Stray Light Elimination in Making Projection Display Measurements

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ABSTRACT

Electronic front-projection display specifications are often based on measurements made in ideal darkroom conditions. However, not everyone has access to such a facility. In many environments, ambient light from other sources in the room illuminates the screen. 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 from the projection screen must be considered. These stray light components contribute to the measured value, giving an inaccurate measurement of the projector light output. Thus, these conditions may make the task of adequately comparing and evaluating different projection systems difficult. We can better verify whether the projector is operating according to its specifications or compare its performance with other projectors by compensating for stray light. A simple projection mask constructed from black plastic and a stray-light elimination tube are presented as solutions that can provide an accurate measurement of projector light output in many ambient light conditions.

Keywords: display measurements, projection displays, projection mask, reflections, stray light

1. INTRODUCTON

Often front-projection displays, those in which the projection screen is not an integral part of the display unit, are compared in order to determine the projector with the superior performance. Quantities such as brightness and contrast typically are used as metrics to evaluate system performance. Ideally, these metrics require measurements performed in a darkroom environment (black walls, floors, and ceilings with no reflective objects) and a black screen. Not everyone can access such stringent conditions. Performing these measurements in a non-darkroom environment exposes the light-measuring devices (LMDs) to ambient light (such as room lights or daylight through a window) or stray light (projected light reflecting off of

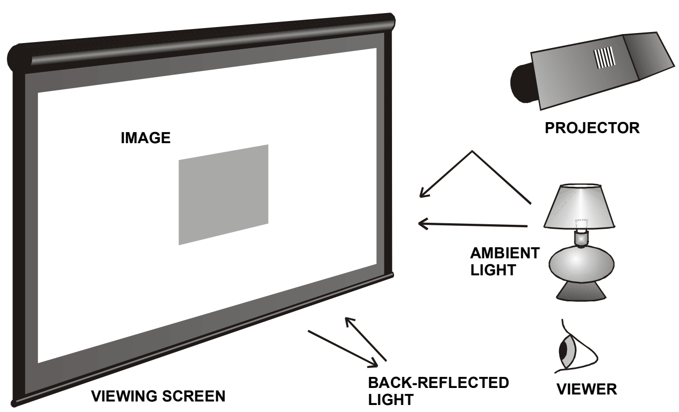

Figure 1. Sources of stray light when viewing a projected image.

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the surface of the screen and reflecting off walls, floor, tables, and other objects back onto the screen). See Fig. 1. Although one could argue that this corruption better describes the environment that the viewer sees, it does not provide any traceability to the intrinsic projector performance, and thus does not allow for fair comparisons or evaluation of projector specifications.

2. STRAY LIGHT EFFECTS

2.1 The effects of stray light.
A typical conference room or boardroom usually does not provide black or dark walls and other surfaces. Often, the room consists of off-white walls, a table with a reflective surface, and possibly windows with blinds. Even with the blinds closed and the room lights switched off, light from the projection screen will back-reflect off of the other surfaces in the room.

One test to observe the effect of stray light is to measure the illuminance of a halation image. Figure 1 shows an image of a black rectangle on a white background. The rectangle is 25% of the screen size based on the diagonal measure. Light from the white area reflecting off of other surfaces, or any other source of stray light, will corrupt any attempt to measure the illuminance of the black rectangle. To illustrate this, an image as described above was projected onto a white screen in a darkroom. In Case 1, no additional light sources were introduced. In Case 2, a second white screen was placed near the projection screen, to serve as a reflective surface. A door leading to a well-lighted room was opened in Case 3, allowing ambient light to enter the projection room. The results[**], shown in Table 1, indicate how surfaces can affect the illuminance measurement. Thus, the task of determining if the projector meets its specifications or determining how the projector's intrinsic characteristics compare to those of another proves difficult.

Table 1. Effect of reflective surfaces on illuminance measurements of projection displays.

