A standard illumination source for the evaluation of display measurement methods and instruments

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ABSTRACT

A prototype display measurement assessment transfer standard (DMATS) is being developed by the National Institute of Standards and Technology (NIST) to assist the display industry in standardizing measurement methods used to quantify and specify the performance of electronic displays. Designed as an idealized electronic display, the DMATS illumination source emulates photometric and colorimetric measurement problems commonly encountered in measuring electronic displays. NIST will calibrate DMATS units and distribute them to participating laboratories for measurement. Analysis of initial interlaboratory comparison results will provide a baseline assessment of display measurement uncertainties. Also, diagnostic indicators expected to emerge from the data will be used to assist laboratories in correcting deficiencies or in identifying metrology problem areas for further research, such as measurement techniques tailored to new display technologies. This paper describes the design and construction of a prototype DMATS source and preliminary photometric and colorimetric characterization. Also, this paper compares measurements obtained by several instruments under constant environmental conditions and examines the effects of veiling glare on chromaticity measurements.

Keywords: Display measurement, color measurement, standards.

1. INTRODUCTION

The virtual explosion in the use of electronic displays in modern commerce and communication has exposed significant deficiencies in the methodologies employed by industry to specify and evaluate display performance. Development of new display technologies and improvements in existing technologies demand quantitative measurements for performance specification and quality control. Displays being used increasingly in medicine for diagnosis must be selected via quantitative performance testing and once installed must be periodically calibrated and re-certified for diagnostic use. E-commerce applications and industries such as automotive, textile, cosmetic, paint, and entertainment are critically dependent on their ability to accurately communicate color information to customers via electronic displays. At some level, all industries that depend upon communication of graphical and image information—from display manufacturers to web site designers—rely upon quantitative measurements of displays.

However, measuring instruments and the procedures commonly used to measure color and other optical characteristics of displays may not be sufficiently accurate. It is not uncommon, for example, for concern to be raised over small differences between color measurements, in the face of much larger unrecognized errors of 10% to 20% or more in photometric or colorimetric measurements due to inadequate technique, uncontrolled measurement environment, poorly calibrated instruments, or all of these deficiencies.

NIST is addressing these display measurement problems through the development and dissemination of measurement techniques and illuminators equipped with optical targets by which industry technicians can evaluate their measurement methodology and instrumentation. By reducing the laboratory-to-laboratory variance in color and other optical measurements, we hope to assist both the manufacturer and the user in specifying and evaluating display performance.

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This paper describes the construction and preliminary characterization of a prototype DMATS illumination source designed to simulate some of the measurement challenges presented by electronic displays. Several measuring devices are used to measure the prototype DMATS source. Examples of several measurement deficiencies are discussed.

2. DMATS

NIST has initiated a program aimed at assisting the electronic display industry, including manufacturers and users, in evaluating and advancing the state-of-the-art of display metrology. A series of interlaboratory comparisons is planned in which participants will execute photometric and spectroradiometric measurements of a standard calibrated light source using their customary procedures. NIST analysis of the data will identify measurements exhibiting unacceptably large uncertainties. This information will be disseminated to industry with recommendations for improved measurement methods. Such information will support standardization of measurement methods and enable improvements in specification of display performance.

The central element of the NIST program is the DMATS, a multi-filter-target light source. The DMATS source covers the gamut of electronic display luminance and color to provide a common reference by which to evaluate the measurement techniques, instruments, and the measurement environments of participating laboratories. The motivating idea was to develop a source that could be replicated and reconfigured at relatively low cost and present a variety of realistic display measurement problems without committing to a single display or display technology.

2.1 DMATS Prototype

Several designs were considered for the prototype DMATS. A conceptual DMATS design is shown in Fig. 1. It consists of a uniform illumination source fitted with an array of color filters and other optical components selected to emulate many of the measurable attributes of electronic displays. Principal design criteria included low cost, robustness for shipping and handling, and selection and positioning of filter targets so as to fully exercise display measurement apparatus and technique.

