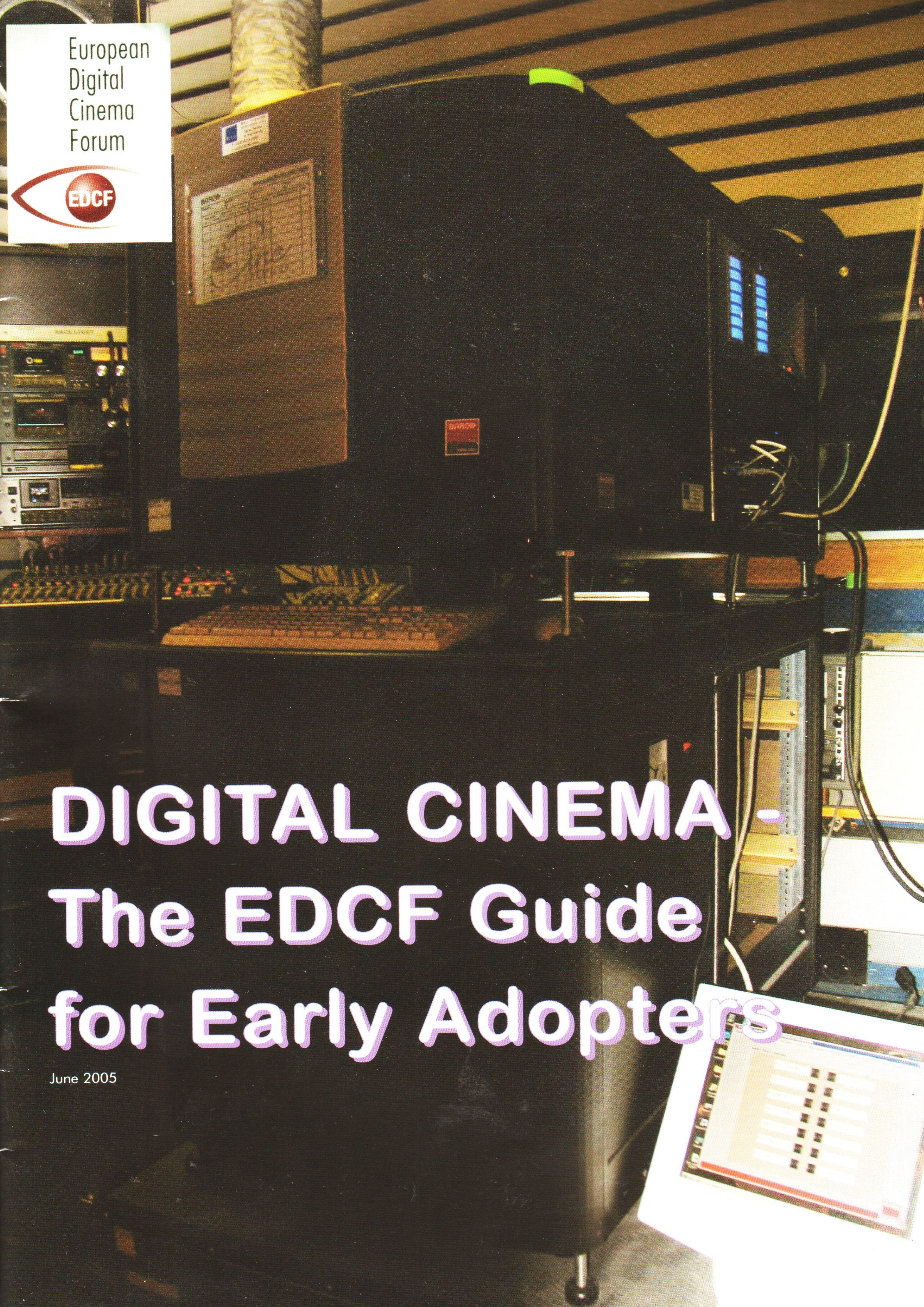
European
Digital
Cinema
Forum
EDCF



DIGITAL CINEMA - The EDCF Guide for Early Adopters

June 2005

The European Digital Cinema Forum

Following liaison between the Swedish Work Group for E-cinema (Swedish Film Institute), the DTI/DCMS Group on Digital Film Production and Distribution (UK) and Groupe de Travail Cinéma Numérique (CNC/CST, France) the EDCF was formed in Stockholm June 13th 2001 at a meeting which gathered thirty representatives of institutions, companies and trade associations within the European film, TV, video and telecom sectors.

EDCF objectives

- To function as a network for European co-operation on E- and D-cinema activities.
- To identify key issues, gather information and create models to encourage private investments and public support schemes.
- To liaise with other relevant bodies to assist in the establishment of appropriate world-wide standards for E- and D-cinema.
- To co-ordinate and establish European user requirements for standards for all parts of the E- and D-cinema chains.
- To initiate and co-ordinate R&D relevant to European digital cinema.
- To stimulate European production with a broad scope of quality content for E- and D-cinema.

The EDCF is a not for profit organisation established as a a "Stichting" (foundation) under Dutch law.
The General Secretary, John Graham, can be contacted through the EDCF Administration Office which is c/o BKSTS (British Kinematograph Sound and Television Society), Pinewood Studios, Iver Heath, Bucks, UK. SL0 0NH
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The EDCF Guide to Early Adopters.

The goal of this booklet is to provide a tutorial and preliminary information and guidelines to early adopters in the digital cinema exhibition business. This booklet cannot pursue all the system architectures, and the intention is to do this in a subsequent complete Theatre Systems Booklet.

The EDCF is extremely grateful to the following Member companies who have sponsored the publication of this *EDCF Guide to Early Adopters*.

The EDCF Guide for Early Adopters

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1 Foreword

Digital Cinema is in its infancy: it is only in the last four years that the technology has been seen as being in any way comparable to 35mm film.

For many years analogue and digital systems for transmission and projection have been used, although these early systems did not meet the stringent requirements of the major Hollywood programme producers. Advances in technology have meant that the gap between a 35mm print and Digital Projection has closed and there is now scope to take up some of the benefits digital technology offers in quality, consistency and potential cost savings in distribution.

The Digital Cinema systems rolled out so far use predominantly one projector technology, and more than one incompatible compression format.

To harmonise requirements, the major studios formed a company called DCI (Digital Cinema Initiatives LLC) to write a document describing the needs of mainstream Digital Cinema. This document will be shortly submitted to the SMPTE for international standardisation. SMPTE is already working on draft versions. As SMPTE is a due process organisation following ISO rules this standardisation may take up to two years.

Much of the technology in the DCI requirements specification is in development, particularly the 4K (4096 Horizontal x 2160 Vertical picture elements, commonly known as pixels) Projection, Server and Compression developments.

Security is a major issue. On the one side the studios wish to increase their control over their content and what happens to it, on the other side the Exhibitors do not wish to decrease their flexibility. Of course Piracy is a major concern as it decreases the revenues of all the legitimate parties.

The EDCF Technical module has a core of around thirty five regular participants and its first job was to take input from the EDCF Commercial module and generate a set of guidelines. These guidelines are at a high level and represent a wider set of applications than the DCI's Hollywood Blockbuster viewpoint. Of course there is no point in making the systems in Europe and the USA dissimilar, so the EDCF has defined two levels (1&2) for Digital Cinema, which are modelled in principle around the DCI requirements. There are also two levels (3&4) for alternative applications and possibly non-Hollywood content.

The DCI is a commercial company and represents the combined views of seven of the most powerful studios in Hollywood in its requirements document.

As SMPTE is a due diligence standards body closely regulated by ANSI (American National Standards Institute) SMPTE must take into account the views of its members and follow very strict ballot procedures. SMPTE cannot be seen to rubber-stamp the DCI requirements into a standard without ample opportunity for input from all its registered committee members.

SMPTE subgroup DC28 and DCI have been working closely for some time, much of the standardisation work has already been started. There are a few areas that involve new science, which will take some time to complete.

