for a definite curve fitting. Measurement with spectral filters can be applied as well if only single measuring points are required.

5.4 Collimator

The collimator may contain a refracting lens or mirror. The collimator has to be adjusted to the aligned components in such a way that full and uniform illumination of the following aperture stop is assured. The axial chromatic aberration of a refracting lens shall be less than or equal to 1 % of its focal length in the spectral range used. An off-axis parabolic mirror or an equivalent system is also suitable as a collimator.

5.5 Aperture stop

The aperture stop should be circular and located close to objective lens of the test specimen if possible. The diameter should be ≤80 % (50 % recommended) of the maximum available aperture of the test specimen, as well as smaller than the opening of the integrating sphere. Auxiliary systems can be used for beam forming to realize these requirements. These systems shall stay in the ray path during measuring with and without test specimen.

Generally, the smallest possible aperture stop should be used which is compatible with the signal-to-noise requirements of the detector.

Special care should be taken when measuring telescopic systems with variable magnification where at some magnification settings the entrance pupil can be considerably smaller than the free objective lens diameter. In this case, it is recommended to take the entrance pupil as the “maximum available aperture”.

5.6 Specimen mounting

The mounting of the test specimen shall be designed in a way that the test specimen can be adjusted and held stable.

The test specimen should be oriented in a way such that no obstructions occur in the measurement beam (e.g. by reticle structures).

5.7 Veiling glare stop

A veiling glare stop with a diameter that is 1,1 times the diameter of the image of the aperture stop is located in the image plane of the aperture stop, consequently in the exit pupil of the telescope. The veiling glare stop shall be dull black on both sides. It shall be designed in a way that the veiling glare resulting from the test specimen and upsetting of the measurement result is reduced as far as possible. It shall further be designed in a way that the necessary radiation for the measurement passes through unobstructed.

5.8 Integrating sphere

The integrating sphere shall be located near the veiling glare stop to ensure that the light passing through the veiling glare stop will be completely collected by the integrating sphere. The integrating sphere has two openings, one for the input of the bundle of rays to be measured and one for the detector. Both openings shall not be located opposite each other. Direct radiation incident on the detector is prevented by baffles. The surfaces of the two openings together shall not occupy more than 5 % of the internal surface of the sphere. The diameter of the integrating sphere opening shall exceed the maximum diameter of the aperture stop (6 in Figure 1) by 5 % to 7 %.

The reflectance of the internal coating of the integrating sphere shall be as high as possible and diffuse across the whole spectral range. The reflectance across the whole spectral range from 380 nm to 780 nm shall be at least 85 %.

5.9 Radiation detector

The linearity of the radiation detector shall be better than 0,5 %, including the accompanying signal processing.

6 Procedure

6.1 Preparation of the test assembly

Insert the test specimen in its mounting with the objective lens facing the radiation source (see Figure 1). Locate the veiling glare stop as required.

Take care to avoid multiple reflections between aperture stop, test specimen, or other parts, which may upset the measurement result, by the use of additional protective screens.

For systems with a reticle at an intermediate image plane, take care that parts of the test specimen's reticle do not obscure any of the light passing through it. Ensure that the ambient light does not influence the measurement result.

6.2 Determination of the measurement values

Carry out the measurements in the spectral range from 380 nm to 780 nm, if trichromatic coefficients shall not be calculated.

First, determine a measuring value $S_0(\lambda)$, which is proportional to the flux of radiation $\Phi_0(\lambda)$ through the aperture stop using the measuring instrument without the test specimen and without the veiling glare stop. Then, insert the test specimen into the ray path and determine the measuring value $S_p(\lambda)$ which is proportional to the flux of radiation $\Phi_p(\lambda)$. The ratio of both values with and without the test specimen gives the spectral transmittance in Formula (2):

$$\tau(\lambda)=\frac{\Phi_p(\lambda)}{\Phi_0(\lambda)}=\frac{S_p(\lambda)}{S_0(\lambda)} \qquad (2)$$

Carry out the procedure at the required wavelengths to determine the spectral slope. The wavelengths shall be chosen in a way that the shape of the transmittance curve can be surely recognized.

