IS 9883 (1981): Photometric and colorimetric methods of measurements of the light emitted by a cathode-ray tube screen [LITD 4: Electron Tubes and Display Devices]

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REAFFIRMED 1992

IS : 9883 - 1981
(Reaffirmed 2003)

Indian Standard

PHOTOMETRIC AND COLORIMETRIC METHODS OF MEASUREMENT OF THE LIGHT EMITTED BY A CATHODE-RAY TUBE SCREEN

UDC 621·385·832·032·3 : 621·317·3

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Price Rs 7·00 *April* 1982

Indian Standard

PHOTOMETRIC AND COLORIMETRIC METHODS OF MEASUREMENT OF THE LIGHT EMITTED BY A CATHODE-RAY TUBE SCREEN

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0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 23 June 1981, after the draft finalized by the Electron Tubes Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This standard covers photometric and colorimetric methods of measurement of the light emitted by a cathode-ray tube screen.

0.3 One of the earliest methods of specifying the emission colour of a cathode-ray tube screen was by means of spectral characteristic curves.

0.3.1 The chromaticity of emitted light is affected by the spectral composition of its emission, but it does not follow that all light of the same apparent colour shall have the same spectral characteristic curve.

0.3.2 In fact, two screens having markedly different characteristics may appear to a viewer to have the same colour.

0.3.3 The calculation of the colour of light sources, therefore, requires not only a knowledge of the spectral composition of the radiation reaching the observer's eye, but also some consideration of the subjective response of the viewer.

0.3.4 The colorimetric characteristics taken into account are those of a ' standard colorimetric observer '; they correspond, at every point in the spectrum, to the mean value, derived from practical experiments. The spectral response characteristics of the standard observer are defined by the spectral tristimulus values:

$$\bar{X}(\lambda), \bar{Y}(\lambda), \bar{Z}(\lambda).$$

0.3.5 These values relate the amounts of three primary colours required by the standard observer to form a stimulus equivalent to a spectral colour; that is, at any wavelength, the values of x, y and z corresponding to that wavelength give the amount of the X (red) primary, Y (green) primary and the Z (blue) primary respectively required to produce, for the standard observer, the colour of the spectrum at that wavelength.

0.3.6 These tristimulus values may then be used in connection with the spectral characteristic obtained by measurement of that light source. It should be stated whether the spectral tristimulus values are $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ intended for observing fields of view of the subtended angle between 1° and 4° or $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ for observing fields of subtended angle greater than 4°.

0.3.7 At the present time, two instruments are employed to measure the colour of cathode-ray tube screens, spectroradiometer and tristimulus colorimeter.

0.4 While preparing this standard, assistance has been derived from IEC Pub 441 (1974) ' Photometric and colorimetric methods of measurement of the light emitted by a cathode-ray tube screen' issued by International Electrotechnical Commission.

0.5 In reporting the result of a test made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2 - 1960*.

1. SCOPE

1.1 This standard specifies the photometric and colorimetric methods of measurement of the light emitted by a cathode-ray tube screen.

NOTE — These tubes include monochrome and colour television picture tubes, oscilloscope tubes and other cathode-ray tubes.

2. TERMINOLOGY

2.0 For the purpose of this standard, the terms and definitions given in IS : 1885 (Part IV/Sec 4)-1970† shall apply in addition to the following.

2.1 Chromaticity — The colour quality of light definable by its chromaticity co-ordinates or by its dominant (or complementary) wavelength and its purity taken together.

2.2 Spectroradiometer — An instrumentation system used in the precise measurement of spectral characteristics.

2.3 Colorimeter — An instrumentation system used in the approximate measurement of chromaticity.

*Rules for rounding off numerical values (*revised*).
†Electrotechnical vocabulary: Part IV Electron tubes, Section 4 Cathode-ray tubes.

2.4 Relative Spectral Energy Distribution — Description of the spectral character of a radiation (description of an illuminant) by the way in which the relative spectral concentration of some radiant quantity (for example, radiance) varies throughout the spectrum.

3. PRECAUTIONS

3.1 The instrument used for measurement shall be calibrated periodically.

3.2 All surrounding surfaces that are near enough to reflect appreciable light on the face of the cathode-ray tube screen shall be rendered as nearly non-reflecting as possible.

