Barco Rear Projection Screens

How to translate perceived image quality into screen specifications?

DATE October 2022 Version 2.0

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Ver.	Name	Date	Reason for revision
1.0	Geert Matthys	October 2022	Document was created
2.0	Geert Matthys	November 2022	Some errors in references to Figure nrs corrected, better page lay-out

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Introduction

Although many direct-view display systems exist (LCD, LED...), there is still an important market for projection display systems. These systems always consist of one or more projectors combined with ***a screen***. The image creation happens on the screen, which makes it crucial for the final experience.

Everybody is familiar with a digital Cinema theatre, where a projector is installed behind the seats of the spectators, illuminating a big screen in the front of the theatre.
This is what is called a *front* projection application. The user and the projector(s) are at the same side of the screen. One big disadvantage is the fact that one cannot come close to the screen, or shadowing will occur, and part of the image will be blocked. We all know this phenomenon when somebody enters the cinema theatre and tries to find a seat in the rows behind you.

So, this type of setup cannot be used for what we call "Close Viewing applications". In cases where the users need to be close to the screen, a *rear* projection screen is preferred. User and projector(s) are now at different sides of the screen.

Rear projection screens come in many different flavors. But as they are the final interface to the user, it is very important to make the correct choice.
Projectors also come in many different flavors, with a continuous effort to increase their capabilities. Brightness levels, resolution and color gamut are 3 of the important parameters in this race towards better performance.
But even with the best possible projector behind the screen, one can still end up with a bad image. Therefore, since more than a decade now, Barco invests in design and manufacturing of its own unique rear screen portfolio. (See Figure 1)

This to enable the best possible combination of projector & screen for our typical applications. As the perfect screen does not exist, it is very important to understand the trade-offs that need to be made when choosing a rear projection screen.

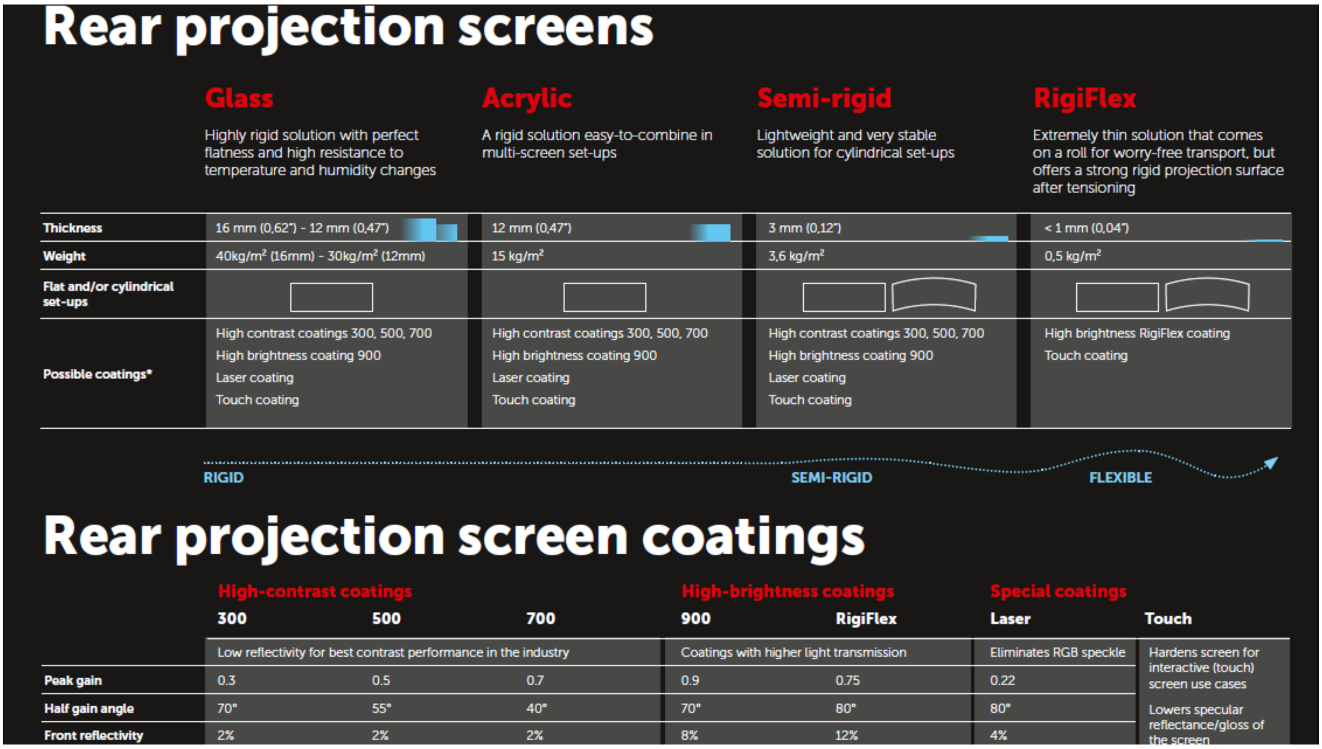


Figure 1: Barco's current screen portfolio

The purpose of this whitepaper is to help the reader understand how the perceived image quality on a rear projection screen can be quantified by a set of screen specifications.

Barco defines **4 main parameters** which help to validate if an image on a screen is perceived as excellent, acceptable, or just bad.

These parameters are **Brightness, Contrast, Sharpness and Color**.

There is no ranking involved, all 4 can be equally important, depending on the use-case.

Brightness is the most straightforward and known parameter. At first glance, the brighter an image is, the better. But there is more to it… Most screen manufacturers are mainly focused on brightness only, and although this is an important parameter, it is far from the only one.

Contrast is often less understood, as contrast specs are not so straightforward. Sequential contrast – as defined by projector manufacturers – has little value in real applications on a rear-projection screen.

Sharpness is the overall term to describe the ability of a screen to display the finest image details.

Color is the overall term to describe the ability of a screen to display the correct colors, as they are designed in the application. A car designer wants the screen to show the exact colors he has in mind.

In this whitepaper, an attempt is made to convert these -often subjective – parameters into real, measurable specs.

Apart from some well-known specs that determine the image brightness (like Peak Gain and Half Gain Angle), we will introduce some other key specifications such as Reflectivity, Ambient Contrast, Local Contrast, Color Critical Angle, …

Next chart gives an overview, that will be explained in full in the rest of this whitepaper.

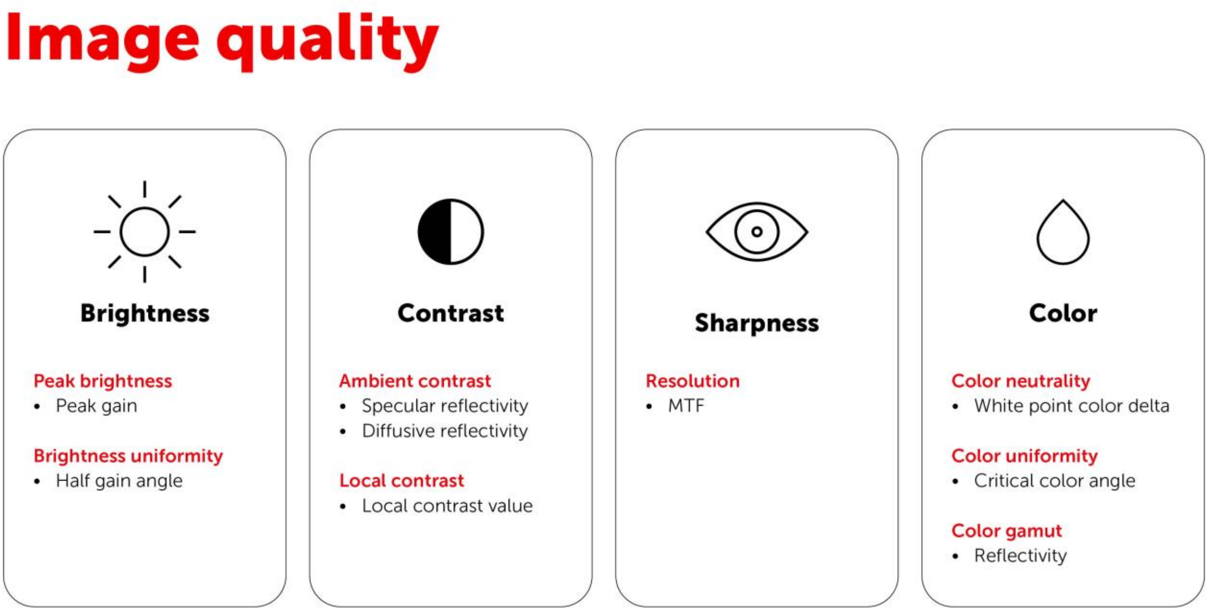


Figure 2: image quality break-down to screen specs

Brightness

In this context, brightness refers to the experience of how bright an image appears on a rear projected screen.

Remark: The scientific correct terminology for what is called "brightness" is luminance. But as brightness is very commonly (mis-)used, we keep it for simplicity

The achieved brightness level on a rear projected screen is defined by the luminous flux of the projector(s) used, the projected area per projector and the screen's transmission characteristics.

The transmission characteristics of a screen are defined by the transmissive gain curve, from which important parameters such as Peak Gain (PG) and Half Gain Angle (HGA) can easily be defined.

'Peak Gain' (PG) is defined as,

$$Peak\ Gain\ (PG) = \frac{Max.Luminance\ from\ screen\ \left({}^{cd}/_{m^2}\right) \times \pi}{Illuminance\ at\ the\ back\ of\ the\ screen\ (lux)}$$

The Peak Gain of a screen can be calculated based on 2 measurements:
First, the illuminance at the back of the screen is measured.
This is done with an illuminance meter (often called "Lux-meter") on-axis in the center of the screen, of which the sensor is pointing towards the projector. The Lux value is noted and the luxmeter is removed to avoid obstruction of the lightpath.
Secondly, the peak brightness (luminance) is measured on-axis with a luminance meter.
Figure 3 gives a top view of a possible setup which enables calculation of the ***Peak Gain*** of a screen: the projector or lightsource and the luminance meter are on the same optical axis. The luxmeter is temporary in the same optical axis, pointing to the lightsource

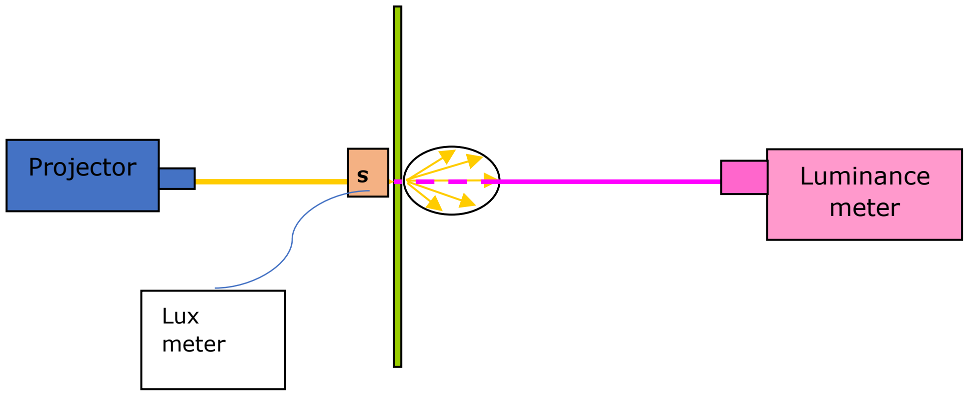


Figure 3: Peak Gain measurement setup, with the luxmeter sensor (S) pointing to the projector.