6.3 Further test methods

Integral and thus much less expensive testing methods are sufficient for many purposes such as comparison measuring or verification of the required transmission values for a standard illuminant. The transmittance can be measured directly by integral testing methods, utilizing the test assembly (see Figure 1), and additional suitable compensating filters, e.g. a conversion filter that modifies the spectral sensitivity of the integrating sphere and the detector to be the same as that of the eye. A calibrated specimen shall be used to verify the accuracy of this simplified test method. If necessary, the measured values of an integral measurement are to be confirmed by a spectral measurement and calculated according to the document. If a measurement set-up without an integrating sphere is used, the photodetector shall be checked to ensure that the readout does not depend on the illuminated area of the photodetector using the procedure specified in Annex A.

7 Precision of the measurement

The repeatability of the respective transmittance value shall not exceed 0,02. The test assembly shall be designed and the parts chosen such that this requirement is fulfilled.

8 Presentation of the results

The measuring results shall be presented in tabular and graphical form, as follows:

a) for presentation in tabular form, the results shall be indicated in a table with three decimal digits;

b) for graphical presentation, the values shall be plotted linearly over the wavelength.

9 Analysis

9.1 Effective transmittance for photopic vision

The effective transmittance for photopic vision (τ_D) valid for the total visible wavelength range, is determined by the spectral radiance of the source, the spectral transmittance of the telescope and the spectral characteristics of the relative luminosity curve for photopic vision. As a radiation function, use the standard illuminant D65 as specified in ISO 11664-2. Thus, Formula (3) is valid for the effective transmittance for photopic vision:

$$\tau_{\mathrm{D}} = \frac{\int_{380\ \mathrm{nm}}^{780\ \mathrm{nm}} S^{\mathrm{D65}}(\lambda)\times\tau(\lambda)\times V(\lambda)\times \mathrm{d}\lambda}{\int_{380\ \mathrm{nm}}^{780\ \mathrm{nm}} S^{\mathrm{D65}}(\lambda)\times V(\lambda)\times \mathrm{d}\lambda} \tag{3}$$

where

$\tau(\lambda)$ is the spectral transmittance of the telescope;

$S^{\mathrm{D65}}(\lambda)$ is the radiation function (relative spectral power distribution) of the standard illuminant D65 as specified in ISO 11664-2;

$V(\lambda)$ is the relative spectral luminosity factor for photopic vision as specified in Table 2 of CIE 18.2:1983.

Wavelength intervals of 5 nm will be adequate for most measurement purposes.

9.2 Effective transmittance for scotopic vision

Formula (4) for the calculation of the effective transmittance for scotopic vision, τ_N, results if the relative luminosity curve for scotopic vision is inserted:

$$\tau_N = \frac{\int_{380\text{ nm}}^{780\text{ nm}} S^{D65}(\lambda)\times\tau(\lambda)\times V'(\lambda)\times \mathrm{d}\lambda}{\int_{380\text{ nm}}^{780\text{ nm}} S^{D65}(\lambda)\times V'(\lambda)\times \mathrm{d}\lambda} \tag{4}$$

where

$\tau(\lambda)$	is the spectral transmittance of the telescope;
$S^{D65}(\lambda)$	is the radiation function (relative spectral power distribution) of the standard illuminant D65 as specified in ISO 11664-2;
$V'(\lambda)$	is the relative spectral luminosity factor of scotopic vision as specified in Table 3 of CIE 18.2:1983, Table 3.

Wavelength intervals of 5 nm will be adequate for most measurement purposes.

10 Test report

A test report shall be presented and shall include the general information specified in ISO 14490-1:2005, Clause 13, and the result of the test as specified in Clause 8 [items a) and b)] and in 9.1 and 9.2.

In addition, details of the aperture stop shall be given.

The presentation of the result as specified in B.1 and B.2 is optional.

