International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 10 – Issue 06 || June 2025 || PP. 46-51

Digital Cinema Stereoscopic Compliance Test Robust 3D Playback across Framerates and Resolutions

Alaric Hamacher[1]
[1](*Kwangwoon University, Republic of Korea)*

Abstract: Ensuring compliance with SMPTE standards for stereoscopic digital cinema playback remains a technical challenge, especially with evolving hardware and software configurations. This paper presents a comprehensive Digital Cinema Package (DCP) test methodology developed to assess stereoscopic 3D playback capabilities across varying resolutions and frame rates. Designed for film festival environments where diverse international content is screened, the proposed compliance test evaluates key parameters such as subtitle rendering (static and dynamic), 3D projection frame repetition modes (triple- and double-flash), and format compatibility. Empirical results from real-world screenings demonstrate that modern projection systems can reliably support a broader range of 3D formats than traditionally assumed, providing confidence for festival organisers and cinema operators in planning 3D programmes**.**

Keywords: digital cinema, subtitles, stereoscopic, SMPTE, compliance

I. INTRODUCTION

With the proliferation of stereoscopic 3D in digital cinema, ensuring that projection systems accurately playback 3D content—including subtitles—has become a key technical and quality assurance challenge. While the standards by the Digital Cinema Initiative (DCI) and the Society of Motion Pictures and Television Engineers (SMPTE) define the requirements for stereoscopic presentation, real-world projector and server implementations can vary significantly, especially as systems evolve with software updates and hardware changes. To address these challenges, a comprehensive compliance test is essential for validating the capabilities of digital cinema projectors, particularly regarding their handling of different framerates, resolutions, and stereoscopic display modes such as triple-flash and double-flash.

II. BACKGROUND

SMPTE standards such as ST 429-2 define how Digital Cinema Packages (DCP) should be encoded, transmitted, and displayed in digital cinema[1]. However, very often two kinds of problems can occur: First, the definition in the standard is optional. This means certain features can be recommended, but it remains uncertain if these features have been implemented in the projection system. For example, the recent specification sheet of the "Barco Alchemy ICMP-X" states[2], the device is compliant with DCI-compliant with the Compliance Test Plan (CTP) version 1.2.[3] This compliance test plan is dated October 10, 2012 and does not cover any of the additional features and updates of the standards during more than ten years. Second, it is very difficult to know which features have been added and implemented after an update of the original software. Key compliance requirements for stereoscopic digital cinema include:

- Support for 3D playback.
- Support for stereoscopic subtitle playback.
- Support for different framerates.
- Support for different picture sizes

The purpose of this research is the implementation of a compliance test to assess the robustness of the stereoscopic playback capabilities of a given digital theatrical projection system. The focus of the assessment is the seamless playback of hundreds of different movies during a film festival such as the Busan International Short Film Festival (BISFF)[4]. It is important to know which content can be displayed on the theatrical projection system. Incompatibilities such as mismatching framerates can generally only be solved by remastering the content. This is a time-consuming and costly process. It requires detailed knowledge which goes far beyond the work of cinema projection. With the projection of more than 200 different movies in one week, the verification of the compatibility of all the DCPs is crucial.

III. TEST DCP DESIGN

This research proposes a test designed to assess some of the most important features from the point of view of a festival [5]. These features mainly include:

- **Frame Rates in Stereoscopic 3D**

While the original standard frame rate for cinema is 24, as a result of 48 for 3D, additional framerates have been introduced to implement compatibility with broadcasting formats and various high frame rate (HFR) formats. Especially young filmmakers like technical challenges and like to experiment with new formats. For festivals focussed on innovation, it is important to determine if the content can be displayed.

- **Resolution in Stereoscopic 3D**

While the first generation of digital cinema was compliant with 2K resolutions, recent projectors are equipped to present images with four times higher resolution in 4K.

- **Static and Dynamic Stereoscopic Subtitles**

Recent standards define the implementation of static stereoscopic subtitles. However, the implementation of dynamic moving stereoscopic subtitles using the element variableZ in the subtitle text file is optional [6]. International festivals often present the movies in their original language and produce subtitles locally. It is therefore essential to understand which kind of subtitles can be commissioned. Previous research also covers the creation of stereoscopic subtitles for festivals [7].

- **Visual Control**

This is a control to be assessed with the naked eye to observe differences in the different settings. This can show expected artifacts such as strobe effects in fast camera panning movement in lower framerates. For technical reference, “The Old, the New, and the Other” by Sebastian Simon is used. The movie was created as part of a 3D Filmmaking for User-Selective ultra-high-definition (UHD) Stereoscopic Media System [8]. It was produced using the highest possible resolution of 4K and 60fps, making it an ideal content from which all other lower versions of resolution and framerates can be derived.