'Half Gain Angle' (HGA) is defined as the viewing angle at which the screen brightness (luminance) drops to half of its maximum value.

To define the Half Gain Angle, the luminance meter is put on a rotating arm. Measurements are taken at different angles. The angle at which the Peak Gain becomes half of the initial value, is the Half Gain Angle.

Remark: Some screen manufacturers describe 'Full Viewing Angle' which is simply twice the 'Half Gain Angle' (Full Viewing Angle = 2 X Half Gain Angle).

This means that for a given amount of projector lumens per area (illuminance), screen types with different PG's and HGA's will give a different brightness experience.

As shown in Figure 4, the illuminance at the back of the screen, will be diffused towards the viewer at the frontside of the screen.

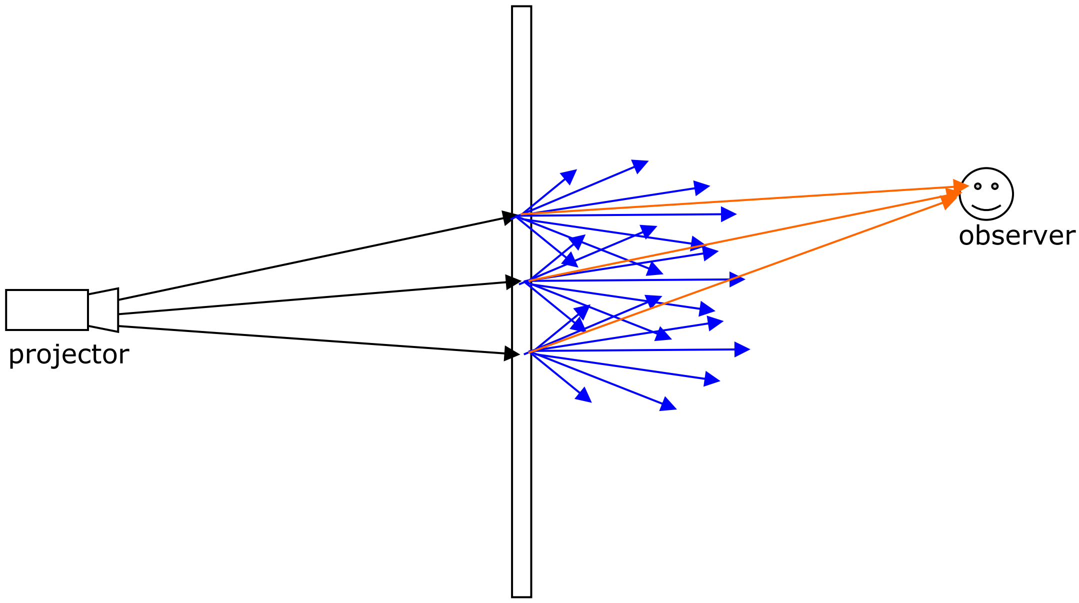


Figure 4: Diffusive rear projection screen

Depending on the screen type, this diffusion can be lower or higher.

With ***lower diffusion***, a higher brightness will be perceived when looking straight along the imagery line between observer and projector. But the fall-off of the brightness will be bigger when looking under bigger angles. Typically, this type of screens will have a higher PG value, and a lower HGA value. Figure 5 shows a theoretical example of a low diffusion screen.

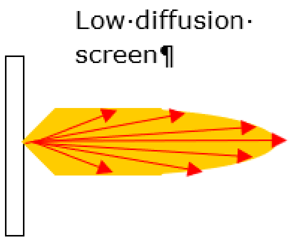


Figure 5

With ***higher diffusion***, a lower brightness is perceived when looking straight, but the fall-off is also smaller when looking under angles. Typically, this type of screens will have a lower PG value, and a higher HGA value. Figure 6 shows a theoretical example of a high diffusion screen.

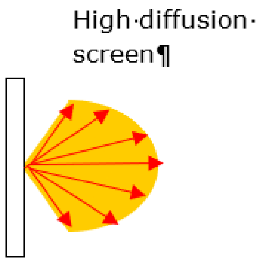


Figure 6

To clarify the effect of different screen types on the overall brightness perception, a simple setup is made in Barco's Simcad (a proprietary simulation tool based on raytracing). The setup consists of a single projector with a rear projection screen, and 2 viewers located at 2 different positions. We call them viewer 1 and viewer 2.

See Figure 7 on the next page.

Viewer 1 is perpendicular to the center of the screen at a distance of 3meter

Viewer 2 is more to the side of the screen, at a distance of 1.2meter.

The screen size used in the simulations is 3840mm x 2400mm, corresponding with a 1mm pixelsize with a 4k projector behind.

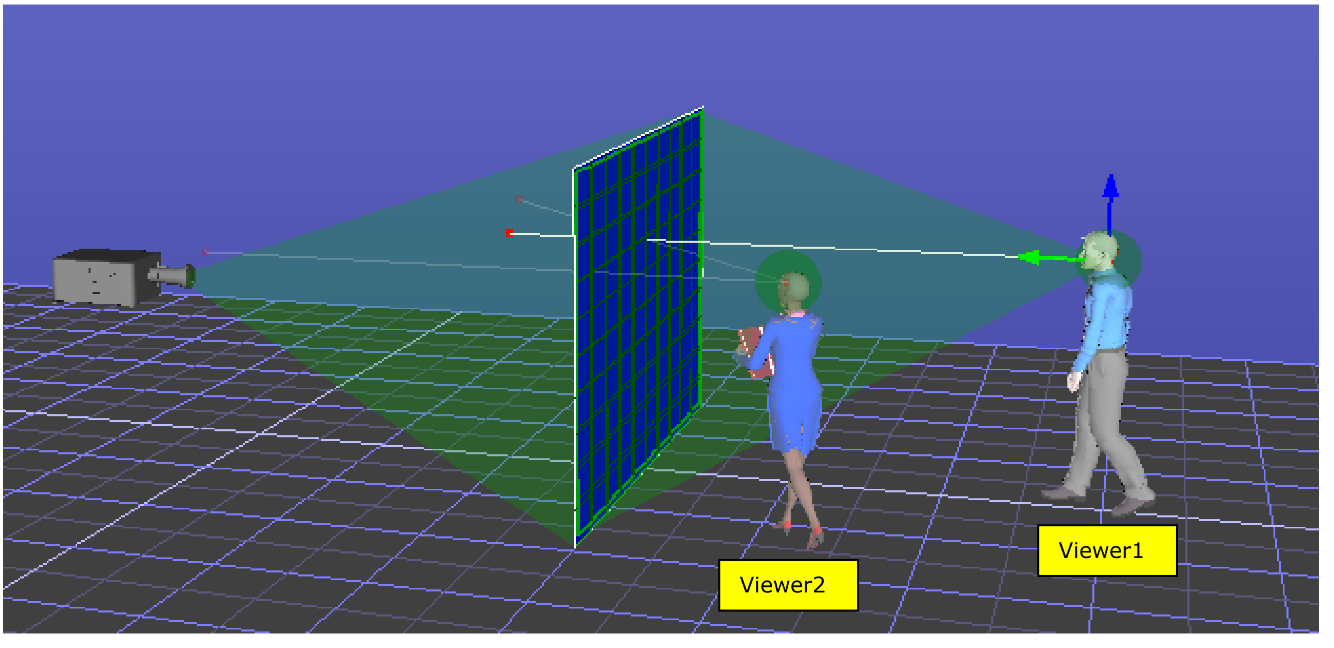


Figure 7: Simcad simulation with 2 viewers at different positions in front of the screen

As Simcad uses the exact screen parameters, we defined a lower diffusion and a higher diffusion screen and ran the simulations for both viewers.

The lower diffusive screen has the transmission characteristics as shown in Figure 8, with a Peak Gain of 1.0 and a Half Gain Angle is 38°

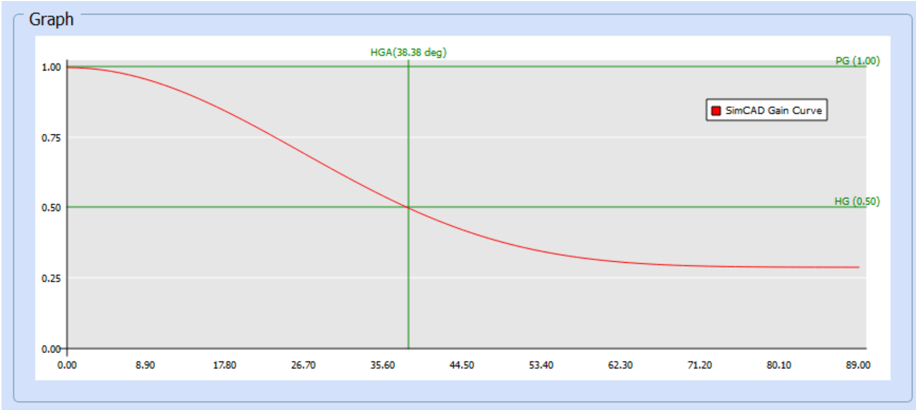


Figure 8: typical transmission curve of a lower diffusive screen

While the lower diffusive screen has a higher peak brightness, it exhibits lower brightness uniformity resulting in darker corners. The effect known as "Hotspot" becomes visible, as shown in the simulation for viewer 1 (Figure 9). So overall brightness uniformity is less good.