EDCF Levels three and four draw heavily on existing TV technology and are therefore supported quite well by existing standards.

1.1 The Guide

Why would the EDCF make a guide for early adopters? In Europe there have been several experimental D-cinema or E-cinema projects in operation, some commercial and others government subsidised.

These projects have used a wide variety of equipment and been used for mainstream blockbusters and the relaying of cultural events or commercials. The mix of equipment used may or may not mean the projects can show Hollywood material. To some extent this depends on the local distributors but the reality is that the Hollywood studios are taking an increasingly hard line on the type of equipment on which they will allow their content to be presented.

Within SMPTE DC28 there was a move to document the systems used by early adopters and issue guidelines on, for example, the way to display a 2.25:1 aspect ratio image on a 1.3K pixel horizontal resolution projector using an anamorphic lens. This Document was called DTIMS. This initially meant Digital Theatre Intermediate Mastering System but was changed to Digital Theatrical Interchange Master Image Format. Pressure from some of the DCI members that were in no hurry to adopt Digital Cinema caused SMPTE-DC28 to drop DTIMS. The information contained within DTIMS will be integrated into the DCDM, Digital Cinema Distribution Master.

The EDCF felt that some guidelines would be useful to operators who wanted to get up and running with Digital Cinema projects in Europe before the standardisation is complete. Although it is not possible for the EDCF to make commercial recommendations regarding individual manufacturers equipment, it was felt we could describe the issues related to the technology that is being used to date and into the near future.

The document will be informative and will explain in plain terms the major issues and terminologies used in Digital Cinema and what their implications are. Potential users will then know what questions to ask equipment manufacturers and movie distributors before investing in equipment. It will also enable the operator to decide what market sector he wishes to trade in.

Peter Wilson
Chair of the EDCF Technical Module
EDCF Vice President, Industrials

2 The EDCF Technical Module

The EDCF Technical Module is chaired by Peter Wilson of High Definition and Digital Cinema Ltd. and the secretary is Robert Spray of BT Exact.

The module has seven subsidiary Topic Groups:

- **Digital Film Acquisition and Digital Intermediate (Chair: David Bancroft, Thomson)**
- **Transport and Delivery (Chair: Wolfgang Ruppel, T-Systems)**
- **Security (Chair: Xavier Verians, Octalis)**
- **Theatre Systems (Chair: Angelo D'Alessio)**
- **Audio (Chair: Jason Power, Dolby)**
- **Projection Systems (Chair: Matthieu Sintas, (CST)**
- **Server Systems (Chair: Benoit Michel, XDC)**

3 Theatre Systems

Section written by Angelo D'Alessio of Cine Design Group

3.1 Categories and Architectures

The definition and understanding of categories and architectures of Theatre Systems is the first step for an (Exhibitor) early adopter that intends to be involved in Digital Cinema and related business.
Without such clarification, Theatre System for digital cinema can be loosely used to describe anything to do with digital projection technology of content.
Three categories of Theatre Systems can be considered:

- For Digital Cinema (D-Cinema);
- For Alternative Content (A-Content);
- For Digital Pre-Show and Advertising.

For each or all of these categories the Exhibitor can build two Architectures:

- Single Screen Architecture or
- Multi Screen Architecture

The terms Digital Cinema, Alternative Content, Pre-Show and Advertising designate the overall quality and performance of the Theatre Systems taking into consideration the performance of the Presentation System (Media Block + Projector), the distribution system, and the preparation of the contents for the three categories.

3.1.1 Digital Cinema

D-Cinema has come to mean the presentation of 'first release feature film' in commercial cinemas using a high studio-quality content and Presentation System (Media Block + Projector) that conforms to approved global standards and specifications and provides a viewing experience equal to or better than 35mm Answer Print film. The storage and projection equipment (The Presentation System) has been designed specifically for motion picture use. The quality of the presentation meets the industry's high standards, specifications and the expectations of critical movie makers like DCI. To the extent that is possible, the Digital Cinema system shall emulate theatre operations and the theatre business model, as it exists today.
Key specs/info are: Distribution by physical media to start / J-Peg2000/10-12Bits depth/Store and forward/SMPTE Standards.

3.1.2 Alternative Content

Alternative Content means the presentation of non-feature film using digital equipment. Typically, the storage and projection equipment used in an Alternative Content installation is off-the-shelf and has been designed, generally, for applications other than movie theatres. Although the equipment is lower in cost, the quality of the presentation can still be high, depending upon the individual system and content being played. Alternative content is included in the so called LSDI - Large Screen Digital Imagery by ITU (International Telecommunication Union).
Key specs/info are: Distribution mostly Satellite /M-Peg2-4/ 8-10Bits depth/ mostly live events/ ITU Standards.

3.1.3 Digital Pre-Show and Advertising

Many cinemas are installing digital equipment as a replacement for the static slide projectors that handle pre-show programming and advertising. While these projectors and related equipment can lead to a more exciting pre-show, the performance of the equipment is inadequate for showing feature content.
It is suggested that the quality of this content will gradually reach the quality of Digital cinema and/or Alternative content.

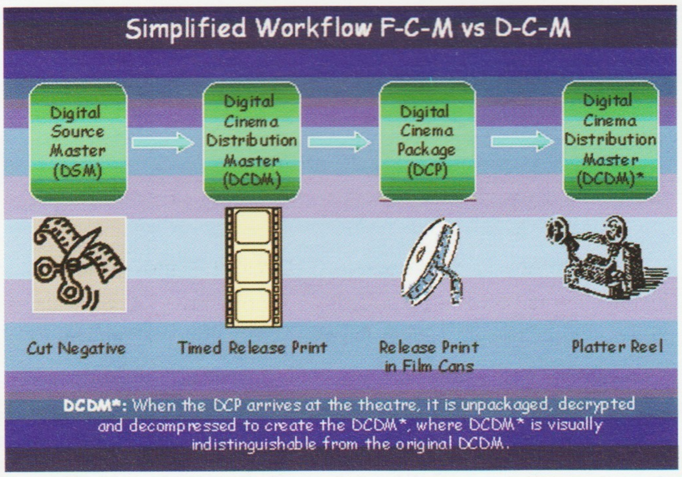
The following table gives a summary of the categories.

Category	Use	Standards	Typical Equipment	
D-Cinema	Mainstream feature movie. Store and forward. Shall not preclude the capability for high end Alternative contents and independent movies.	Open published industry standards that are widely accepted and codified by international standards bodies such as: SMPTE, ANSI and ISO/IEC.	Projectors:	Studio approved and with cinema specific features. Typically secure links, wider color space, enhanced contrast ratio and resolution (4K&2K).
			Players:	Studio approved compression.
A-Contents **(LSDI)**	Alternative contents. Mostly live events. Mainstream movies only at the Studio's and Distributors discretion	Being developed by ITU.	Projectors:	High-brightness, high-resolution (HDTV), large-venue projectors with light output greater that 4,000 ANSI lumens
			Players:	Mostly M-Peg2-4 compression.
Pre-Show and Adv.	Pre-show and advertising.	Set by the specific implementation.	Projectors:	Range from professional theatre quality projectors to the use of D-Cinema and A-Contents systems.
			Players:	Any compression with preference to D-cinema and A-contents compression.