Case	Condition	Illuminance of black rectangle (lux)
Case 1	reflective surface removed	2.32
Case 2	reflective surface in close proximity	2.78
Case 3	ambient light entering room	8.45

Short of constructing a darkroom in every end user's facility, we suggest a couple of alternatives that greatly reduce the contribution of stray light to the measurement. One method provides an estimate of the stray light contribution, which can then be subtracted from the measurement to obtain a more accurate indication of the projector performance. The second method eliminates most of the stray light, but is more difficult to construct. Both methods are described below, and are compared with the no-compensation condition.

1.2 Measurement equipment and conditions.
In all of the measurements, we used two different LCD projectors, both with metal-halide lamps. The signal was generated using presentation graphics software on a laptop computer. The VGA images were projected onto a 2.3 m $\times$ 2.5 m white screen.

The measurements were performed in a darkroom with black floor tiles, and walls and ceiling painted flat black. All lab furniture and equipment was either painted flat black, constructed with flat black material, or covered with black felt. The operators donned dark clothing and covered hands with black felt when appropriate.

All of the illuminance measurements were performed with a hand-held type illuminance meter. The meter was mounted onto a tripod to provide stability and to avoid reflections resulting from a person holding the meter in place. Screen gain and luminance measurements were made with a hand-held luminance meter, also mounted on a tripod.

[**] 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 2.

3. PROJECTION MASK

3.1 Description of projection mask.
Utilizing a glossy black patch offers a simple but effective solution to the stray-light problem. The patch, called a projection mask, should be placed near the screen, between the image and the projector, such that the shadow of the patch eclipses the rectangle image and the sensor of the light measuring device (LMD). See Fig. 2. With the mask in place, the illuminance meter will obtain a reading that approximates the contribution of stray light from the viewpoint of the meter. The projection mask is then removed, and another reading is taken. The difference between the two reading offers a more accurate measurement of the illuminance of the projected black rectangle. Table 2 demonstrates a typical measurement using the image and configuration in Fig. 2, and the conditions as described in Table 1. Note that for the three cases, the corrected measurements were within 2% of each other.

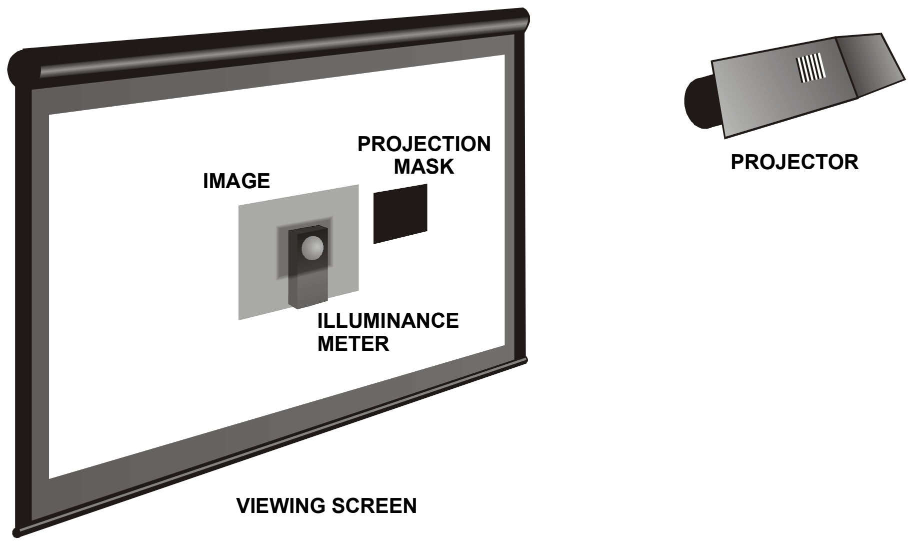

Figure 2. Projection mask method of stray-light compensation.

Table 2. A typical illuminance measurement using a projection mask for stray light compensation.

