# test and measurement

# Measuring the Contrast Ratio of Displays

There would seem to be few things that are simpler, but many manufacturers and users have been understating their contrast ratios for years.

## by Paul A. Boynton and Edward F. Kelley

CONVENTIONAL METHODS of measuring the contrast ratio of displays usually involve measuring the luminance of a black region and the luminance of a white region on a black-and-white pattern on a screen (Fig. 1). The ratio of white to black luminance is the contrast ratio.

What could be wrong with such a simple measurement? Just this: Different measurement methods and circumstances can produce widely varying results because of the uncertainty in the black measurement. Because of that, many manufacturers feel that their displays exhibit more contrast than they can reliably measure and report. Further, display users grow frustrated when they can't reproduce the same contrast ratios that the manufacturer's specifications claim.

What is wrong with the measurement indicated in Fig. 1? The light outside the field of

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view can contribute to the measurement of the luminance of the image. This can greatly affect the black-luminance measurement, but it also affects the white-luminance measurement. This effect, often called *veiling glare*, occurs in all lens systems, including telescopic, photographic, and microscopic systems. Eyeglasses and even the human eye suffer from veiling glare.

#### **Veiling Glare**

Contrast measurements of white and black on the screen can suffer serious uncertainties because of veiling glare, also known as "lens flare." This effect results from the light outside the aperture field of view scattering and reflecting at lens surfaces, imperfections in the glass, dirt on the glass, and the barrel, iris, and other mechanical parts of the lens. This



Fig. 1: Traditional determinations of contrast ratio involve measuring the luminances of a black region and a white region on a black-and-white pattern on a screen. The circles delineate the areas measured by the luminance meter. The ratio of white to black luminance is the contrast ratio.

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Fig. 2: Three display patterns typically used to make contrast-ratio measurements are (a) a checkerboard pattern, (b) a black rectangle on a white screen, and (c) a white rectangle on a black screen.

glare falsely contributes to the measurement of the luminance of the image, reducing its contrast.

Veiling glare can corrupt contrast measurements, white measurements, reflection measurements, and color measurements. This concept has been understood and characterized for many years,<sup>1</sup> but many users of measurement equipment in the display industry are unaware of the consequences of glare. Problems in high-contrast measurements become more serious for displays with antiglare coatings and newer technologies exhibiting darker blacks, including both cathode-ray tubes (CRTs) and flat-panel displays (FPDs).

The contribution of veiling glare - sometimes called the *flare factor* - can be defined as the ratio of the luminance of the ideal image without glare to the luminance of the additional flare light. Various lenses will display different flare factors, depending upon their design. Some lenses reduce the glare by focusing the light entering the meter so that only the light from the aperture falls onto the detector head. Not all detector lenses have this corrective feature. But even if we are careful in our procedures and setup, we normally can't suppress the flare to less than 3% of the image luminance without great difficulty.<sup>2</sup>

### Some Current Methods Three possible test patterns that can be used

to judge display quality based on a contrastratio measurement are the black-and-white checkerboard, a single black rectangle on a white background, and a single white rectangle on a black background (Fig. 2). When using the checkerboard, the two center black rectangles are typically measured and averaged to obtain the dark luminance, and the two center white rectangles are measured and averaged to obtain the light luminance. The size of the rectangles can be varied.

With the single-rectangle patterns, the rectangle is measured at different percentages of total screen size. The luminance may vary as the size of the rectangle is changed. In the case of a white rectangle, any changes in luminance are referred to as *screen loading* and are considered to be a characteristic of the display.

Why can't we avoid the glare problem by simply measuring the full-screen white-toblack ratio? The reason is that many people in the display-standards arena feel that to get an accurate indication of contrast we need to measure a character stroke on a white screen – or some other pattern; i.e., the screen must be measured under conditions of typical use. But we have to ask ourselves if our metrology is sufficiently good to measure such contrasts.



Fig. 3: The traditional method for making luminance measurements involves aiming a luminance meter at the area of interest on the screen. The measurement can be improved to varying degrees by making the measurement through either (a) a flat mask or (b) a cone mask.

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Fig. 4: Because a mask reduces veiling glare – or lens flare – it can make the measurement of black-area luminance essentially independent of the size of the black rectangle on a screen.