For viewer 2 this effect is even more visible. Although the perceived peak brightness remains the same, the brightness fall-off to the right side of the screen is much more pronounced now.(Figure 10)

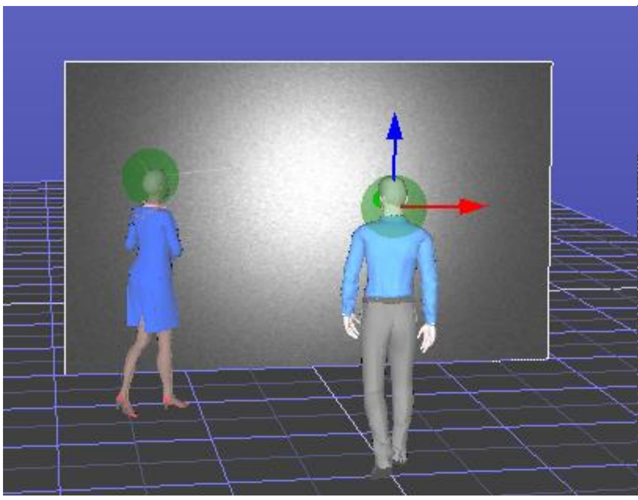


Figure 9

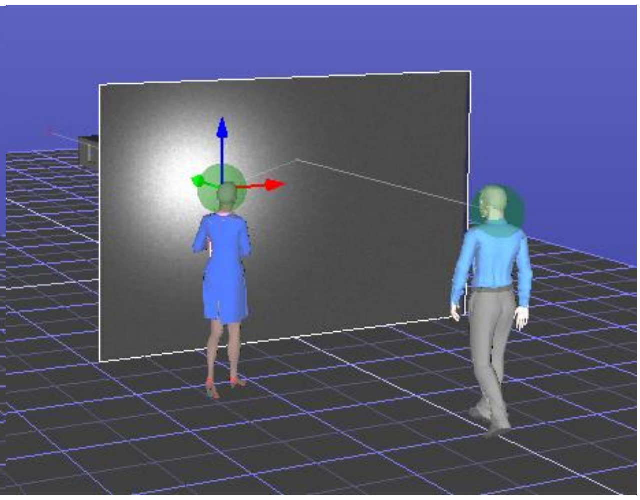


Figure 10

The higher diffusive screen has the transmission characteristics as shown in Figure 11, with a Peak Gain of 0.70 and a Half Gain Angle of 60°

Figure 11: typical transmission curve of a higher diffusive screen

While the higher diffusive screen has a lower peak brightness, it exhibits better brightness uniformity resulting in less dark corners. The effect known as "Hotspot" becomes far less visible, as shown in the simulation for viewer 1 (Figure 12). So overall brightness uniformity is a lot better than with the lower diffusive screen.

For viewer 2 the effect of hotspot is also far less visible than with the lower diffusive screen. The brightness fall-off towards the right-hand side of the screen is now much less disturbing. (Figure 13)

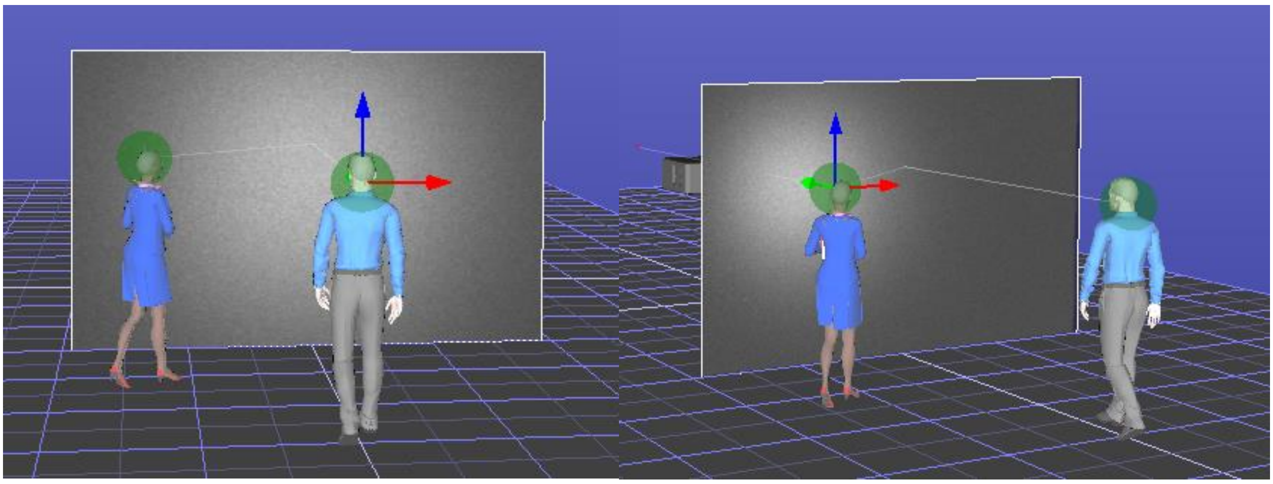


Figure 12 Figure 13

ENABLING BRIGHT OUTCOMES

Important remarks:

- These simulations are showing the effect of hotspot more pronounced than in reality. But it is only for the purpose of showing the impact of the screen parameters on the peak brightness and the brightness uniformity.

- The simulations make use of a perfectly uniform projector which is also not the case in reality. So real applications will be different too.

- It is obvious that the effect of hotspot will be worse in following conditions:

    - Projectors with shorter throw lenses are used. The closer the projector to the screen, the more this hotspot gets critical. Especially as so-called UST lenses (Ultra Short Throw) are used more and more, it is very important to make a good choice between peak brightness and brightness uniformity.

    - Viewer is closer to the screen and/or watching the screen from a bigger angle

Bottom line: to make the right screen choice with respect to brightness and brightness uniformity, the final system setup and use case needs to be very well understood.

Contrast

Contrast on a display is usually defined as the ratio between the maximum brightness and the minimum brightness values that the display can show.

The contrast behavior of a rear projection screen is maybe one of the most important parameters as the human eye has the ability to adapt to higher or lower brightness values but is not able to adapt to low contrast. Screens with low contrast behavior are not able to show details in blacks, will miss fine details and show less punchy colours.

Contrast behavior on a rear projection screen is a combination of both **ambient contrast** and **local contrast**

• Ambient contrast

Ambient contrast relates to the behavior of a rear projection screen in different lighting conditions.

One end of the scale is when there is no ambient light at all . This means that the rear projection screen is used in a fully darkened room.
The contrast experience will be mainly defined by the contrast spec of the projector(s) used.

On the other end of the scale, a lot of ambient light is entering the room via big windows on a bright day. The contrast experience will be mainly defined by the contrast spec of the rear projection screen used.

A typical example of a completely dark room is a cinema theatre. As this is a front projection application (see introduction chapter) on a white screen, all ambient light would reflect back to the visitors, which would hide all the details in dark scenery and result in pale, non-punchy colours.

As it is not possible to work in front of a rear projection screen in completely dark environments, some ambient light coming from the room-lighting, windows or others is always falling on the screen. This ambient light can drastically reduce the ambient contrast of the system unless the screen is engineered to minimize the reflection of ambient lights towards the user. This is one of the big advantages of rear projection screens vs front projection screens: the reflective behavior, affecting contrast, can be decoupled from the transmissive behavior, affecting brightness (see previous chapter)

The key screen characteristic that determines ambient contrast behavior is the screen reflectivity. Reflectivity of a rear projection screen has two main components: Specular reflectivity and Diffuse reflectivity. See Figure 14

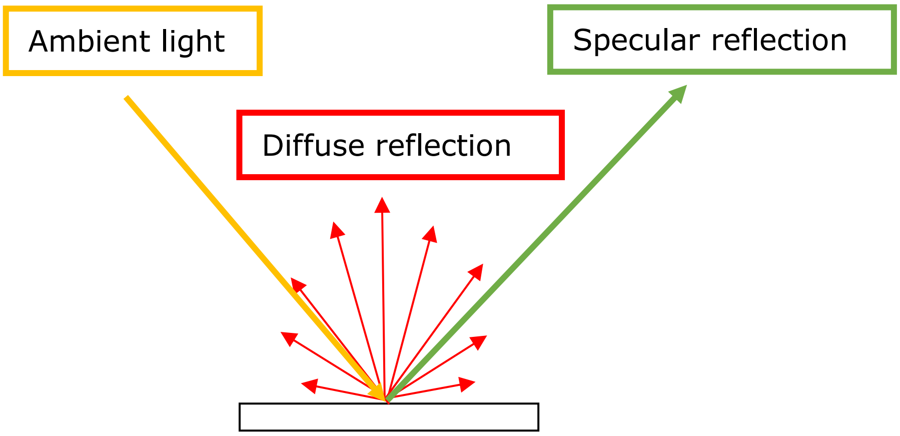


Figure 14

The *Specular* component comes from the mirror-like surface finish of the screen. The *Diffuse* component comes from the surface and the subsurface screen characteristics.

When the screen has a high specular reflection, it acts like an undesirable mirror. You can almost see a mirror image of e.g., the lamp in the room, or other bright objects. In such case the system contrast will be **very low** if the user is positioned on a specific location, looking straight into the reflected specular rays coming from the ambient light source. With glossy tablets or other hand-held devices, high specular reflection is not an issue, as the user can reposition her/him or the device eliminating the specular reflection. Unfortunately, this is not possible with large video walls. So, it is preferable that the rear projection screens avoid too much specular reflection, as this can ruin the contrast completely for a specific position of the user in front of the screen.

Specular reflection can be reduced by surface treatment of the screen, but this will introduce a higher diffuse reflection component. But also, this diffusive component needs to be as low as possible, as diffuse reflection will be visible from all positions in front of the screen.

It is key to understand the trade-offs and engineer the screen to both combine an acceptable specular reflection with a low diffusive one.

To visualize the differences between different screen types, we made again some simulations in the Barco Simcad tool. See Figure 15 on the next page.
Ambient light is created and falls on the top half of the screen.

