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21.4: Compensation for Stray Light in Projection Display Metrology

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Abstract
Electronic projection display specifications are often based on measurements made in ideal darkroom conditions and assume ideal measurement instrumentation. However, not everyone has access to such a facility, and the light-measuring devices may not necessarily provide the desired information. Simple tools are discussed that address some of these concerns.

1. Introduction
Attempting to compare different electronic projection displays or to evaluate the specifications of a particular display can be a daunting task, especially in uncontrolled environments. Ambient light from other sources in the room may illuminate the screen (Fig. 1). This includes room lights directly illuminating the screen and the reflection of these light sources off of walls, floors, furniture, and other objects. Additionally, back-reflections arising from the image on the projection screen must be considered. These stray light components contribute to the measured values and give rise to an inaccurate measurement of the projector photometric and colorimetric output, especially for low-level measurements. However, even in a darkroom with a black screen, significant errors can result. The ideal approach would be to separate out the various components of the display and environment: the "intrinsic" performance of the projector (including the lens), the reflective properties of the display screen (for projectors whose screens are not integrally part of the display), and the contributions of the particular room. Using relatively uncomplicated tools and a simplified room model, one can easily measure the projector independent of the environment, and approximate the contributions of the screen and room for a given projector.

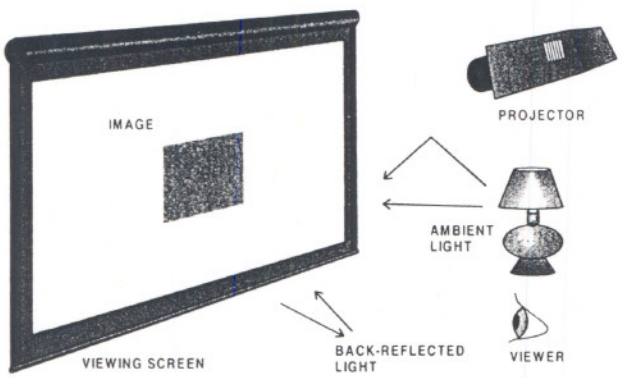

Fig. 1. Sources of stray light when viewing a projected image.

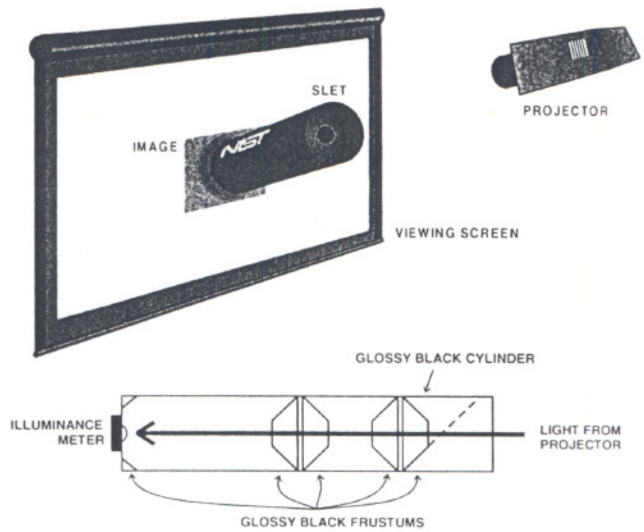

Fig. 2. The Stray Light Elimination Tube (SLET).

2. Stray Light Elimination Tube
Solutions to avoid the effects of stray light on light-measuring devices (LMDs) have been documented in earlier work by Boynton and Kelley [1]. This reference describes use of glossy black frustums (incorrectly called "cones" in the paper) with 90° apex angles used to direct any stray light away from the lens. These frustums have been used in a device designed and built at NIST to prevent reflections from corrupting the measurement of projection displays. Preliminary results of the use of this tool, called the stray light elimination tube (SLET), have been documented in [2].

The SLET used at NIST was constructed out of 15 cm (inner diameter) polyvinylchloride tubing painted glossy black on both exterior and interior surfaces (see Fig. 2). The 61 cm long tube was fitted with two opposing-pair frustums with 90° apex angles, and a single frustum with a shallower angle surrounding the LMD port. The projected light enters one end of the tube, and the illuminance meter is placed on the opposite side.