Fig. 1. Each DMATS unit will consist of a uniform illumination source with a suite of optical targets mounted in a removable, reconfigurable faceplate. The unit will be shipped with power supply, photodiode monitors and picoammeters, digital thermometer, and a laptop computer for automatic logging of photodiode current and operating temperature.

2.2 Uniform Illumination Source

The uniform illumination source was constructed by mounting two tungsten-halogen lamps into a closed-cell white polystyrene foam box. Such polystyrene foam sources have been shown to be remarkably uniform and to maintain uniformity even with moderate physical abuse [1, 2], an important feature for units to be shipped repeatedly. Later versions of the DMATS might use a more conventional integrating sphere. However, polystyrene boxes are inexpensive and easily modified for experimental purposes. It should be noted that the boxes used are of the type designed for transport and temporary storage of biological materials, such as organs. They have thicker walls and are made of a denser polystyrene than that found in the most inexpensive picnic coolers, for example.

Each of the two tungsten-halogen lamps is powered by a regulated DC power supply providing the lamps with constant current of 1.83 A at approximately 30 V. The dual-output power supply is programmable and equipped with GPIB (general purpose interface bus, IEEE-488.2) interface for control via a laptop computer to be shipped with the DMATS.

2.3 Target Faceplate

The DMATS was conceived not merely to provide a set of calibrated standard targets, but to present the targets in a configuration representative of display measurement situations. Hence the targets are arranged on the faceplate in a planar array and to some extent juxtaposed in order to challenge the metrologist's ability to avoid contamination of measurements from adjacent regions. Narrow-band and wide-band interference filters cover the color gamut while wide-band glass filters provide interior points within the gamut. Polarizers, differing in density and orientation, test the polarization sensitivity, while neutral density filters test the linearity of the measuring device. Opaque white and gloss-black targets provide indicators of the measurement environment and the sensitivity of the instrumentation to glare. A Ronchi ruling, gray rulings, and a mura (non-uniformity) target test detail and contrast measurement capabilities. Various cutoff filters test the effect of out-of-band or band leakage on the measuring instrumentation.

The present faceplate configuration is shown in Fig. 2. The numbered targets are narrow-band interference filters having peaks centered at the indicated value and full width at half maximum bandwidth (FWHM) of approximately 10 nm. Wide-