Annex A
(informative)

Calibration procedure for the photoreceiver/measuring instrument

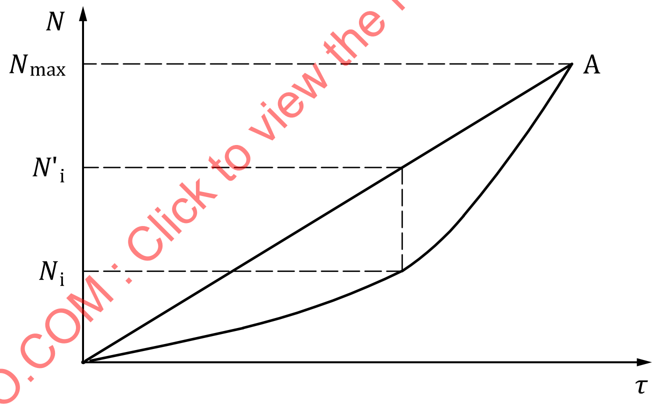
A.1 Control of proportionality of the photocurrent measured by the instrument to the illuminance on the light-sensitive surface of the photoreceiver

A.1.1 The measurements should be carried out by one of the following methods.

a) Method 1

Place standard neutral filters having different transmittances, τ_i, in succession between the light source and the photoreceiver. Each time, take the readings, N_i, from the indicating device accordingly to the diminishing light flux. Repeat the measurements for at least five times.

Based on measurement results, plot the values of transmittance of neutral filters on the X-axis with the readings of the indicating device on the Y-axis as shown in Figure A.1.



Key

N instrument readout

τ transmittance (or $1/l^2$)

Figure A.1 — Instrument readout versus transmittance (or versus inverse square of distance *l*)

b) Method 2

Reduce the illuminance on the light-sensitive surface of the photoreceiver by changing the distance between the light source and the photoreceiver.

Perform the test at a photometric bench. Observe the common rules of photometric measurements.

Direct the light from the source to the light-sensitive surface of the photoreceiver that is placed normally to the axis of the incident light bundle.

Measure the distance, *l*, between the light source and the photoreceiver and take the readings, N_i, of the indicating device.

Repeat the measurements for at least five times.

Based on measurement results, plot another graph using the values of the inverse of the square of the distance between the light source and the photoreceiver on the x-axis with the readings of the indicating device on the y-axis (as shown in Figure A.1 in parentheses).

A.1.2 The straight line connecting the origin of coordinates with Point A corresponding to the maximum scale reading shall be plotted on the graph (see Figure A.1).

The values of corrections, $\Delta' = N'_i - N_i$, shall be calculated. These characterize the deviation from proportionality of the indicating-device readings as to the illuminance on the light-sensitive surface of the photoreceiver.

A.1.3 If the values of corrections (Δ'/N) 100 % exceed 1 %, a graph (see Figure A.2) is plotted wherein the readings, N, of the indicating device are plotted in x-axis and the values of corrections Δ' are plotted in y-axis. The graph shall be attached to the certificate of the test arrangement.

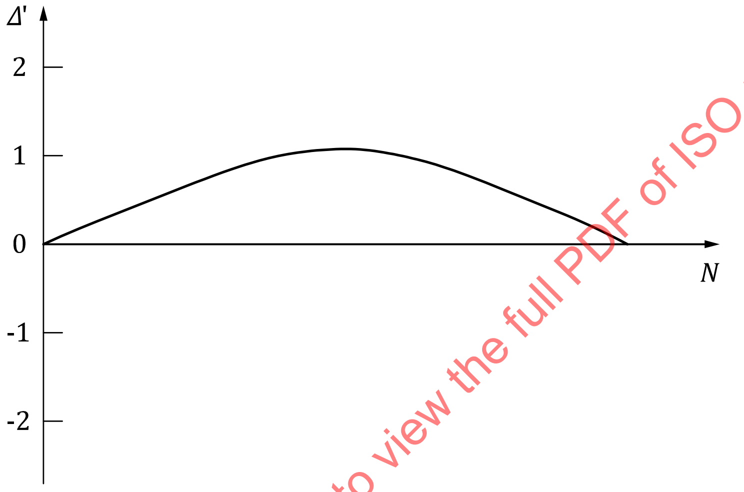


Figure A.2 — Corrections versus indicating-device readings

A.2 Checking the independence of readings of the indicating device in relation to the size of the illuminated surface of the photoreceiver in the case of constant light flux

Perform the measurements at a photometric bench.

Direct a divergent light bundle normally onto the photoreceiver surface so that uniform illuminance is obtained across each round light spot formed in planes of cross-sections with the bundle.

