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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Obtaining Colorimetric Data From a Visual Display Unit by Spectroradiometry[1]

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INTRODUCTION

The fundamental procedure for characterizing the color and luminance of a visual display unit (VDU) is to obtain the spectroradiometric data under specified measurement conditions, and from these data to compute CIE chromaticity coordinates and absolute luminance values based on the 1931 CIE Standard Observer. The considerations involved and the procedures to be used to obtain precision colorimetric data for this purpose are contained in this test method. The values and procedures for computing CIE chromaticity coordinates are contained in Method E 308. The procedures for obtaining spectroradiometric data are contained in Test Method E 1341. This test method includes some modifications to the procedures given in Method E 308 that are necessary for computing the absolute luminance values of VDUs. This procedure is intended to be generally applicable to any VDU device, including but not limited to cathode ray tubes (CRT), liquid crystal displays (LCD), and electroluminescent displays (ELD).

1. Scope

1.1 This test method prescribes the instrumental measurements required for characterizing the color and brightness of VDUs.

1.2 This test method is specific in scope rather than general as to type of instrument and object.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 284 Terminology Relating to Appearance[2]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[2]

E 1341 Practice for Obtaining Spectroradiometric Data from Radiant Objects[2]

2.2 *CIE Publications:*

Publication CIE No. 18 Principles of Light Measurements[3]

Publication CIE No. 15.2 Colorimetry, 2nd ed., 1986[3]

Publication CIE No. 63 Spectroradiometric Measurement of Light Sources, 1984[3]

2.3 *IEC Publications:*

Publication No. 441 Photometric and Colorimetric Methods of Measurement of the Light Emitted by a Cathode-Ray Tube Screen, 1974[4]

3. Terminology

3.1 The definitions of appearance terms in Terminology E 284 are applicable to this test method.

4. Summary of Test Method

4.1 Procedures are given for obtaining spectroradiometric data and for the calculation of CIE tristimulus values and other color coordinates to describe the colors of VDUs. Modifications to the standard calculation procedures of Practice E 308 are described.

5. Significance and Use

5.1 The most fundamental method for obtaining CIE tristimulus values or other color coordinates for describing the colors of visual display units (VDUs) is by the use of spectroradiometric data. (See CIE No. 18 and 63.) These data

[1] This test method is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.06 on Appearance of Displays.

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] Currently available through the U.S. National Committee of the CIE, c/o Mr. Thomas M. Lemons, TLA-Lighting Consultants, Inc., 7 Pond Street, Salem, MA 01970-4819.

[4] Available from International Electrotechnical Commission (IEC), P.O. Box 131, 1211 Geneva, 20 Switzerland. Electronic mail: dn@iec.ch.

are used by summation together with numerical values representing the 1931 CIE Standard Observer and normalized to K_m, the maximum spectral luminous efficacy function.

5.2 The special requirements for characterizing VDUs possessing narrow or discontinuous spectra are presented and discussed. Modifications to the requirements of Practice E 308 are given to correct for the unusual nature of narrow or discontinuous sources.

6. Requirements When Using Spectroradiometry

6.1 When describing the measurement of VDUs by spectroradiometry, the following must be specified:

6.1.1 The radiometric quantity determined, such as the irradiance (W/m^2) or radiance (W/m^2-sr), or the photometric quantity determined, such as illuminance (lm/m^2) or luminance (lm/m^2-sr or cd/m^2). The use of older, less descriptive names or units such as phot, nit, stilb is not recommended.

6.1.2 The geometry of the measurement conditions, including, whether a diffuser was used and the material from which it was constructed, the distances from the VDU, the size of the area to be measured on the VDU, the uniformity of the VDU across the area to be measured, the microstructure of the VDU picture elements, and the presence of any special intermediate optical devices such as integrating spheres.

6.1.3 The spectral parameters, including the spectral region, wavelength measurement interval, and spectral bandwidth. These must be specified since the various VDU technologies may demand more or less stringent requirements.

6.1.4 The type of standard used to calibrate the system, a standard lamp, a calibrated source, or a calibrated detector, and the source of the calibration.

6.1.5 The physical and temporal characteristics of the VDU including, refresh or field rate, convergence and purity adjustments (if the manufacturer allows such), luminance level, and any spectral line character in the emission from the VDU. The integration time of the detector system should be noted in relation to the refresh or field rate of the VDU. (See IEC No. 441.)