3.2 Theatre System: the core system for the D-cinema exhibitor.

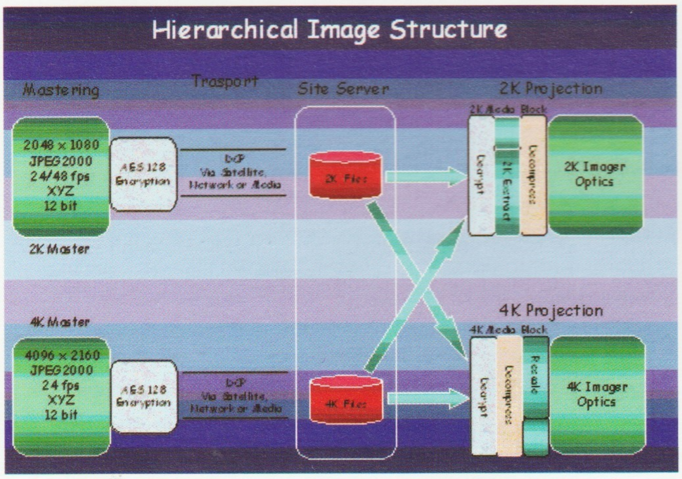
The Theatre System contains the requirements for the system equipment installed at a theatre for presentation, control, scheduling, logging and diagnostics.
One of the key factors that is important for the exhibitor, not considering other important issues like financial and business models, is interoperability.
Interoperability takes on special importance with cinema exhibitors. Exhibitors recognize that it is unlikely that all 35mm screens will be changed out to digital at one time. The process of rolling out D-cinema is expected to take many years. So the hardware and software used in the Theatre System should be easily upgraded as advances in technology are made. Upgrades to the format should be designed in a way so that content may be distributed and compatibly played on both the latest hardware and software, as well as earlier

adopted equipment installations. If systems installed in year five are to work with the infrastructure built in year one, the interoperability at system level is mandatory for a successful rollout.
The D-movie that the exhibitor will receive from the distributor is called DCP (Digital Cinema Package). The DCP is the compressed, encrypted file or set of files containing the content (the D-movie) and its associated data. In order to familiarise ourselves with new terms let us analyse the content's relationship between the Film-Centric-Model (the 35mm model) and the Data-Centric-Model (the D-Cinema).
The following figure gives a simple explanation of this relationship.



For the Film-Centric-Model practically only one quality level is in use (the 35mm), for the D-cinema two quality levels of DCP have been specified. They are called 2K and 4K.

The DCP and the Theatre System will use a Hierarchical Image Structure that provides both 2K and 4K resolution files, so that studios can chose to deliver either 2K or 4K DCP copies/files and both 2K and 4K projectors can be deployed and supported. The arrangement is shown in the diagram below. This implies that all servers shall be capable of storing a compressed DCP of 2K or 4K resolution. Media blocks for 2K projectors shall be able to extract and display the 2K resolution file from the 2K/4K DCP file. Media blocks for 4K projectors shall be able to display the full 4K DCP while being capable of re-sizing a DCP containing only a 2K file.



Note: It is suggested that when using a 2K projection system, a dedicated 2k delivery system would be preferred, rather than on-site down-conversion from 4K.

3.3 Theatre System

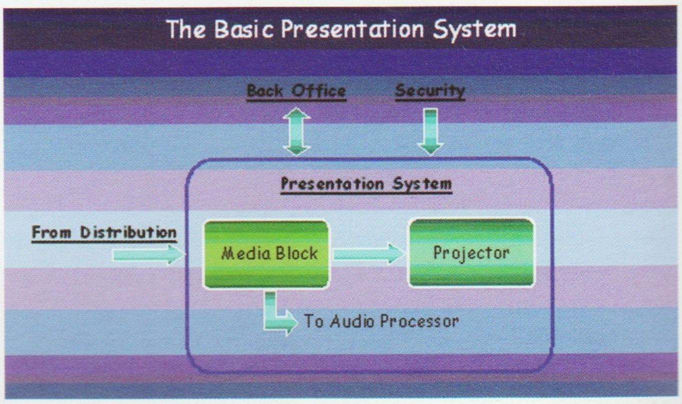
The Theatre System includes all the equipment required to make a theatrical presentation within a theatre and within an auditorium located within a Theatre complex. This encompasses projectors, secure media blocks, storage, sound system, DCP ingest, theatre automation, interfaces, Screen Management System (SMS) and Theatre Management System (TMS). The Theatre Management System controls supervises and reports on all the equipment in the theatre. The Screen Management System is the human interface for the Theatre Manager for local control of the theatre operations such as start, stop, pause, select a show play list and edit a show play list. The Theatre System architecture, the equipment and the interconnections within the Theatre, can be related to:

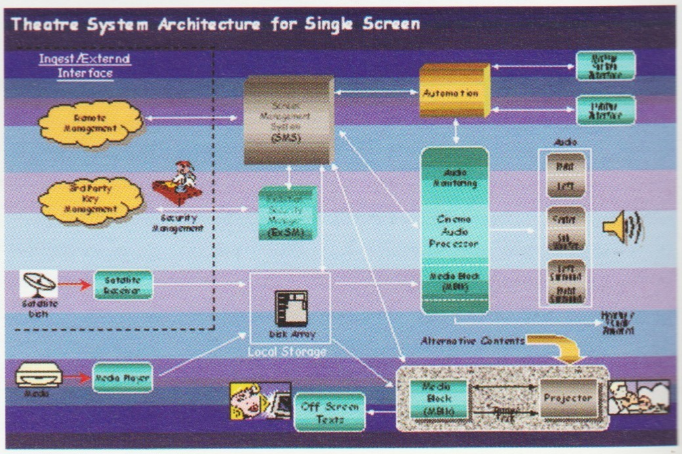
- Single Screen Architecture; or
- Multi Screen Architecture.

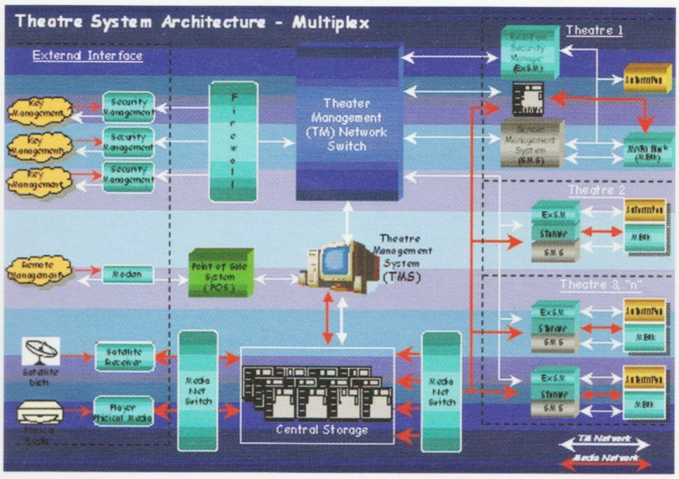
Theatre Systems have a wide range of tasks. They provide a theatrical presentation in a timely manner, as well as controlling the environment in which it is presented. The complex systems contain several components, interconnections and human interfaces.

The human interfaces, the Screen Management System and Theatre Management System, allow for control, programming, security, troubleshooting, asset management and monitoring the status of the digital cinema equipment and systems. There shall be one Screen Management System for each auditorium and one Theatre Management System for a multi screen. This type of implementation requires that the Theatre Management System can be controlled or accessed by a local or remote Master Theatre Management System. There may also be the possibility of a Point of Sale System that would need to interface to the Theatre Management System for scheduling purposes.

The following figures illustrate the basic Presentation System and the basic Theatre System Architecture for Single Screen and Multi Screen applications.







All Theatre Systems have some basic requirements:
Reliability, maintenance, test shows, monitoring and diagnostics, easy assembly of content, movement of content within the multiplex, storage capacity per screen, security, show play list, editing play list etc.

There are many different scenarios for each and within the three specified Categories of:

- D-Cinema;
- A-Content (LSDI);
- Digital Pre-Show and Advertising.

The goal of this booklet is to provide a tutorial and preliminary information and guidelines to early adopters in the digital cinema exhibition business. This booklet cannot pursue all the system architectures, and the intention is to do this in a later complete Theatre Systems Booklet. The Theatre System for Digital Cinema is a complex system and only high level expert professionals can design and built efficient and effective systems.

