Report on Additional Frame Rates for Digital Cinema

By Jim Wilkinson and Kommer Kleijn

INTRODUCTION

The scope of the "Additional Frame Rates" study group was to investigate the user requirements for digital cinema (D-Cinema) frame rates in addition to those that have been, or are in the process of being standardized by the DC28 Technology Committee (This committee is now called 21 DC.). Accurate playback of these additional frame rates is required to support the artistic intent of the content producers and support historical frame rates that form a significant part of archives.

This paper reports the findings of the study group on the user requirements, the technologies, the potential for implementation, and the impact on existing SMPTE DC28 Standards and Recommended Practices.

HISTORY AND BACKGROUND

The frame rates currently standardized by the DC28 Digital Cinema Technology Committee are 24 and 48 frames/sec. These frame rates are associated with a given pixel array, so that the 24 frame/sec rate may be used with pixel arrays of both 2048 x 1080 pixels and 4096 x 2160 pixels but, for practical reasons, the 48 frame/sec rate is limited for use with the single pixel array of 2048 x 1080 pixels.

However, the history of filmmaking is littered with other frame rates from 16 to 60 frames/sec, and there is support for making films using readily available equipment made specifically for the film production market.

USER INTEREST AND PROPONENTS

There has been widespread interest in this subgroup activity and many European organizations and companies expressed their requirements for additional frame rates. The full report lists all the interested parties and their input to the study group.

USER REQUIREMENTS

Avoidance of Frame-Rate Conversion

This study group started its work on the premise that D-Cinema content will be produced at frame rates that differ from 24 (and 48) frames/sec and that exhibitors should be able to present the content at its natural frame rate. Frame rate conversions can severely damage the quality of moving imagery and should therefore be avoided whenever possible. Thus, it is extremely desirable that D-Cinema installations support a number of additional frame rates through the entire chain of distribution and exhibition, in order to better accommodate source material in its native frame rate.

Limitations of the Sole Use of 24/48 Frames/Sec

The use of the proposed additional frame rates will permit the production of new content using frame rates that have a better compatibility with the subsequent distribution of the D-Cinema content in the popular "after-market" sector as a now widely accepted practice to expand the sources of income from film content.

Use of Crossover Products

With the move from interlaced scanning to progressive scanning through the introduction of high-definition television equipment, the classically inadequate video equipment is rapidly closing the quality gap. There has long been a history of shooting film with video equipment, but this has often been done for a certain visual effect. However, recent video camcorder introductions have narrowed the gap significantly and the resultant quality can be used to good effect. This trend is expected to continue. Thus, as the quality of video equipment increases, the use of crossover products will also increase. Indeed, some recent films (*Borat*, for example) have used video equipment for capturing the entire film production.

Delivery of Artistic Intent

One of the key issues in content distribution has been the change of frame rate from 24 frames/sec to 25 frames/sec or 25 frames/sec to 24 frames/sec for presentation, which has resulted in a 4% pitch and tempo change. The best way to avoid this change is to present the content at the original frame rate.

Films created at the primary additional frame rates should be delivered at the master rate in order to deliver the creative intent to the consumer.

Support for Archive Material

The film industry has a record of preserving historic material dating back to the early 20th century and even earlier. This material has a very high historic value that must be preserved for future

generations. For future generations to appreciate the original creative intent and storyline, the content needs to be presented in the original form that the filmmaker intended.

PROPOSED ADDITIONAL FRAME RATES

The frame rates currently proposed by the DC28 Technology Committee are 24 and 48 frames/sec.

The proposed additional frame rates recommended by the study group are divided into two classes:

Class 1 represents the correct presentation of a wide base of existing and new D-Cinema content. Class 2 represents the correct presentation of historic film material that exists in the many film archives throughout the world. The frame rates are listed in the following sections.

The proposed class 1 list is as follows:

1. 25 frames/sec at both the 2048 x 1080 and 4096 x 2160 pixel array.
2. 30 frames/sec at both the 2048 x 1080 and 4096 x 2160 pixel array.
3. 50 frames/sec at only the 2048 x 1080 pixel array.
4. 60 frames/sec at only the 2048 x 1080 pixel array.

In all four cases, the study group recommends that the frame rate should be an exact integer number.

Notes on these four proposed frame rates are as follows:

I. 25 frames/sec: In some regions, a significant amount of both theatrical and non-theatrical content is shot and post-produced in 25 frames/sec; this has been done for many years. Furthermore, some cinemas have set their film projectors to run at 25 frames/sec. Supporting 25 frames/sec in D-Cinema systems would allow all these movies to be shown at their correct and native speed. It would also allow installations to offer D-Cinema with the same functionality provided by film projectors.