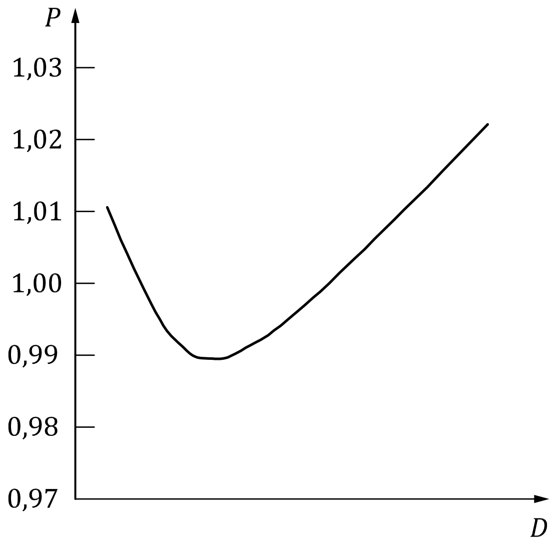
When the photoreceiver is moved along the axis of such a bundle, illuminated spots of various diameters will be formed on the light-sensitive surface of the photoreceiver while the incident luminous flux is retained constant.

Record the photocurrent produced in each case by taking readings N_1, N_2, ... N_k, ... from the indicating device.

Calculate the values of correction factors $P_1 = N_k/N_1$, $P_2 = N_k/N_2$,..., where N_k is the reading of the indicating device corresponding to any chosen diameter D of the illuminated circle on the photoreceiver.

If the calculated factors P_1, P_2, ... differ from 1 by more than 1 %, the graph (see Figure A.3) shall be plotted.

On the graph, plot the values of the illuminated spot diameters, D_i, on the x-axis with the values of correction factors, P_i, on y-axis. The graph shall be attached to the certificate of the test arrangement.



Key

D illuminated spot diameter

P correction factor

Figure A.3 — Correction factors versus diameter of the illuminated circle

Annex B
(informative)

Trichromatic coefficients and colour contribution index

B.1 Trichromatic coefficients

The trichromatic coefficients x and y are determined by the standardized spectral values of the 2°-standard observer, the spectral transmittance of the test specimen and the radiation function [see Formulae (B.1) and (B.2)]. The standardized spectral values are defined in ISO 11664-1. As a radiation function, use the standard illuminant D65 as specified in ISO 11664-2.

$$x = \frac{\int_{380\ \text{nm}}^{780\ \text{nm}} S^{\text{D65}}(\lambda) \times \tau(\lambda) \times \bar{x}(\lambda) \times \text{d}\lambda}{\int_{380\ \text{nm}}^{780\ \text{nm}} S^{\text{D65}}(\lambda) \times \tau(\lambda) \times \left[\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda)\right] \times \text{d}\lambda} \tag{B.1}$$

$$y = \frac{\int_{380\ \text{nm}}^{780\ \text{nm}} S^{\text{D65}}(\lambda) \times \tau(\lambda) \times \bar{y}(\lambda) \times \text{d}\lambda}{\int_{380\ \text{nm}}^{780\ \text{nm}} S^{\text{D65}}(\lambda) \times \tau(\lambda) \times \left[\bar{x}(\lambda) + \bar{y}(\lambda) + \bar{z}(\lambda)\right] \times \text{d}\lambda} \tag{B.2}$$

where

$\tau(\lambda)$	is the spectral transmittance of the telescope;
$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$	are the standardized spectral values of the standard observer given in ISO 11664-1:2007, Table 1;
$S^{\text{D65}}(\lambda)$	is the radiation function (relative spectral power distribution) of the standard illuminant D65 as specified in ISO 11664-2.

Wavelength intervals of 5 nm will be adequate for most measurement purposes.

NOTE The calculation of the trichromatic coefficients is itemized in ISO 11664-1:2007, Clause 7.

B.2 Values for the colour contribution index

NOTE This calculation has been taken from ISO 6728:1983, 4.5 and has been adapted for use with telescopes.

The colour contribution index (CCI) of a telescope is calculated by transforming (by $\log_{10}$), normalizing, and simplifying the values obtained for effective transmittance in the blue, green, and red ranges.

