Stray light compensation in small area contrast measurements of projection displays

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ABSTRACT

The accurate measurement of small area-black levels is important in projection display characterization. For example, techniques can be used to determine resolution of projection systems by measuring the contrast of alternating grille patterns or fully-modulated sine waves of various spatial frequencies. Unfortunately, the measurement of the contrast of these patterns may be influenced by stray light, either from ambient and reflected light in the environment, or from veiling glare scatter in the lens of the light-measuring device. Such stray-light corruption can lead to large errors in contrast determination, providing an inaccurate characterization of the projector. For large-area measurements, various techniques have been employed, including the use of frustums and masks, to minimize such unwanted effects and provide a more accurate measurement. With some modifications, these same tools may be used for small-area measurements with similar results. The design, construction, and implementation of these tools will be discussed. Results will be shown comparing small-area contrast measurements of projection systems, including resolution determination, with and without stray light compensation, for different measurement instrumentation.

Keywords: Display measurement, projection displays, stray light, resolution, small area contrast, replica mask

1. INTRODUCTION

Measurement of electronic projection displays can be affected by stray light from either ambient or reflected sources in the measurement environment [1]. These include room lights directly illuminating the screen and the reflection of these light sources off walls, floors, furniture, and other objects. Back reflections from the image on the projection screen must be considered as well. Figure 1 illustrates a typical environment.

For example, a horizontal grille pattern, consisting of alternating white and black lines of single pixel width (see Fig. 2), was projected by a front-projection system onto a white screen in a darkroom, and measured using an illuminance meter mounted with a slit aperture (this apparatus is described in more detail in the next section). The projected black and white levels were measured for various room conditions, and are shown in Table 1‡. In Case 1, the room lights were switched off and all reflective surfaces were covered with black felt. In Case 2, reflective material was placed near the projection screen (at a right angle to the screen). In Case 3, the reflective material was removed, but several low-level incandescent lamps attached to the ceiling at the rear of the room were switched on, illuminating the projection screen with 0.13 lx at the measurement area of the screen (with the projector off). The results indicate how the room environment can affect the measurement of light output. 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.

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‡ The data presented in this paper are for illustrative purposes only, and do not constitute a calibration. Unless stated otherwise, the relative expanded uncertainty in all described measurements is estimated to be ± 10% of the measurand using a coverage factor of 2.

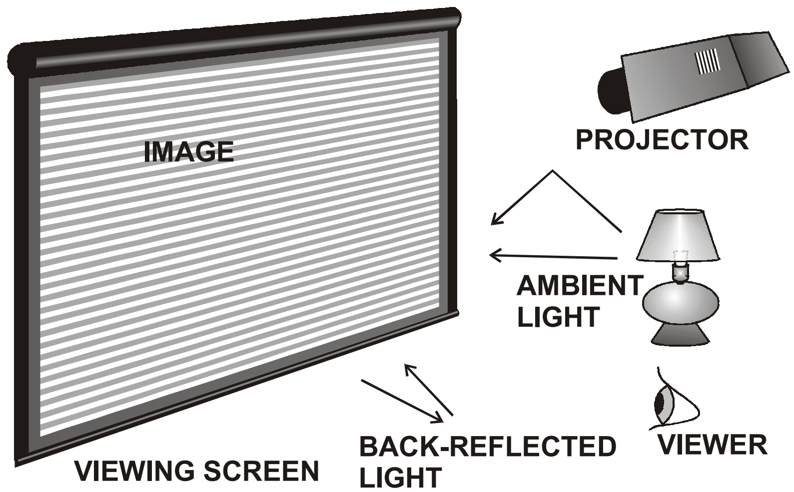

Fig. 1. Sources of stray light when viewing a projected image.