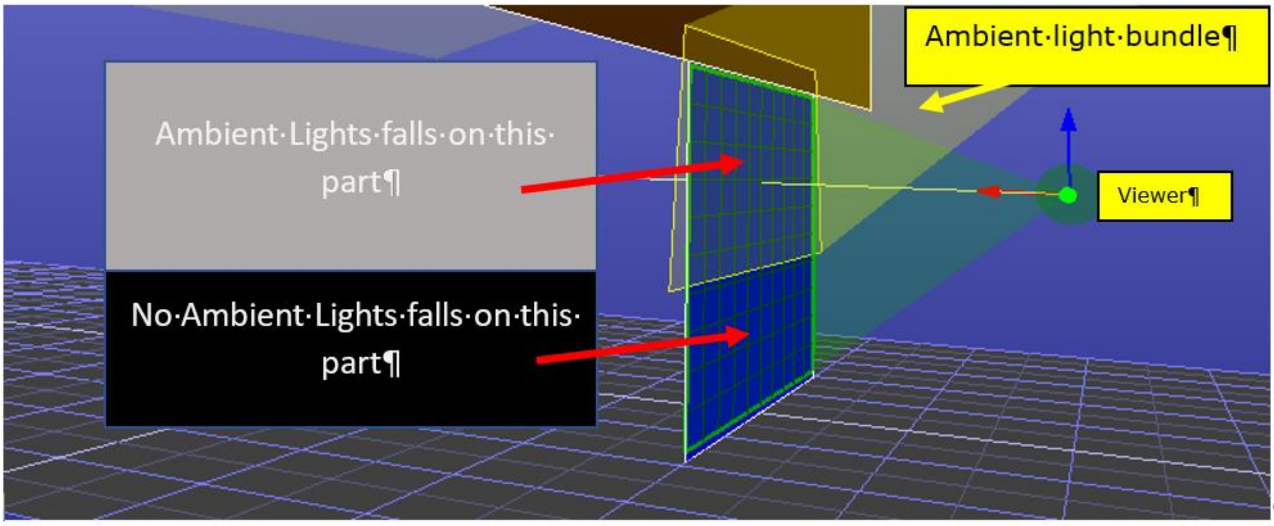


Figure 15

The viewers eyes are at 1.65m high and at 2m perpendicular to the screen center.
If we now do simulations with different screen types, the bottom half of the screen will be perfectly black as no ambient light is hitting it. But the top half will show the effect of the ambient light, both the effect of the specular and the diffusive reflection.
We do the simulations for 4 different screen types:

Screen type A: high diffusive reflection, high specular reflection
This is typically a white looking glossy screen

Screen type B: high diffusive reflection, low specular reflection
This is a white looking matte screen

Screen type C: low diffusive reflection, high specular reflection
This is a dark looking glossy screen

Screen type D: low diffusive reflection, low specular reflection
This is a dark looking matte screen

In the top half of the simulations, you will see the effect of both the diffusive reflection as the specular reflection.

The top half of the screen is brighter than the bottom half, due to the reflection of the ambient light. This is the effect of the *diffusive reflection* component. Screens A & B have a high diffusive reflection, resulting in a brighter top half than screens C & D which have a low diffusive reflection. The diffusive reflection is independent of the position of the user and will define the lowest black level possible in the final projected image.
In screens A & B, black levels which are lower than the reflected ambient light will not be visible. Screens C & D will be able to show the deepest black level. They are called High Contrast screens (HC)

Result of the simulations with the viewer at 2m distance to the screen

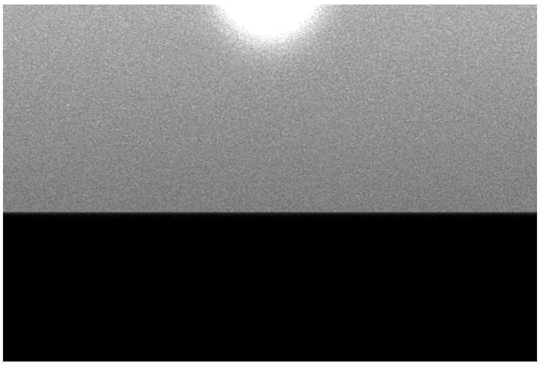


Figure 16: Screen Type A

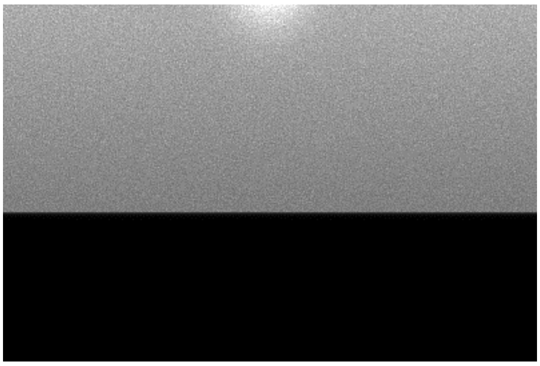


Figure 17: Screen Type B

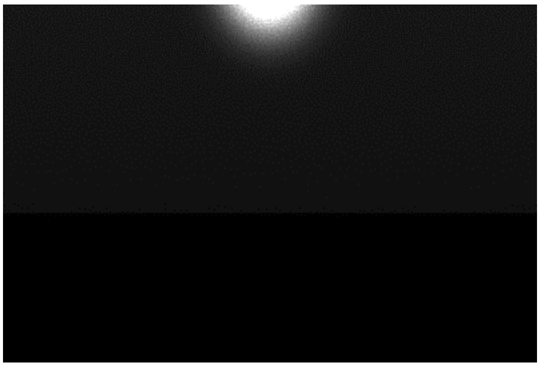


Figure 18: Screen Type C

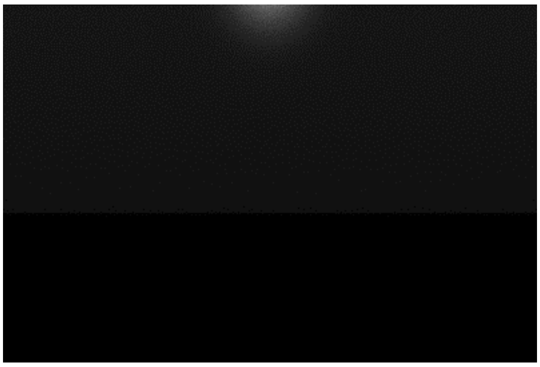


Figure 19: Screen Type D

The specular reflection is dependent on the user position: with the ambient light source as simulated, the specular reflection will not be visible for any user further away from the screen but will become more visible when going closer to the screen. See simulations in Figures 20 and 21 as an example.

Effect of user position on the specular reflection of **screen Type C**

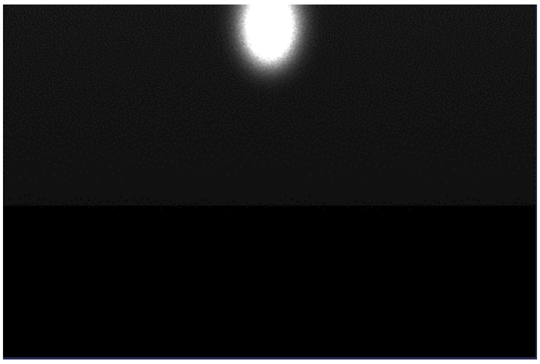


Figure 20 User at 1m to the screen

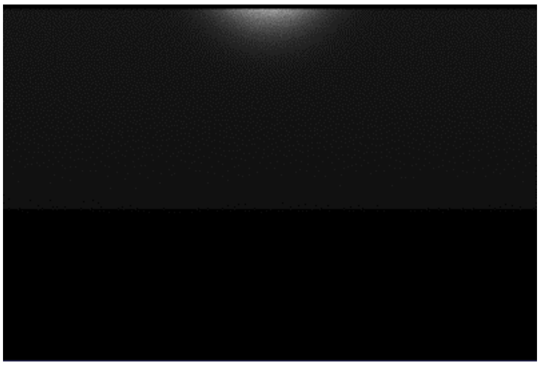


Figure 21 User at 3m to the screen

It is clear that a carefully designed ambient lighting is very important to guarantee the best image quality. However, even the projected light will reflect back on people and objects in the room and thus limit the contrast in case the screen has a high diffusive reflection.

The ambient contrast of a system can be predicted using the **Reflectivity curve** of the screen.

'Reflectivity (%) is defined as the ratio of Luminance reflected from the screen to the Ambient Illuminance falling on the screen.'

Barco screens have the diffusive reflection close to a lambertian spread i.e. the reflectivity remains relatively equal for all angles away from the specular peak. To give a fair idea of *Screen Reflectivity*, we use the reflectivity value of a screen at 45° to the incident ambient light source.

$$Reflectivity\ \% = \frac{Reflected\ Luminance\ (cd/m^2)}{Incident\ Illuminance\ (lm/m^2)}$$

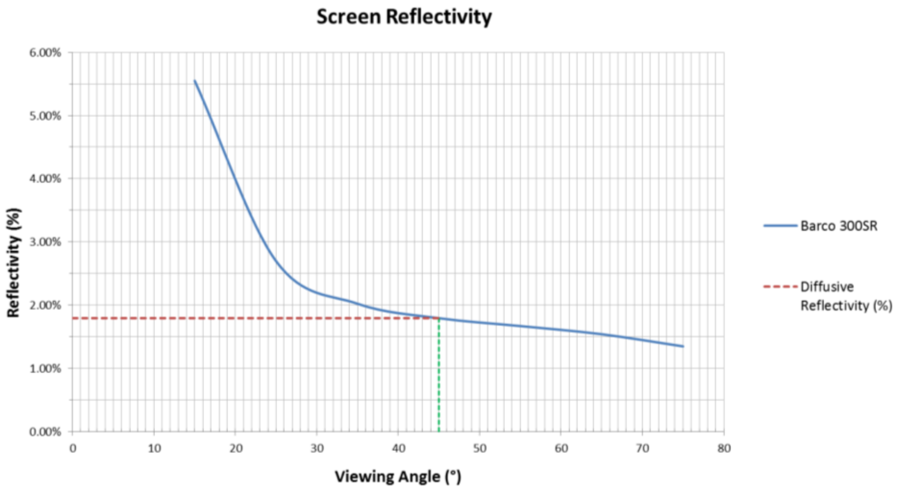


Figure 22: Typical Reflectivity curve of a high contrast Barco screen.

The Barco Screen reflectivity spec gives information on the diffusive reflection of a screen. It is expressed as a percentage. A screen with a reflectivity of 10% will reflect 10 nit (cd/m²) when "hit" by ambient light with an illuminance of 100 lux.

A screen with a reflectivity of 5% will reflect 5 nit when hit by 100 lux ambient light.

This diffusive reflection can be lower or higher for a specific screen. The lower, the more ambient light will be absorbed and the better the contrast will be. Barco has in its screen portfolio screens with a reflectivity lower than 2%.