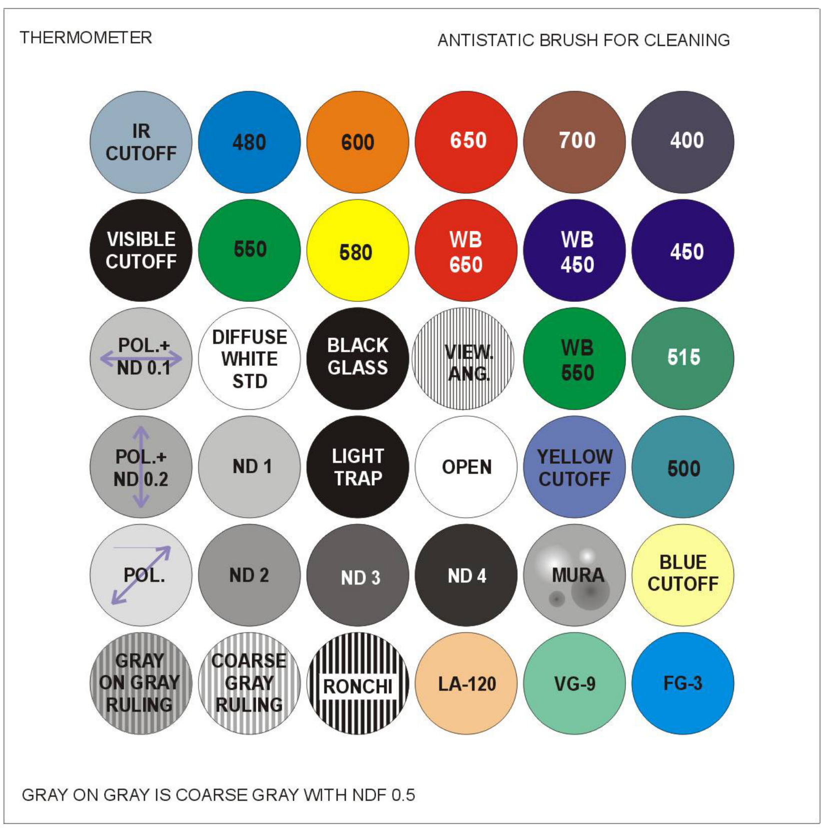

Fig. 2. Arrangement of targets on DMATS faceplate.

band interference filters, designated with "WB", have FWHM ≅ 40 nm. The position labeled "OPEN" actually contains a clear, optically flat, glass disc through which source illumination may be measured.

2.4 Light Source Monitors

The DMATS source is equipped with two calibrated silicon photodiode detectors, one of them fitted with a photopic correction filter, to monitor the light source. Data recorded from these two detectors are used to monitor stability and health of the source and to provide a reference for the measurements. The current outputs of these detectors are monitored via picoammeters, which are equipped for automatic logging to the computer via GPIB ports.

2.5 Temperature Monitor

The temperature of the faceplate is monitored with a thermometer or thermocouple probe to provide additional data on environmental factors having potential effects on measurements. Record of operating temperature also will aid in evaluating the longevity of filter targets. In this regard, we already have observed sloughing of metallic coatings of neutral density filters from one source, presumably due to heating of the faceplate during temperature sensitivity experiments.

3. DMATS CHARACTERIZATION

Libert, *et al*, [2] described initial measurements to characterize an earlier DMATS prototype. The reported measurements were aimed at (1) determining the temporal stabilization baseline of the unit; (2) measuring the uniformity of the illumination source, including evaluation of the suitability of several interior surface materials; (3) making a coarse measurement of the luminance and chromaticity coordinates of the filter targets; and (4) making an initial assessment of the effects of warming on the faceplate and targets. For the present paper, a second DMATS unit was constructed using a different arrangement of the lamps and cooling components. The modifications preserved most of the features of the first prototype discussed in [2]. However, the maximum luminance of the second prototype unit was reduced from 4100 cd/m^2 to 3650 cd/m^2, as measured by a luminance meter at the clear glass port of the faceplate (labeled "OPEN" in Fig. 2). These modifications vastly simplified and improved the cooling of the system. A third design, presently under construction, may recover some of the lost light output.

In the present investigation, selected filter targets were measured using a newly acquired double grating monochromator (DGM). For comparison, the filters were also measured with a photodiode array spectroradiometer, and a tristimulus filter colorimeter. Photometric output (luminance in cd/m^2) was measured with these three instruments and also with a luminance meter. The DGM was calibrated in the NIST Flat Panel Display Laboratory (FPDL) and the spectroradiometer was calibrated by the manufacturer using a NIST traceable source. The luminance meter was newly acquired and calibrated by the manufacturer. The colorimeter had not been recently calibrated. All measurements were taken in a darkened laboratory room with flat-black walls. Also, unless otherwise noted, measurements were made through the 2.54 cm aperture of a 90° gloss-black frustum positioned close to each target to reduce veiling glare and stray light contamination of measurements [3].

We have planned an interlaboratory comparison study and will publish NIST measurements of the DMATS with those of participating laboratories, as appropriate, in a later paper that will detail the uncertainty associated with each of the measurements. For the present, we will display our preliminary measurements graphically.