Table 1. Effect of stray light on small-area illuminance measurements of projection displays

Case	Condition	Illuminance of white line (lx)	Illuminance of black line (lx)
Case 1	lights off, no reflective surface	3.58	0.325
Case 2	lights off, reflective surface in close proximity	3.69	0.347
Case 3	lights on, no reflective surface	3.71	0.456

Furthermore, the contributions of veiling glare resulting from the lens of the light-measuring device (LMD) acquiring the measurement may also corrupt the measured value [2]. Veiling glare results from light from outside the measurement area scattering off baffles, irises, glass surfaces, and other parts of the lens. These stray light components contribute to the measured values and give rise to an inaccurate measurement of a projector's photometric and colorimetric output, especially for high-contrast measurements. However, even in a darkroom with a black screen, significant errors may result.

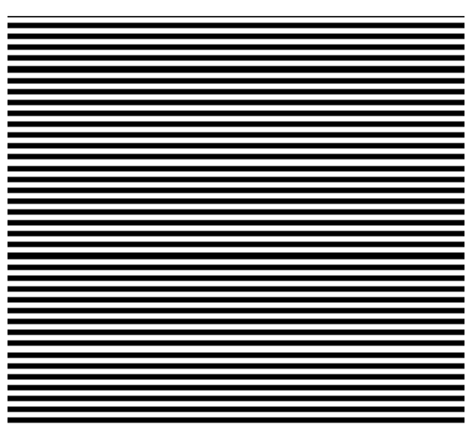

Fig. 2. Portion of a 1 × 1 pixel horizontal grille pattern.

Small area measurements are particularly sensitive to stray light [3]. This can prove critical for the evaluation of projectors, for these measurements are used to evaluate the capability of the projection system to display fine detail. It is critical that influences of the room environment and LMD be minimized so that an accurate assessment of the projector can be established. The use of frustums or masks has been demonstrated as a method of compensating or reducing the stray light contribution to large-area measurements of front and rear projection displays [4]. With modifications of these tools, similar results can be achieved for small-area measurements of projection display systems.

2. STRAY LIGHT MANAGEMENT TOOLS

2.1 Stray-Light Elimination Tube (SLET)

Solutions to avoid the effects of stray light on light-measuring devices (LMDs) have been documented in earlier work by Boynton and Kelley [2]. This reference describes use of glossy black frustums (incorrectly called "cones" in the paper) with 90º 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 [1,4]. For small-area measurements, a modified SLET may be used.

The SLET used in the following tests was constructed out of 0.25 mm (0.010 in) glossy black vinyl plastic rolled around black acetal plastic rings into a 12.4 cm (4.5 in) diameter, 30 cm (12 in) long tube (see Fig. 3). The tube was fitted with a set of opposing-pair frustums with 90º apex angles at the center of the tube (15 cm or 6 in), and a single frustum with a shallower angle surrounding the LMD port. These frustums are attached to acetal plastic rings for stability. The projected light enters one end of the tube, and the illuminance meter is placed on the opposite side, with the frustums effectively preventing stray light from reaching the instrument measurement head.

Glossy black was used because the diffuse reflectance of flat black is much larger (typically around 5%) than the diffuse reflectance of good glossy black surfaces (typically ≤ 0.2%). Furthermore, the plastics' specular component provides for control of reflections so that stray light may be directed away from the measurement device.