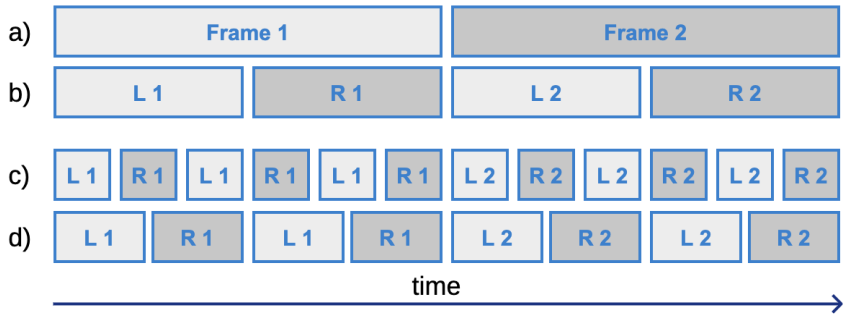

Figure 1: triple-flash and double-flash projection principle

Fig. 1 shows the schematic principle of triple and double flash. This technology is used since the frequency of 24 frames per second can cause a very significant flicker. In order to avoid an uncomfortable viewing experience, each frame is screened several times. a) shows the frames of the DCP that enter the projector. b) shows a right and a left subframe for each frame. c) shows the output of the projector where every frame is shown three times. This is commonly called triple-flash. d) shows a double-flash where every frame is only shown two times.

$$F_{2D} = E \qquad (1)$$

$$F_{3D} = 2E \qquad (2)$$

$$P_f = F_{3D} * f \qquad (3)$$

Each projector has a maximum framerate. The DCP specification defines the edit rate E as the unit in editing; in cinema, this is commonly 24 frames per second. In 2D, the framerate F coincides with the edit rate as shown in equation 1. However, in 3D, there is a left and a right image for each frame. The framerate F in 3D is therefore double as shown in equation 2. For a 24 fps movie, the 3D framerate F is 48. In the first generation of projectors, 3D was conceived to be comfortable for viewing when each frame is shown three times. f is the number of repetitions for each frame. In a triple-flash projection, the value is 3. Equation 3 shows the projector framerate that is necessary for playback. In this case, the number is 144. This computation shows the necessary projector framerate for a given framerate in a 3D movie. However, due to technical limitations, the projector

framerate cannot be scaled up to infinity. Limitations include image transfer bitrates and processing power in the media server.

Table 1: BARCO ALCHEMY ICMP-X product features Integrated Cinema Media Processor

Format	Supported Performance	Annotation
DCI 4K 2D	up to 60fps	
DCI 4K 3D	24 or 30 fps per eye	
DCI High Framerates	2K 3D up to 120fps	60fps per eye
JP2000 bitratesEG	up to 625Mbps	

Table 1 shows the product features of the Integrated Cinema Media Processor of a Barco Alchemy ICMP-X as it is used in one of the theaters of the Busan Cinema Center[2], [9]. The maximum framerate of the projector is not specified, but itis expected to be slightly above 144 in order to show the indicated framerates either with triple-flash or double-flash. Since in 3D the projector framerate is distributed evenly on the right eye and the left eye, drops in framerates can reduce the viewing comfort more significantly than in 2D.

Additionally, the transfer speed of the images encoded in JPEG2000 is equally limited. Since a 3D movie has two images where the 2D movie has one, each image of a 3D movie is encoded at a maximum of half of the maximum bitrate. 3D movies can be more sensitive to reductions in encoding bitrate, especially in 4K format. With these technical parameters as a reference, it is part of the assessment to identify at which framerate the projector changes from triple-flash to double-flash, if visible differences can be observed, and if any problems occur in the communication between the server, the projector, and the 3D device in front of the projector (e.g. an alternating polarizer).

IV. METHODOLOGY

The test content was authored with industry-standard tools such as DaVinci Resolve, allowing precise control over image format, stereoscopic settings, and subtitle encoding. Each DCP was structured to:

- Present both burned-in and dynamically rendered subtitles for direct visual comparison.
- Include sequences that stress-test subtitle rendering at different depths and during rapid transitions.
- Log projector behavior, particularly noting at which framerate the system switches from triple-flash (typically used for 24fps 3D to minimize flicker) to double-flash
  (used at higher framerates for efficiency).
- Observe, if certain combinations of framerates and resolutions cannot be displayed, or only displayed with errors.

