Overview

A quick glance at the datasheet of almost any projector will typically show that the first two specifications listed are light output and contrast ratio. Of all the parameters that define the performance of a projected image, these two are widely considered the most important.

There’s a good reason for that – roughly 70% of our perception of a full-color image is actually due to the luminance or brightness information it contains. A projector’s light output and contrast ratio both greatly affect the way that brightness information is conveyed and in particular the image’s impact and clarity under conditions of less than perfect ambient illumination. But while these specifications may seem simple, there is more to them than meets the eye.

Light output

Light output is an important specification because it determines both the largest size of screen that a projector can support for a desired image brightness and the amount of ambient light that the image can tolerate before it is perceived as being “washed out.” A higher light output will support a larger image and will tolerate more ambient light.

The light output from a front-screen projector is usually specified in lumens, the international unit of luminous flux. This number does not directly define the brightness of an on-screen image because the brightness also depends on the screen’s size; for a given number of lumens, a larger screen results in a dimmer picture.

This can be illustrated by analogy with a fish tank full of water (Figure 1). Take the same water and pour it into a larger tank, and the water line will be lower. In the same way, take a given amount of light from a projector and use it to illuminate a larger screen and the brightness will be reduced, in direct proportion to the ratio of the area of the smaller screen to the larger one.

The same rule also applies to rear-screen projectors. However, the screen of such a projector is considered an integral part of it, as if the combination were a direct-view display. Hence, the light output is not specified in lumens, but in nits (officially candela per square meter), which is a measure of the light emitted from the screen.

It would be natural to assume that a projector’s light output specification is the maximum amount of light it produces when every pixel in the image is full white. However, in truth the number is only an approximation since it is derived from a measurement taken using a light meter and hence depends on the measurement method.

For digital projectors, the industry standard measurement method currently used is defined in IEC 61947-1 from the International Electrotechnical Commission. This standard specifies that light readings be taken at nine points on the screen surface; precisely defined to be in the centers of nine rectangles formed by dividing the image into three points vertically and three parts horizontally (Figure 2). The nine readings are then averaged.

When measured in this way, the units of light output for a front-screen projector are universally called “ANSI lumens,” named after an older standard from the American National Standards Institute that was superseded by IEC 61947-1 several years ago. They are not different units – a lumen is a lumen – they are simply measured in a specific way.

The ANSI (now IEC) method is very commonly used, but unfortunately not by every projector manufacturer. If there is no “ANSI” qualifier on a light output number, it was most likely measured at a single point – directly in the center of the screen. Because of the properties of projection optics the center of the image is typically its brightest point, with the light falling off toward the edges and corners. Hence, a center-only number will always be considerably higher than the ANSI number, which takes the fall-off into account. Since the eye judges display brightness averaged over the screen’s surface, the ANSI number more accurately reflects what the eye perceives.

An example using representative numbers is illustrated in Figure 3, which shows a group of measurements taken at the nine ANSI points (the actual measurement units here are immaterial, since we are calculating a ratio). The average of the nine readings is about 28.5 ANSI lumens.
are then calculated by multiplying this number by the screen's area (in appropriate, matching units). Using the center reading of 32 alone would result in a light output number approximately 12% higher than it should be.

Contrast ratio

Contrast ratio is the second most important specification of a projector because it affects both the clarity of the image and its impact.

There are actually two types of contrast ratio (CR) measurements. The first is known as sequential, full-field or "full on/off." It is a measure of the total range of light the display can usably output – the brightness of the highest white it can produce divided by the brightness of its lowest black (There is almost always some light output even at full black.). The IEC standard describes how to measure the full-field CR of a digital projector. With the projector calibrated such that all of the gray levels in the signal between full black and full white are visible (i.e., that blacks and whites are not crushed) light outputs of a full white image and a full black image, both averaged over the nine ANSI points, are measured in succession in a dark room. The full-field CR is the ratio of the white-image number to the black-image number.

The second type of contrast ratio specification, also defined in the IEC standard, is known as "ANSI CR." With the projector set up as described above, a checker-board test pattern is displayed, dividing the image into a 4 x 4 grid of alternating black and white rectangles (see Figure 4.) Light readings are taken at the center of each rectangle. The sum of the measurements for the white rectangles is then divided by the sum for the black. (Note that special techniques must be used to avoid errors in the measurement; in particular to prevent light from the image that bounces around the room from getting back onto the screen.)

The intent of the ANSI CR specification is to quantify a display's contrast performance when showing a typical data image that contains a large number of bright pixels (e.g., from a computer). Scattering of light rays in the projector's optical system will cause a small fraction of the light from those bright pixels to be diverted to other parts of the screen. Pixels that should be entirely black, for example, will become dark gray. This reduces the contrast in the image.