As a reference: a Lambertian front projected white screen will reflect 31,8%(*), so 31,8 cd/m² when the same illuminance of 100 lux. So, this is the reason why the cinema theatres need to avoid all ambient light, as it would kill the black details in the movies. An easy way to check if a system with a rear projection screen will have a good ambient contrast is to judge the color of the screen in normal ambient conditions, without a projected image. If the screen looks quite white, the ambient contrast will be low. If the screen looks greyish to black, the ambient contrast will be higher.

(*): we suppose a white screen with a Lambertian gain of 1.0, hence the reflectivity is Lambertian gain divided by π(Pi)

Definition of ‘**Simulated Ambient Contrast** (Triple 100 rule):

As the ambient contrast behavior of a screen is dependent on the screen parameters, on the projector and on the amount of ambient light once installed, it is not always easy to define a specification that helps the user to compare.

Therefore, Barco defined the **"simulated ambient contrast"** as the system contrast for a screen with known reflectivity, with a ***Luminance value of 100 Nit*** (cd/m²), with a projector that has at least ***100:1 ANSI contrast*** ratio and with ***100 Lux ambient light*** falling on the screen surface. This parameter is quite useful to get an idea of contrast levels that can be obtained with a screen and to compare different screens.

Remarks: sometimes the term reflective gain is used by some manufacturers. To make a correct comparison, one needs to divide this reflective gain spec by a factor π (Pi =3.14) to compare with the Barco ‘Reflectivity' value.

For the white front projection Lambertian screen, the reflective gain is 1.0, so the reflectivity is 1.0 divided by π. This gives us 0,318 or 31,8% reflectivity

- # Local contrast

Local contrast is a parameter that quantifies the ability of the rear projection screen to display bright details on dark backgrounds or vice versa.

Unlike ambient contrast, this is not affected by the reflectivity of the screen. Local contrast is mostly depending on the composition of the screen substrate (material) and the optical (diffusive) layer that is applied to the screen. Even when no ambient light is present, local contrast can still be bad if the screen is not properly designed. It is perceived/seen as a "halo" around bright objects, or as fewer dark details on bright background (excel sheets are typical example).

To our knowledge, only Barco is specifying local contrast.

Pictures 23 to 27 show some examples of how this halo can ruin the contrast of the system.

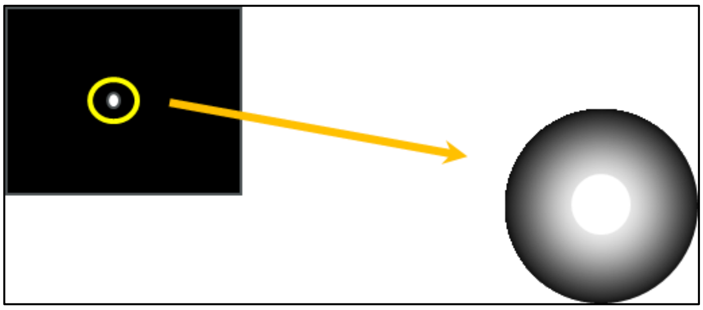


Figure 23: A typical example of the 'halo' with a white dot in the dark black background.

Figure 24 and 25 are real pictures, showing the result of low and high local contrast on a white grid testpattern on a black background. The halo is clearly visible on the screen with low local contrast.

Figure 24: poor local contrast

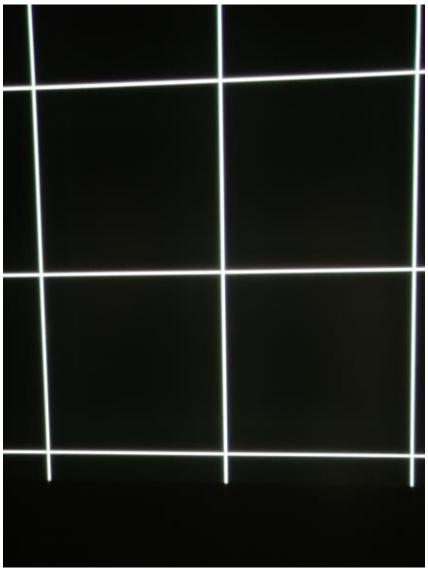


Figure 25: good local contrast

Figure 26 and 27 are real pictures, showing the result of low and high local contrast on a typical design detail in an automotive application (car headlights)

Due to the halo-effect, the headlight does not look like in real life and this will disturb the design engineers.

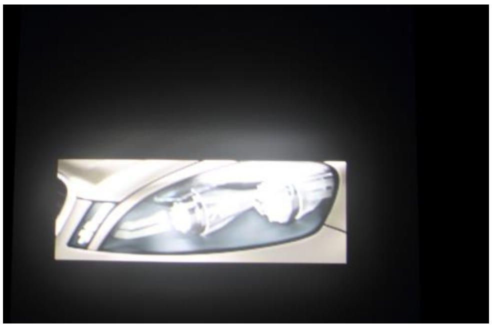


Figure 26: poor local contrast

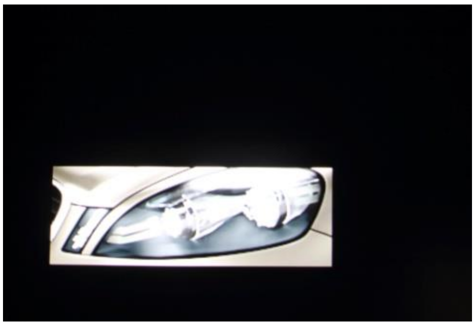


Figure 27: high local contrast

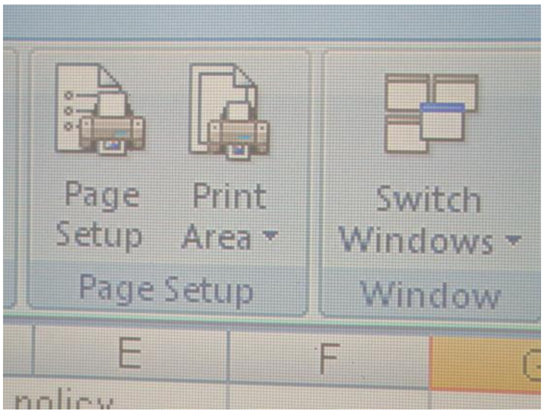


Figure 28

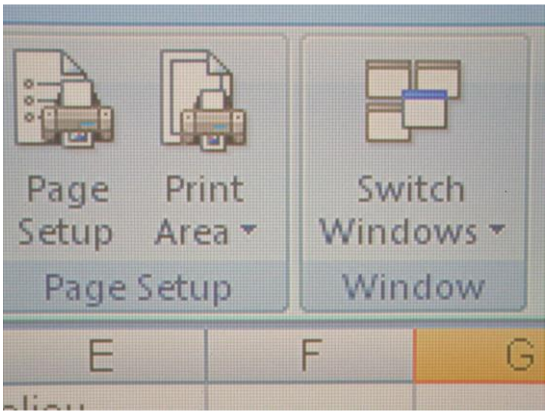


Figure 29

Figure 28 and 29 are real pictures of an excel detail. Due to the halo-effect, the fine black details in the text and icons on the excel are affected.

In Barco's screen portfolio, through the material composition, the Semi-Rigid, Glass screens and Rigiflex are designed to provide best in class local contrast values.

To our best knowledge, no screen manufacturer apart from Barco is currently quantifying the local contrast. Descriptions of this halo-effect or blooming effect are given, but no figures to enable objective comparison between different screens.

Measurement Method for Local Contrast

A very small checkerboard pattern (185mm X 94mm) is projected onto the screen sample. Because the checkerboard pattern is so small, the white boxes pollute the black levels of the black boxes. This pollution of black level, as discussed, is due to the halo. If the checkerboard boxes are made much bigger, as it is done for ANSI contrast measurement, then this effect disappears. Hence, the ANSI contrast value is not a reliable indicator of the true black levels for high resolution images.

Luminance values are measured in the center black box (B1) and the 4 surrounding white boxes (W1 to W4). Figures 30 and 31 show the measurement setup and the testpattern. A simulation of the pollution of black levels due to surrounding white content is shown in the image.

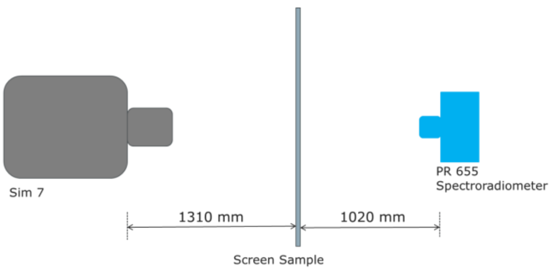


Figure 30

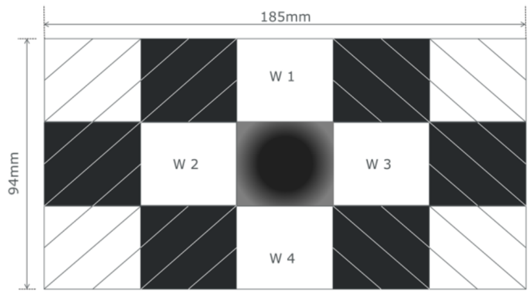


Figure 31

From the measurements, the local contrast is calculated as the ratio between the average of the 4 surrounding white boxes (W1 to W4) and the centre black box. (B1)

$$Local\ Contrast = \frac{Avg.Luminance_{White}}{Luminance_{Black}} = \frac{(\sum W)/4}{B1}$$

Sharpness

The main 2 drivers for new developments in projectors are increased brightness and increased resolution. Resolution is the number of pixels which are finally displayed on the projection screen. A 4K image contains of 4096x2160 pixels. With multi-projector setups, any resolution can be displayed on a projection screen. Together with the screen size, the resolution will define the pixelsize on the screen.
On a screen with a size of 4096mm x 2160mm, the 4K image will have pixels of 1mm. On bigger screens, the same resolution ends up with bigger pixels, on smaller screens with smaller pixels.

Whereas projectors provided luminous flux values in a range up to 10k lumen a decade ago, current developments provide values of 30 to 50k lumen. Some even go to 60k lumen and beyond.

These increased brightness's allow for bigger projected surfaces with a single projector, but also drive the need to increase the provided resolution.
Increased pixelsizes of a bright HD projector on a big projection surface, would make the individual pixels visible and have negative influence on the user experience.

A continuous offer in higher resolution projectors was the logic result of this. From UXGA, over WUXGA to different 4k formats (UHD, True 4k). Recently, discussions have started about 8k resolution.