Glossy black paint was chosen over a flat black because the diffuse reflectance of flat black is much larger (typically around 5%) than the diffuse reflectance of good glossy black paint (typically $\leq 0.2\%$). Furthermore, the paint's specular component provides for control of reflections so that stray light may be directed away from the measurement device and trapped.

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3. Projection Mask

Alternatively, a small black plastic mask may be used to determine stray light contributions in non-extreme cases of stray-light contamination (see Fig. 3). An illuminance measurement is made and recorded. Then the projection mask is placed in position so as to eclipse the projector from the meter measurement head. Another reading is taken, representing the stray-light contributions, which is subsequently subtracted from the no-mask measurement. This adjusted value provides an estimate of the projector light characteristics independent of the screen properties and room conditions.

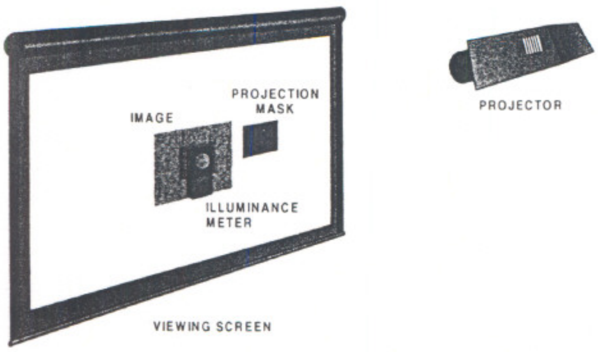

Fig. 3. Projection mask method of stray-light compensation.

The optimum distance of the mask from the illuminance meter varies depending upon the distance of the projector from the meter and the configuration of the room. If the mask is placed too close to the meter, some of the reflected light will be obscured. If situated at too great a distance, diffraction around the mask and forward scattering of light (due to particles of dust in the air) may contribute to the measurement. The mask must be large enough to effectively eclipse the projector and cast a shadow across the meter sensor area.

4. Front Projection Displays

For projection systems in which a screen is not integrally a part of the display (i.e. front projection systems), the SLET or mask may be used as shown in Figs. 2 and 3. Photometric and colorimetric measurements were performed in a room with black floor tiles and with walls and ceiling painted flat black. A projection screen hung behind the meter. The image was focused on the detector head, which was 26.5 cm away from the screen and 155 cm from the floor. Matte screens were placed in close proximity to the LMD to simulate the effect of reflective walls. A three-panel liquid-crystal-display front-projection system with a metal-halide lamp was used to project a 2 m diagonal image onto the screen at a distance 366 cm away. Images were generated on a laptop computer and distributed to the projector as a VGA signal. When used, the projection mask was placed 60 cm in front of the illuminance meter such that the projector was eclipsed.

Photometric measurements were made with an illuminance meter and colorimetric data was taken using a diode-array spectroradiometer mounted with a cosine-corrected collector. Because relative phenomena were being measured, neither instrument was calibrated prior to use, although the performances of both LMDs have been established through laboratory intracomparisions.

Results** of the effectiveness of the SLET and projection mask are shown in Tables 1 and 2, and in Fig. 4. As demonstrated in Table 1, for this particular configuration, the SLET successfully removed practically all of the stray light from the measurement device when the overhead fluorescent lights were switched on.

Table 1. Using the SLET to measure illuminance in different ambient light conditions.

condition	Measured illuminance with no SLET	Measured illuminance with SLET	deviation
	lx	lx	
room lights off	6.43	3.63	77%
room lights on	319	3.79	8317%

A halation test was performed and results are shown in Fig. 4. A black rectangle on a white field was projected onto the screen, and the illuminance of the black rectangle was measured for various rectangle sizes (the rectangle linear size was varied as a percent of the projected image linear size). This test provides an indication of the degree to which light is scattered within the projection lens; one would expect the black level to decrease proportionally to the rectangle size. However, the measured illumination using the SLET begin at a lower illuminance and decrease at a lower rate that the data taken in the non-mask condition, indicating than this test can be easily corrupted by room and screen contributions. Note that the SLET and mask-corrected data are nearly identical.