Moreover, working in this new scenario requires prepared and trained professionals. An effective and efficient learning and training methodology must be considered at international, and more importantly, at local level. Co-operation with education and training organisations is mandatory if we are to be sure that the advancement of the technologies is in line with the skills required to support the roll-out of Digital cinema and related categories.

3.4 FAQs: Frequently Asked Questions

The following are some key questions the exhibitors need to answer before planning for the transition to d-cinema.

- Use of Alternative Content. Do the theatre owners intend to exhibit any form of entertainment in their cinema other than motion picture? If yes, which form of product? (concerts, educational programming, sport events etc.).
- Is it a new theatre or an old one? How many screens are involved? Size of each auditorium and screen?
- Which digital sound systems, if any, are now in place? How good is the sound performance of the theatre?
- Cinema content security. Is movie piracy a problem in your theatre? What steps are taken presently to ensure the security of their premises and content (movies)?
- Solutions for those with disabilities. Any new innovations to be considered to provide help for people with hearing problems and visual impairments?
- Screen advertising. Which type? Need local editing?
- Trailers. Are trailers attached to the feature film?

4 2K or not 2K?

Section written by Peter Wilson of *High Definition & Digital Cinema Ltd. Supported by Snell and Wilcox.*

hddc

SNELL & WILCOX
Engineering with Vision

In response to a series of announcements regarding mastering for 2K and 1.3K it was obvious that the 'sound byte' terms 1.3K, 2K & 4K were not well understood, nor were the practical Implications they bring with them. This section is based on a presentation made for the EDCF Management Team and aims to unscramble the meaning of 1.3K, 2K, 4K.

A Digital Image is made up from Horizontal and Vertical Picture Elements called Pixels. If you look closely at a modern Plasma or LCD Flat Screen Display you will see a pattern of dots, these are the pixels. These elements are scanned from left top to right bottom just like a regular Cathode Ray Tube Television.

A Progressive Scan image starts at the top left and scans to the bottom.

An Interlace Scan image starts at the left top and scans to the bottom centre then moves to the top centre and scans to the bottom again. Hence two half pictures vertically are interlaced together.

4.1 Pixels

As mentioned above a Pixel is a picture element. In most displays there is a pixel for Red, Green and Blue light. The Pixels are electronic elements able to change digital or analogue values into amounts of light. There are several different schemes for making colour pictures, as inherently the pixels only display monochrome brightness.

4.2 What is a K?

A K or Kilo is normally the Metric representation of 1000.
A K in Digital Cinema is the Binary representation of 1000 (2 to the power of 10) or 1024.
Is the term K used properly, No!! It is relatively meaningless.

4.3 Common Ks

When Kodak Developed the Cineon System for digitally processing film they developed film scanners and recorders. In the scanner they equated scanning the full frame of a piece of 35mm film with a 3μ scanning spot size as a 4K scan. So,

- 35mm Photochemical to Digital conversion with 3 micron scanning beam 4096 pixels x 3112 pixels academy aperture = 4K, actually 12 million pixels or Megapixels
- 35mm Photochemical to Digital conversion with 6 micron scanning beam 2048 pixels x 1556 pixels academy aperture = 2K actually 3 Mega pixels

• 4K DCI Digital Cinema transmission container and projection array 4096 x 2160 actually 8.8 Mega pixels
• 2K DCI Digital Cinema transmission container and projection array 2048 x 1080 actually 2.2 Mega pixels
• 1.3 K PC graphics chip in early D-cinema projectors 1280 x 1024 actually 1.3 Megapixels (Used with Anamorphic lenses for wide screen)

For reference, consumer HDTV @ 1920 x 1080 is actually 2.1 million pixels.

Indicating the gross number of pixels in the frame as in stills photography is the best way to describe the true potential resolution. This is not the common way in D-Cinema, for political reasons. The reason that the DCI did not just adopt the Kodak numbers for presentation is because there are no big feature movies shot with the academy aspect ratio any more. Most are widescreen or 'Scope.

4.4 Broad Projection Categories

Digital Cinema

Wide Colour Gamut
High Contrast
Specified Resolution

Large Venue

TV Colour Gamut
High Brightness
Varied resolution

Home Cinema

TV or Wide Colour Gamut
Limited Brightness and contrast
Varied resolution

Business Graphics

TV / PC colour gamut
Very limited Brightness and Contrast
PC graphics resolution

Apart from the D-cinema projectors, none of the systems are calibrated end to end.

4.5 Mastering

D-cinema containers are 4K - 4096h x 2160v or
2K - 2048h x 1080v
The following numbers are utilised:

Level	Pixels Horiz	Pixels Vert	Aspect Ratio	Pixel Aspect Ratio
1	4096	1714	2:39	1:1
2	3996	2160	1:85	1:1
1	2048	858	2:39	1:1
2	1998	1080	1:85	1:1

An early D-cinema format often referred to as DTIMS (Digital Cinema Interim Mastering System) used anamorphic lenses with the 1.3K, 5x4 aspect ratio D-cinema projector. These are the commonly known 1.3K projectors which are still installed in many cinemas round the world. Anamorphic lenses magnify more in the Horizontal direction than vertical and compensate for the fact that the 5x4 aspect ratio chips are really the wrong shape.
Non D-cinema projectors using 5x4 chips can lose excess vertical resolution without anamorphic lenses for scope movies.

4.6 Mastering Process (2K)

• **Prepare the Digital Source Master (DSM)**
Today this can be one of two approaches,
2048 x 1080 container, file based (Digital Intermediate or Film Scan). Although this is "true 2K" you may note that the whole container is not filled up. (See DCI Table above)
1920 x 1080 container real time based, the Film is transferred to HD tape from a Telecine machine. Colour corrected using a Digital Cinema projector and output to file as a DSM. In this case the signal will most likely be in component format with bit depth limited to 10 bits. A significant number of today's Digital Cinema releases are made this way.

4.7 Digital Cinema Distribution Master

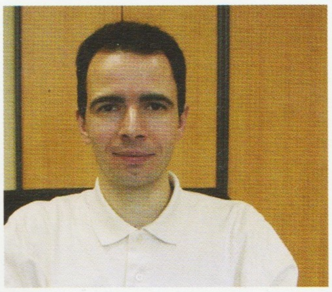
The DCDM preparation is typically started by taking the DSM and preparing it for compression in the following formats:
• 2.35:1 2048 x 858, JPEG 2000 flat lens in a 2048 x 1080 container
• 2.35:1 1920 x 818 MPEG 2, flat lens in a 1920 x 1080 container
• 2.35:1 1280 x 735 MPEG 2, 1.3K projection, 1.35:1 lens in a 1920 x 1080 container
NB: The above formats are generated by a hardware scaler just before Packaging into the Digital Cinema Package.
There was a confusion regarding 1.3K projectors as the very first units did not have vertical scaling. These have virtually all been replaced with 1.3 projectors that can scale the image horizontally and vertically. In this case one master can be created at 2K/HD and the 1.3K projector will scale the image to fit the 1.3K light modulators.
Cinema Net Europe master at 2K/HD even though their network uses predominantly 1.3K projectors and much of their content is from Standard Definition TV.

4.8 Digital Cinema Package

Once the Picture elements are compressed they are Encrypted and wrapped together with the other elements required to make a show. Typically that is multiple audio tracks encompassing surround sound, multiple language tracks, Audio Description tracks, Subtitle data and Metadata to describe information and settings required for presentation. The Wrapper uses MXF, the Media Exchange Format, which is a SMPTE standard.

5 Digital Projection

Section written by Mathieu Sintas of CST.



D-Cinema and E-Cinema will require the use of the best electronic projection technologies. Some of these technologies are currently available and others are under development. This section provides a brief survey of those technologies.

5.1 E and D-Cinema, and standards

Manufacturers generally give the main parameters of their products, measured in lab conditions. For D and E applications, users may want to achieve a minimum level of quality for their audience. This will need a combination between the performance of the projector and the characteristics of the screening room to be accomplished.