But what about the behavior of a rear projected screen towards this increased resolution? How are you sure that the bright expensive high-resolution projector will still provide a sharp image on a rear projected screen? Can we provide a specification that corresponds with the ***sharpness experience*** on a rear projection screen, rather than just mentioning the projector resolution?

Screen manufacturers hardly provide any info on the capability of their screens towards the ability to display high resolution content. Other info than "4k capable" is hard to find. The reason for this is that it is far from obvious to provide any specification on the capability of a screen to show high resolution content without downgrading the original capabilities of the projector.

At Barco, we did an attempt by means of local contrast measurements of high-frequency content on the screen samples.
This contrast measurement procedure is part of the Modulation Transfer Function (MTF) measurement procedure, which is well-known as a quality verification method for optical systems, hence also for projector lenses.

In MTF measurement, a sinewave with increasing frequency is used as input signal.
When the output signal has the identical amplitude as the input signal, the MTF is 1 or 100%.
With increasing frequency of the input signal, the amplitude of the output signal of any optical system wills start to decrease. An MTF of 0.5 or 50% means that the amplitude at the output is only half of the amplitude at the input. An MTF of 0 or 0% means that the output signal does no longer show any amplitude variation.

In a practical setup to measure MTF of a screen, we use a projector with a very good lens. Input signal to the projector is a pixel ON/OFF signal that can be increased in resolution.
We always use only the center of the lens for the projected image, so that we assure that the lens does not become the limiting factor in the measurement. (all lenses have tendency to be less sharp in the corners, hence having lower MTF values to start with)

Instead of the sinewave, used in MTF measurements, a specific testpattern is used as input. This testpattern has different pixel ON/OFF parts oriented in vertical and horizontal directions. In the example, we are using a white testpattern. Green only is also possible, if one wants to exclude the effect of convergence errors between the primary colors (like 3-chip projectors can have).

To compare different screen samples with different peak gains (see chapter 2) in a correct way, neutral density filters in front of the lens are used to match the brightness level as good as possible.

Pictures 33 and 34 are examples of the result of this testpattern on 2 different screen samples.
The right screen sample in Figure 34 shows a lower "sharpness" than the left one in Figure 33 when you look carefully.

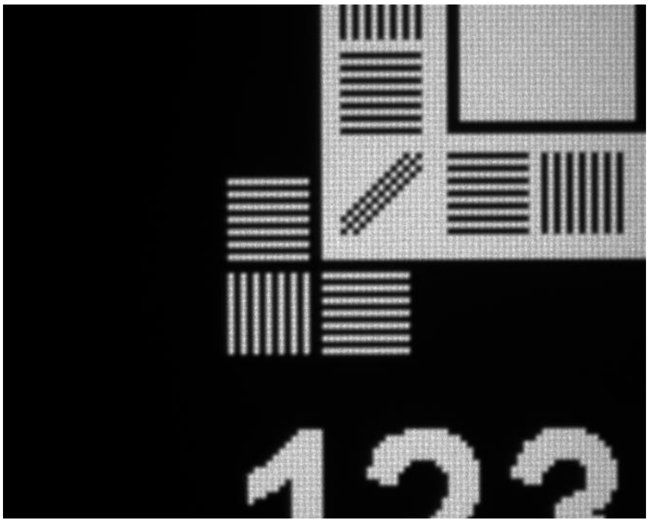


Figure 32

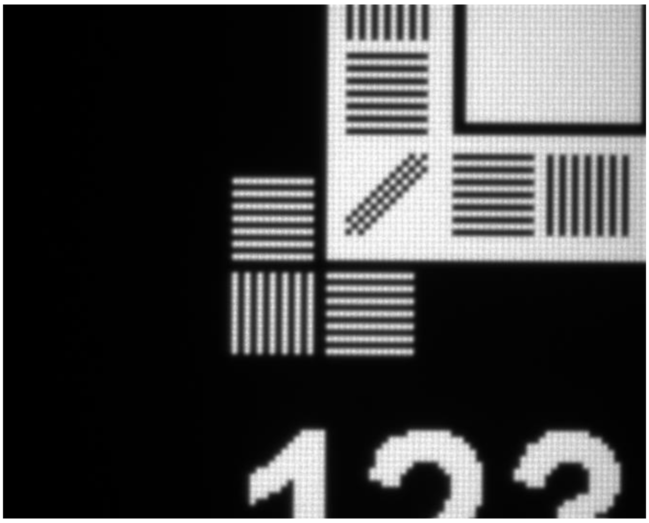


Figure 33

This sharpness difference is related to the decreased amplitude of the "output" signal, as does happen in MTF measurements. But the challenge is now, how to translate this small visual difference into a specification

This is done by performing a contrast measurement on the pixel ON/OFF areas of the testpattern, following next procedure. This contrast measurement corresponds with the amplitude measurement like described in MTF.

Image analysis is done by measuring the intensity profile by means of a camera and suited SW

An example is given in figure 35: with the image analysis SW, information is gathered on the intensity of the white and black lines. In the example, this is done along the horizontal yellow line, to determine the contrast of the screen sample in horizontal direction.

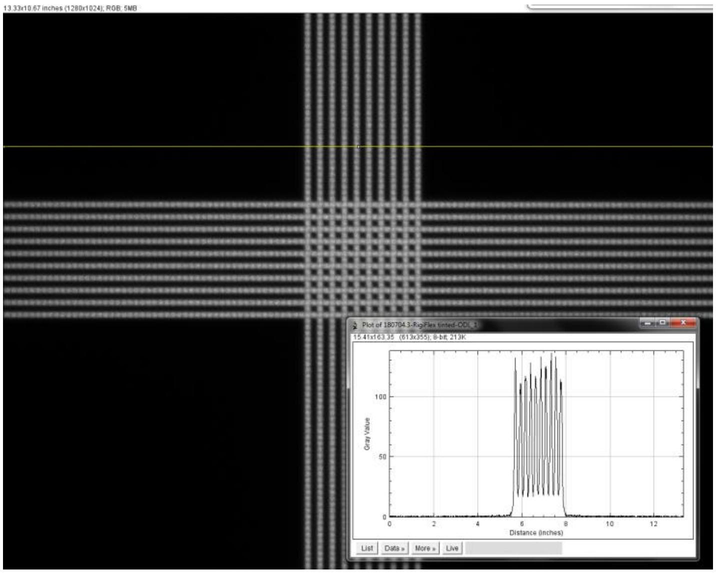


Figure 34

Figure 36 shows the measuring area more in detail.

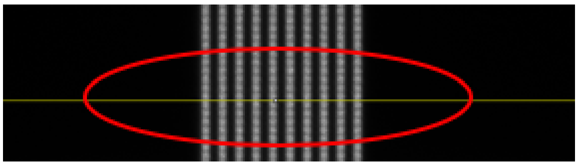


Figure 35

Figure 37 shows details on the analysis result:

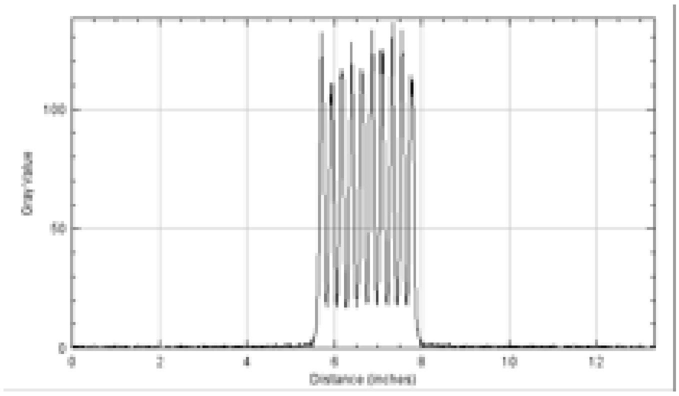


Figure 36

For a given projected resolution, sometimes also expressed in OLP/cm, the contrast or MTF can be calculated by following formula:

$$Contrast = (Max_{Avr} - Min_{Avr}) / (Max_{Avr} + Min_{Avr})$$

Average of the different peaks and bottoms in used, to have a more correct final value.

With this procedure, different screensamples can be compared on their ability to display high resolution details for a give pixelsize on the screen, or 1 sample can be measured on its ability to display higher resolutions with decreasing pixelsize.

Important note: Barco's complete screen portfolio is designed and validated to enable high resolution projection. It is clear that also the ***local contrast*** value is very important to enable good contrast in high resolution details.

MTF/contrast values on a specific screen type are only provided on special request.

Color

"Colors should be reproduced correctly everywhere on the screen, and they should not change when viewed at different angles or under different ambient conditions."

The importance of a good color reproduction on a rear projection screen cannot be underestimated! Again like with the other screen parameters, the screen can have a big impact on the color experience.

Remark: to fully understand the following chapter, some knowledge on color science is mandatory. Just google on CIE (Commission internationale de l'Eclairage) and you will find a wealth of information on color science.

As visualized in the chart in Figure 3, three different rear screen parameters are important for color reproduction: Screen color neutrality, Color uniformity and Color Gamut.

• Screen Color Neutrality

In first instance, the screen should maintain the projected colors, meaning that the color temperature of full white shall only minimally be affected by the screen. It is not the intention that the screen by itself has a colored tint (yellowish, brownish …), but it should remain neutral in color.

'Screen Color Neutrality' can be quantified by comparing the screen color points in the CIE Lu'v' space with a white diffuse reflectance standard. These values are depicted by Δu' and Δv' and referred as 'White-point Color Delta'.

• Color Uniformity

When viewing the screen from different positions, thus under different angles, the color reproduction should be maintained as well as possible. As visible light is composed of a broad spectrum of wavelengths, a different color might be perceived especially when the user is watching the screen under different (big) angles. This phenomenon is known in our industry as ***color shift*** .

The rootcause for this phenomenon is the size of the screen scattering particles with respect to the wavelength of the different colors.

To investigate this issue, the transmissive gain curve for the 3 primaries red (R), green (G) and blue (B) needs to be measured.

Ideally, the transmission characteristics for R,G,B are identical when measured over different angles.

In reality, 2 deviations from this ideal behaviour can occur:

- The gain of the 3 primaries at 0° angle (perpendicular) is not identical. There is a difference in gain in the screen for R,G and B. Although this might change the initial whitepoint from the projector, this is in general not a big issue as the whitepoint can be corrected with projector settings

- The difference in gain, measured at 0°, changes when measured under bigger angles.