Attempts at determining the colorimetric values of images may present similar problems. Several low-level primary colors were

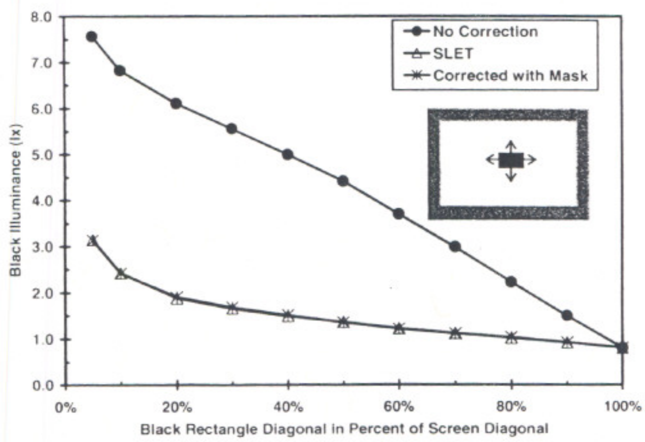

Fig. 4. Comparison of mask and SLET.

measured as a small rectangle (10% of total image linear size) on a field of white or complementary color. Inaccuracies in illuminance and chromaticity were observed with the no-mask condition. The mask and the SLET both provided results without significant stray-light contribution (Table 2 and Fig. 5). Note how

** The data presented in this paper are for illustrative purposes only, and do not constitute a calibration. Unless stated otherwise, the expanded uncertainty in all described measurements is estimated to be ± 10% of the measurand using a coverage factor of two.

the tristimulus values of the mask can be subtracted from the non-mask condition to obtain results similar to those of the SLET.

Table 2. Deviation of non-corrected and mask-corrected data from SLET measurements for measured tristimulus values.

projected pattern	no correction			correction with mask		
	ΔX	ΔY	ΔZ	ΔX	ΔY	ΔZ
red box on white field	41%	68%	72%	0%	2%	0%
green box on white field	55%	33%	69%	4%	4%	2%
blue box on white field	63%	127%	16%	2%	1%	5%
red box on cyan field	30%	64%	76%	1%	0%	1%
blue box on yellow field	75%	138%	0%	1%	1%	2%

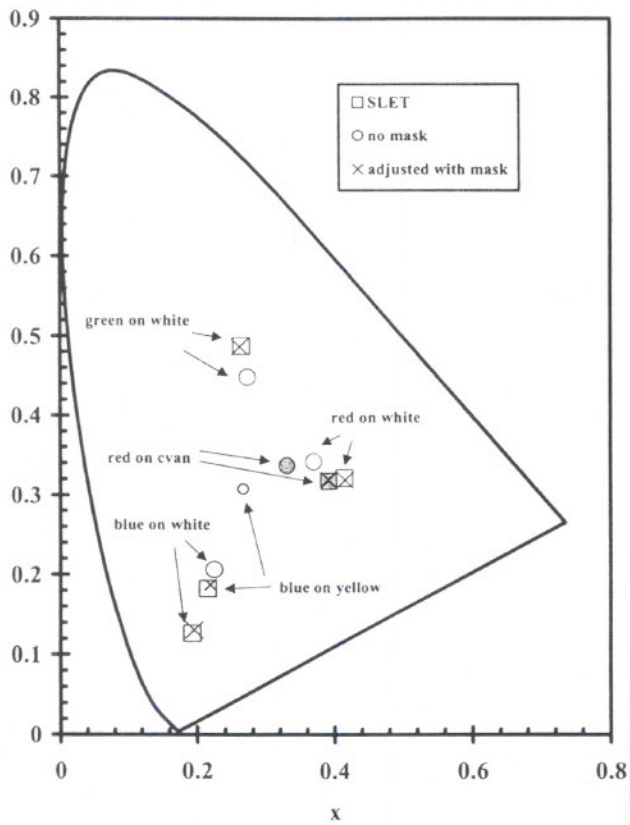

Fig. 5. Effects of stray light on chromaticity measurements.

