Barco | Whitepaper

Advancing color accuracy in cinema postproduction: results and implementation of industry study on metamerism

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Introduction

This white paper addresses the need for accurate color reproduction in cinema postproduction and proposes a metameric offset correction approach for laser illuminated projection. By aligning color perception between Xenon-lamp-based and RGB laser projectors, this solution aims to ensure consistent and faithful color reproduction on the screen.

One of the first digital revolutions in the domain of imaging happened when pixels came to replace film grain and analog images based on pigment sensitivity were replaced by discrete pixels in a grid. Though the image representation became digital, the illumination of the displayed images remained analog. A second revolution arrived when the illumination itself went through its digitization transition.

At home, LED lighting has largely replaced the incandescent bulb allowing for a vast choice of illumination (white temperature, colored lighting…) and they are now professionally widely used on movie sets. In flat panel television, backlight technology or pixel light emission technology (OLED, QDot) have also gone through digitization going from the use analogous linear light-sources to discrete ones based on the combination of multiple narrower spectrum sources. This transformation in illumination technologies is facilitated by the shift from the conventional mechanism of light generation through incandescence, characterized by the heating of a metal in a gaseous environment leading to the production of a broad yet non-uniform range of contiguous color wavelengths. In contrast, modern illumination is achieved through solid-state methods, wherein the generation of single-wavelength colors is orchestrated through quantum leaps within semiconductor materials. Consequently, the resultant spectrum is no longer analog but rather discrete, encompassing an assemblage of individual wavelengths. Notably, the precise count of wavelengths varies contingent on design considerations and application requisites, especially in contexts where the reduction of speckle necessitates a broader selection of wavelengths.

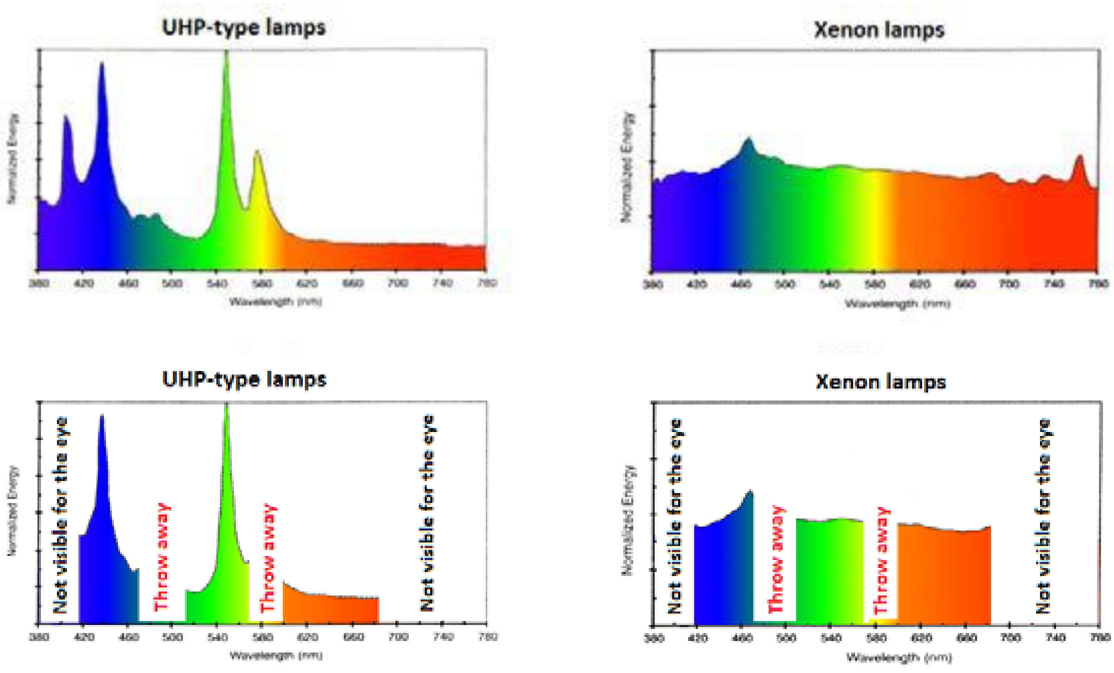

Fig.0 Top line: full colorspectrum ,Bottom line: color spectrum filtered for RGB representation

In Digital Cinema projectors this digitization of the light-source arrived with the introduction of laser-illuminated projection systems. While these projectors already employed a 3-color reproduction system, the light source was previously filtered lamp light with wide bandwidth. Laser-illuminated projectors, on the other hand, utilize lasers with narrow bandwidths for Red, Green, and Blue image production. Different technologies are used leading to hybrid solutions, for example the use of Blue direct lasers combined with light generated by a yellow phosphor surface "pumped" by another laser source, creating contiguous Green and Red light.

