

Barco

Optical efficiency in Digital Cinema projectors

**How to maximize the amount of
light your projector shines onto
the screen**

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INTRODUCTION

In this white paper, we discuss all the things that impact how much light shines onto the cinema screen ... after it leaves the lamp. We take a close look at the components that influence key parameters such as image quality, total cost of ownership, and serviceability.

Our goal is to illuminate the impact of product design, craftsmanship and manufacturing on projector performance. We want to provide you with an inside view on what's 'under the hood' of your projector and how it really affects performance.

We hope that, after reading this white paper, you will better understand how a digital cinema projector works and the elements that contribute to the stunning performance these state-of-the-art devices deliver.

THE LIFE OF RAY

Digital Cinema projection is all about maximizing the light that shines onto your screen. In this section, we discuss the various components that impact a ray of light as it leaves the lamp. We'll work sequentially, following your digital cinema projector's light path.

Here's an overview of the components involved:

1. Lamp with reflector
2. Cold mirror
3. Integrator rod
4. Aperture
5. Lenses
6. Folding mirror
7. Notch filter
8. Engine
9. Prime lens



Reflector

The reflector is an elliptical or parabolic structure that is placed around the lamp to capture as much light as possible from the lamp and send it into the projector's optical path. An important parameter is the smoothness of the reflector's surface: manufacturers of high-end devices use reflectors that are perfectly smooth, while others use processing techniques that introduce small imperfections. Compared to the others, the high-end reflectors can reflect as much as 15% more light.

It is also important to understand that a badly designed or manufactured reflector can undo all of the light concentration

that comes from using short-arc lamps. Moreover, a well-designed reflector adds to the projector's capacity to generate and dissipate heat.

Filters

After being captured and sent into the optical path by the reflector, the light is filtered. It first goes through a UV filter, and later through an IR filter. These filters remove the spectra of light that can damage a projector's interior – and so they have a huge impact on the projector's lifetime.

On the other hand, filtering out too much of your light's spectrum means that you will have to compensate later on, which reduces your overall optical efficiency. However, as these filters work far from the sweet spot of the spectrum of visible light, their impact on image quality is low. But their impact on projector lifetime is significant.

Optical engine

After the dangerous wavelengths have been filtered out, the light enters the projector's optical engine, which contains passive (light rod, relay lenses and prism) and active (chip) components. Coating materials are applied at the interfaces of these components to further improve performance.

- **Passive optical components**

The optical engine contains a light rod and relay lenses to transport and diffuse the light. The materials that compose these components have an impact on the projector's performance. Badly designed engines use materials that absorb too much of the short wavelength (blue) light. This causes them to turn yellow (the way you get a sunburn when you forget to put on your sun block) or even melt! Clearly, this has a major impact on image quality.

The materials also define the energetic capacity of your projector – that is, the amount of light you can send through. The material can break if it cannot transmit the high load that bright projectors generate. The brightest digital cinema projectors – like Barco's DP2K-32B – have been specifically designed to transmit the load that is created by projecting more than 32,000 lumens.

▪ Active optical components

Two technologies are used for the active chip in digital cinema: DLP™ (from Texas Instruments, which has about 90% market share) and LCoS (from Sony, which has about 10% market share). A digital cinema projector contains three of these chips, one for each color channel (red, green and blue). The active chip is by far the most important component of your digital cinema projector – it even impacts optical efficiency. Its compact size and accurate angular action make it the central component, defining the design of all other optical components.

For DLP™ technology, the overall optical efficiency of the chip is defined by a combination of:

- **The chip's size:** it is easier to 'aim' light on a bigger chip than on a smaller chip. This is one of the reasons why projectors using the 1.2" DLP Cinema® chip are 10% more efficient than those with the 0.98" DLP Cinema® chip. For the same reason, 4K projectors with a 1.38" DLP cinema® chip have a higher optical efficiency than those using the 1.2" DLP Cinema® chip.
- **The fill factor:** the fraction of the surface that is active and reflects the light.
- **The surface reflectivity:** the amount of light that is reflected from each mirror. This is defined by the maturity of the manufacturing process – and DLP™ technology brings this value close to the maximum achievable.
- **Diffraction:** when light strikes structures of a small size (such as DLP™ mirrors), a small portion of the light is always diffracted (reflected at non-perpendicular angles). As technology miniaturizes, it will become more important to manage this factor.