	Measurement with no mask (lux)	**Measurement with projection mask (lux)**	**Corrected measurement (lux)**
Case 1	2.32	0.76	1.56
Case 2	2.78	1.24	1.54
Case 3	8.45	6.88	1.57

3.2 Considerations that may affect measurements.
Several factors can substantially affect the measurements, including distance of mask from the image, size of mask, and mask mounting. Figure 3 illustrates the effect of the distance of the mask from the projector. If the mask is placed too close to the screen, some of the reflected light will be obscured. If the mask is moved too far away, diffraction around the mask and forward scattering of light by dust particles in the air may contribute to the measurement. For our measurements, 35 cm to 60 cm was the optimum range for the mask distance, based on the configuration of our laboratory and the position of the projector and screen (see Fig. 3).

The size of the projection mask should be no smaller than the diameter of the projection lens so that the projector is effectively eclipsed. However, the mask must be larger than the sensor area of the LMD. We would recommend the patch to be 50% larger than the projection lens size.

The mask was mounted using a floor stand and aluminum rods covered with black felt. Suspension from the ceiling with black string or thread, or other suitable means may be employed. Be careful to ensure that the mask is held steady and parallel to the image plane, and that any mounting equipment does not add reflected light to the measurements.

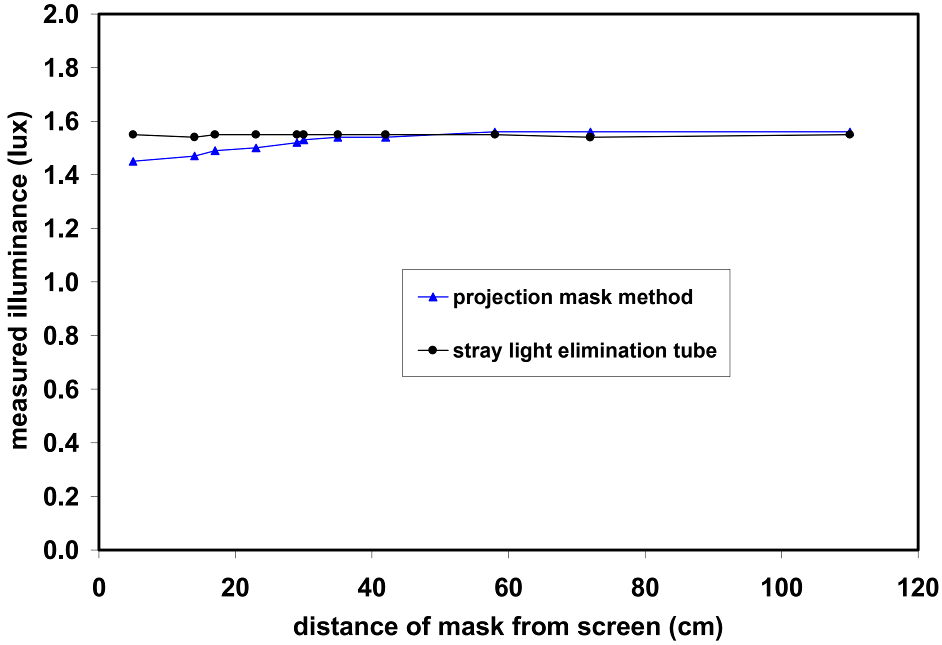

Figure 3. Effect of Mask Distance from Projection Screen

3.3 An example: measuring contrast ratio.
In order to demonstrate the effectiveness of the projection mask, we use a typical metric for measuring projection system performance, contrast ratio. The American National Standards Institute (ANSI) defines a procedure for measuring the contrast ratio of projection displays[1,2] using a 4×4 checkerboard pattern for the projected image.