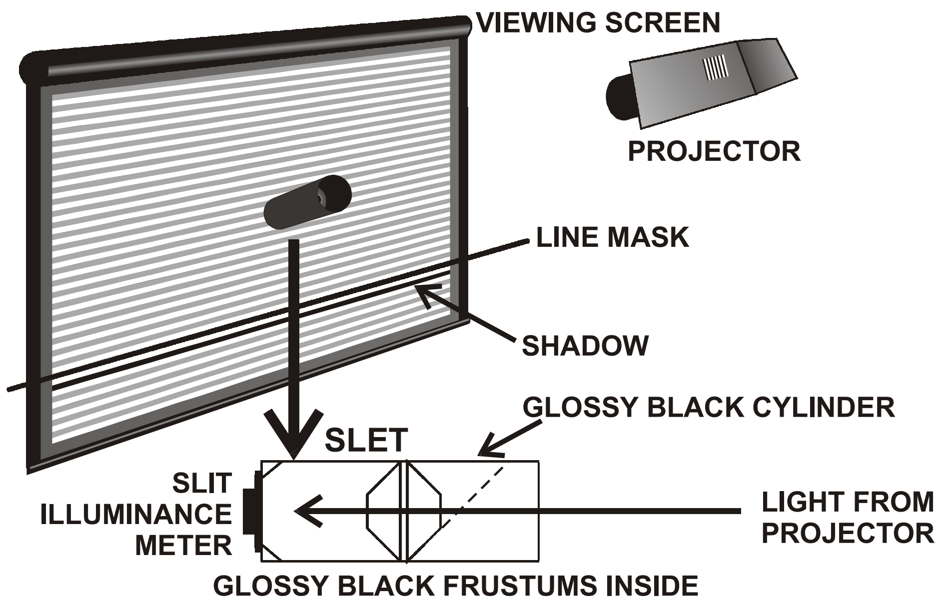

Fig. 3. Stray Light Elimination Tube (SLET) and line mask.

An adapter was built (using black acetal plastic) to mount the LMD, so that various detector heads could be centered at the rear of the SLET (see Fig. 4). To accommodate the small measurement areas, a slit, using razor blades painted in glossy black, was devised to create an adjustable aperture. The blades are secured with set screws to provide for adjustment. This allows the user to control the area of the projected image to be measured. This adapter, mounted directly to a tripod, can be used with or without the SLET attached, and thus has a diameter of 12.4 cm (4.5 in).

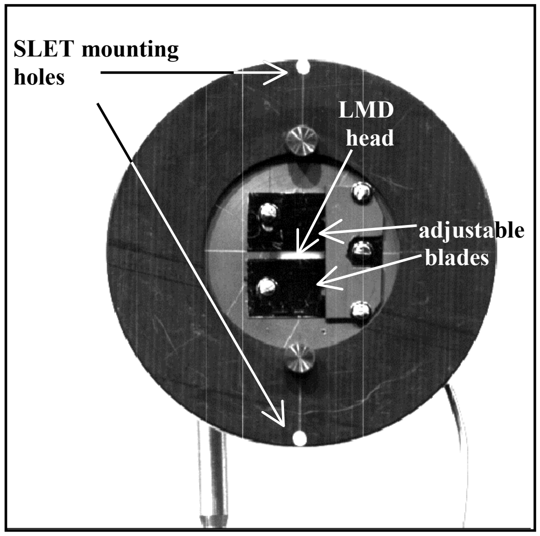

Fig. 4. Slit adapter for illuminance meters.

2.2 Line Masks
Utilizing a black patch offers a simple but effective solution to the stray-light problem. The particular patch used in these tests, called a line mask, was placed near the screen, between the image and the projector, such that the shadow of the mask eclipsed one of the black lines (see Fig. 3). The light-measuring device (LMD) sensor was positioned to measure this shadow. With the mask in place, the illuminance meter thus obtained a reading that approximated the contribution of stray light from the viewpoint of the meter. Then either the projection mask was then removed or the LMD was positioned to a nearby black line, and another reading was taken. The difference between the two readings offered a more accurate measurement of the illuminance of the projected grille pattern.

For the 1-pixel-width grille pattern, we employed a length of string painted black with a permanent marker. One end was secured to a vertical aluminum pole, which was inserted to a portable floor stand. A length of balsa wood, also painted black, served as the mask for the 2-pixel width grille pattern. For the other patterns, masks were constructed out of black vinyl plastic and attached to the balsa rod.