With LCoS projection technology, other parameters come into play, like the inefficiencies related to using polarized light. When all of these elements are combined, DLP™-based digital cinema projection yields higher efficiencies than LCoS-based projection.

One more important consideration: the chips must be kept free of dust to maximize their lifetime and to maintain high image quality over time. Therefore,

sealed engines – such as those patented by Barco – keep the chip surface clean and help prevent scattered light and spots on the screen.

- **Coatings**

Two types of surface coatings are typically used on the optical materials:

- **Anti-reflection (AR) coatings:** these coatings minimize the light being bounced off the optical materials and maximize the light injected into, and transmitted through, the engine. A well-designed engine uses these AR coatings wisely and can achieve a transmittance of more than 99% through the passive optical components. By blocking reflection, the amount of scattered light in the engine is reduced, which has a positive impact on the contrast ratio.
Be aware: any dust particles on the interface surfaces undo the benefits of using AR coatings. They also cause dark spots or zones on the screen. That's one of the reasons why Barco's sealed engine design is so important.
- **Color separation coatings:** these coatings are used in the heart of the light engine (the prism) to separate the incoming light into the red, green and blue channels that are sent to the three different chips. As their name indicates, the coatings must clearly separate the three parts of the color spectrum. Just like you need a sharp knife to make a clean cut, you need a sharp filter to separate the spectrum of light cleanly. Over the past few years, improved manufacturing techniques have significantly sharpened this filter 'cut-off'. High-end devices use filters with a sharp cut-off, leading to better color separation – which impacts both optical efficiency and image quality.

Color calibration

Amongst other things, the Digital Cinema Initiative (DCI) standard emphasizes the white point and color gamut of the image on the screen. These parameters do not perfectly match the output of an uncalibrated projector (one where you build in

the components, without tuning or tweaking them, and power up). Therefore, to achieve the color points set by the DCI specification, you have to compromise slightly on light output – and this reduces optical efficiency by 5-10%.

Projection lens

The projection lens is the last component the light ray travels through before leaving the projector. To achieve the high level of focus that we know in digital cinema (and from the distances typical in theater environments), this component must be designed to deliver the highest optical precision. Although we call it a lens, it is actually composed of multiple small lenses, each contributing to the overall performance. Like the other passive optical components described above, the quality of the projection lens also depends largely on the choice of materials and the careful coating of interfaces. State-of-the-art lenses yield an overall efficiency of about 85%.

Beyond the projector

Most exhibitors overlook the impact of parameters that influence the light after it has left the projector. These can range from dirty porthole windows to dirty screens (with low or high gain). Now that you realize the amount of design and precision that go into maximizing the performance of your projector, you can appreciate what a waste it is to allow dirty materials to spoil the intensity of your light.

PUTTING IT INTO NUMBERS

In order to quantify a projector's optical efficiency objectively, we measure the lumens per watt (lm/W): that is, the light output (in lumens) divided by the electrical power input (in watts). This metric allows us to compare optical efficiency across technologies and across brands.

A typical digital cinema lamp (only the lamp!) achieves 40-50 lm/W. A typical digital cinema projector (everything described above + lamp) achieves 4-5 lm/W. This means that all of the contributions we have discussed here yield, on average, an optical efficiency of 10%!

CONCLUSION

Many factors influence your projector's optical performance. In fact, designing a projector is as much art as it is science. It takes knowledge and experience in optics, electronics, mechanics and cooling techniques to design a world-class projector.

When selecting your projector, be sure to find out how the supplier has handled these factors. Choosing a brand that attends carefully to all of them will make your projector a high-quality, high-performance and safe choice for the future!