Figure 4 illustrates the measurement configuration. The illuminance of the center of each of the sixteen rectangles was measured with an illuminance meter, and the ratio of the average illuminance of the white regions (ΣE_W) to the average illuminate of the black regions (ΣE_B) was calculated as follows:

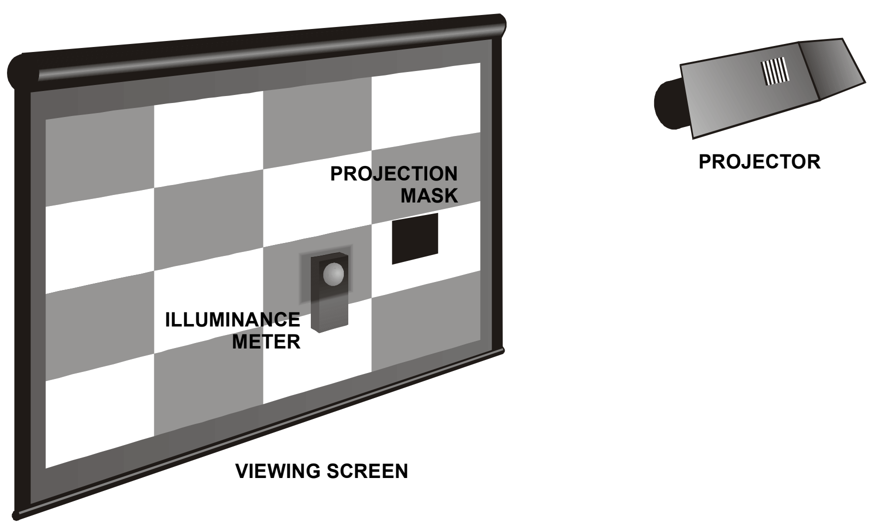

Figure 4. Using the projection mask to perform contrast ratio measurements.

$$C_R = \frac{\Sigma E_W}{\Sigma E_B}. \qquad (1)$$

The results in Table 3 compare the contrast ratio measured utilizing the projection mask and measured with no mask. As the data indicates, the measured contrast increases by 34% using the projection mask in our laboratory conditions. Note that improvement will vary according to room conditions and position of the projector and the projection screen.

Table 3. Comparison of methods for measuring contrast ratio.

method	average white illuminance (lux)	average black illuminance (lux)	contrast ratio C_R
no mask used	97.0	1.37	71:1
projection mask used	97.0	0.90	107:1

4. STRAY-LIGHT ELIMINATION TUBE

4.1 Description of method.

Though more complicated than the projection mask the stray light elimination tube (SLET) provides an alternative for greater reduction in stray light effects. Figure 5 illustrates the configuration. The SLET is a 61 cm long tube with a 15 cm inner diameter. Its exterior and exterior are painted glossy black, and the tube is mounted on a black, three-axis tripod. The projected light enters one end of the cone, and the illuminance meter is placed at the opposite end (see Fig. 6). The projected image is focused onto the meter detector surface. Inside the tube, a series of five glossy-black cones are inserted. Four cones are placed in opposing pairs, and the fifth shallow cone surrounds the meter detector surface. The apex angles of the cones are 90º (45º from each side of the symmetry axis of the cone).

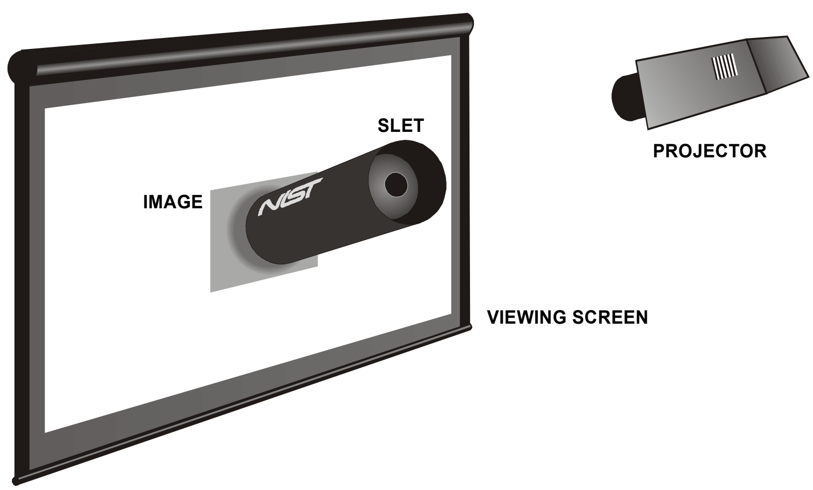

Figure 5. Using the SLET to reduce stray light effects in illuminance measurements.