For this reason the ANSI CR measurement is usually considerably lower than the full-field number for a given projector. However, it is the true measure of the quality and contrast performance of the projector's entire optical system.

To the eye a high ANSI CR image typically looks clearer and sharper than an image with a lower ANSI CR. This is because the perceived sharpness of an image is greatly affected by the contrast ratio between adjacent pixels, which typically increases with higher ANSI CR values.

While ANSI CR provides a measure of the contrast performance for data images, it is also important for continuous-tone video images. Nevertheless, such images are affected to a much greater extent by a projector's full-field CR performance. The reason is that the bright area of most video scenes is considerably smaller than the bright area of the ANSI test pattern (which is 50% of the image). Hence, the contrast performance achieved during a typical movie, for example, will be better than the ANSI CR would indicate most of the time and will approach the full-field CR for very dark scenes.

Generally speaking, a higher full-field CR will yield a deeper black level at a given peak brightness. As black levels get deeper, images get noticeably better, especially video images. Color saturation, in particular, improves greatly and the images are often described as having more "punch".

However, a high contrast image can easily be robbed of its high contrast if ambient light is allowed to fall on the screen. In the case of front-screen projection even a small amount of light will reduce the contrast significantly. If it is not possible to adequately control the lighting within the room, one possible solution is to use a special screen that can reject a portion (but usually not all) of the light that hits it from sources other than the projector.

Another way to combat ambient illumination is to use a brighter projector. This is illustrated in Figure 5. The image from projector A outputting 500 lumens has an effective contrast ratio of only 10:1 because of a relatively high level of ambient illumination.
The image from projector B outputting 2000 lumens has a much higher contrast of 40:1 due solely to its greater light output. Note that these numbers are for the actual contrast ratio in the room environment, which is dominated by the effect of ambient illumination. The laboratory measured contrast ratios of the two projectors could well be the same.

As a rule, ambient light is much less of a problem for rear projection because most rear-projection screens include, in their structure, an embedded matrix of black stripes or other means to reject ambient light hitting the front (non-projection) surface.

<table>
<thead>
<tr>
<th>Contrast ratio</th>
<th>Installation scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:1</td>
<td>Minimum acceptable for presentations</td>
</tr>
<tr>
<td>20:1</td>
<td>Minimum for all sources to be called ‘good’</td>
</tr>
<tr>
<td>35:1</td>
<td>Typical rear-projection in high ambient setting</td>
</tr>
<tr>
<td>50:1</td>
<td>Minimum for control rooms</td>
</tr>
<tr>
<td>200:1</td>
<td>Best case for rear-projection in high ambient setting</td>
</tr>
<tr>
<td>1000:1</td>
<td>Good contrast in movie theatre</td>
</tr>
</tbody>
</table>

Table 1. - Rules of thumb for in-room contrast ratios

Dynamic contrast

Another contrast ratio number is now commonly quoted on projector datasheets. Known as “dynamic contrast ratio” the number is typically much higher than the full-field CR (which in turn is higher than the ANSI CR).

Simply put, dynamic contrast is a feature that varies the intensity of a display's light source with image content. In the case of a digital projector employing a high-intensity discharge lamp (Xenon or Mercury-vapor) it is realized using a motorized iris inside the projector that “throttles” down the light from the lamp before it reaches the micro-display(s). See Figure 6.

Dynamic contrast takes advantage of the fact that images don’t always contain the full range of pixel intensities from full black to full white. In the case of video images in particular, it is also common to have considerably more dark pixels than bright pixels in the image. When there are no (or few) bright pixels, a deeper black level is achieved by automatically closing the iris to reduce the projector’s light output. The light output is automatically increased for scenes containing more bright pixels in proportion to their number and relative brightness.

Of course, implementing dynamic contrast is not quite as simple as that. The specific manner in which the light output is varied with image content is critical to avoid obvious and visible changes in image brightness. In addition, the mathematical relationship between pixel values and brightness – the gamma – must also be appropriately manipulated.

When done well, dynamic contrast can yield a very significant increase in the perceived contrast performance of a display for sources with changing image content, particularly motion video. It does not, however, improve subjective contrast for static images. Nor would it be generally applicable over the whole of a tiled or edge-matched array, since the black levels and brightness of the individual images in the array need to remain precisely matched at all times.

Conclusion

Light output and contrast ratio are widely considered to be the most important specifications of projector performance. When evaluating these specifications, it is important to understand how the numbers are measured and whether industry standards are followed. But it is even more important to understand the factors that influence the measurements and which measurements most affect the image brightness, contrast and clarity required for a given application.