II. 30 frames/sec: Libraries of film material shot at 30 frames/sec are available, specifically for use in 60 Hz regions. Some films intended for theater release have also been shot at 30 frames/sec (the first Todd-AO films were shot at 30 frames/sec). Furthermore, the stereoscopic industry is looking to 60 frame/sec systems to carry left and right images each at 30 frames/sec. 30 frames/sec would also permit the efficient distribution of mono versions of 30 frame/sec (60 Hz) stereoscopic movies. Thus, there is the option to carry single-channel film content at 24, 25, and 30 frames/sec and stereoscopic film material as a frame pair at 48, 50, and 60 frames/sec.

III. 50 frames/sec: This higher frame rate provides for better movement quality than 24 frames/sec or 25 frames/sec, and will provide greater liberties of movement, allowing for new developments in film expression. 50 frames/sec is widely supported today among digital production equipment, both in acquisition and post-production. 50 frames/sec is increasingly likely to be used by production in 50-Hz regions. Content produced in the 50-Hz areas is likely to use 50 frames/sec in both television and movie production (rather than 48 frames/sec), in the same way that 25 frames/sec is used in both fields today. Support for 50 frame/sec projection is desired to show these movies at their native speed. 50 frames/sec has the potential to be reduced to 25 frames/sec when care is taken to limit movement during the shoot. The result can then be shown at 25 or even 24 frames/sec. This is useful for distribution on film prints during the transition period.

IV. 60 frames/sec: Like 48 frames/sec and 50 frames/sec, 60 frames/sec provides for a better movement quality than 24 frames/sec or 25 frames/sec, and will provide greater liberties of movement allowing for new developments in film expression. However, once D-Cinema is widely established, 60 frames/sec may become a more interesting and economical frame rate for movie production than 48 frames/sec, for two main reasons. First, 60 frames/sec will translate better to the "after-market" and second, it will greatly simplify post-production. Unlike 48 frames/sec, 60 frames/sec is widely supported today among digital production equipment, both in acquisition and post-production. It is also increasingly used by television production in 60 Hz regions. Support for 60 frame/sec projection is also desired, to show this content at its native frame rate when applicable.

Additionally, there has been interest for 60 frames/sec from the 3-D stereoscopic community on the basis that 60 frame/sec functionality would allow for stereoscopic projection at 30 frames/sec per eye. The DC28.0 Stereoscopic Digital Cinema Study Group Report of March 2, 2005 limited itself to 24 frames/sec per eye. It is known that there is an apparent 3-D flicker threshold for fusing images, which would drive toward a 30 frame/sec (2 eye double flash = 120 frames/sec) presentation, instead of 24 frames/sec.

The proposed class 2 list is as follows:

1. 16 frames/sec
2. 18 frames/sec
3. 20 frames/sec

These frame rates were chosen to allow presentation of a film at close to its intended frame rate.

Some motion artifacts may be due to erratic "hand-cranking" of the camera, and these are difficult to eradicate. It is not expected that all equipment will support all of the historic film rates.

IMPACT ON VISUAL PERFORMANCE

Changes in Frame Rates

This subsection describes the impact of content created at one frame rate being displayed at a different frame rate.

25 frames/sec

The issues of raising the 24 frames/sec frame rate to display on 25 frame/sec devices were described in the section on "Delivery of the Artistic Content."

30 frames/sec

If 30 frame/sec content is displayed on a 24 frame/sec projector, the results will be objectionable.

50 frames/sec

50 frame/sec content could be displayed on a projector operating at 48 frames/sec, but the same issues of 25->24 frames/sec arise.

60 frames/sec

If 60 frame/sec content is displayed on a 48 frame/sec projector, the results will be objectionable.

Class 2 Frame Rates

Frame rates of 18 and 20 frames/sec cannot be gracefully played on a 24/48 frame/sec projector. 16 frame/sec frames can be presented three times in a 48 frame/sec sequence. If class 1 frame rates are supported, 20 frames/sec can be presented three times in a 60 frame/sec sequence.

Changes in the Bits/Picture Allocation

The maximum bit rate has been defined for D-Cinema use, therefore, the bits per picture may need to decrease in proportion to any frame rate increase.

If the maximum bit rate is being used, the increase of 4% in picture rate values for the 25 frame/sec frame rate requires a 4% reduction of bits per picture, compared to the 24 frame/sec frame rate. This small change in bits per picture results in no observable change in picture quality. The same result applies to the 50 frame/sec versus 48 frame/sec frame rates.

In the case of 30 frames/sec and 60 frames/sec, if the maximum bit rate is being used, the bit allocation is reduced by 20% compared to the allocations for 24 frames/sec and 48 frames/sec, respectively. To date, only minor additional impairments have been found. So although the bits per picture is lowered at frame rates of 30 frames/sec and 60 frames/sec, there is no evidence to suggest that the compression is close to a cliff edge.