For example, the manufacturer gives the luminous flux of the projector and the standards for D-Cinema will require a certain luminance on the screen. The bigger the screen is, the more powerful the projector should be. The following information is based on the draft standards and recommendations as they are today (April 05), concerning the level of performance that could be required. These recommendations are based on the ITU Standards on LSDI (Large Screen Digital Imagery, i.e. E-Cinema), draft SMPTE standards and recommended practices, based on DCI and AFNOR draft standards for digital projection.

5.1.1 E-Cinema

As far as E-cinema is concerned, there are few recommendations on the projection aspect, except from the use of the SLET (Stray Light Eliminator tube) that is mentioned in doc ITU BT R 1686.

5.1.2 D-Cinema

For D Cinema all the documents agreed that the minimum resolution of the matrix should be 2K (2048 x 1080), and that the colour gamut should include at least the primaries of the DLP Cinema technology.

The luminance of a white picture is 48cd/m^2 in the DCI/SMPTE and AFNOR draft standard.

The contrast ratio required is measured by the difference between a full white and a full black picture. The value for screening rooms in the DCI/SMPTE documentation is 1200, and 1000 in the AFNOR draft standard.

Status of the documents

All these documents aren't mandatory. But some distributors (the Hollywood majors for example) may require the projection to be compliant with the SMPTE standards to show their movies. In France the administration will require compliance with the AFNOR standards to allow theatres to project movies digitally (applies to short, long and documentary films).

5.2 Image Format

The main image formats usable for wide screen are those defined by DCI (2K and 4K) and the HD defined by ITU BT R 709 (1920 x 1080). When the images are projected, some processing may be required. If the projector's native pixel format differs from the image pixel format, scaling of the image is required. If the projector's native display format is to update all pixels simultaneously, and if the image is interlaced, then de-interlacing or frame rate processing will be required somewhere in the chain. There are techniques to convert between interlaced and non-interlaced image representations. These techniques range from simple line doubling to sophisticated motion tracking systems. The most sophisticated (and purportedly highest quality) de-interlacing techniques employ significant processing and can be expensive.

5.3 Deployed Projection Technologies

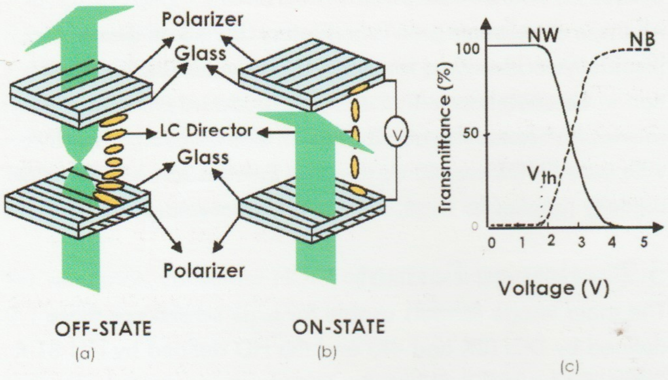
Early projectors used CRTs for low brightness applications and light valves (either oil film or later LCD-based) for high brightness applications. In all three cases, the image was drawn using an electron beam in a raster scan configuration. These early projectors easily operated with an interlaced signal. All three technologies have been superseded by the DMD™, the D-ILA™and the LCD.

There are currently two large screen digital projector technologies widely deployed. They are the transmissive LCD and the reflective DMD (Digital Micro-mirror Device). Some projectors based on reflective LCD (D-ILA) devices have also been deployed. All of these technologies employ planar devices with individually addressable pixels. In the large venue projectors employing these technologies, all pixels in the image are updated simultaneously.

5.3.1 LCD

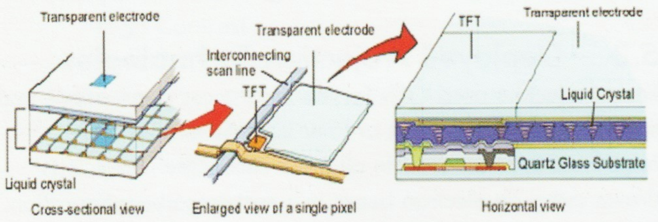
The transmissive LCD is a digitally addressed analog modulated technology that uses an LCD crystal to modulate the light polarization at each pixel location. The light source is generally an HMI lamp because LCD has a poor luminous efficiency.

The LCD has analog-like properties that can vary the intensity of light at each pixel based on how much the pixel's crystal is twisted. As the crystal twists, the light's polarity is changed. The intensity changes are then realized by using polarising filters in the light path. Each LCD panel handles one colour signal; the projectors employ 3 panels to handle RGB colour images.



The diagram shows the LCD matrix in on and off states.

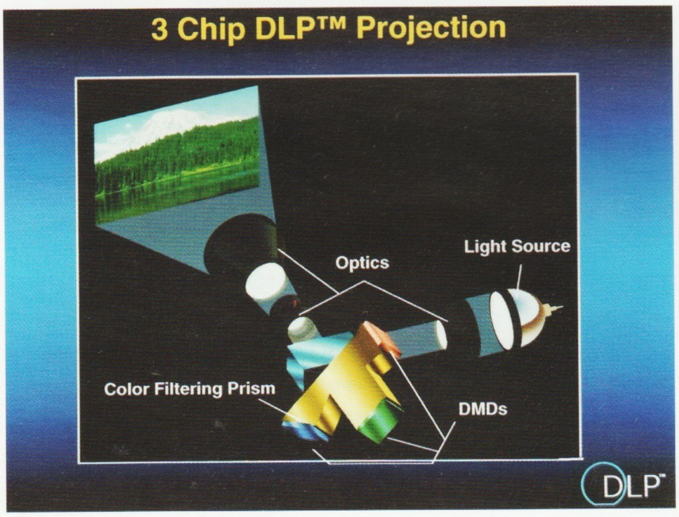
The LCD technology is found in small to medium brightness front projectors. The brightness can be as high as 6K lumens for some models. Typical large venue resolutions are SXGA (1280 x 1024), although models with 1920 x 1080 resolution are now available. The projectors using transmissive LCDs update the entire image at once. These projectors can accept and display interlaced content as they contain the appropriate processing circuitry as part of the projector electronics.



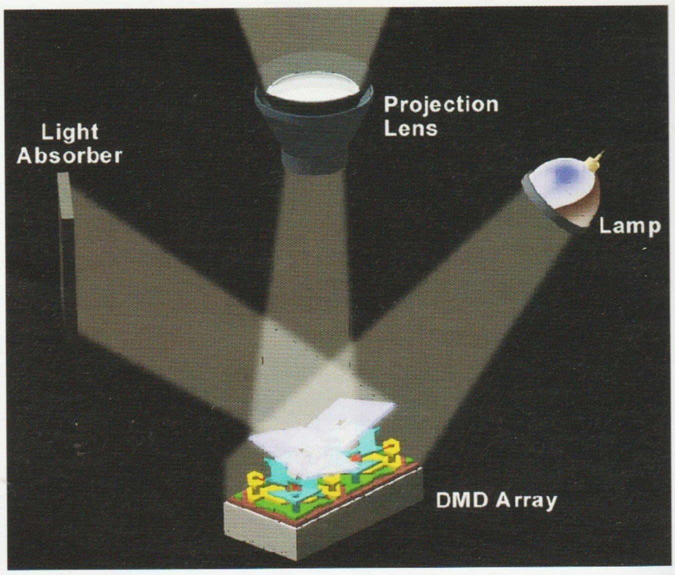
Transmissive LCP panel (source: Epson)

5.3.2 DMD and DLP

The DMD™ (digital micro-mirror device), also called DLP™ (Digital Light Processing), is a binary reflective technology developed by Texas Instruments that uses pulse width modulation to achieve an analog-like representation of brightness at each pixel location. Each pixel is created by a mirror mounted on a movable post that can be toggled to reflect light either onto the screen or into a light dump. The entire image is loaded into a frame buffer and each mirror is then modulated based on the brightness value of the pixel. The fraction of time the mirror is in the 'on' position is directly proportional to the brightness of the addressed pixel. Each device containing an array of mirrors handling one color component. Projectors employ 3 devices to handle RGB color images. The DMD is widely deployed in very high brightness front and rear view projectors because of its high tolerance to heat and light. DLP projectors update the entire image at once and require interlaced content to be processed prior to display. Some models can accept and display interlaced content as they include appropriate processing circuitry as part of the projector electronics.