Figure 38 shows an example of two screens, with transmissive gain curves measured for each primary color separately.

Screen 1 has a large gain difference between the RGB colors at 0°.
This difference gets smaller when the screensample is measured under angles.
So this screen will introduce a color shift when viewed under angle. It will show less red and more blue than when viewed under 0°.

Screen 2 has very little difference in gain for RGB at 0°. Furthermore, this difference remains very small when measured under bigger angles. This screen will have no color shift at all.

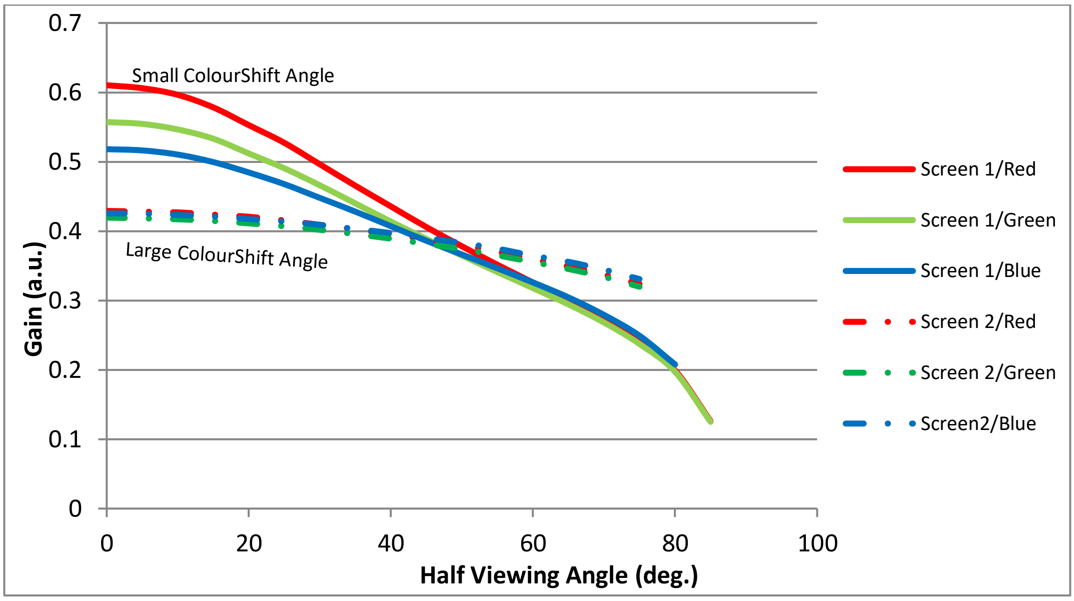


Figure 37

To compare the color shift behaviour between screens and define a specification for it, different approaches are possible, based on color distance measurements in a specific color space.

For instance, ΔE* in the CIELAB color space can be used, combined with the JND (Just-Noticeable Difference) spec.

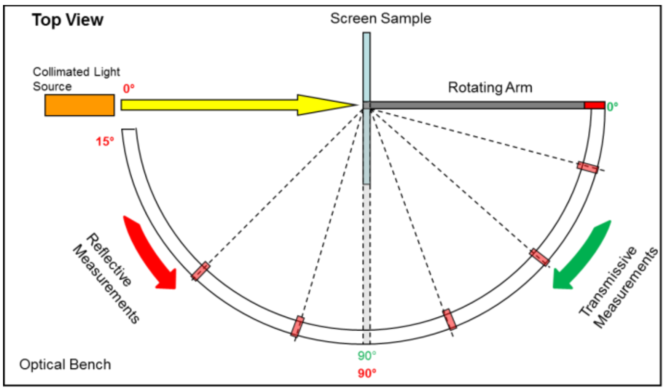
Barco simplified this calculation method, as our only purpose is to compare the behavior of the whitepoint of a screen when seen under different angles.

Barco introduces the **'Color Critical Angle' (CCA)**. This is the viewing angle at which a certain screen will start to show a noticeable color shift in white

To define this CCA, a specific screen sample is put in the measurement bench. Full white is displayed and x,y color coordinates are measured under different angles, starting with the on-axis measurement at 0°.
This measurement gives the initial color coordinates x,y of the whitepoint and is used as reference point.

Via color coordinate conversions, u'v' color coordinates are calculated and the differences Δu'v' between each measurement and the reference is calculated. The angle at which this Δu'v' exceeds 0.0042, is the Color Critical Angle of that screen sample.

The value of Δu'v' =0.0042 is based on a maximum difference of 0.003 for both u' and v' at the same time
This maximum is experimentally defined in Barco, during the development of a color auto-alignment system for projectors.



u'v' are measured on white at 0°
This is the reference value

u'v' are measured on white at different angles

Figure 38: concept of the measurement bench

Figure 40 is an example of such a measurement: Screen 1 has a CCA of about 50°, whereas Screen 2 has a CCA of more than 80°.

Based on our long-time expertise, a CCA of more than 40° is acceptable for most applications.

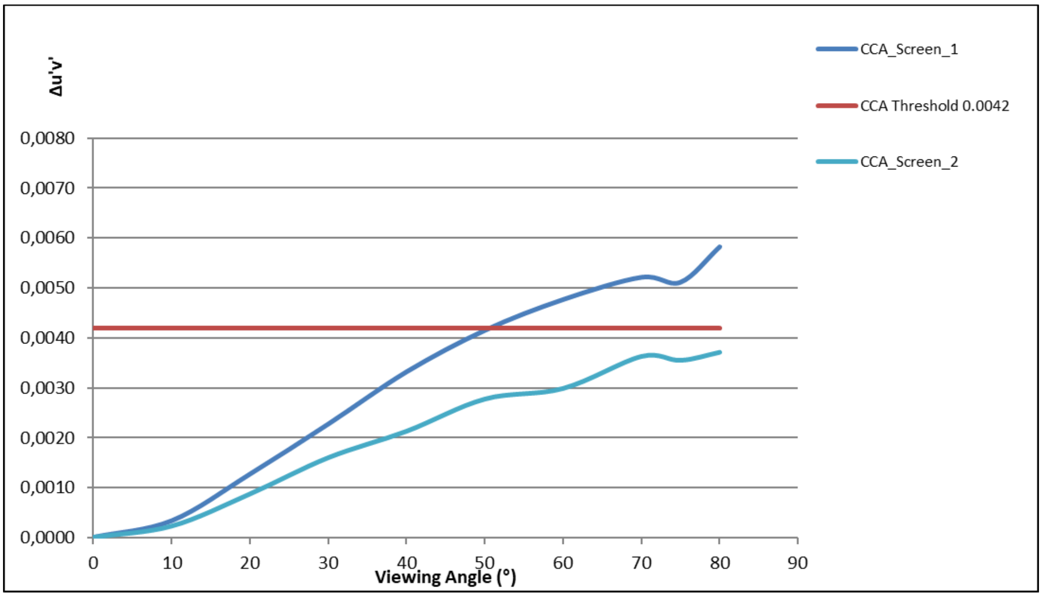


Figure 39

- ## Color Gamut

Together with the brightness & resolution increases in new projectors, a bigger color gamut is also part of the game to better performance of projectors.
With the full laser projectors, extensive color gamut of REC2020 is possible now.

Figure 41 shows the difference between the REC 709 and RED 2020 color gamut

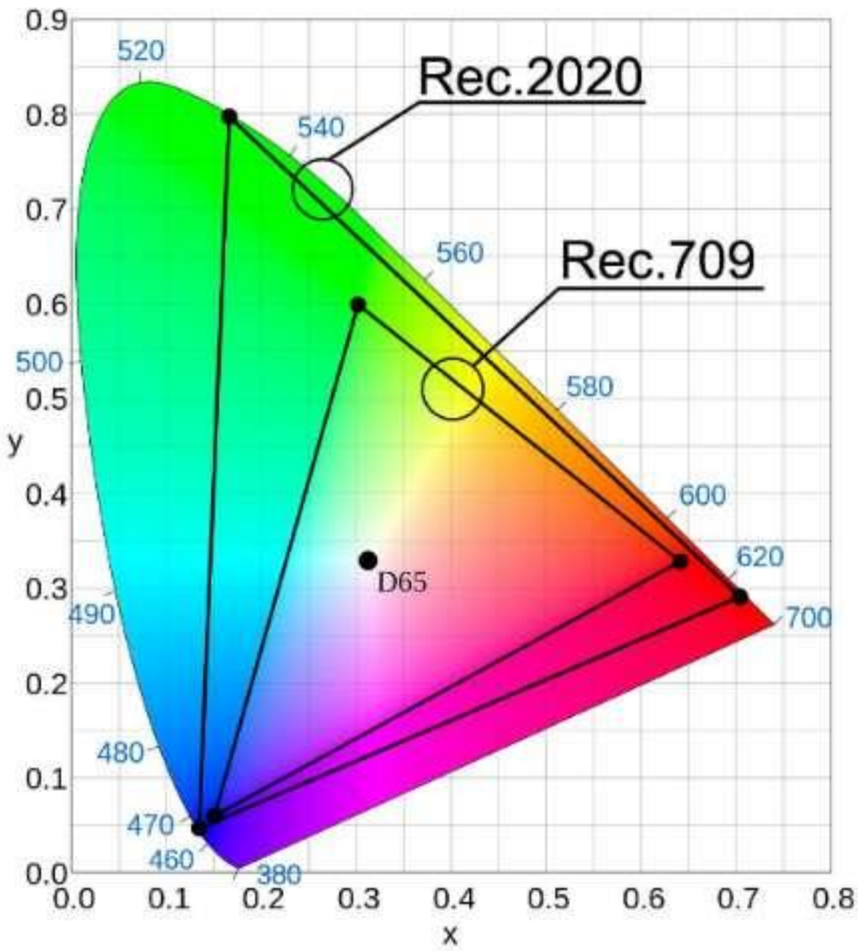


Figure 40

But here again, the correct screen choice will be crucial in how the projected colors will finally be perceived!

The reflectivity of the screen plays an important role in the final color experience.

If the screen has a high diffusive reflection, a considerable amount of ambient light will reflect back to the user (see chapter on Contrast). But as this ambient light is in general white light, the color saturation of all colors will be reduced too. In other words, even if the projector is capable of showing all the colors as defined in REC 709 or REC 2020, the final color gamut will be far smaller in case of high reflective screens.

