Is the Measurement of Front-Projector Characteristics an Impossible Task?

A lot goes on between the projection lens and the eye that projector manufacturers can't control, but it is possible to make accurate front-projection-display measurements in stray-light conditions – if we're careful. This is the third in a series of articles from NIST.

by Paul A. Boynton and Edward F. Kelley

SPECIFICATIONS of electronic projection displays such as contrast ratio are often based on measurements made in ideal darkroom conditions. But everyone does not have access to a facility that provides such conditions. Stray light from sources in the room, both direct and reflected off surfaces such as walls and tables, as well as back-reflections, contribute to the measured value and give an inaccurate indication of the projector's light output. So how can we verify that the projector that we have purchased is operating according to its specifications?

Leveling the Playing Field

When measuring front-projection displays - those in which the screen is not an integral part of the system - the goal is to establish the intrinsic characteristics of the projector, independent of the screen and viewing room. This allows for a more accurate comparison of the display quality of different projectors. Minimizing the effects of ambient light achieves "a level playing field."

What we see in a typical front-projection environment is more than simply the performance of the projector (Fig. 1). In a typical user environment, a projector is set up and an image is projected onto a screen. The observed quality, however, depends not only on the projector performance, but also on the reflective properties of the screen and the surrounding environment, as well as any ambient-light sources.

If we wish to quantify what the viewer observes, then we must account for the stray light falling upon the screen and for screen gain. These are not trivial tasks, and because the environment affects the displayed image they do not necessarily provide useful infor-

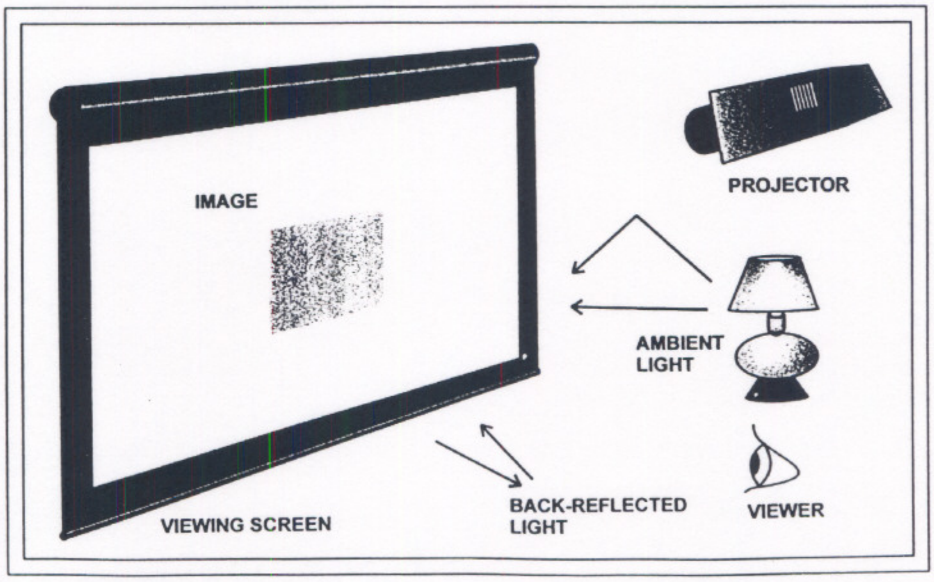

Fig. 1: The quality of the image we see in a typical front-projection environment depends not only on the projector performance, but also on the reflective properties of the screen and the surrounding environment, as well as any ambient-light sources.