4.2 Effectiveness of the SLET.

Most stray light entering the tube is reflected away from the detector surface by the cones and the interior wall of the tube. This method has proven ideal for extreme conditions, such as when the overhead room lights are switched on. We find that with the SLET, we obtain the same results (within 1%) with either the lights on or off. Of course, measuring in such conditions without the SLET results in significant error (see Table 4).

Table 4. Using the SLET to measure illuminance different ambient light conditions.

method	Measured illuminance with no SLET (lux)	Measured illuminance with SLET (lux)	deviation
room lights off	2.33	1.55	50%
room lights on	266	1.56	16951%

This method is limited by the ability of the SLET to be positioned at the appropriate location in the image. For instance, the tube may prove too cumbersome to maneuver into position at the center of each rectangle of a 4 × 4 checkerboard pattern.

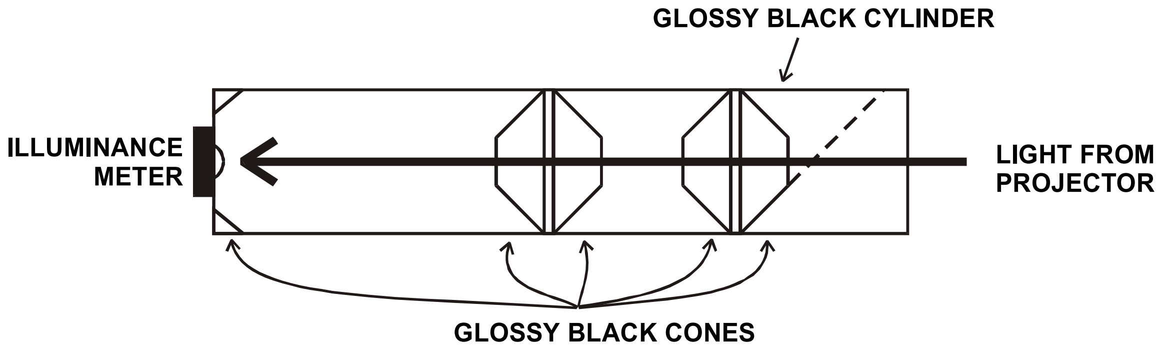

Figure 6. The Stray Light Elimination Tube (SLET)

5. RESULTS

To verify the degree of improvement of the proposed methods over conventional procedures, we employed the halation image (as shown in Fig. 1). We measured the projector illuminance at the center of the black rectangle, varying the rectangle size from 5% to 100% of image size (linear size based on the diagonal of the image) using the illuminance meter. Figure 7 shows that the black illuminance level decreases with increasing rectangle size. However, the plots of the illuminance measurements utilizing the two stray light compensation methods are nearly identical, and are lower than the measurements taken without compensation. This suggests that reflections corrupt the uncompensated measurements (even in the laboratory) and that the two compensation methods provide similar correction. As one would expect, as the size of the black rectangle increases, the amount of stray light contribution (due to back reflection) decrease, and thus the plots tend to merge at 100%. The curve of the compensated plots may indicate the presence of veiling glare in the projection lens.

To check the measurement procedure, one could use the relationship between luminance and illuminance. Using a luminance meter, we measured the 25% black rectangle projected onto the screen. To eliminate the effects of screen gain, we placed in the image plane a Lambertian diffuser with a rated luminance factor of 99%. (See Fig. 8.) Because of the following relationship between luminance and illuminance:

$$L = \frac{\rho}{\pi} E \,, \tag{2}$$

where ρ is the reflectivity of the sample, and L is the luminance of the sample, one can easily calculate the illuminance E. Often, however, the sample will demonstrate a gain, such that the reflectivity is higher when measuring normal to the sample surface and decreases as the LMD moves off-axis. The reflectivity of the sample is often calibrated in an integrating sphere, and thus the stated reflectivity may not correctly characterize the percentage of reflected light in this particular configuration.