7. Apparatus

7.1 The basic instrument requirement is a spectroradiometric system designed for the measurement of spectral radiance or irradiance of light sources. See Practice E 1341 for details on each of the parts of a spectroradiometer and how to calibrate and use the instrument.

7.2 *Calibration Sources*:

7.2.1 The standard calibration source for spectroradiometry is a tungsten-filament lamp operated at a specified current. It is preferable to have more than one standard lamp to permit cross-checks and to allow calibration at a range of luminance levels.

7.2.2 Monochromatic emission sources such as a low-pressure mercury arc lamp or tunable laser should also be available for use in calibrating the wavelength scale.

7.2.3 The electrical supplies for the calibration sources should be of the constant current type. The supply should be linear and not a switching supply. Current regulation should be maintained to better than 0.1 %. At this level the radiant flux from the calibration source is at least an order of magnitude more stable than the flux from a VDU.

7.2.4 There should be a standard for length measurements available (such as a high quality metric rule) since absolute irradiance calibration must be performed at an exact distance from the filament of the calibration lamp.

7.3 *Receiving Optics*—To maximize the light throughput the number of optical surfaces between the source of light should be kept to a minimum. In extended diffuse sources (such as VDUs) only a set of limiting apertures will be needed. In some instances, it may be desirable to image the VDU with an intermediate focusing lens or mirror assembly. Care should be taken to use a magnification that will adequately fill the entrance slit when viewing both the calibration and test source.

8. Calibration and Verification

8.1 Calibration and its verification are essential steps in ensuring that precise and accurate results are obtained by spectroradiometric measurements. They require the use of physical standards, some of which may not be normally supplied by commercial instrument manufacturers. It remains the user's responsibility to obtain and use the physical standards necessary to keep his instrument in optimum working condition.

8.2 *Radiometric Scale*:

8.2.1 *Zero Calibration or Its Verification*—All photometric devices have some inherent photocurrent, even in the absence of light. This so called "dark current" must be measured and subtracted from all subsequent readings either electrically or computationally.

8.2.2 *Radiometric Scale Calibration*—A physical standard of spectral irradiance is normally used for calibration. After the dark current has been measured, the calibration source is positioned in front of the receiving optics at the specified distance and operated at the specified electric current. This provides a good approximation to a Plankian radiator across the visible spectrum. The calibration source is measured and the values of the dark-current-corrected photocurrent are recorded. These photocurrents are then related to the calibration values of spectral irradiance that were provided by the standardizing laboratory. The ratio of spectral irradiance to photocurrent becomes the instrument calibration factor. All subsequent measurements are multiplied by this ratio.

8.2.3 *Linearity Verification*—Periodically after the radiometric and zero scale readings are established, the linearity of the scale should be verified.

8.2.4 All calibrations should be performed using the same integration time constant that will be used during the measurement of the VDU.

8.3 *Wavelength Scale*:

8.3.1 *Scale Calibration and Verification*—Since the output of a cathode ray tube (CRT) type VDU contains some line structure, the wavelength scale must be precise and accurate enough to characterize this line structure. Generally, the best method of calibration or verification of the wavelength scale is to determine the difference between the measured peaks, or more preferably the wavelength centroids, and the tabulated positions of the emission line of mercury or neon arc lamps. Most monochromators exhibit significant nonlinear errors in addition to the random linear errors. Generally, the best method of either calibration or verification of the wavelength scale is to determine the differences between the measured peaks and the tabulated positions of the emission lines of the arc lamps. The differences should be averaged and reported. Random errors larger than 1.0 nm should be cause for concern.

9. Procedure

9.1 *Selection of Measurement Parameters*:

9.1.1 If the VDU is small or highly directional so that the solid angle subtended by the instrument aperture is a large fraction of the VDU area then measure the spectral irradiance. If the VDU is large, then measure the spectral radiance. Utilize the appropriate calibration source. Mount all pieces of the apparatus solidly in place. An optical table or bench is highly recommended.

9.1.2 Select the spectral region, measurement interval, integration time constant and the spectral bandwidth (if possible). Try to keep the spectral bandwidth and measurement interval equal. The bandwidth should be no greater than 5.0 nm. For VDUs with narrow band emitters, such as the P22 red CRT phosphor, the spectral bandwidth should be less than 2.0 nm. (See IEC No. 441.) The default spectral region should be 380 to 780 nm. This region may vary slightly depending on the technology of the VDU being characterized. It is unnecessary to scan a VDU in a spectral region where there is no radiant output but the actual extent of region should be determined experimentally.