3.1 Photometry of Selected Filter Targets

We were interested in comparing luminance measurements of the selected targets using the four instruments. In order to enable a comparison among instruments short of recalibration over the full spectrum, a simple gain adjustment was applied to the data. The DGM was taken as the "standard," and the measurements of the other instruments adjusted such that all measurements of the white source would be equal. Thus, for each instrument p a correction factor C_p was calculated as

$$C_p = \frac{L^{DGM}_{white\ source}}{L^{p}_{white\ source}}, \quad p = \{LumMeter, Colorimeter, Spectrorad\}.$$

Then the luminance values for each instrument were multiplied by the correction factor C_p. Each corrected luminance value was subtracted from the corresponding DGM measurement, resulting in the error values displayed in Fig. 3. The circulating DMATS units will be equipped with neutral density filters that would enable testing the linearity of the measurement instruments, information that would help explain luminance disparities such as those observed here, .e.g., resolving non-linearity, contamination, or spectral mismatch problems.

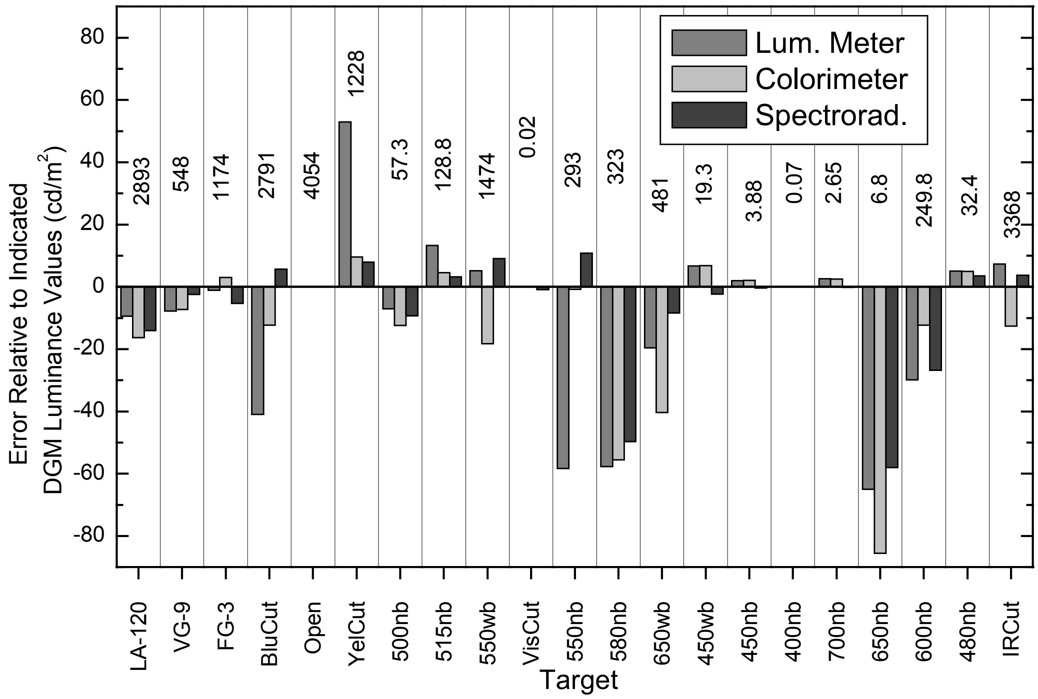

Fig. 3. Error in corrected luminance values of Luminance Meter, Colorimeter, and Spectroradiometer with respect to DGM measurements for DMATS targets .DGM luminance values are indicated for each target.

3.2 Colorimetry of Selected Filter Targets

Figure 4 shows the Commission Internationale de l'Eclairage (CIE 1931) x, y chromaticity coordinates as measured by the three instruments. Boynton *et al*., [4] discuss the use of interference filters to characterize colorimeters and spectroradiometers. Moreover, they suggest how the displacement vector of measured values from theoretical values may be diagnostic of particular sources of measurement error, such as stray light in the monochromator or spectral mismatch of the tristimulus filters of the colorimeter. Prior to additional verification, the chromaticity coordinates shown in Fig. 4 are considered tentative. However, several qualitative observations and interpretations can be made.