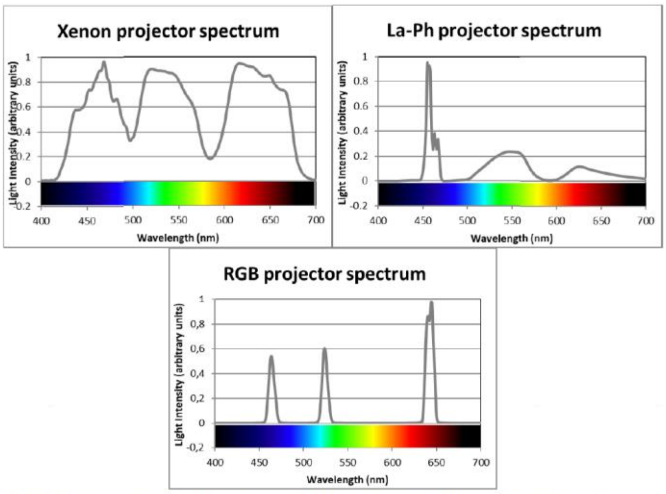

Fig. 1 Top Left – a spectrum of a xenon-based projector. Top Right – Laser-phosphor spectrum. Bottom: RGB projector spectrum

The use of narrow bandwidth illumination sources has raised concerns about color perception variations. To address this, manufacturers of grade-1 reference monitors have introduced calibration methods biased to compensate for these variations[1].

This white paper by Barco aims to ensure color accuracy in the visually critical image industry. By addressing the impact of narrow bandwidth illumination on color perception, Barco provides solutions that uphold the highest standards of color fidelity and consistency in professional workflows.

[1] https://pro.sony/s3/2021/01/22153606/ColourMatching_Between_OLED_and_CRT_E.pdf

Understanding metameric variability

In 2018 Barco issued a White Paper[2] describing the phenomenon of Metameric variability, caused by variations in spectral power distributions and differences in individual color perception, that can lead to perceptual color disparities between projector technologies. This poses challenges for color accuracy in cinema postproduction.

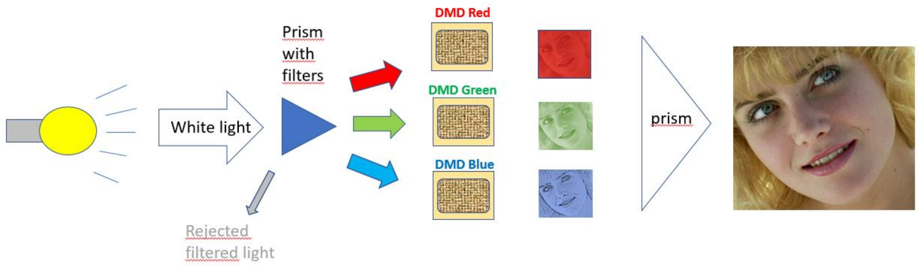

Fig.2 Lamp-based Digital Cinema imaging

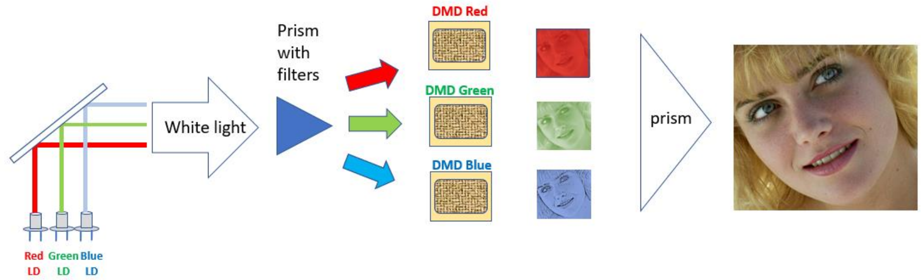

Fig.3 Laser-based Digital Cinema imaging

Observer Metameric Variability is a significant factor contributing to the transition between Xenon-lamp-based projectors and RGB laser projectors in cinema postproduction. The root cause is two-fold: spectral variations and individual differences in color perception.