3.3 The observation room shall be dark.

3.4 The luminance of the display shall be held constant for the duration of the measurement. To this end, well regulated power supplies to the tube electrodes and deflection circuits are essential and control of ambient temperature may also be necessary.

3.5 In the case of multiple phosphor tubes, such as shadow-mask tubes, the tube shall be adjusted for normal use.

3.6 Particular care shall be taken to ensure purity of excitation of the individual phosphors. Purity shall be checked by microscopic examination of areas of phosphor exciting one colour at a time. At the same time, visual examination for obvious contamination of each phosphor by one of the other phosphors shall be made. This contamination may be present in limited areas of the screen only. These facts shall be noted and measurements made in appropriate areas.

4. CONDITIONS OF MEASUREMENT

4.1 The tube to be measured shall be operated according to the operating conditions recommended by the manufacturer.

4.2 The luminance of areas to be measured shall be set at typical operating levels as given by the manufacturer.

A display typical of the normal use of the tube and of uniform luminance shall be used.

4.3 The screen area on which the measurement is made shall be of uniform hue and luminance and shall be appreciably larger than the area that corresponds to the field of the measuring instrument.

4.4 The position of the axis of the measuring instrument relative to the screen shall be specified.

NOTE — It may be necessary to examine areas other than in the centre of the screen.

5. SPECTRORADIOMETER MEASUREMENTS

5.1 The spectroradiometer (*see* **5.4**) gives a spectral energy distribution of the light source being measured from which the chromaticity can be calculated.

5.2 Measurements

5.2.1 With the spectroradiometer in the specified position, readings are taken and recorded for broad-band spectra at equal intervals (normally 10 nm) over a stated portion of the visible spectrum (400-760 nm).

For line spectra, additional readings shall be made at smaller intervals.

If different intervals $\triangle\lambda$ are used, the results of these measurements have to be adjusted to the value used for $\triangle\lambda$ in the formulae of **5.3.1**.

5.3 Resolution of the Measurement Data

5.3.1 *Chromaticity in Broad-Band Spectra*

5.3.1.1 Using the readings obtained and the calibration constants of the instrument, chromaticity co-ordinates of the light being measured can be calculated using the method of weighted ordinates as follows for broad-band spectra:

a) Let $G(\lambda)$ = reading at a certain wavelength λ.

b) Let $S(\lambda)$ = relative spectral power entering the slit of the instrument.

c) Thus, $K(\lambda) = \dfrac{S(\lambda)}{G(\lambda)}$ is the calibration for the instrument.

K is dependent on the spectrometer band-pass $\overline{\triangle}\lambda$ and is obtained by calibration (*see* **5.5**).

d) Obtain $F_x = K\bar{x}(\lambda)$, $F_y = K\bar{y}(\lambda)$, $F_z = K\bar{z}(\lambda)$ where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the spectral tristimulus values taken from the tables set up for the ' standard colorimetric observer '.

e) Compute the tristimulus values X, Y, Z from the equations:

$$X = \sum_{\lambda = 400\text{ nm}}^{\lambda = 760\text{ nm}} G(\lambda)\, F_x(\lambda)\, \triangle\lambda$$

$$Y = \sum_{\lambda = 400\text{ nm}}^{\lambda = 760\text{ nm}} G(\lambda)\, F_y(\lambda)\, \triangle\lambda$$

$$Z = \sum_{\lambda = 400 \text{ nm}}^{\lambda = 760 \text{ nm}} G(\lambda) F_z(\lambda) \Delta\lambda$$

Obtain $S = X + Y + Z$

Then the chromaticity co-ordinates are:

$$x = \frac{X}{S}, \quad y = \frac{Y}{S}, \quad z = \frac{Z}{S}$$

Since by the nature of the calculations $x + y + z$ is always equal to 1, it is usual to state values for x and y only.

5.3.2 *Spectral Characteristic Curve (Broad-Band)*

5.3.2.1 If instead of using the values $\bar{x}$, $\bar{y}$, $\bar{z}$, values of $K(\lambda)\,G(\lambda)$ are calculated for each wavelength, points defining the relative spectral energy distribution curve are obtained.