As one might expect, the tristimulus colorimeter was the least accurate of the three devices. In several cases, we observed it to be wildly inaccurate, such as with the 400 nm and 700 nm narrow-band filters and with the visible light cutoff filter. In these cases the instrument places the chromaticity values far from the loci of the other measurements. However, one should expect the greatest error in the color filters used in the colorimeter at the extremes of the color gamut. In spite of these errors, it is reassuring that this comparatively simple instrument performs quite respectably over much of the gamut. Moreover, Ohno, Brown, and Hardis [5, 6] describe means by which to correct measurements of tristimulus colorimeters.

The DGM and the spectroradiometer appear to be in fairly close agreement for most of the targets. A notable exception is the 400 nm narrow-band filter for which chromaticity coordinates from both measurements are displaced toward the center of the diagram. Inspection of the filter under 10X magnification revealed approximately 6 to 8 pinholes in the thin-film coatings. The greater displacement of the DGM measurement was due to sampling a slightly larger area of the filter, hence a greater number of pinholes. Filters to be used in the circulating DMATS units will be closely screened for such defects and periodically inspected for these and other visible changes in the surfaces.

Another large disparity occurs with the visible cutoff filter. In this case, the chromaticity coordinates of both the DGM and the spectroradiometer are shifted toward the center of the diagram. Figure 4 indicates that the disparity might result from stray light, either external or internal to the spectroradiometer. We used a frustum (see discussion in section 3.3) to reduce the effect of stray light from neighboring areas of the faceplate, but it remains possible that some visible light was able to reach the detector. A small space between the frustum opening and the faceplate could allow light to pass into the frustum. Dust