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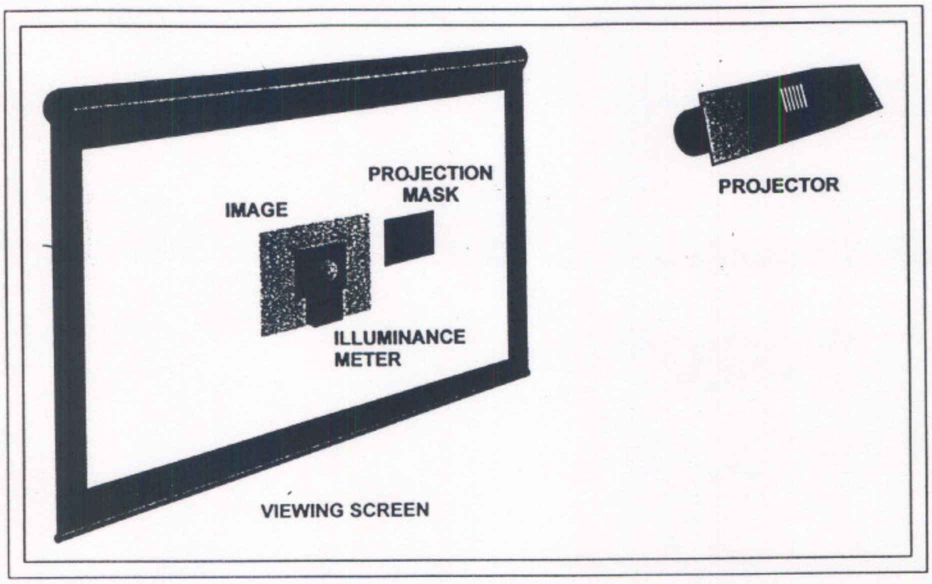

Fig. 2: By using a black projection mask to eclipse the projected light, an illuminance meter will indicate the approximate amount of stray light illuminating the detector.

mation about whether a particular display performs according to specifications or how it compares with other displays. Use of a black screen would reduce back-reflections, but we might still need to contend with other stray-light sources. The use of a simple black mask - called a projection mask - will provide us with the compensation we need to assess our display without corruption from stray light.

Using a Projection Mask

Let's assume we want to measure the luminance of a black rectangle on a white background, with the black rectangle being 25% of the screen size, based on diagonal measure (Fig. 2). The light output at the center of the rectangle in the image plane of the screen is measured with an illuminance meter. This measurement includes contributions from any stray light. Next, a black mask is placed less than 1 m away from the screen such that the projected light striking the screen and the illuminance meter is eclipsed. With this projection mask in place, the illuminance meter, placed in the image plane of the screen, will provide a reading that indicates the approximate amount of stray light illuminating the detector. By subtracting this value from the first measurement, a more accurate value of the black luminance of the projected image is obtained.

The size and distance of the projection mask can have a substantial effect. For our tests, the optimum distance of the mask from the projection screen was between 30 and 50 cm, but this can depend upon the room and projector configuration. If the projection mask is placed too near the screen, it will obscure some of the reflected light. If too far away, the diffraction around the mask and forward scattering by dust particles in the air may contribute to the measurement. To be safe, the projection-mask size is kept no smaller than the diameter of the projection lens to ensure that the projector is effectively eclipsed. Of course, the mask must be larger than the measurement area.

The projection mask can be mounted on a floor stand with rods, suspended from the ceiling with string, or by any other suitable means. Whatever method is employed, the mask must be held steady and parallel to the image plane. If a stand is used, it should be covered with black felt to minimize reflections that would interfere with the measurements.

Stray-Light-Elimination Tube

A second, more complex approach involves using a series of glossy black cones inside a glossy black tube (Fig. 3). The projected light enters one end of the tube, which has a 15-cm inner diameter. An illuminance meter is placed at the other end of the tube, 61 cm away. Four cones are placed in opposing pairs, while a shallow fifth cone surrounds the meter. The apex angle of the cones should be 90°, *i.e.,* 45° on each side of the symmetry axis of the cone.

The projected image is focused onto the meter. Any stray light entering the tube will be reflected away from the detector surface by the cones; hence the name, stray-light-elimination tube (SLET). For extreme conditions, such as a room with overhead lights switched on, this method is preferred because it eliminates a great deal of stray light. Using the SLET, we have obtained the same results (within 1%) with room lights either on or off. The SLET is still in its evaluation stage but was used to verify the projection-mask method for this article.

Halation and Contrast

To demonstrate the effectiveness of these methods, as well as to indicate the seriousness of back-reflections, we projected a series of halation images - a black rectangle on a white background - onto a white screen using a liquid-crystal-display (LCD) projector with a metal-halide lamp. The laboratory walls, ceiling, floor, furniture, and equipment were painted flat black, covered with black felt, or manufactured with black material.