5.3.3 *Spectral Characteristics and Chromaticity of Mixed Broad-Band and Line Spectra*

5.3.3.1 Usually, line emission does not exist without the presence of broad-band emission. This section describes the manner of calculating the chromaticity of the combination. The computations apply to either a single line phosphor or a combination of line and broad-band phosphors.

5.3.3.2 It is necessary to integrate correctly the energy within the band to obtain the correct contributions to the tristimulus values; several methods are possible:

a) The relative spectral energy is measured at 1 nm intervals over the part of the spectrum where line emission is present (allow proportionately reduced spectral tristimulus values in this interval).

The large amount of data so produced makes the use of a computer almost essential. The calculation then follows the method of **5.3.1**.

b) A method of integration which reduces the amount of data to be processed can be used if the spectroradiometer has a constant bandwidth.

The bandwidth $\Delta\lambda$ is set to a suitable value (typically 5 nm) and measurements of output taken at the same intervals $\Delta\lambda$.

Alternatively, similar results may be obtained by electrically integrating the output signal with respect to wavelength and measuring at fixed wavelength intervals $\triangle\lambda$.

This integration is facilitated if the wavelength band scanned per unit of time is constant, as will usually be the case with recording instruments.

c) Another method is to obtain the tristimulus values X_c, Y_c, Z_c of the continuous broad-band spectrum as in **5.3.1**.

An adjustment in the amplitude of the line spectrum is required to integrate it properly into the chromaticity computation.

The measured amplitude of each line spectrum is adjusted to give

$$G(\lambda) = [G_1(\lambda) - G_c(\lambda)][\bar{\triangle}\lambda / \triangle\lambda]$$

where

$G_1(\lambda)$ = maximum output reading at wavelength λ.

$G_c(\lambda)$ = output reading for the continuous spectrum at the same wavelength λ.

$\triangle\lambda$ = wavelength interval of the continuous spectrum measurement (for example, 10 nm).

$\bar{\triangle}\lambda$ = spectrometer band-pass in nanometres.

The band-pass $\bar{\triangle}\lambda$ is a function of the spectrometer slit system. A band-pass not greater than 3 nm is recommended for adequate line spectrum resolution. The band-pass used here is the half-width of a line component of the spectral energy distribution.

Obtain the tristimulus values X_1, Y_1, Z_1 for the line spectrum using the adjusted $G(\lambda)$. Then combine the tristimulus values:

$$X = X_c + X_1$$
$$Y = Y_c + Y_1$$
$$Z = Z_c + Z_1$$

Obtain $S = X + Y + Z$; then the chromaticity co-ordinates are:

$$x = \frac{X}{S}, \quad y = \frac{Y}{S}, \quad z = \frac{Z}{S}$$

5.4 Spectroradiometer System

5.4.1 *Spectrometer*

5.4.1.1 The spectrometer may be either of the transmission type employing lenses and a prism or may use reflecting type optics and utilize a diffraction grating for dispersion of light.

5.4.1.2 In order to avoid stray light, it is advisable to use a double-monochromator.

5.4.1.3 If a single monochromator is used, additional filters shall be used in front of the entrance slit of the monochromator to reduce the intensity of undesired spectral regions.

5.4.2 *Photosensitive Device*

5.4.2.1 A photomultiplier may be used to measure the intensity at the output of the spectrometer.

5.4.2.2 Its sensitivity shall not change too much with wavelength over the visible spectrum, especially over each range of wavelengths on which elementary measurements are made; its amplitude linearity shall also be checked over the range of intensities used for measurement.

5.4.3 *Power Supplies*

5.4.3.1 Power supplies shall be adjustable and well regulated to at least 0·1 percent.

5.4.3.2 It is necessary to wait for sufficient time after switching on the power supplies 'ON' to ensure that stability has been achieved.

5.4.4 *Current Indicator*

5.4.4.1 A current indicator with a maximum sensitivity of at least 0·000 5 μA per millimetre (10 cm scale) is necessary to measure the output of the photomultiplier.