Spectral variations refer to the differences in the spectral power distribution of light emitted by different light sources. Xenon lamps and laser diodes have distinct spectral characteristics, resulting in variations in the colors they produce. As a result, the same color displayed on a Xenon-lamp-based projector may appear slightly different when projected using an RGB laser projector.

Additionally, individual people perceive colors differently due to variations in their visual systems, including the number and distribution of cones in their eyes. These variations in color perception can lead to discrepancies in how individuals perceive and interpret colors displayed by different projectors.

[2] "Achieving a perceptual match between lamp and laser illuminated projectors" by Goran Stojmenovik

The combination of spectral variations and individual differences in color perception contributes to the metameric offset observed between Xenon-lamp-based and RGB laser projectors. This can cause colors to appear slightly different, impacting the accuracy and consistency of color reproduction in cinema postproduction.

This white paper also underlines another important aspect: the CIE1931 color reproduction equations (Color Matching Functions) used for the XYZ colorspace in the movie industry aren't flawless. This "imperfection" becomes more relevant when dealing with narrow bandwidth light sources like LED or Laser. Despite multiple scientific efforts to improve these equations since their inception in 1931, these improvements haven't been widely adopted by the entire industry, making them less practical.

To address the variability in color perception, arising from both mathematical discrepancies and individual responses, Barco has devised a practical approach to tackle this challenge, which is discussed in the following section.

The Metameric Offset Correction (MOC) approach

Barco proposed to apply a Metameric Offset Correction (MOC) to the native calibration of the laser-based projectors to correct for the metameric mismatches in postproduction. The application of an offset in Measured Color Gamut Data (MCGD) is also minimizing the possibility of errors since it is applied in color linear space rather than in color gammatized space.

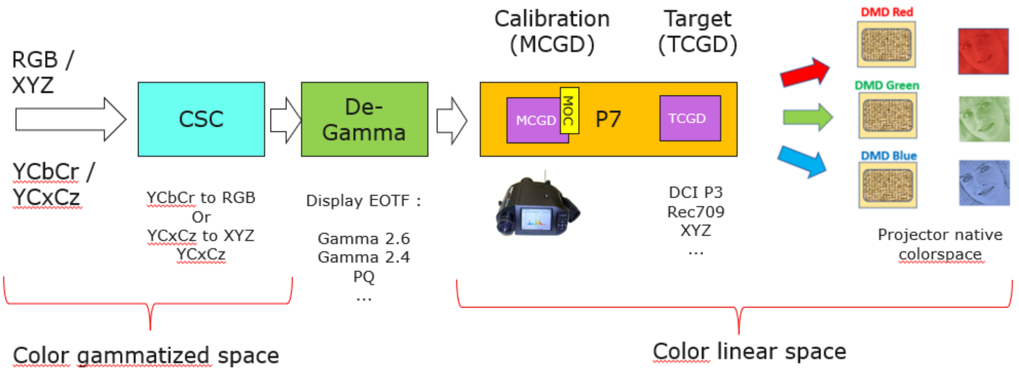

Fig.4 Video-path of a Digital Cinema Projector

The choice to alter the calibration values with an offset instead of modifying the target color values in digital cinema workflows is driven by the goal of maintaining consistency and adherence to industry standards. Here are the reasons behind this decision:

Preserving industry standards:

The target color values in digital cinema workflows have been established as industry standards over time. These standards ensure consistency across different theaters, screens, and devices, allowing filmmakers' creative intent to be faithfully reproduced. Modifying these target color values would require a widespread and coordinated effort to redefine and implement new standards across the industry. Such a process would be complex, time-consuming, and may face resistance from various stakeholders.

Minimizing disruption:

Altering the target color values would necessitate significant adjustments to the entire color grading and postproduction processes. It would require recalibrating all existing content, modifying color grading techniques, and retraining professionals on the new standards. This level of disruption could hinder the smooth transition from Xenon-lamp-based projectors to laser projection. By applying an offset to the calibration values, the metameric offset correction approach minimizes the need for extensive changes in the existing workflows, reducing disruption and facilitating a more seamless transition.

Preserving artistic intent:

Modifying the target color values could potentially impact the artistic intent of filmmakers. By introducing a bias or offset to the calibration values, the metameric offset correction approach preserves the original artistic intent of the content creators. It ensures that the colors envisioned by the filmmakers are accurately reproduced on screen while compensating for the metameric mismatches introduced by different projector technologies.