3. SMALL-AREA LIGHT MEASUREMENTS

3.1 Equipment and Room Environment.
To evaluate the effectiveness of these stray-light tools, a front-projection system using a single digital micromirror device and a color wheel was used to project a 1024 × 768 image onto a matte projection screen. The grille patterns were measured using an illuminance meter and a scientific-grade charge-coupled device (CCD) camera with a 400 mm lens. A spectroradiometer fitted with a fiber-optic head was also considered, but rejected for two reasons: the receptor head was too small, and thus became sensitive to the pixel-to-pixel non-uniformity of the projector, and the meter did not provide enough sensitivity to measure the low black levels. The tests were performed in a 7.32 m × 6.53 m × 3.33 m

room with walls and ceiling painted black, black floor tiles, and reflective lab equipment and furniture covered with black felt. For some measurements, incandescent ceiling lamps near the wall opposite the projection screen were switched on, illuminating the center screen with 0.126 lx (4.35 lx without the slit). The screen was a commercially available projection screen. The CCD was positioned approximately 2.5 m from the screen.

3.2 Procedures

The black and white light level for various horizontal grille patterns were measured: 1 pixel on × 1 pixel off, 2 × 2, 3 × 3, and 4 × 4. The illuminance meter, mounted in the slit adapter and tripod, was placed as close to the plane of the projection screen as possible. The slit was adjusted so that only the center of the line would be illuminating the detector head. The meter was positioned at the shadow generated by the line mask, and a reading was then taken. Then the meter was moved to the nearest horizontal black line and a reading was taken, and likewise for the white line. Several white and black lines were measured and respectively averaged. This procedure was repeated using the SLET mounted to the slit adapter. Finally, the CCD camera acquired an image of the measurement area (see Fig. 5).

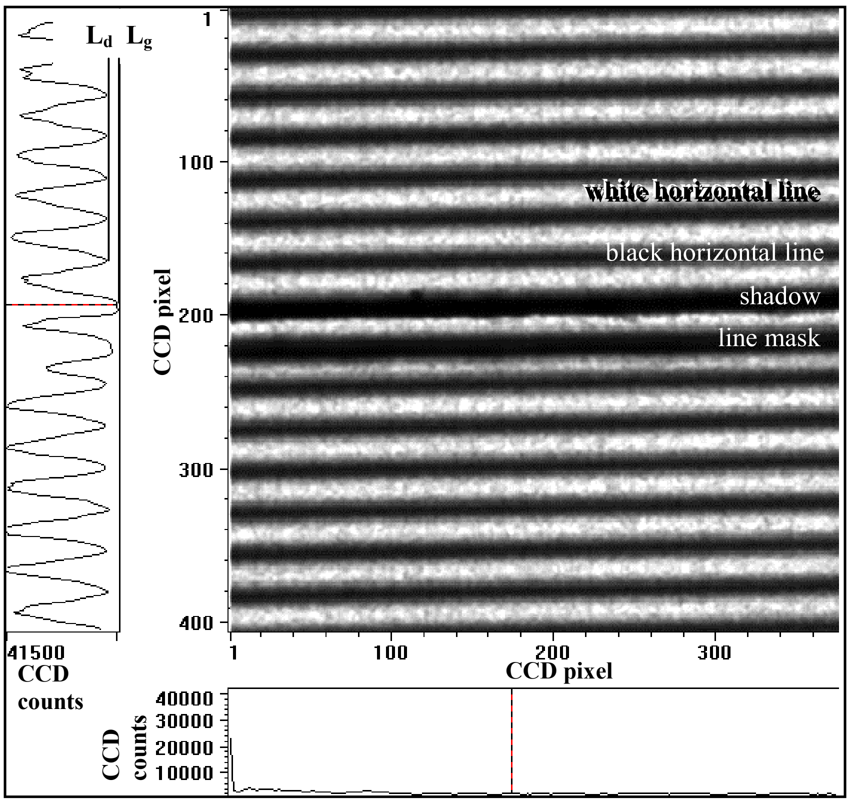

Fig. 5. CCD image of test pattern and line mask.

The grille patterns were chosen because they are used in display standards for the determination of small area contrast and resolution [5, 6]. Note that in the plot of the cross section shown along the vertical axis in Fig. 5, the sinusoidal pattern represents the modulation transfer function of the projector for this spatial frequency.