IMPACT ON ASSOCIATED ESSENCE TYPES

Audio

25 frames/sec

See section on "Delivery of Artistic Intent."

50 frames/sec

See section on "Delivery of Artistic Intent."

30 frames/sec and 60 frames/sec

There is a simple integer relationship between the picture frame rate and the audio frame rate; thus there is no degradation.

Class 2 Rates

Most class 2 rates do not have any original soundtracks. In cases where they do, the track will most likely be analog and can thus be digitized as needed.

Data Essence (Subtitles)

Subtitles are affected by a change of frame rate, however, they are mostly defined by the action within the pictures or sound. Thus there is no impact of a change of frame rate on the subtitles within a presentation.

RELATIONSHIP TO EXISTING DC-28 STANDARDS AND RECOMMENDED PRACTICES

The proposed additional frame rates should be defined by one or more new documents that supplement the current SMPTE D-Cinema standards, recommended practices, and engineering guidelines.

The following subsections summarize the additions.

Technical Impact

The technical impact is as follows:

1. Frame rates: Addition of class 1 and class 2 frame rates as listed above in a new SMPTE document.
2. Picture sizes: No change.
3. Image structure: Limited to the pixel array of 2048 x 1080 for all frame rates >30 frames/sec.
4. Colorimetry: No change.
5. Bit depths: No change.
6. Dynamic signal range: No change.
7. Image metadata: No change.
8. Image compression and file format: No change.
9. Audio: For all frame rates with the exception of 18 frames/sec, the number of audio samples per frame is an integer number at both 48-KHz and 96-KHz audio sampling rates. In the case of 18 frames/sec, the number of audio samples is an integer number over a 3-frame duration for both 48-KHz and 96-KHz audio sampling rates.
10. TIFF: No change.

Digital Cinema Digital Master (DCDM) Documents

The DCDM image standard will need to be supplemented with the additional frame rate values. This can be done in the form of either an amendment or a new document that provides extensions to the current standard.

Two DCDM documents (DCDM TIFF and DCDM Image Metadata) refer to SMPTE 428.1M (Image Characteristics) for frame rate values, and simple amendments will be needed to support the ad-

ditional frame rates. A new DCDM Constraints document will be needed to support the additional frame rates.

In the case of the SDI mappings, one or more new documents will be required for the 25, 30, 50, and 60 frame/sec mappings. For the class 2 additional frame rates, it is likely that they will remain unsupported in SDI links and must therefore be connected to the projector by some other interface that will probably be asynchronous and not defined by SMPTE standards.

Digital Cinema Packaging (DCP) Documents

There is no direct impact on the structure of any of the Digital Cinema Packaging standards except where specific frame rate values are defined. In the cases of the DCP-Operational Pattern (429-2), DCP JPEG 2000 Application (429-4), and the proposed DC-PCM documents, they have a normative reference to the DCDM Image standard and documentation of additional frame rates will need to be added in the form of an amendment in each case.

Digital Cinema Exhibition (DCE) Documents

There is no known impact on the provisions of any of the Digital Cinema Exhibition standards.

Stereoscopic Pictures Documents

Adding to the 24 frame/sec frame rate used in current stereoscopic systems is certainly possible. Should such extension be required in the future, there is no technical reason why frame rates of 25 and 30 frames/sec could not be implemented in the same way as 24 frame/sec-based stereoscopic systems today. Within the study group discussions, there have been specific expressions of interest in operating stereoscopic systems at 30 frames/sec using the 60 frame/sec frame rate. It is alleged that the increase in motion by 25% has resulted in a much better stereoscopic viewing experience. No stereoscopic documents have yet been standardized so the additional frame rate values can be added where specific frame rates are defined.

Refer also to section 5.1.IV from the DC-28.0 Stereoscopic Digital Cinema Study Group Report of March 2, 2005. This same report also states (on pages 5, 9, and 14) concerns over the proposed standard for D-Cinema—Digital Cinema Distribution Master (DCDM) Image Structure with the following words: "Limitation of Frame Rate to 24 or 48 may limit artistic choices of filmmakers. There is belief in the 3-D community that a flicker fusion threshold of 120 Hz needs to be achieved to provide adequate motion rendition."

Digital Cinema Operations Documents

There are no known changes or additions required in any of the Digital Cinema Operations documents.

Digital Cinema Quality Documents

There are no known changes or additions required in any of the Digital Cinema Quality documents.

IMPACT ON HARDWARE IMPLEMENTATIONS

The impact in regard to the support of manufacturers for the proposed additional frame rates is as follows:

In the case of 24 frame/sec systems, an increase to 25 frames/sec is just slightly more than a 4% increase in clock frequency, but it is expected that most manufacturers will have the tolerance in their designs to accommodate this increase.