The details of each single test have been described in detail in previous research[10]. Figure 3 shows a screenshot of a test playback using a software player. However, in order to test the real-world compliance, the test has to be executed on a real digital cinema projection system. The initial DCP is therefore recreated for every resolution and for every framerate. This requires a complete, renewed authoring for every version. While the duration of each DCP stays identical, the number of frames displayed per second changes. With higher frame rates, the number of frames increases.

Regarding the subtitles, it is expected that they will have the same timing in all DCPs independently of the frame rate. So one could imagine that it would be possible to use the same subtitles with timecode information for all the DCP variants. Unfortunately, this is not the case. Figure 2 shows how the XML files need to be rearranged to match the EditRate of the main picture in the DCP.

a)	b)
<ReelNumber>1</ReelNumber> <Language>en</Language> <EditRate>24 1</EditRate> <TimeCodeRate>24</TimeCodeRate> <StartTime>00:00:00:00</StartTime> <DisplayType>MainSubtitle</DisplayType>	<ReelNumber>1</ReelNumber> <Language>en</Language> <EditRate>25 1</EditRate> <TimeCodeRate>25</TimeCodeRate> <StartTime>00:00:00:00</StartTime> <DisplayType>MainSubtitle</DisplayType>

Figure 2: Digital Cinema XML Subtitles with different frame rates.

The Subtitle XML file contains a TimeCodeRate tag in addition to the EditRate tag. Figure 2a) shows an excerpt of the XML file for a 24 fps DCP. Figure 2b) shows the identical part for a 25 fps DCP.

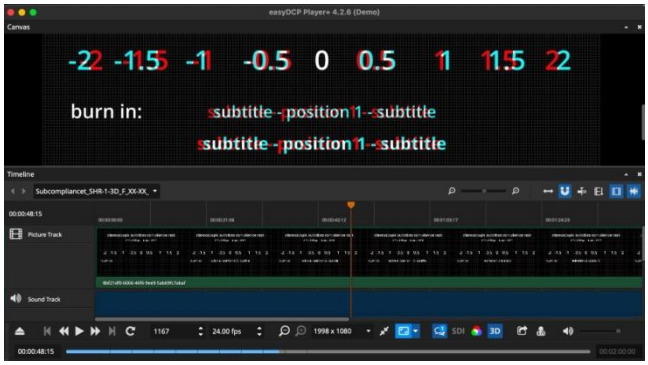

Figure 3: playback of the test DCP

The assessment will be qualified as passed if a version of a DCP can be played without limitations. The assessment will be qualified as not passed if a DCP version does not play, or any other error occurs during the playback that makes this DCP combination unusable during the automated projection process of a film festival.

V. RESULTS AND DISCUSSION

Each test DCP contains a succession of tests for resolution, static and dynamic subtitles, as well as a visual reference to detect motion artifacts in real images. Table 2 shows the list of all individual test DCPs with their respective specifications, the observations during the projection in the theater, and the test results.

Table 2: 3D Screening results and observations

Framerate	Resolution	Container Format	Annotation	3D Subtitles	Flash	Result
24	2K	Flat (1998×1080)	Triple-flash baseline	static	triple	passed
24	4K	Full (4096×2160)	Triple-flash baseline	static	triple	passed
25	2K	Full (4096×2160)	Broadcast frame rate	static	triple	passed
25	4K	Full (4096×2160)	Broadcast frame rate	static	triple	passed
30	2K	Flat (1998×1080)	Broadcast frame rate	static	triple	passed
30	4K	Full (4096×2160)	Broadcast framerate	static	triple	passed
48	2K	Flat (1998×1080)	HFR (High Frame Rate)	static	uncertain	passed

48	4K	Full (4096×2160)	HFR (High Frame Rate)	static	uncertain	passed
50	2K	Flat (1998×1080)	Broadcast HFR	static	uncertain	passed
50	4K	Full (4096×2160)	Broadcast HFR	static	uncertain	passed
60	2K	Flat (1998×1080)	Broadcast HFR	static	double	passed
60	4K	Full (4096×2160)	Broadcast HFR	static	double	passed (*)
120	2K	Flat (1998×1080)	not supported	not tested	not tested	not passed
120	4K	Full (4096×2160)	not supported	not tested	not tested	not passed

The test marked with (*) is a 4K 60fps DCP. While the manufacturer's description states only DCP in 2K resolution can be displayed at 60fps, it displayed well in the projection. This was a positive result not only from the technical perspective but also for the festival programmers.

Only the two DCPs with 120fps failed the assessment as expected. The projector did not show any image. It was not possible to identify if the limitation was created by the playback server or the projector itself or both.