White and black light levels were measured with both LMDs using the line mask and the SLET. Both grille contrast and Michelson contrast were calculated (the latter may be used in the determination of resolution). These metrics were formulated as follows:

$$L_w = L_h - L_g \tag{1}$$

$$L_b = L_d - L_g \tag{2}$$

$$C_G = L_w / L_b \tag{3}$$

$$C_m = \frac{L_w - L_b}{L_w + L_b} \tag{4}$$

where L_g is the stray-light correction, L_h is the white line (high) light measurement, L_d is the black line (dim) light measurement, L_w is the net white value, L_b is the net black value, C_G is the grille contrast, and C_m is the Michelson contrast (also know as contrast modulation). The relationship in Eq. 2 is illustrated in the plot along the vertical axis in Fig. 5. L_g is measured at the mask shadow, and if no stray light were present, would be zero. The presence of light provides an indication of the amount of stray light (room contributions and veiling glare) in the system. The measured black line L_d is then reduced by the stray light estimation, providing a more accurate black value.

3.3 Results

Figures 6, 7, 8, and 9 show the results of the measurements, for both room lights on and room lights off. Both instruments suffered from stray light contributions when the back room lights were switched on. However, the illuminance meter measurements improved when these lights switched off, although reflections appeared to make some contribution. The CCD camera indicated only a small improvement when the lights were extinguished, indicating a rather large veiling glare effect due to the camera lens. All of the measurements decrease as a function of descending grill line width. This most likely results from the optics and electronics of the projector. Note the measurements of both instruments, when stray management tools were applied, only varied within ±5%. The SLET and mask methods only varied within ±4%. The repeatability of the CCD was ±2% and the illuminance meter was ±2%

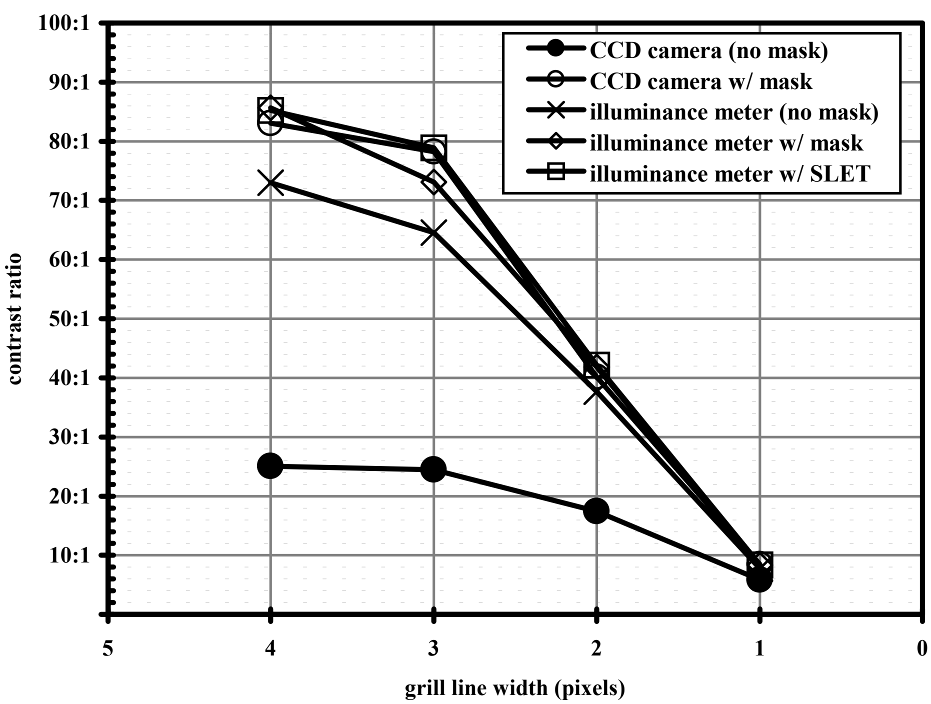

Fig. 6. Grille contrast for various meters and stray-light management tools—room lights off.