Flexibility and compatibility:

The approach of applying a calibration offset provides flexibility and compatibility with a wide range of content and systems. It can be implemented without requiring specific modifications to the content itself, making it applicable to existing libraries of films and future productions. This approach also allows for the coexistence of Xenon-lamp-based projectors and RGB laser projectors in the transition phase, ensuring compatibility between different projection technologies.

The proposed approach involves applying a 3x3 correction matrix to the physical calibration values of RGB laser projectors. This matrix, derived from extensive research and empirical data, addresses the narrow-bandwidth illumination of laser projectors and aligns color perception to bridge the gap with Xenon-lamp-based projectors. This approach allows for a smoother transition from Xenon-lamp-based projectors to laser projection while effectively compensating for metameric mismatches and ensuring consistent and accurate color reproduction in the cinema industry.

Validation and empirical evidence:

A statistical approach was crucial in the validation of the proposed metameric offset correction, given the nature of metameric failures occurring in the brain and the need for large-scale data analysis. To capture a comprehensive understanding, the experiments conducted for metameric matches encompassed various aspects.

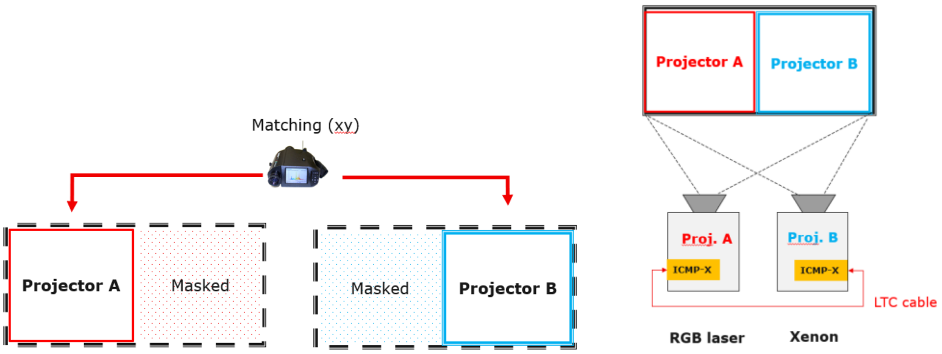

Fig.5 Projector setup for side-by-side comparison

The testing process involved matching not only test patterns of small (2° observer) and large sizes (10° observer), at different saturation levels, but also natural static images and actual movie content. These real-world elements included color-memory critical elements like skin-tones, skies, and grass. By evaluating the color perception across a wide range of stimuli, the experiments replicated the conditions encountered in cinema postproduction.

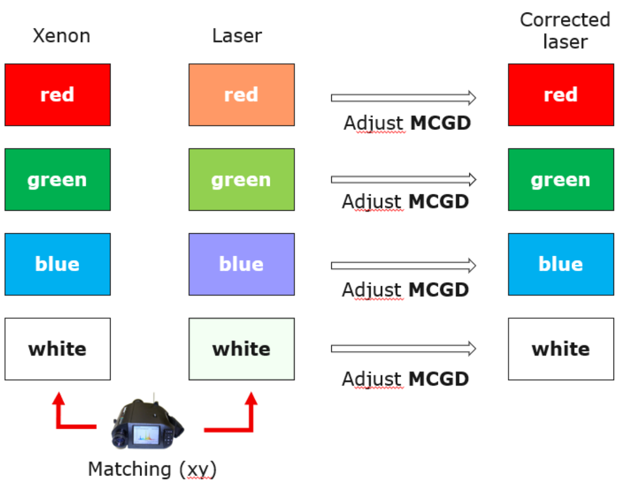

Fig.6 Color-matching experiment via MCGD adaptation

Moreover, the experiments were carried out in a side-by-side setup, comparing the color output of Xenon-lamp-based and RGB laser projectors simultaneously. This setup allowed for direct and immediate comparisons, minimizing potential variations and ensuring accurate assessments of the metameric mismatches.

The participation of professional colorists and experts from the image industry was crucial to the validation process. Their keen eye and experience in color grading provided valuable insights and feedback, validating the effectiveness of the proposed metameric offset correction in capturing critical color elements in images and movie content.

To conduct this meticulous series of experiments, Barco enlisted the support and expertise of industry leaders and esteemed color professionals across three continents, spanning Denmark, the UK, Germany, India, the United States, China, and Japan. This collaborative effort facilitated the gathering of as many as 80 individual observer datasets within a rigorously controlled and meticulously documented experimental framework.