The black rectangle was varied from 5 to 100% of screen size (linear size based upon the screen diagonal), and the black-luminance level was measured and plotted against rectangle size. The black-luminance level decreases with increasing rectangle size (Fig. 4), but the level varies less dramatically if back-reflections are taken into account. The SLET and the projection-mask methods produce similar results.

Halation refers to light from bright areas of an image leaking into dark areas. An example would be the internal reflections between the front glass of a cathode-ray-tube (CRT) display and the phosphor surface. The increase in the black luminance with decreasing box size after making corrections for stray light is probably due to the veiling glare from the projection lens. (Veiling glare is a result of light scattering and reflecting at lens surfaces, at imperfections in the glass, at soiled areas on the glass, and at the barrel and other mechanical parts of the lens.)

Another common projection-display measurement is the contrast ratio of a 4 × 4 checkerboard pattern at 16 points (Fig. 5).[1,2] The illuminance at the center of each rectangle is measured, and the average of the white levels divided by the average of the black levels gives one measure of contrast. Our results show a 34% improvement in the contrast measurement when using the projection-mask method.

What About Luminance Measurements?

So far, we have only discussed measurements using an illuminance meter. Using a luminance meter poses a more difficult problem because we must now consider the reflective properties of the screen and the veiling glare of the light-measuring-device (LMD) lens (Fig. 6). Many screens direct or "shape" most of the projected light back in the direction of the viewer more than a perfectly white Lambertian surface would. Such shaping is called "screen gain" and can been defined as the ratio of the luminance of the screen at a specific point (usually center screen) to the luminance of a Lambertian diffuser placed at the same point on the screen.

However, when considering stray light, we must realize that the screen's reflective properties are rather complicated. The reflected light measured from the screen depends upon the incident angle of the various light sources (such as the projector, room lights, and reflections), the viewing angle of the measurement, and the reflection properties of the screen surface. [A general way to express this reflection is through the bidirectional reflectance distribution function (BRDF), a rather complex measurement.[3]]

Ideally, we can avoid the screen issue altogether. Using a nearly perfectly white Lambertian standard at each measurement point in the image plane would provide an accurate measurement unaffected by screen gain. Thus, measuring the luminance of the white standard with and without the projection mask, and taking the difference, will provide us with a measurement point corrected for reflections. Because the surface is Lambertian, the angle of measurement can be slightly off-axis with negligible error.

We can take advantage of the diffuser's properties to convert from a luminance measurement (in cd/m^2) to illuminance measure-