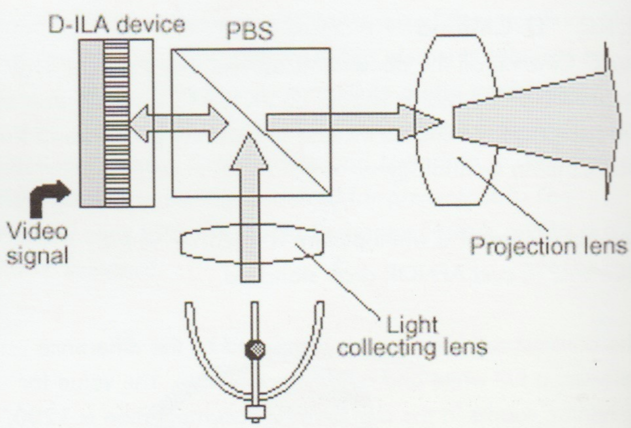
Three DMD configuration (source: Texas Instruments)



Two micro-mirror tilting (source: Texas Instruments)

5.3.3 DLP Cinema

DLP cinema is an evolution of the technology that uses a wider colour gamut (by using an alternative set of optical filters in the light path). It also uses a better digital processing to address more precisely the low level of the picture.
A DLP Cinema projector does not have a remote control with access to brightness, gamma, hue, like we might find in other projectors. All these settings are made during a calibration process, with a precise measurement of the light reflected by the screen. This process is done by connecting a PC with specific software to the projector.



Representative diagram of a D-ILA and LCOS projection system. Tri-colour devices have three optical paths for Red, Green and blue channels

The highest quality DMD projectors, including those installed in Digital Cinema applications, are currently 2K (2048 x 1080). Projectors based on DMD devices are available that can handle xenon arc light sources up to 6-7 kW, and can provide light output as high as 20K lumens.

5.3.4 Reflective LCD and D-ILA

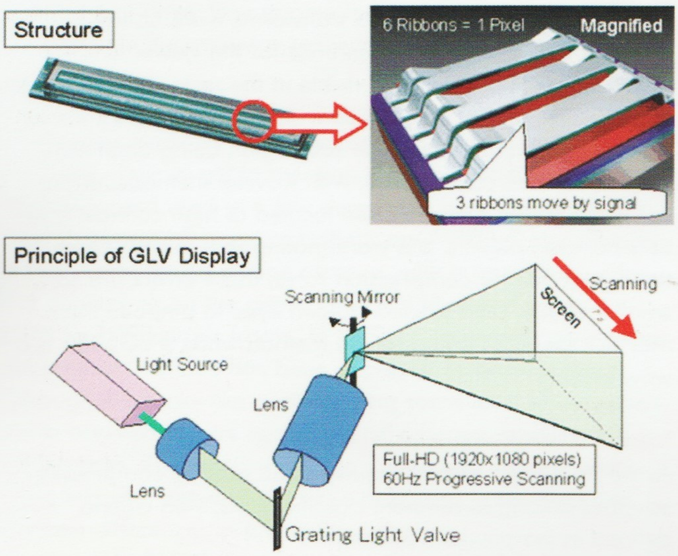
Reflective LCD displays, commonly known as LCoS (Liquid Crystal on Silicon) and D-ILA (Digital Image Light Amplifier - technology developed by JVC), use a mirrored substrate with an LCD structure to modulate the light. The reflective LCDs tend to be less efficient than the transmissive LCD or the DMD. D-ILA and LCoS displays can be manufactured with higher pixel densities and higher fill factors than the DMD, but suffer from the same temperature and heat capacity issues as the Transmissive LCD technology.

Projectors using reflective LCD devices are on the market for use on screens up to 10 metres, and prototypes for larger screen venues have been shown. Resolutions for the D-ILA are as high as QXGA (2048 x 1536) and a demonstration of a 3840 x 2048 projector has been conducted. These projectors all update the entire image simultaneously. Current D-ILA projector models can accept and display interlaced content as they include appropriate processing circuitry within the projector.

5.4 Summary

The display technologies currently deployed in the theatrical environment are planar pixel addressed topologies that, as applied in commercial projectors, update all pixels simultaneously. This a good match to current progressive image capture devices that capture all pixels in the image simultaneously. Future projectors based on devices in development are also planar, with the exception of the GLV (Grating Light Valve), which is a line refresh device. All devices use a frame buffer to store the pixels prior to display.

Any interlace content destined for large screen display will,



due to the nature of the commercially available projectors, require processing prior to actual display. Because of the large screen display, and likelihood of close viewing distances (1-3 picture heights), all image processing should be performed with the highest quality possible.

5.4.1 4K x 2K Display Systems

CRL (Communications Research Laboratory) and JVC (Victor Company of Japan) have jointly developed a display system with 2000 scanning lines called Quadruple HDTV. The projector employs three LCD panels of 3840 by 2048 pixels. The light output of the projector is 5200 lumens and the contrast ratio is more than 750:1. The resolution of this system corresponds to 2 x 2 times that of a 1920 x 1080 pixel display.

NTT (Nippon Telegraph and Telephone Corporation) has also developed a digital cinema system that can store, transmit, and display images of 2000 scanning lines, with 10-bits each for R, G, and B components. The projector of the system is the same as that of CRL - JVC. Image sources of the system are 35 mm motion films of 24 Hz, and the system operates at frame rates of 24 Hz or 48 Hz. The projector displays the images with a frame rate of 96 Hz in order to avoid any flicker disturbance. The resolution of this system also corresponds to 2 x 2 times that of a 1920 x 1080 pixel display.

Sony recently presented a 4K projector using LCoS technology. This projector is using three panels of 4096 x 2160 pixels and it has been announced as providing 10,000 lumens.

5.4.2 Measurements

Measurements on digital projectors (both for E and D cinema) are described in international documents such as IEC 61947-1 (well-known as an ANSI standard) and ITU R BT 1686 (for the use of the SLET (Stray Light Eliminator Tube) and VESA FPDM Measurement Standard v2.0.

We can distinguish between two methods of measurement. One concerns only the performance of the projector in a laboratory. In this case the illuminance is measured with a lux meter.

For doing such measurement in a theatre we need to use a SLET to eliminate all stray light in the screening room.

The other method is to consider the luminance reflected by the screen and measure what the audience will see. Is this case we will measure the luminance of the screen with a luminance meter in cd/m^2.

To calculate the luminance of the screen with a given luminous flux (ANSI Lumens) the following formula could be used if the system is using a Lambertian screen with a gain of 1.

$$L = \phi / \pi A$$

Where:

L is the luminance of the screen in cd/m^2

A is the area of the screen

ϕ is the luminous flux of the projector in Lumens

Note that the efficiency of the lamp decreases with time and at the theoretical end of its life (ANSI procedure) the luminous flux of the projector will be half the initial value.

6 Compression and Packaging

Section written by Wolfgang Ruppel of *T-Systems* and Benoit Michel of *XDC*

6.1 Introduction

When we examine the delivery of content to cinemas, three major technical areas have to be considered: first, the compression formats for the image and audio essences (including uncompressed audio), secondly the packaging format which serves as a container for the compressed essence streams and associated metadata, and, as the third area, the applied encryption scheme. This section is about compression and packaging formats, while the encryption choices are considered in another section of this document.