The relative spectral transmittance $\tau(\lambda)$ of a telescope is multiplied by the weighted spectral sensitivity values for the blue $W_{\text{B}}(\lambda)$, green $W_{\text{G}}(\lambda)$, and red $W_{\text{R}}(\lambda)$ ranges, as shown in Formulae (B.3) to (B.5):

$$\tau_{\text{B}} = \frac{\sum W_{\text{B}}(\lambda) \times \tau(\lambda)}{\sum W_{\text{B}}} \tag{B.3}$$

$$\tau_{\text{G}} = \frac{\sum W_{\text{G}}(\lambda) \times \tau(\lambda)}{\sum W_{\text{G}}} \tag{B.4}$$

$$\tau_R = \frac{\sum W_R(\lambda)\times\tau(\lambda)}{\sum W_R} \tag{B.5}$$

where

τ_B, τ_G, τ_R	are the effective transmittance in the blue, green and red range;
$W_B(\lambda)$, $W_G(\lambda)$, $W_R(\lambda)$	are the weighted spectral sensitivity values specified in Table 3 of ISO 6728:1983 (reproduced in Table B.2 for ready reference);
$\tau(\lambda)$	is the spectral transmittance of the telescope.

Log_{10} effective transmittance values are determined to two decimal places. To simplify, make the smallest element of this three-number-designation equal to zero by subtracting it from all three log– values. A further simplification occurs if the decimal is eliminated by multiplying by 100. The final reduction of the three numbers is called the “colour contribution index” (CCI) for the particular telescope evaluated.

These calculations are illustrated in Tables B.1 and B.2.

NOTE An example for the calculation as applied to camera lenses is found in ISO 6728:1983, Annex A.

Table B.1 — Example of calculations to obtain the colour contribution index (CCI)

Colour	Blue	Green	Red
Effective transmittance, τ	τ_B = 0,89	τ_G = 0,99	τ_R = 0,97
$Log_{10}\tau$	$\log_{10}\tau_B$ = −0,05	$\log_{10}\tau_G$ = 0,00	$\log_{10}\tau_R$ = −0,01
Simplification	subtract the smallest value (here, 0,05) from all three log– values		
	0,00	0,05	0,04
	Multiply by 100		
CCI	0	5	4
	CCI = 0/5/4		

Table B.2 — Weighted spectral sensitivity values

Wavelength (λ) nm	Blue $W_B(\lambda)$	Green $W_G(\lambda)$	Red $W_R(\lambda)$
380	1		
390	3		
400	7		
410	10		
420	12		
430	12		
440	13		
450	13		
460	12		
470	8	1	
480	4	1	
NOTE 1 Values reproduced from ISO 6728:1983, Table 3.			
NOTE 2 The values in this table are used with transmittance values.			

Table B.2 *(continued)*

Wavelength (λ) nm	**Blue** $W_B(\lambda)$	**Green** $W_G(\lambda)$	**Red** $W_R(\lambda)$
490	2	1	
500	1	2	
510	1	4	
520		5	
530		8	
540		15	
550		25	1
560		13	1
570		13	1
580		9	2
590		2	3
600		1	4
610			6
620			8
630			12
640			19
650			22
660			16
670			4
680			1
NOTE 1 Values reproduced from ISO 6728:1983, Table 3.			
NOTE 2 The values in this table are used with transmittance values.			

B.3 CIELAB values

This subclause is a description of an alternative method for the determination of a colour hue (tint) of the visible image.

To get a reasonable idea of the colour hue of the test specimen's image, it is also possible to use the CIELAB colour space to determine the values L*, a*, and b*. The value L* is not necessary for this method.

CIELAB is a colour space with perceptually uniformly spaced colour distribution.

The normalized standardized spectral values X_n, Y_n, and Z_n for the white point of D65 and the 10° observer are taken from Table B.3.

Table B.3 — Normalized standardized spectral values $X_{10W} = X_n$; $Y_{10W} = Y_n$; $Z_{10W} = Z_n$

Standard illuminant	x_{10}	y_{10}	z_{10}	X_{10W}	Y_{10W}	Z_{10W}
D65	0,313 8	0,331 0	0,355 2	94,81	100,00	107,34

From the spectral transmittance, the values *X*, *Y*, and *Z*, according to ISO 11664-1, are calculated. With these and the standardized spectral values, the following values *X**, *Y**, and *Z** are calculated.