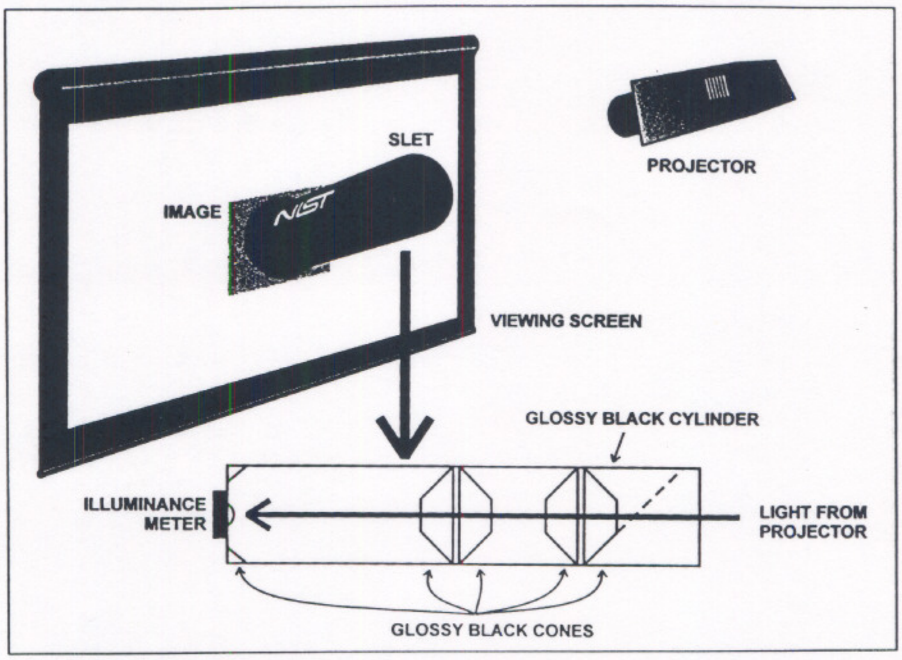

Fig. 3: A stray-light-elimination tube (SLET) is a more complicated device than a projection mask. But for extreme conditions, such as a room with overhead lights switched on, this method is preferred because it eliminates a great deal of stray light.

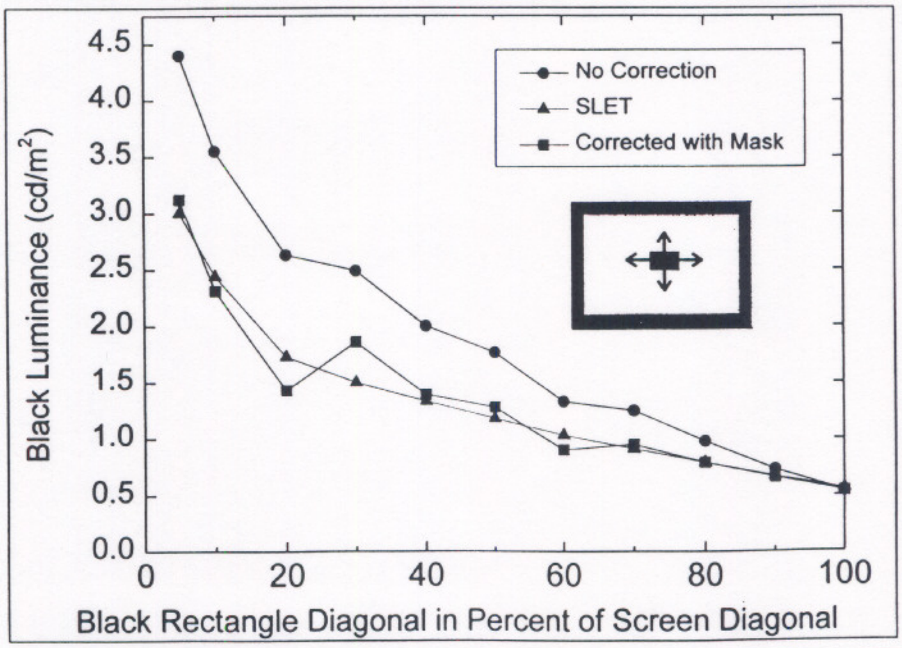

Fig. 4: As the size of the black rectangle in a series of halation images increases from 5 to 100%, the black-luminance level appears to decrease, but the level varies less dramatically if back-reflections are taken into account. The SLET and the projection-mask methods produce similar results.