5.4.4.2 A recorder system of sufficient sensitivity may be used in place of the current indicator.

5.4.4.3 The linearity of the device shall be checked over the intensity range used for measurement.

5.5 Method of Determination of Calibration Constants

5.5.1 *Checking of Wavelength Scale*

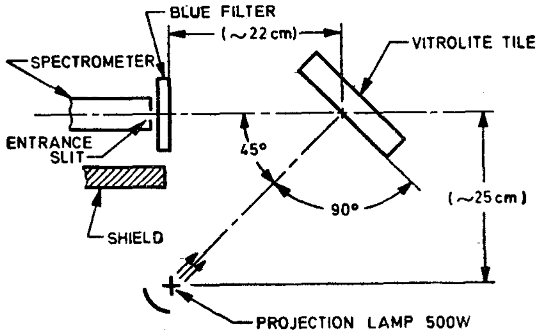
NOTE — Before any measurement or calibration is attempted on the instrument, the wavelength scale shall be checked or adjusted to read correctly. This can be done by comparing the wavelength reading with the location of peaks from known spectral emission lines of a gaseous discharge source, such as a mercury-cadmium lamp.

5.5.2 *Determination of Calibration Constants*

5.5.2.1 A requirement for proper calibration of the instrument is that the area viewed shall be uniformly illuminated with a light of known spectral composition.

5.5.2.2 Another desirable condition for calibration is that the light level used shall not be greatly different from that encountered in use, so that any required change in sensitivity can be taken care of by adjustment of dynode voltage on the photomultiplier without a change in the slit width.

5.5.2.3 These conditions can be met by the arrangement shown in Fig. 1.



NOTE — Only diffusely reflected non-specular light should reach the entrance slit. A 45° reflectance angle is suggested as a standard for cross-reference purposes.

FIG. 1 DETERMINATION OF CALIBRATION CONSTANTS

5.5.2.4 The radiation source may be a special 500 W tungsten-ribbon lamp, so calibrated that the voltage or current required to obtain illuminant A is known. The vitrolite tile is a block of white glass with known spectral reflectance.

5.5.2.5 The blue filter is a glass (for example, Corning CS 1-71) which has been calibrated for spectral transmission.

5.5.2.6 This filter is designed to convert the spectral energy distribution from an incandescent lamp at a colour temperature of 2 856 K (illuminant A) to that of a black body at 6 500 K.

5.5.2.7 The shield is to prevent heat from the lamp from reaching the spectroradiometer.

5.5.2.8 With the arrangement shown in Fig. 1 and the lamp operating at the specified voltage, or current, a series of readings are obtained for the range 400-760 nm. Several runs shall be made and the variation in the readings at any point shall not differ by more than 0·5 percent of full scale reading. These are the G_c values used to calculate the calibration constants.

Then

$$F_x = \frac{S_a R_v T \bar{x}}{G_c}$$

$$F_y = \frac{S_a R_v T \bar{y}}{G_c}$$

$$F_z = \frac{S_a R_v T \bar{z}}{G_c}$$

$$K = \frac{S_a R_v T}{G_c}$$

where

S_a = relative spectral emission of standard lamp illuminant A.

R_v = relative spectral reflectance (diffused only) of vitrolite tile.

T = relative spectral transmission of blue filter.

NOTE 1 — An alternative light source is the tungsten-halogen incandescent lamp which operates at a higher colour temperature and may be used without conversion filters.

NOTE 2 — For the most precise measurements the relative spectral energy distribution of the standard lamp must be known.

NOTE 3 — The spectroradiometer can be complemented by an analogue or digital computer that makes the above calculations and gives the numerical results.

6. TRISTIMULUS COLORIMETER MEASUREMENTS

6.1 General

6.1.1 The tristimulus colorimeter consists of one or more photodetectors, filters to modify their spectral response to the desired tristimulus functions, and either a readout device or analogue computer.

6.1.2 The tristimulus functions most generally used for cathode-ray tube measurements are the functions $\bar{x}$, $\bar{y}$ and $\bar{z}$.

6.1.3 The $\bar{x}$ and $\bar{y}$ functions are approximated by several filter-photodetector combinations.

6.1.4 The $\bar{z}$ function is in general approximated by one filter-photodetector combination.

6.1.5 Some instruments have simple readout devices that provide data from which the x and y co-ordinates are computed.

6.1.6 Other types of colorimeters incorporate analogue circuits, the outputs of which provide chromaticity co-ordinates directly.