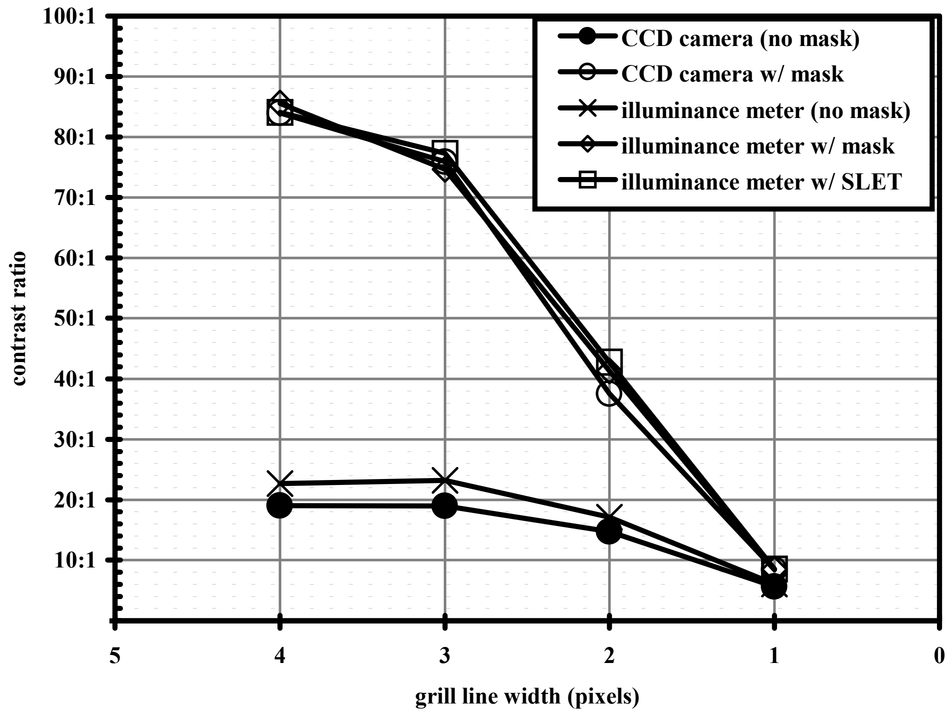

Fig. 7. Grille contrast for various meters and stray-light management tools—room lights on**.**