The combined results from these experiments, covering both technical test patterns and real-world movie content, reinforced the suitability of the proposed correction approach. By considering color perception across a diverse range of stimuli and involving professionals with color-memory critical tasks, the validation process ensured that the metameric offset correction addressed the challenges faced in cinema postproduction accurately.

Practical implementation and integration:

Implementation of the Metameric Offset Correction (MOC) can seamlessly integrate into existing workflows without requiring extensive modifications. When performing calibration using traditional calibration tools, the projector will generate two calibration files: one based on the accurate physical calibration using industry standards, and the other appended with "_MOC," which contains the modified file with the metameric offset correction.

The first calibration file serves as a reference to ensure the equipment is calibrated according to industry standards. This verification step ensures that the projector is functioning correctly. The second calibration file, incorporating the metameric offset correction, is specifically designed for visually adapted calibration and is used for all color-critical work in postproduction activities.

The Barco projector's internal software automatically computes the Metameric Offset Correction, utilizing the results obtained from various metameric matching experiments conducted worldwide by Barco. This ensures that the correction is based on a comprehensive understanding of the color perception variations observed across different stimuli and viewer perspectives.

By employing this approach, the implementation of the Metameric Offset Correction seamlessly integrates into the calibration process, allowing for both adherence to industry standards and visually adapted calibration. It provides a practical and efficient solution that fits within current workflows, enhancing color accuracy and consistency in cinema postproduction activities.

Industry collaborations and endorsements

The successful implementation of the Metameric Offset Correction (MOC) in the cinema postproduction industry relies on strong collaborations, endorsements, and an eye towards future perspectives and evolution.

Collaboration among industry stakeholders, including projector manufacturers, color grading software developers, and postproduction facilities, is crucial for the widespread adoption of the MOC. By working together, industry standards can be updated or developed to include guidelines for implementing the correction approach effectively. This collaboration ensures a unified approach and promotes a seamless integration of the MOC into existing workflows.

Endorsements from renowned professionals, industry organizations, and institutions further validate the effectiveness and reliability of the MOC. Their support and recognition create a solid foundation for acceptance and encourage other stakeholders to embrace the correction method.

Initiating a much-needed industry evolution, Barco has taken the first stride by establishing substantial collaborations with diverse industry leaders and color experts. The invaluable feedback garnered from these collaborations not only supplies a plethora of essential data points for the proposed solution but also sparks discussions on practicalities, phased approaches, scientific intricacies, and real-world usability outcomes. These partnerships have proven instrumental in realizing the objectives of this intricate study.

Future perspectives

Looking towards the future, continuous improvement and evolution of the MOC are essential. Feedback from users, ongoing research, and advancements in color science should drive further refinements to the correction approach. This iterative process ensures that the MOC remains at the forefront of color accuracy in the ever-evolving cinema postproduction industry.

Furthermore, future perspectives include exploring the potential of artificial intelligence and machine learning algorithms to enhance the precision and efficiency of the MOC, while still trying to integrate the latest work of the scientific community. Leveraging these technologies can lead to automated calibration processes, reducing manual intervention and improving overall accuracy.

The adoption of the MOC sets the stage for a future where laser-illuminated projection becomes the industry standard. As more stakeholders embrace the correction approach and witness its benefits, its integration will become more widespread, leading to a paradigm shift in color accuracy and consistency in cinema postproduction.

By fostering collaborations, securing endorsements, and maintaining a forward-thinking approach, the industry can ensure the continued success and evolution of the MOC. This commitment to improvement and innovation will drive the industry towards a future where laser-illuminated projection and the Metameric Offset Correction are integral components of a seamless and visually stunning cinematic experience.

Conclusion

Barco takes great pride in presenting the findings of our year-long study, conducted across multiple continents, as we introduce the Metameric Offset Correction (MOC) into our latest software. This groundbreaking solution addresses the color discrepancies between Xenon-lamp-based and RGB laser projectors in the cinema postproduction industry. Our comprehensive research, statistical analysis, and collaboration with industry professionals have resulted in a robust correction approach that ensures accurate color reproduction. We are thrilled to offer the MOC to our professional clients, providing them with a cutting-edge tool to enhance color precision and consistency in their postproduction workflows. By harnessing the power of the MOC, Barco remains committed to delivering unparalleled visual experiences and driving the industry forward into a new era of laser-illuminated projection.

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