The observation of the change from triple-flash to double flash was flawless. Some slight changes in flicker could be observed between the frame rates between 48 and 60. It did not represent a significant change in the quality of the projection. The observation proved the reliability of the communication between the server, the projector, and the 3D polarizer triggered via a general input and output port (GPIO). It could be confirmed that the whole setup changes automatically according to the specifications of the DCP. No manual intervention of the projectionist was required. This was a very positive result for the technical team operating the projections.

As a result, the compliance test managed to exhaustively assess the playback capacities for stereoscopic DCP with subtitles. The results confirmed that all frame rates from 24 to 60 could be displayed seamlessly in 2K and 4K with the projection system.

Additionally, although the projection system is said to be conforming to the DCI Compliance Test Plan 1.2 from 2008, it displays the later defined static stereoscopic subtitles correctly. However, the optional dynamic stereoscopic subtitles could not be displayed.

VI. CONCLUSION AND FUTURE WORK

The present compliance test for assessment of stereoscopic playback in digital cinema allowed determination with certitude of the capabilities of the projection system. For a film festival dealing with hundreds of movies in different film formats, sizes, and frame rates, it is crucial to anticipate technical questions. In the past, it was common practice to limit the acceptance of stereoscopic 3D movies only to movies in 2K and with a framerate of 24, as this was the minimum acceptable standard that was confirmed for all DCI-compliant projection systems. The present compliance tests give confidence for festival organizers and operators and determine if their projection system allows the screening of more different formats.

The compliance test mainly focused on the playback of the 3D capability. Future research could include a stress test for the 3D projection system in regard to the JPEG2000 bitstream to show limitations and the influence on the image quality.

The present test is an assessment every cinema operator can operate on their own, without the need for any assistance or permission from the manufacturer or maintenance service company. The present research can help the proliferation of the new formats for stereoscopic cinema above the initial 24fps in 2K. The authors wish this assessment could also encourage more cinemas and festivals to show 3D movies.

VII. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

VIII. ACKNOWLEDGEMENTS

The present research has been conducted by the Research Grant of Kwangwoon University in 2025. This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2024S1A5C2A02046083). The Authors would like to thank the Busan Cinema Center and the management team of the Busan International Short Film Festival (BISFF) for their kind support.

IX. REFERENCES

[1]. *SMPTE ST 429-2:2020 D-Cinema Packaging — DCP Operational Constraints*.
[2]. "Barco Alchemy ICMP-X Spec Sheet." Barco nv., 2025. Accessed: Jun. 30, 2025. [Online]. Available: https://assets.barco.com/m/2630ba090c4b8bca/original/Barco-Alchemy-ICMP-X-en-Spec-sheet.pdf
[3]. "Digital Cinema System Specification Compliance Test Plan." Digital Cinema Initiatives, LLC, Oct. 10, 2012. [Online]. Available: https://www.dcimovies.com/compliance-test-plan?ctp-version=v1.2
[4]. "Busan International Short Film Festival," BISFF Homepage. Accessed: Jun. 30, 2025. [Online]. Available: https://www.bisff.org/eng/page/?pid=ticket
[5]. "« Cinéma & Son » : les coulisses du BISFF 2025 avec Alaric Hamacher." Accessed: Jun. 29, 2025. [Online]. Available: http://rki.kbs.co.kr/service/contents_view.htm?lang=f&menu_cate=people&id=&board_seq=457535&page=1
[6]. *SMPTE ST 428-7:2014 Digital Cinema Distribution Master – Subtitle*, 2014.
[7]. A. Hamacher, "Digital Cinema Stereoscopic Subtitle Workflow," *IJLEMR*, vol. 9, no. 2, pp. 51–59, Feb. 2024, doi: 10.56581/IJLEMR.9.02.51-59.
[8]. M. Cha, A. Hamacher, and S. Simon, "3D Filmmaking for User-Selective UHD Stereoscopic Media System: A Case Study on the Film The Old, the New and the Other," *Journal of Multimedia Information System*, vol. 8, no. 4, pp. 277–284, 2021, Accessed: Jun. 29, 2025. [Online]. Available: https://koreascience.kr/article/JAKO202102565122225.page
[9]. "Busan Cinema Center > Facilities > Cinemountain," Busan Cinema Center. Accessed: Jun. 30, 2025. [Online]. Available: https://www.dureraum.org/bccen/contents/contentsView.do?rbsIdx=238
[10]. A. Hamacher, "Test DCP for Stereoscopic Subtitles Compliance with SMPTE Specifications," *IJLEMR*, vol. 10, no. 1, pp. 12–17, Feb. 2025, doi: 10.56581/IJLEMR.10.01.12-17.