9.1.3 Place the calibration source at the specified distance from the monochromator entrance aperture. Measure the VDU at the identical distance from the monochromator entrance aperture.

9.2 *Selection of Computational Parameters*:

9.2.1 Depending on the geometry of the measurements, select either radiance or irradiance calculations. Determine if correlated color temperature calculations are required and use the correct CIE chromaticity coordinates and formulae for the calculations, the 1960 uniform chromaticity scales and the 1931 CIE color matching functions are the correct choices.[5] Use $K_m = 683$ lm/W for the maximum spectral luminous efficacy. Note that neither luminance nor color temperature are defined in terms of the 1964 CIE Supplementary Standard Observer.

9.2.2 Practice E 308 indicates that CIE tristimulus values are to be normalized by a constant that is calculated for the illuminant-observer pair. Here, the VDU is both the object and the source of light. To calculate CIE absolute tristimulus values, multiply each spectroradiometric reading (in Watts) by the value of a CIE 1931 color matching function ($\bar{x}$, $\bar{y}$, or $\bar{z}$) for that wavelength. Sum these products over all wavelengths for each of the color matching functions. (See CIE No. 15.2.) Multiply the sum by K_m, the maximum spectral luminous efficacy, which equals 683 lm/W.

9.3 *Measurements*:

9.3.1 Determine the zero scale first. This can be done either by scanning the spectral region with the entrance slit blocked and subtracting the reading from subsequent scans, or by manually adjusting the radiometer to read zero when the entrance slit is blocked.

9.3.2 Scan the calibration source and determine the system's spectral calibration factor by ratioing the tabulated spectral radiance (irradiance) values to the measured photocurrent.

9.3.3 Replace the calibration source with the VDU and scan the test source using the same settings. Multiple the readings by the spectral calibration factor, wavelength by wavelength.

9.3.4 For many radiometric measurements, the unknown phase relationship between the integration period of the spectroradiometer and the field refresh rate of the VDU dominates the measurement error. Two alternative measurement techniques are suggested. First one could synchronize the radiometer integration time interval with the VDU refresh cycle and then integrate for an integral number of refresh cycles. Second, one can integrate for a large number of refresh cycles that exceed the inverse of the precision desired in the measurement.

10. Report

10.1 The report of the color measurement of a VDU shall contain the following:

10.1.1 Identification of the type of VDU (CRT, EL, LCD, etc.).

10.1.2 Date of measurement.

10.1.3 Orientation of the VDU relative to the spectroradiometer.

10.1.3.1 This should include the relationship in spatial and temporal parameters between the VDU and spectroradiometer. Field rate and integration time constant, distance between the entrance aperture and the source, surface properties such as microstructure (dot triad geometry), convergence and purity (if appropriate), and setting of brightness and contrast controls.

10.1.4 Size of the measured area, in linear dimensions.

10.1.4.1 All dimensions shall be reported in SI units (metres).

10.1.5 The spectral region, spectral bandwidth, and measurement interval.

10.1.5.1 All wavelength related parameters shall be reported in SI units (nanometres).

10.1.6 The radiometric or photometric scale used.

10.1.6.1 All radiometric related parameters shall be reported in SI units, either watts per square metre—nanometre for irradiance or watts per square metre—nanometre—steradian for radiance.

10.1.6.2 All photometric related parameters shall be reported in SI units, either lumen per square metre—steradian for luminance or lumens per square metre for illuminance.

10.1.6.3 The use of certain archaic names or units such as phot, nit, stilb, is not recommended.

10.1.7 The spectral data in the form of tables of wavelength and measured quantity.

10.1.8 The CIE absolute tristimulus values and chromaticity coordinates.

10.1.9 The CIE uniform chromaticity scale coordinates (if required).

10.1.10 The correlated color temperature in kelvin (if required).

[5] Robertson, A. R., "Computation of Correlated Color Temperature and Distribution Temperature", *J. Optical Society of Am., 58*, pp. 1528–1535, 1968.

11. Precision and Bias

11.1 Precision and bias for VDU measurements have not been determined at this time. An experiment to determine this is being prepared. A lower limit can be obtained from the precision and bias statement in Practice E 1341.

12. Keywords

12.1 brightness; calibration; CIE color-scale system; CIE tristimulus values; cathode ray tubes (CRTs); color; illuminance; instrumental measurement (color/light); instrumental measurement (spectroradiometric); irradiance; liquid crystal displays (LCDs); luminance; radiance; radiometry; self-luminous displays; spectroradiometers; spectroradiometry; tristimulus values; video/visual display units (VDUs)