6.1.7 It shall not be assumed that published spectral data for fitlers and photodetector are accurate enough to design a precise colorimeter.

6.1.8 For most accurate results, the spectral transmittance of filters and the spectral response of photodetectors shall be measured and tailored to each other to obtain accurate duplication of the tristimulus functions.

6.1.9 In the measurement of screens that have appreciably different persistence over different portions of their spectral output, lack of correspondence between the detector and the human eye in the integration of pulsating light may introduce errors. The magnitude of these errors is believed to be small.

6.2 Calibration

6.2.1 The recommended calibration standard is a cathode-ray tube whose colour has been determined by means of a spectroradiometer. Three-filter non-analogue colorimeters require one standard tube, whose colour should be similar to the colour to be measured. Four-filter non-analogue colorimeters require two standard tubes that are sufficiently different in chromaticity to bracket the colour to be measured.

6.2.2 To calibrate the analogue-computer type of instrument, the amount of light from the standard tube impinging on the detectors is adjusted or the electrical gain is changed until the output x and y values of the colorimeter agree with the x and y values of the calibrated tube.

6.2.3 Colorimeters without analogue circuits require the determination of a series of constants K_n. Readings are made of the photodetector-filter combinations on calibrated tubes having known x, y and z co-ordinates.

6.2.4 The constants are determined from the following equations:

a) *Three-filter colorimeter* — This requires at least one calibrated tube.

i) $$K_1 = \frac{G(x - 0{\cdot}167\, z)}{yA}$$

ii) $$K_3 = \frac{Gz}{yB}$$

iii) $K_2 = 0{\cdot}167\, K_3$

where

A = output through amber ($\bar{x}$) filter,
B = output through blue ($\bar{z}$) filter,
C = output through green ($\bar{y}$) filter.

b) *Four-filter colorimeter* — This requires at least two calibrated tubes whose screens have emissions of different spectral-energy distribution.

i) $\epsilon_1 = \dfrac{G_1}{y_1} \qquad \epsilon_2 = \dfrac{G_2}{y_2}$

ii) $K_1 = \dfrac{x_1 \epsilon_1 D_2 - x_2 \epsilon_2 D_1}{A_1 D_2 - A_2 D_1}$

iii) $K_3 = \dfrac{G_1 z_1}{y_1 B_1} = \dfrac{G_2 z_2}{y_2 B_2}$

iv) $K_4 = \dfrac{x_2 \epsilon_2 A_1 - x_1 \epsilon_1 A_2}{A_1 D_1 - A_2 D_2}$

where

D = output through blue ($\bar{x}$) filter.

6.3 Measurement

6.3.1 The operating conditions are adjusted in accordance with the published data for the particular cathode-ray tube type under test.

6.3.2 The viewed raster size and luminance are adjusted to be the same as those used for calibration. Raster linearity and focus are carefully adjusted. The readings on the analogue computer type of instrument will be the co-ordinates as discussed above. The non-analogue instruments yield a set of readings that are entered into the following equations to give x and y:

a) Three-filter instruments:

$$x = \frac{K_1 A + K_2 B}{K_1 A + G + (K_2 + K_3) B}$$

$$y = \frac{G}{K_1 A + G + (K_2 + K_3) B}$$

b) Four-filter instruments:

$$x = \frac{K_1 A + K_4 D}{K_1 A + K_4 D + G + K_3 B}$$

$$y = \frac{G}{K_1 A + K_4 D + G + K_3 B}$$

7. PRESENTATION OF RESULTS

7.1 Whichever is the method of measurement of chromaticity co-ordinates the presentation of results should be:

a) either in tabular form;

b) or as dots in a graduated graphical reproduction of the colour triangle, in the form 'x, y' or preferably 'u, v'.

It is recalled that:

$$u = \frac{4x}{-2x + 12y + 3} \quad \text{and} \quad v = \frac{6y}{-2x + 12y + 3}$$

When necessary, limits can be presented as zones which, in the 'u, v' triangle, can be a circle for each colour.