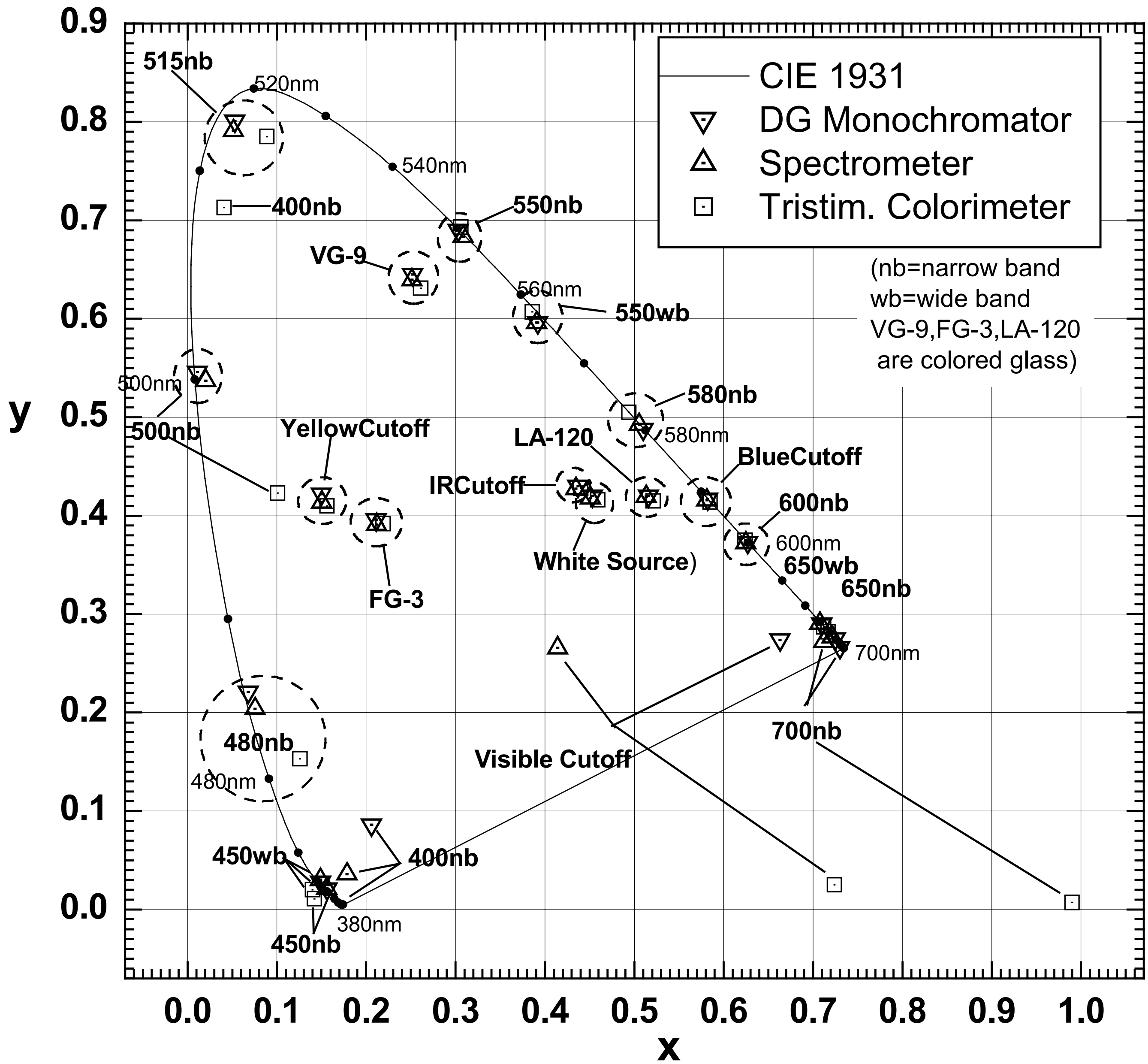

Fig. 4. CIE 1931 chromaticity diagram showing color coordinate positions of selected DMATS targets as measured with three color measurement devices.

either on the filter or on the inner frustum surface could reflect white light to the instrument thereby contaminating the measurement. Noise or scattering internal to the spectroradiometer may be indicated by the rather jagged appearance of the spectrum shown in Fig. 5.

3.3 Stray Light and Veiling Glare Effects

That stray light might be involved in the measurements described above is suggested also by Fig. 6. The diagram depicts chromaticity measurements of a few targets made only by the DGM both with and without use of a gloss-black frustum. Improvement is small, but noticeable for many of the measurements. The improvement is profound in the case of the visible cutoff filter. Reference to Fig. 2, showing the filter positions on the DMATS faceplate, might further reinforce the importance of using the frustum, particularly as the visible cutoff filter is neighbored above and below by two visible light ports, the IR cutoff filter and a polarizer. That the frustum alone might not be sufficient in this case is suggested by comparing the chromaticity coordinates of the visible cutoff filter as shown in Figs. 4 and 6. Both DGM measurements were made with the