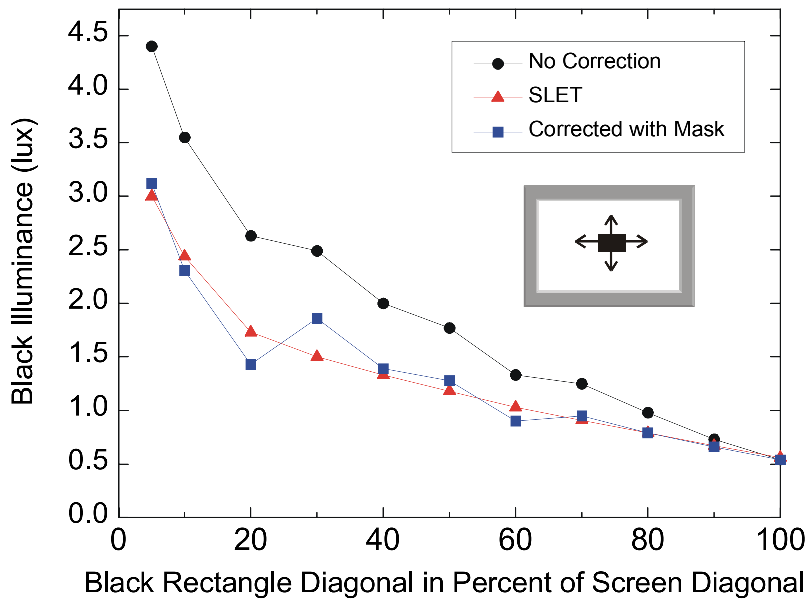

Figure 7. Comparison of Mask and SLET

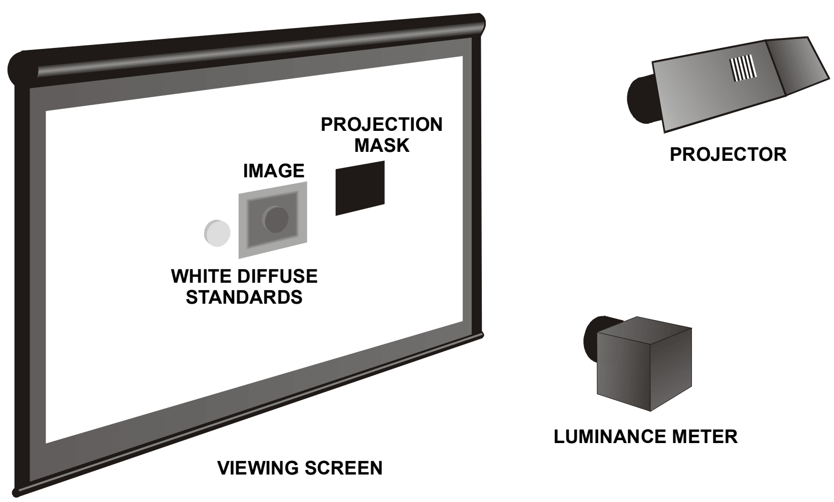

Figure 8. Using the projection mask to measure luminance of a projector.

6. CONCLUSIONS

Because many facilities do not have ideal darkroom conditions, establishing the intrinsic photometric properties of a front-projection system must involve compensating for or eliminating back reflections, ambient light, and other stray light contributions. Failing to do so will make difficult intercomparisons and evaluations, for the user will be unable to determine whether the projector, the screen, or the room environment is creating the effect that the observer sees. Using compensating methods such as the two described levels the playing field on which to compare projectors, and offers a technique for determining the effect of room conditions on the projector performance.

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[1] ANSI/NAPM IT7.228-1997 "American National Standard for Audio-Visual Systems—Electronic Projection—Fixed Resolution Projectors."

[2] ANSI/PIMA 177.228-1998 "American National Standard for Audio-Visual Systems—Electronic Projection—Variable Resolution Projectors." Draft, July 1998.