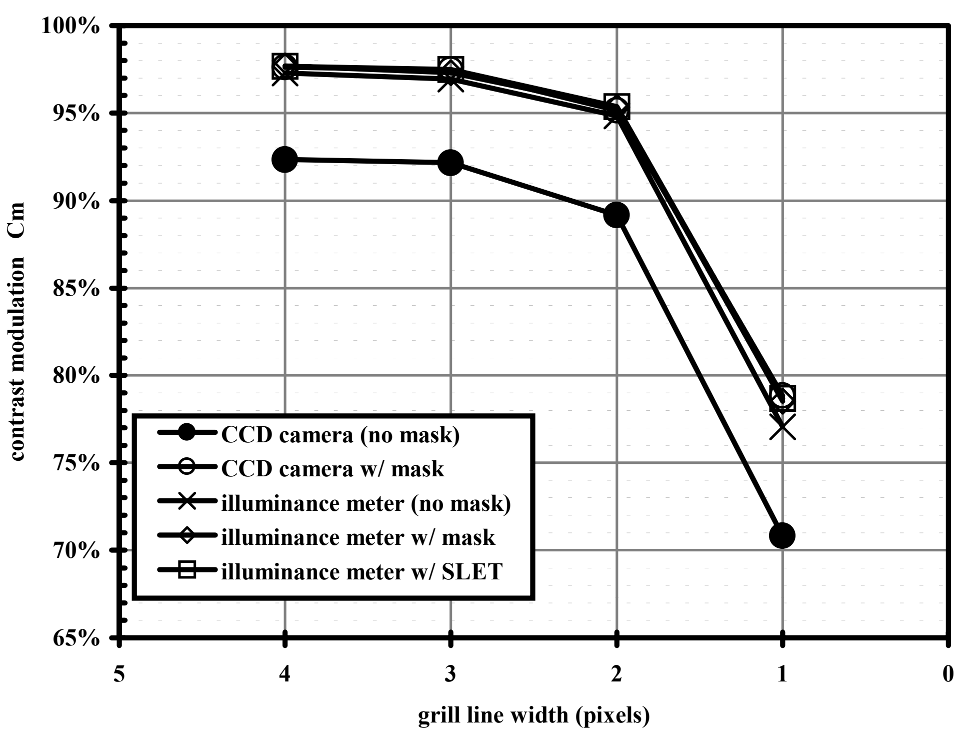

Fig. 8. Contrast modulation for various meters and stray-light management tools—room lights off.

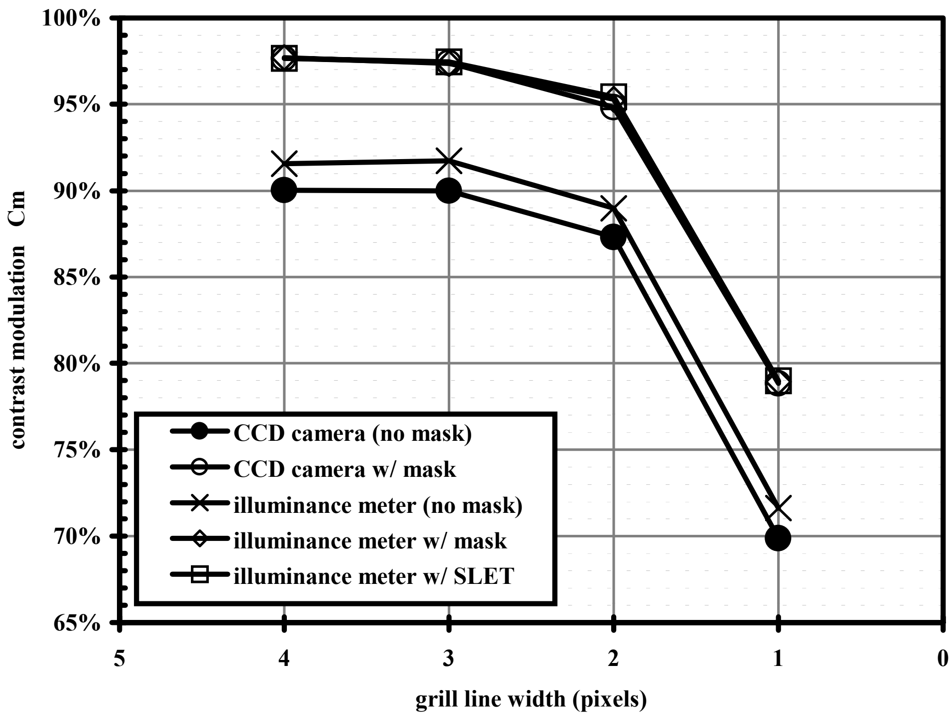

Fig. 9. Contrast modulation for various meters and stray-light management tools—room lights on.

3. CONCLUSIONS

Projection displays may be penalized unfairly if they are characterized in a particular viewing environment unless some action is taken to separate out the effects of the room and the veiling glare in the lens of the measurement device. Simple tools and techniques are easily constructed and employed to minimize or eliminate such corrupting parameters. Taking appropriate care can provide for an accurate evaluation of the intrinsic projector performance, allowing for better knowledge as to the influences of the various projector and room components upon image quality.

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5 VESA Flat Panel Display Measurement Standard, version 2.0, June 2001. See *302-2 N×N Grille Luminance and Contrast, 303-7 Resolution from Contrast Modulation,* and *A220 Measures of Contrast—A Tutorial*.

6 ANSI/NAPM IT7.228-1997 Electronic Projection—Fixed Resolution Projectors. See *4.4 Small area contrast ratio for alternating black and white pixel lines.*