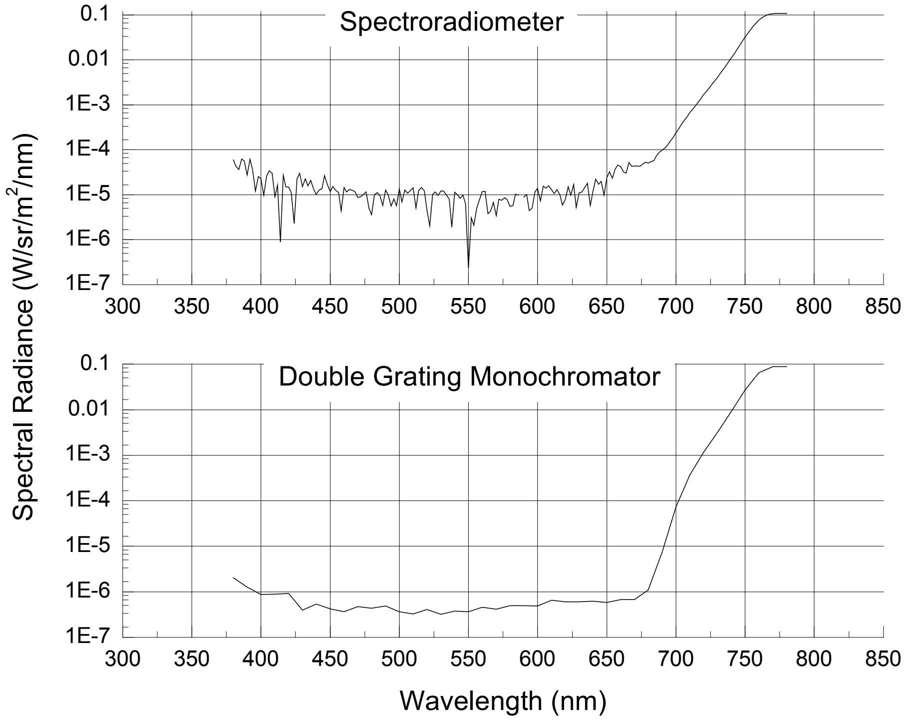

Fig. 5. Spectra for the visible cutoff filter as measured by the spectroradiometer (top) and the DGM (bottom) showing relative contribution of stray light to chromaticity measurements of the two instruments.

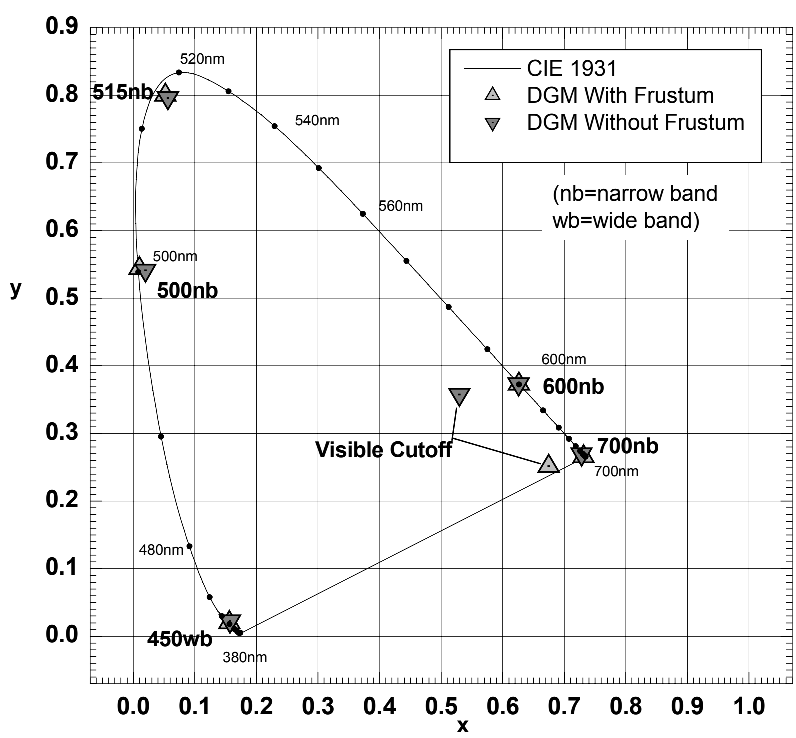

Fig. 6. Comparison of chromaticity coordinates of selected targets measured with DGM both with and without use of the 90° frustum.

frustum, but for the demonstration of the frustum effects (Fig. 6), additional care was taken to position the frustum in direct contact with the faceplate to reduce the leakage of light around the edges. For previous measurements, the frustum was

positioned close to, but not touching, the faceplate surface in order to prevent its interference with the motorized positioning of the DMATS. In order to evaluate further external stray-light and veiling-glare effects, we will use more aggressive stray light elimination devices such as described in [7]. This will enable us to better resolve, for example, the relative error contributions of calibration differences, spectral mismatch, stray-light scattering, and instrument noise.

4. CONCLUSION

By making standard illumination sources available to display metrologists, we expect to facilitate identification and diagnosis of deficiencies in measurement protocols, instrumentation, or environments. Data to be collected during a planned interlaboratory comparison will enable us to evaluate the interlaboratory variability of various types of measurements and to identify measurement methods in need of improvement. Moreover, providing the use of the DMATS units and maintaining a measurement database should facilitate self-certification of measurement laboratories and calibration of measurement systems. These factors should improve the specification and testing of electronic displays to support the growing role of such devices in virtually all fields of commerce and industry.

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