THe best example of this is a front-projection white screen, in full ambient light in a meeting room: all colors projected will look pale instead of saturated, because the reflected ambient white light will be dominant.
If the screen has also a bigger specular reflection component, the effect on the colors will even be worse when the user looks into the specular reflection (see chapter on Contrast)

As explained, the reflectivity of the screen is key to maintain the full color gamut, hence fully saturated colors. In full darkness, so no ambient light at all, all screens will show saturated colors. But with some (white) ambient light, the colors will "de-saturate" and the full color gamut, of which the projector is capable of, will no longer be reached.

The final result is very much dependent on the amount of light falling onto the screen and the reflectivity of the screen. So, the screen reflectivity, both specular and diffuse, is the key spec that will define the final gamut under ambient lighting. An ideal screen with no reflection at all, will maintain the full gamut under any ambient lighting. But this type of screen does not exist. It should be a perfect matte black screen which absorbs all ambient light. Even this would be theoretically possible, this kind of rear projection screen would also absorb all light coming from the projector, which defeats its purpose.

So, in conclusion, the screen spec to link to color gamut reproduction is reflectivity.

How to quantify the described desaturation because of reflectivity?

One could think of a screen spec called 'color gamut reduction', and measure the R,G,B primaries with no ambient light and with an ambient light of 100 lux on the sample.
As the color gamut is a triangle, the ratio between the full gamut with no ambient light and the reduced gamut with ambient light, could give a good estimate on the behavior of the screen towards color reproduction in ambient light.

As an example, we measured 2 screen samples. One has low reflectivity, one has higher reflectivity. The results are in Figure 42

The projector used to measure the samples was capable of providing the REC709 gamut.

Without any ambient light on the samples, this results in a 100% coverage of the Rec709 gamut.

However, with as low as 25 lux onto the samples, the low reflective sample has already a reduction to 83% of the REC709 gamut, whereas the high reflective sample is only capable of displaying less than half of the original REC709!!!!

calculated	x_R	y_R	Y_R	x_G	y_G	Y_G	x_B	y_B	Y_B			gamut denominator
measured	Rec709									gamut REC709	gamut REC2020	
fixed data	0,64	0,33		0,3	0,6		0,15	0,06		100%	53%	0,2241
	Rec2020											
	0,708	0,292		0,17	0,797		0,131	0,046		189%	100%	0,4237
	x_R	y_R	Y_R	x_G	y_G	Y_G	x_B	y_B	Y_B	**gamut REC709**	**gamut REC2020**	
Low reflective sample	0,6250	0,3653		0,2966	0,6466		0,1552	0,0805		101%	53%	
Low reflective sample + ambient	0,5968	0,3656		0,3029	0,6298		0,1778	0,1097		83%	44%	
High reflective sample	0,6278	0,3634		0,2983	0,6487		0,1511	0,0793		102%	54%	
High reflective sample + ambient	0,5420	0,3707		0,3179	0,5849		0,2326	0,1883		48%	25%	

Figure 41

Potentially there are better ways to estimate the loss of saturation under ambient light, that are more tuned to perceptual quantities, then just the gamut expressed in xy coordinates. More research is needed on this.

Currently Barco does not use yet this ‘Color gamut reduction’ spec, but this might come in the future.

Other screen specifications

• Esthetical Screen specs

Flatness:

The flatness of the screen is mainly related to the flatness of the chosen substrate. Only the best quality substrates are used for Barco Screens.
Apart from the esthetical aspect (people do now want screens that bow), excellent flatness is important in case that the application requires perfect geometry in the displayed content. For instance, if interior car designers want to validate a new cockpit design, it is very important that the geometry of all objects is perfect. Any bow in the screen would give some image deformation, leading to wrong decision making.

The flatness is given as a % of deviation of a perfect flat surface, related to the smallest screen size (in general the screen height).

The glass (GL) used for Barco screens is of the highest quality and provides the best flatness of all 3 substrates: ±0,1%.

Rigid acryl (RA) used for Barco screens, is specially manufactured to achieve the best possible flatness among acrylic sheets: ±0,3%[1].

Semi-rigid (SR) substrate combined with Barco’s special mounting method, has the flatness: ±0,5%[2].

Our unique Rigiflex screens, if installed with the appropriate tensioning, have also a nearly perfect flatness, close the flatness of glass. The only difference is that when you push onto the screen, it will slightly bend inwards. But without any touch, it behaves almost identically to a rigid screen with perfect flatness.

Imperfections in the substrate and/or the coating:

Barco strives to meet its high quality standards each and every time, but sometimes due to the limitation of the manufacturing process itself some imperfections can't be avoided. There can be small bubbles, dust particles, debris and/or scratches in the screens. Some local brightness variation may also be present, especially on the high contrast screens. These local brightness variations are called mottle or cloudiness in the screen industry. Although visible for a trained eye with full color testpatterns, these local variations should have no impact on any normal application with detailed content.

However, these imperfections, if present, never deteriorate the system performance. For more information, please refer the production specification sheet.

- ## Screen lifetime

"A screen might display a perfect image at first, but it should also maintain this quality over time"

With respect to screen lifetime, 3 critical points need to be taken care of:

Aging over time due to UV-light

Although there is hardly any UV-light coming out of most projectors, often a screen is in a room where some sunlight is entering. And even if window glass filters out the higher energy UV-light quite well, some UV-A will always hit the screen. Depending on the strength and the duration of the UV exposure the screen can show a discoloration over time. 'Yellowing' of the screens is a typical phenomenon.

Barco screens have been tested and qualified in a solar radiation test. Even after extensive testing under full solar spectrum with no window glass, Barco screens showed no changes.

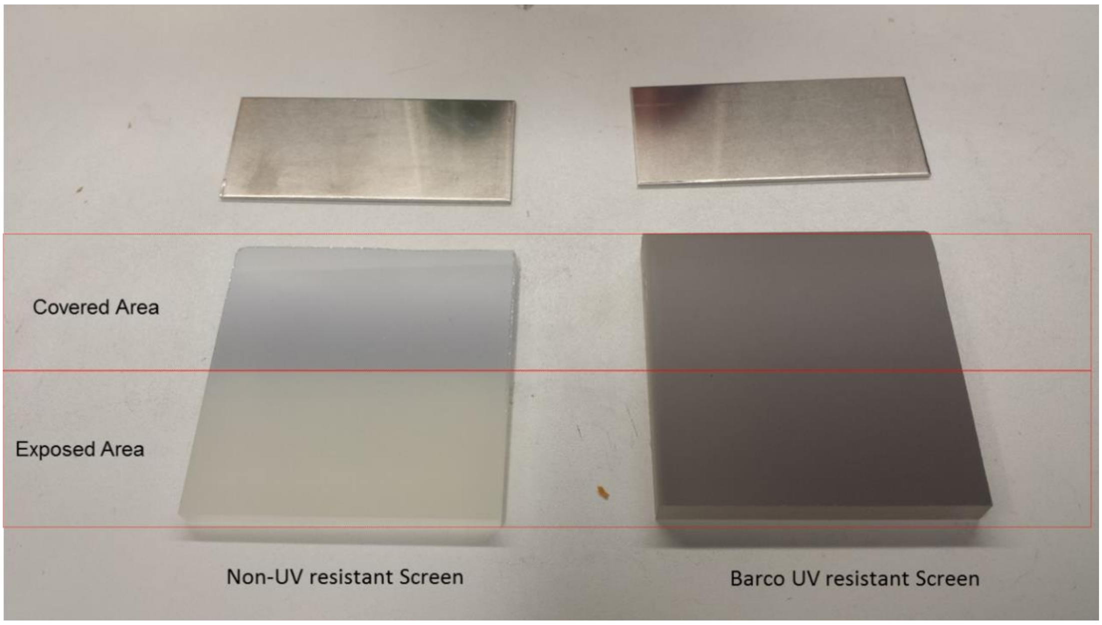


Figure 42: Results of the Solar Radiation testing of two screen samples. The sample screen on the left side shows important discoloration of the exposed area while the Barco sample on the right is developed to be extra robust to UV exposure

Humidity and Temperature

These are the other two key parameters that can have an effect on the screen lifetime. Please refer to the specification sheet for storage and usage 'Humidity and Temperature conditions'. It is important that the screen environment remains within these specifications to guarantee the best screen performance. If not, then it is possible that some artefacts such as white spots start appearing on the screen surface.

Stickyness

Some rear projection screens make use of plasticizers in the production process. After some years, those plasticizers might migrate to the surface of the screen and feel als very sticky when touched.

Barco's proprietary coating process does not use these plasticizers at all

- ## Touch resistance

Currently the screens are not meant to be used in touch applications. If the user touches the screen by mistake, then the screen should be cleaned immediately with lens tissue and de-ionized water. For detailed cleaning instructions please refer to the manual.
Also, the screen can be damaged by improper handling resulting in scratches. The hardness of the diffusive surface is the key in this case. Barco screens have a well-defined hardness spec.

Barco developed a so-called Touch coating, which can be applied on all screen types as an option. This Touch-coating serves two purposes, one is to make the screen surface less vulnerable for people touching the surface with their hands and fingers, second is that it also makes the surface rougher, so that the specular reflection (see chapter on Contrast) is reduced a lot

Note: In theory, the non-coated side of the screen can be pointed towards the user to avoid damage by touching or taping on the screen. However, as this causes specular reflection it's not a common practice.

Even when special anti-reflective or antiglare coatings are applied, some specular reflection will always be there, especially on dark content in ambient light conditions. The screen substrate acts as an unwanted mirror, reflecting the objects and people in the room. Moreover, such coatings might lead to some other undesirable effects such as loss of resolution or sharpness.

Conclusion

In many high-end applications, rear projection systems are still state-of-the-art display solutions.

Apart from the projector choice, the correct screen choice is very important to assure the best possible final image quality.

This whitepaper is an attempt to translate image quality into a set of screen specifications. It should be clear for the reader that as long as the one and only perfect screen does not exist, this is a world of trade-offs, where sometimes conflicting parameters need to be balanced again each other.

While most screen manufacturers only focus on brightness and sacrifice other primary parameters such as system contrast, Barco has chosen not to focus only on the brightness parameters of screens but also to emphasize on 'Contrast, Sharpness and Color reproduction

As this white paper shows, Barco screens have been designed to achieve the right balance between all different screen parameters, allowing to combine the best screen type with the best projector(s).

As such Barco screens are a crucial component in a high quality projection system where brightness, contrast, image sharpness and accurate reproduction of colors distinguish an excellent display system from an average display system.