6.2 Image Compression

Digital Cinema distribution includes the process of transmitting motion pictures to movie theatres and their subsequent projection. Compression is thus needed to reduce the cost and time of transmission and storage of the movies. For day to day use, compression ratios are expected to be higher than for the archive by permitting lossy but visually lossless compression. Visually lossless is understood to mean that the reconstructed moving picture after decompression shall not be distinguishable from its original by a human observer when exposed to typical viewing conditions in a theatre.

Digital Cinema has been generating much work in industries involved in high quality video coding, as well as in university labs and standardization bodies. The ideal requirements for Digital Cinema may be summarised as follows:

- High resolution: minimum resolution of 1920/2048 x1080 pixels (a.k.a. 2K) or, even better, four times that size (4K)
- Frame rates up to 150Hz/120Hz,
- Color coded with 10 or 12 bits per component, log or linear, with pre-correction for linear
- Compression ratios that support fast transfers of Digital Cinema programs - typically around 10:1 to 20:1, according to the compression method and the complexity of the image content; notice that for TV and HDTV distribution, these ratios are around 60:1 to 200:1
- Support for various resolutions, frame rates, quality levels,
- Low cost and small size implementation for embedding in projector systems,
- Visually lossless coding for distribution when the size of transferred files is important.
- Completely lossless coding for archive applications when top quality is required and the file size seen as less important.

The standardization bodies SMPTE and MPEG have set up study groups on Digital Cinema aimed at defining a standard for digital cinema video compression, considering two main applications, archiving and distribution. Major actors in these activities included industry and universities. The proposed solutions were competing to be the baseline for potential future Digital Cinema compression standards. MPEG finally decided to stop this activity because of a lack of cooperation of the industries involved (probably due to intellectual property issues). More recently, joint efforts have led DCI to recommend a technological solution for distribution which is based on a development of JPEG2000.

The compression schemes belong to two main classes: intra-frame and inter-frame coding. The 'intra' class is composed of compression methods addressing a movie frame by frame in an independent way. Each image is compressed, stored or transmitted, then the next one is compressed, etc. These methods have several advantages, such as a easy access to any image in a movie and simple schemes to 'splice' or assemble several sequences together.

The 'inter' class of compression methods use the redundant information between consecutive frames to further reduce the transmitted amount of information. The gigabytes spared because of this advantage are used to gather more detailed information within each frame, leading to a similar quality for less space or to a better quality for the same space as compared to the results from the first class. The price to pay for this advantage is complication within the compression algorithms and the need to decode several images before being able to display a single one. A typical example of intra-frame compression is JPEG2000, while a typical example of inter-frame compression is MPEG-2.

Another way to classify compression methods is by their internal algorithms. Here again, two main classes exist: direct cosine transform methods (DCT) and wavelet methods. DCT deals with the picture by dividing it into small, usually square regions, while wavelet transforms work on the picture as a whole. The practical difference for the viewer is in the way compression errors are visible in the restored image after compression and decompression: with DCT methods, errors are small and confined to the sub-region being dealt with, typically an 8x8 pixel square; with wavelet methods, errors are more global and are often located at high contrast frontiers between objects. It is worth noting that in both cases, at the digital cinema compression rates, those errors are so small that you need trained 'golden eyes' to pinpoint them. MEPG-2 is a DCT compression method while JPEG2000 is a wavelet one.

Image Compression in the future

As we have seen before, the two main existing compression schemes belong to different classifications, with criteria defined in the previous section.

As the following table shows, the ideal combinations of advantages seem to be in the inter-frame line and in the wavelet column of the table. In the distant future, there could be opportunities to create a new compression scheme taking the best parts of both existing worlds, and some research teams are already working on that.

Compression class	DCT algorithm	Wavelet algorithm
Inter-frame	MPEG-2 (long gop variant)	
Intra-frame	MPEG-2 (I-only variant)	JPEG2000

Another way to classify the available compression methods is to compare their main characteristics. The table shows the main features of both compression methods and that advantages and disadvantages clearly exist with both methods. MPEG-2 gives the best economy in today's applications, while JPEG2000 offers potentially better quality but at a higher price.

Compression method	Compression ratio	Color resolution	Spatial resolution	Random access to any image	Maximal throughput
MPEG-2	Typ. 20:1	8 bits /component	1920x1080 std 2048x1080 non-std	Difficult	Guaranteed
JPEG2000	Typ. 10:1	8 or 10 bits +/component XZY space	1920x1080 2048x1080 +4K	Easy	Not Guaranteed

The MPEG group is currently defining a new coding scheme called "MPEG-21 part 13", also known as "Scalable Video Coding" or SVC. This new standard, to be issued at the end of 2006, aims at providing an efficient and seamless scalable video coding solution. The Post-Production industry will be strongly interested by this new standard, since scalability allows proxies to be edited with less powerful computers or over lower bandwidth networks. In case of non-adoption of JPEG2000 compatibility in MPEG SVC, another strategy will be to promote the introduction of inter-frame coding over JPEG2000 within the JPEG group. This solution would potentially have the support of numerous industries that have already invested in JPEG2000. However interesting those solutions could be, they remain long-term goals and don't interfere with the everyday reality we are facing now.

6.2.1 Current Image Compression Choices

As of today, basically two compression formats have been deployed, if we forget to mention the Microsoft Windows Media9 format used in a few demonstrations. For Level 1 and Level 2, almost all implementations use MPEG-2 Main Profile at High Level for the image essence, with a usual picture format depending on the aspect ratio but inscribed inside a 2048 by 1080 pixels frame. In addition, a proprietary wavelet compression scheme has been deployed by one vendor. Although this looks like guaranteeing some level of interoperability between theatre equipment of different vendors, this is not the case. The reasons are the differences between packaging formats, between the ways metadata is handled and between differences in encryption schemes.

Windows Media9 Compression has also been implemented by some vendors, allowing for the presentation of HDTV at an ever higher compression rate.

The major studios do accept MPEG-2 as a current practice technology, although they insist on JPEG2000 as mid-term codec. Windows Media9 is not accepted by the studios for Level 1, but has its applications for pre-show and arthouse content where quality constraints are more relaxed.

6.3 Packaging Choices

As of today, due to the absence of standards in the past, the theatre system manufacturers have deployed different packaging formats, mainly concerning the way metadata is wrapped into the distributed packages and the multiplexing scheme. Examples of current practices are MPEG-2 transport stream and MPEG-2 video elementary stream. These data streams are encapsulated within GXF or MXF files: GXF (Generic eXchange Format) is currently used, but expected to be replaced by MXF (Media eXchange Format), the emerging standard.

The variety in existing schemes has led to inefficiency on the distribution side from the studios because of the need to create different distribution packages of a movie to cover the whole installed base. Almost all theatre equipment vendors are making efforts to overcome this situation by agreeing upon an interoperable file interchange scheme based on MPEG-2 compression and SMPTE/DCI-compliant MXF based packaging and encryption. This scheme has been specified by the MPEG Interoperability Initiative, an industry forum open to all server manufacturers. It is very likely that the MPEG Interop Scheme will be adopted by all major vendors for Level 1 and Level 2 theatre systems and will lead to one single packaging format for almost all theatre systems. It will be possible to upgrade the already deployed systems to the MPEG Interop format, leading to a commonly agreed packaging format which will ease the production of digital products and lower the barrier for the content providers to go digital.

6.4 Roadmap for Level 1 D-Cinema

The MPEG Interop format is the first step towards fully DCI/SMPTE compliant systems. This format already offers image, sound and security keys packaging. The security keys are distributed in a small encrypted message called a KDM or Key Delivery Message.

The second step will be the shift from MPEG-2 towards JPEG2000 based compression for the mainstream distribution business.With the first step, DCI/SMPTE compliant packaging will be deployed as well as DCI/SMPTE compliant security mechanisms and key delivery although the compression format will - at least for a transition period - still be MPEG-2.