**Testing Proposals and Alternatives** We examined the two test patterns described above, measuring the luminance of an activematrix liquid-crystal display (AMLCD) with a charge-coupled-device (CCD) array lens system. We used three methods (Fig. 3). First, we tried the conventional approach, simply measuring the pattern with the detector in darkroom conditions. Second, we placed a flat sheet of matte black plastic with a 5-mm aperture in front of the screen so that only the center of the target patch was visible. Finally, we used a 45°-angle cone with a 5-mm aperture. Constructed from glossy black plastic, this cone minimizes light reflecting back onto the screen as well as light from the rest of the screen reaching the detector lens. Because of the cone angle, light reflecting from the screen will be directed away from the screen, not toward it. At the same time, light from the display that enters through the aperture at oblique angles will be reflected away from the lens. Both the cone and the matte aperture masks were placed directly against the display.

We measured the luminance of the black rectangle with the CCD and a 135-mm lens and obtained some interesting results (Fig. 4). When no mask is used, we do indeed see a change in luminance with increasing size of the black area. However, when we repeat the measurements using the matte and cone aperture masks, we see less than a  $\pm 0.3\%$  standard deviation in luminance over the range of sizes

of black areas, which is roughly the uncertainty in the instrumentation. We have just shown that if the effects of veiling glare are not properly taken into account, the display is blamed for deficiencies that it does not possess.

What happens when we measure the luminance of a white rectangle on a black background (Fig. 5)? When no mask is used, we obtain the now expected change in luminance as we increase the size of the white area. These data show a 3% increase in luminance. However, when we repeat the measurements using the cone aperture mask, we see a less than  $\pm 0.2\%$  standard deviation in luminance over the range of sizes of white areas.

The variation in these data may be due to temporal aliasing between the detector and the screen. When we measure a checkerboard pattern using the same methods as above and calculate the contrast ratio, the use of the apertures in contact with the screen gives us a fivefold improvement in contrast ratio, from approximately 50:1 to 250:1. (Note that the absolute uncertainty of the luminance measurements is on the order of  $\pm 5\%$ , and the uncertainty of the contrast-ratio measurements is less than  $\pm 2\%$ .)

But if we can't lay the aperture directly against the display, which is better: the matte



Fig. 5: Using a mask also improves the reliability of white-area luminance measurements on a black screen, although the percentage difference is – predictably – far less.

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Fig. 6: A cone mask is far more effective than a flat matte mask when the masks can't be placed very close to the screen.

or the cone aperture mask? Some technologies will not permit the mask to be in close proximity to the pixel surface. For instance, a CRT has a layer of glass across the screen. Reflections off the back of the flat matte mask influence the luminance measurement of the black area as the mask is moved away from the display. Because of its 45° angle, the cone reflects the light away from the screen. Therefore, the cone maintains a relatively constant measurement as a function of distance compared to the matte mask (Fig. 6). Because of the reflections off the surface of the matte mask, it performs better than the cone mask only when placed on or very near the pixel surface. The back of the surface of the matte can be covered with black velvet, which may reduce these reflection problems.

The cone aperture mask appears to be a simple and practical method for virtually eliminating the effects of veiling glare in many display measurements. Use of such a device may lead to more reproducible and accurate results, approaching the "true" contrast that the eye sees. Even if a luminance meter provides a "flare-free" lens, the cone can be used to characterize the performance of the optics.

## Metrology Is an Attitude

The moral of this story is to remember that

metrology is more an attitude than a set of procedures – an attitude of skepticism. We need to be asking questions before we begin specifying metrics. Are we really measuring what we think we are measuring? Have we considered establishing simple diagnostics to see if a particular measurement method is reasonable? If we can't perform a particular measurement with the desired accuracy, then we should avoid the grief of requiring ourselves to measure that metric, or we should define one that we can measure. If veiling glare is not appreciated, we may find it difficult to measure such things as the contrast ratio of character strokes on a white background.

Problems like veiling glare will not go away. Being aware of them and developing solutions – or exploring other possibilities – may prove difficult at times, but the alternative is inconsistency and inaccuracy in the measurement. Good metrology should be at the foundation of all industrial endeavors.

## Notes

<sup>1</sup>Methods of Characterizing Illuminance Meters and Luminance Meters, CIE Publication No. 69 (1987).

<sup>2</sup>S. Matsuda and T. Nitoh, "Flare as Applied to Photographic Lenses," *Appl. Opt.* 11, No. 8, 1850-56 (August 1972). ■

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