In the case of 48 frame/sec systems, the percentage increase in clock frequency in order to obtain 50 frames/sec is the same at slightly more than 4%.

In the case of 60 frame/sec systems, there is a more significant increase in clock frequency of 25% and some manufacturers systems may need a considerable level of upgrade to support this frame rate.

Reports from individual manufacturers in regard to their support of the proposed additional frame rates address their various concerns, including disc media, memory issues, and the JPEG 2000 codec.

Interfaces

The SMPTE Serial Digital Interface (SDI) is the primary realtime interface for connections between the media block and the projector. Other interfaces can be used for connections within secure housings but are not regulated by SMPTE standards (or any other internationally recognized standards development organization). Rather, most widely used computer monitor standards are governed by industry associations and subject to the influences of their industry members.

Serial Digital Interface (SDI)

The final report includes an annex that summarizes possible uses of SDI connections that could be used for the class 1 frame rates.

The table in that report illustrates the need to balance the sampling structure (4:4:4, 4:2:0, etc.), the bit depth (10 and 12 bits), and the number of 1.485 Gbit/sec links needed. SDI links operating at 2.97 Gbits/sec could be used to reduce the number of cables indicated by half.

Many SDI specifications, such as SMPTE 372M and 425M are limited to 1920H pixels, not 2048H pixels as needed by D-Cinema. Both have undergone revision to accommodate the higher horizontal pixel count.

Link Encryption

The link encryption standard, SMPTE 427M, will need to be extended for support of the additional frame rates.

Processing Issues

Some manufacturers are reporting that their equipment cannot be guaranteed to deliver the 25% increase in the signal bandwidths associated with frame rate changes from 24 frames/sec to

30 frames/sec (and from 48 frames/sec to 60 frames/sec) and is beyond their current design capability. This seems to be a design issue rather than a fundamental issue, and if designs were initially targeted at 30/60 frame/sec frame rates, then the problem would be solved. This is somewhat of a "chicken and egg" issue, because manufacturers will not commit to a 30/60 frame/sec design unless it looks certain to be standardized and 30/60 frame/sec material will not be created until there is manufacturer support.

CONCLUSION

The study group has found a large base of users who create cinema content in electronic form for public display and who have strongly requested the support of the proposed additional frame rates within the D-Cinema specifications to ensure that editorial intent is accurately conveyed to the viewer.

The group recommends two categories of additional frame rates—those that are in widespread current use (class 1) and those that are required to present historical content (class 2).

Input from European filmmakers who support the proposed additional frame rates has been documented.

The study group has concluded that one or more SMPTE documents can define the proposed additional frame rates with minimal impact to existing DC28 documents. Indeed, it is recommended that all necessary provisions from the current DC28 suite of documents be accepted for use with the proposed additional frame rates.

The study group believes that the proposed additional SMPTE documents will ensure greater interoperability between those communities who require additional frame rates and avoid divergence of implementations.

ACKNOWLEDGMENTS

Thank you to the members who served on the "Study Group on Additional Frame Rates for D-Cinema Use." This group is now disbanded, but the record of the group remains useful.

Wilkinson

Jim Wilkinson began his broadcasting career at IBA's engineering headquarters in 1974. In 1979, he joined the newly created Advanced Development Laboratories of Sony Broadcast as one of the founding members. His many activities and projects during his 28 year-tenure at Sony include digital video recording, image compression and processing, digital audio, and metadata and filestream formats.

Wilkinson has been awarded over 80 patents. He has participated in many standards activities in the Audio Engineering Society (AES), the European Broadcasting Union (EBU), and SMPTE. He was an active and prolific member of the EBU/SMPTE Task Force and is now equally active within the SMPTE engineering committees on the follow-up work now being undertaken, with particular emphasis on metadata and filestream formats. In 1995, he was awarded the Alexander M. Poniatoff Gold Medal for Technical Excellence by SMPTE.

Wilkinson retired from Sony in 2006 and now works as an engineering consultant in the areas of video and sound with an ongoing interest in compression and filestream formats. He currently chairs the IBC papers committee and is a Chartered Engineer and fellow of the Institution of Engineering and Technology (IET) and SMPTE.

Kleijn

Kommer Kleijn is a director of photography specializing in visual effects and special formats. He shoots and supervises visual effects for commercials, animation, large format and special venue movies, many of which he has also photographed. Kleijn's work includes nine stereoscopic productions (one IMAX 3-D), most of which combine live footage and CGI. He also works on equipment design and is an instructor at three film schools. Kleijn is an active member in IMAGO (the European Federation of Cinematographers) and is an SBC and European Digital Cinema Forum (EDCF) board member. Web: www.kommer.com.