5. Portable Darkroom

For projection systems in which the screen is an integral part of the display (i.e. rear projection systems), the SLET may be used to eliminate stray light, albeit with a few modifications. As illustrated in Fig. 6, a SLET may be placed up near the rear-projection screen. The front edge of the SLET tube needs to be covered with black felt or other protective material to reduce light leakage around the instrument. Furthermore, to prevent stray light from striking and subsequently internally reflecting within the screen, the screen should be cloaked with black felt or other light-blocking material with low reflectance properties.

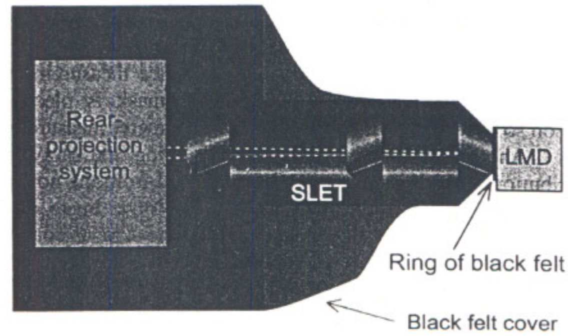

Fig. 6. Portable darkroom SLET.

A halation test, similar to the one in section 3, was performed on a 52 inch (132 cm) cathode-ray tube rear-projection television. The halation images were produced as an NTSC signal by a video generator. The data shown in Fig. 7 indicate that the effects of ambient room conditions can be reduced in this case.

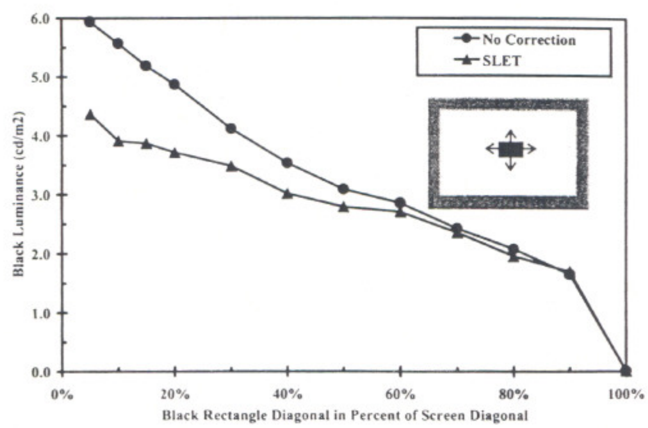

Fig. 7. Effect of portable darkroom SLET.

6. Room Modeling

If the characteristics of the projector independent of the environment can be accurately measured, and the screen properties can be determined (for example, see [3]), then the only unknown component is the room contribution. The perceived brightness (and contrast) of a projected image will be affected by at least two components: the illuminance E_A from ambient light sources and the illuminance E_R of the light from the screen reflected off the surfaces of the room and back onto the display. Thus the total illuminance E_C contributed by the room environment is:

$$E_C = E_A + E_R \qquad (1)$$

One can use a hemispherical approximation to estimate how much light will reflect back onto the projection screen. The hemispherical model is shown in Fig. 8 and described in [4]. The back-reflected light can be expressed as:

$$E_R = \frac{\beta_d LA}{\pi r^2} \int_0^{2\pi} d\phi \int_0^{\pi/2} \cos^2\theta \sin\theta d\theta = \frac{2\beta_d LA}{3r^2} \qquad (2)$$

where β_d is the estimated reflectance factor of the room from the point of view of the center of the projection screen, L is the total luminance of the projection screen, A is image area, and r is the estimated spherical radius of the room model.