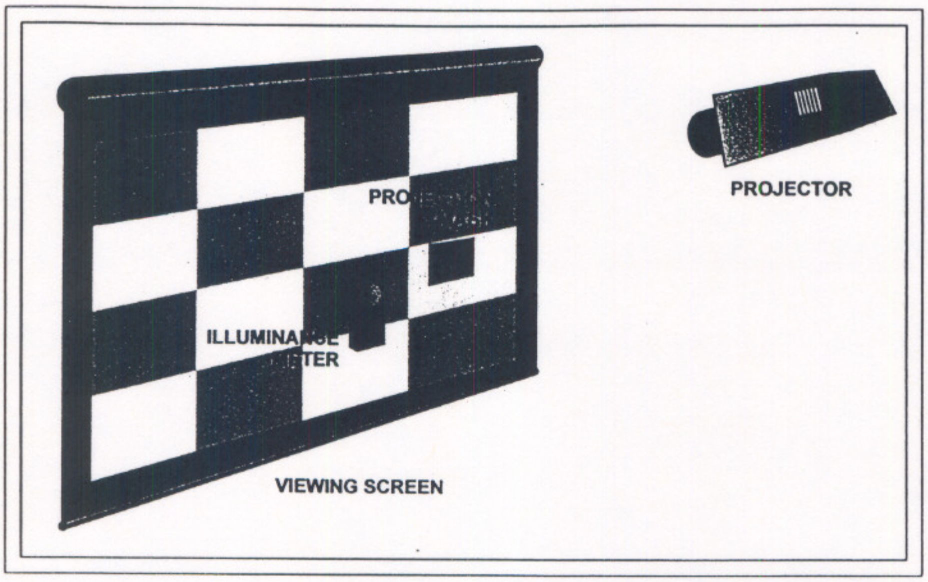

Fig. 5: Using a projection mask produced a 34% improvement in a contrast measurement made in our laboratory.

ments (in lm/m^2, or lux). By using the simple relationship $L = (\rho/\pi)E = qE$, where ρ is the fraction of light reflected from the surface (luminance factor), and $q = \rho/\pi$ is called the luminance coefficient. This equation is only valid for a Lambertian reflector. Materials with $\rho \geq 99\%$ can be obtained.

Because we are subtracting two measurements with the same surrounding background, any veiling-glare contribution from the LMD lens will cancel out. However, if we wish to make an absolute measurement with stray light included, then some technique must be employed to minimize this glare. We can accomplish this using a black cone mask with an apex of 45°.

The cone mask is placed in front of the LMD such that the outer (larger) diameter faces the LMD and prevents any light from the display from reaching the LMD lens. The inner diameter (aperture) should be small enough to keep out stray light but large enough to prevent vignetting between the LMD aperture and the aperture of the cone. This cone mask has been used to improve the measurement of black luminance of direct-view transmissive displays by reducing the effect of veiling glare in the lens of the measuring instrument.[4]

If we wish to determine the veiling-glare contribution of our LMD lens, we can place a glossy black mask across the black image, tilting it slightly if necessary to eliminate specular reflections from the projector. We must be sure the mask displays only reflections from a dark area of the room, from a light trap, or from some other essentially black reference. The measured luminance of this mask gives an indication of the degree of veiling glare in the LMD.

Other Precautions

Although many readers may find them obvious, we'll mention a few other precautions. Illuminance measurements can be sensitive to deviations off the normal axis. In our measurements, a 3% error resulted from a 10° misalignment of the luminance meter's axis with the screen perpendicular. This sensitivity is a function of distance from the source – the closer to the projector, the more important normality becomes.

Room reflections and other stray-light sources may increase this variability. Varying the distance of the detector from the projector also changes the illuminance. As the distance of the detector from the projector increases, the illuminance decreases at a rate of $1/r^2$, where r is the distance from the projector (inverse square law). So, if $r = 3$ m, then a 10-cm error in the placement of the illuminance meter represents a 0.7% error in the illuminance measurement. If the operator must hold the instrument in the image plane for the duration of the measurement, then care should be taken to avoid reflections from the operator's face, arms, hands, and clothing. Standing as far off to the side as possible and wearing dark clothing will help to minimize such contributions. Finally, we must be sure that the mask or the projected image of interest completely covers the detector surface or completely covers the measurement aperture.

Take Nothing for Granted

As in all measurements, take nothing for granted. If in doubt about whether the viewing room produces back-reflections onto the screen, try using the small black projection mask and determine how much stray light contributes to the measurements (if at all). We certainly found stray-light contributions in our darkroom environment. Straightforward techniques, such as those described in this article, are simple to implement and will help provide assurance that we are accurately characterizing our projection display.

References

[1] ANSI/PIMA 177.228-1997, "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 5.

[3] E. F. Kelly, G. R. Jones, and T. A. Germer, "Display reflectance model based on the BRDF," *Displays* **19**/1, 27-34 (June 1998).

[4] P. A. Boynton and E. F. Kelley, "Accurate Contrast Ratio Measurements Using a Cone Mask," *SID Intl. Symp. Digest Tech. Papers,* 823-826 (May 1997). ■