By using a calibrated white sample, measure the reflectance factor β_d of the various walls, ceilings, floors, and other surfaces of the room, averaging the values with appropriate weights. The weights are a ratio of the area of the surface measured $A_{S(i)}$ to the total surface area of the room A_T (do not include the back wall). Thus for a room with n reflecting surfaces:

$$\beta_d = \sum_{i=1}^{n} \frac{L_{s(i)}}{L_{w(i)}} \frac{A_{S(i)}}{A_T} \qquad (3)$$

Determine the spherical radius of the room by measuring its volume and setting it equal to the volume of a hemisphere:

$$V = l \times w \times h = \frac{2}{3}\pi r^3 \qquad (3)$$

Then solve for r:

$$r = \sqrt[3]{\frac{3}{2\pi} l \times w \times h} \qquad (4)$$

The ambient illuminance E_A is measured in the image plane without the SLET and with the projector switched off. The projector illuminance E_P is measured with the SLET. The total amount of light illuminating the screen E_T then becomes:

$$E_T = E_A + E_R + E_P \qquad (5)$$

How well the sum of the illuminance contributions E_T compares to the illuminance measurement E_M with projector and room lights both switched on is an indicator of the robustness of the model.

Two rooms were evaluated using this methodology and compared with SLET measurements. Results shown in Table 3 indicate that this model may be used to estimate the stray-light contributions of the room. Room A had a dimension of 7.32 m × 3.26 m × 3.33 m with black walls, ceiling, and floors, and contained overhead fluorescent lighting. Room B was a 6.53 m × 7.32 m × 3.33 m room with off-white walls and ceiling, and dark carpet, and contained overhead incandescent track lighting.

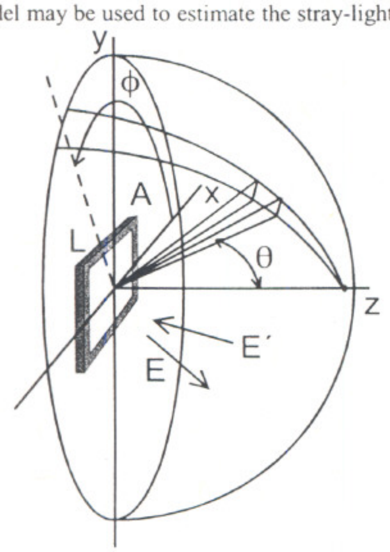

Fig. 8. Hemispherical model for room reflections.

Table 3. Evaluation of hemispherical room model.

ROOM	E_R	E_A	E_P	E_T	E_M	deviation
	lx	lx	lx	lx	lx	
A	0.36	266.56	1.57	268.42	267	0.53%
B	0.95	4.41	49.19	55.55	55.92	2.45%

The model proved adequate for simple office- and small conference room-sized facilities. The robustness has yet to be evaluated for larger rooms, such as auditoriums, or for rooms with more complicated structure.

7. Conclusions

In order to determine accurately the characteristics of a projector and estimate how it would perform in a given environmental condition, the system must be separated into its components of projector, screen, and environment. The SLET and mask provide means of measuring the intrinsic light-output properties of the projector. Thus the projector performance is not penalized by ambient conditions. Using the hemispherical model to approximate a particular environment, one can then estimate the effects of the environment on the projected image, allowing the user to determine the appropriate specifications of the projector to adequately perform the user's required task. Furthermore, a useful set of parameters can be determined that can be utilized to evaluate and possibly optimize the separate components to help achieve the desired image characteristics.

8. References

1. P. A. Boynton and E. F. Kelley, "Accurate Contrast Ratio Measurements Using a Cone Mask," Society for Information Display International Symposium Digest of Technical Papers, Boston, MA, May 11-16, 1997, vol. XXVIII, pp. 823-826.
2. P. A. Boynton and E. F. Kelley, "Stray Light Elimination in Making Projection Display Measurements," Proceedings of the SPIE Vol. 3636, pp. 232-239, January 1999.
3. VESA Flat Panel Display Measurement Standard (FPDM), Section A225: Gain of a Display, version 1.0, p. 250, May 1998.
4. VESA Flat Panel Display Measurement Standard (FPDM), Section A216: Reflection from Room Walls onto Screen, version 1.0, pp. 225-226, May 1998.