With the second step, which is expected by the studios to be made in about 2 years from now, the MPEG-2 compression will be replaced by the JPEG2000 compression which allows not only an even better picture quality but also a more straightforward access to every frame inside a movie.

7 Audio for Digital Cinema

Section written by Jason Power of Dolby

7.1 Background

Over the last decade, digital sound systems have been introduced widely into cinemas. The majority of feature film releases now feature a digital soundtrack, in addition to an analogue track for backwards compatibility. The digital soundtrack systems enable delivery of high quality audio with a wide dynamic range, using multiple surround speaker channels and a low frequency effects channel to create involvement and impact. These systems typically use 5.1 channels (front left, front centre, front right, left surround, right surround and low frequency effects), 6.1 channels (with additional back surround channel) or 7.1 channels (with additional front inner left and right channels). In digital as well as analogue cinema sound formats, the centre screen speaker plays an important role, helping to fix dialogue and other on-screen sounds in the correct place for listeners in all parts of the auditorium. Whilst existing audio systems for conventional cinema offer a high level of performance, it is considered that digital cinema systems could offer further enhancements, including the potential for more channels and for multi-language support.

7.2 Content Preparation

Audio post production editing and mixing for cinema release is already widely performed in the digital domain using non-linear hard disk editing and playback. The same equipment and techniques can be used for creating the soundtracks for digital cinema releases. Soundtracks for current cinema releases are prepared under standardised conditions representative of cinema conditions. They are then replayed in cinemas aligned to the same standards. This enables the director and crew to make creative decisions based on how their audio will be heard by the final audience. Relevant standards include ISO2969 for the room acoustic response. The perceived loudness of content such as advertisements and trailers is also starting to be regulated according to BS5550 7.4.2. It is noted that soundtracks prepared specifically for DVD or broadcast are not generally prepared in a standardised environment representative of cinema conditions, and therefore can give variable results if replayed directly in the cinema. It is also noted that large room acoustics, screen construction and the performance implications of producing speakers that can deliver wide coverage patterns are perhaps bigger constraints on audio quality than the delivery medium itself.

7.3 Audio Delivery

Requirements for levels 1 and 2 above (future and current first run cinema) are likely to be heavily influenced by the needs of the worldwide market for Hollywood movies. The extensive work being conducted by SMPTE in this area is noted, particularly in the DC28 groups. Although work is still underway at the time of writing, there is a common expectation that the D-Cinema system will be file based, store and forward, and that replay equipment should allow for future distribution of digital cinema packages with up to 14 main channels plus one for hearing impaired (HI) listeners and one for visually impaired (VI) listeners. Various different configurations have been proposed for the extra channels, including additional surround speakers and height speakers towards the top of the screen. These channels can be downmixed on playback to a minimum configuration of 5.1 + HI + VI. It is foreseen that digital interfaces will operate with at least 48 kHz sampling, 24-bit resolution. Internal to the delivery system, compression is neither prescribed nor precluded, but the requirement for an end-to-end system that gives no perceptible impairment has been noted. This corresponds to a rating of 5 with reference to the ITU impairment scale .

Some audio delivery standards already exist which may be useful in defining delivery of alternative and live content. At a basic level, the industry standard AES3 audio interface is flexible, and can carry audio in both PCM and coded form (SMPTE337M , also note consumer equivalent which is implemented in devices such as consumer DVB set-top boxes and DVD players IEC61937). AES3 audio can be carried in MPEG2 Transport Streams (according to SMPTE302M , which allows for four AES3 streams to be carried under a single Program ID). SD and HD encoding and decoding hardware already exists to support this. It is likely that delivery and replay systems will need to support a minimum of 5.1 audio channels. Parts of DVB TR102154 are also relevant, as they define carriage of AES3, AC3 and MPEG multichannel audio within MPEG2 Transport Streams. The ITU has conducted listening tests on various audio systems, classifying them as Broadcast Quality (4.0 on the ITU scale, see BS1196-1-2001) and Distribution Quality (4.5 on the ITU scale).

7.4 Cinema playback equipment

Current cinemas are equipped with an audio processor, known as a Cinema Processor, which decodes the film digital or analogue soundtrack, handles source selection, speaker and redundancy switching, and performs level and EQ processing that matches the characteristic of the room to that of the studio where the production was mixed. The Cinema Processor also interfaces to the show automation system to enable automated control of features including format selection and level control. Many existing installations feature older cinema processors, where the only external multichannel input is an analogue 6 channel input, which is usually used for connection of an external decoder for the digital film soundtrack. Interfaces are available that enable this input to be shared between a D-Cinema source (multichannel AES3 input) and a conventional film decoder source (analogue input). Cinema Processors are also now becoming available with multichannel digital (AES3) inputs for direct connection of D-Cinema servers.

Current 35mm cinemas are generally installed with 3 or more front (screen) speaker channels, a subwoofer speaker, and multiple surround speakers configured as up to 4 independent arrays. It is noted that some sound mixers have expressed interest in using the additional channels potentially available in digital cinema to create additional height, surround or other effects, although downmix compatibility with existing 5.1 cinemas will be essential. It is also noted that research work in the field of spatial reproduction is being conducted by a number of organisations, such as the University of Delft, which may in the future enable enhanced surround effects to be created, or enable surround effects to be created using fewer speakers.

8 Protecting content

Section written by Xavier Varians of Octalis

8.1 Introduction

The cinema industry is very sensitive to the phenomenon of piracy. Billions of dollars are lost each year due to the pirate distribution of movies through DVD, through the Internet or through any other means.

The digitalisation of movies may potentially offer new opportunities for pirates. A digital copy is identical to the original. The digital form of the content simplifies pirate lives, as they only need computers to reproduce and distribute the content multiple times.

Two main piracy sources are directly damaging to the theatrical exhibition industry: the theft of content before or during its theatrical release window and the camcording of a movie off a theatre screen. Both are very damaging because pirate copies can be available before or during the theatrical release window, cutting down revenues early in the movie life. This part of the document focuses on the description of the mechanisms and tools that can be used to avoid or combat piracy related to the theatrical distribution and exhibition. The purpose is to detail how such systems are built and what are their main forms of deployment. Descriptions are more detailed on the parts that will be standardized and shorter on the parts that will not. This part of the document is not a cryptography course or a how-to guide on how to build a content protection system. Descriptions have been kept simple in order to remain accessible to a large audience.

Content protection is a hot topic in Digital Cinema. It has technical but also business implications. A content protection system can be very constraining for some business entities, or modify the business balance between distributors and exhibitors. Such discussions are still under way and have been evolving tremendously over the past 4 years. This document avoids entering such discussion, as it should be solved by the business entities themselves - i.e. the studios, distributors and exhibitors - and not by any security expert.

8.2 Protecting digital movies

Security, or more precisely, content protection in digital cinema is often associated with the prevention of piracy. A movie protection system has various purposes:

- Preventing the theft of high-quality content,
- Controlling the access to content,
- Enforcing business usages.

The first purpose is clearly the most important one. Preventing movie theft is mandatory, especially during (or before) the first weeks of its release window. The consequence of content theft is often the distribution of pirate version of the movie on DVD or through the Internet.

The second purpose is collateral to the first one. Protecting content shall be coupled with a system that allows authorised users to access the content. This system shall be designed in such a way it does not affect the business usages significantly.

The two first purposes form the basics of a security system.

The third purpose is integrated by solutions exploiting the presence of the security system to help enforce or control the application of business usages or contracts.

Those purposes are detailed in the following sections.

8.2.1 Preventing content theft

One of the first things studios, distributors or exhibitors want to avoid is the possible theft of high-value content that can then be burned on pirate DVD or distributed on the Internet. Theft can arise at very different stages of the content value chain. Depending on the content nature, two types of solutions can be used:

- **Digital content encryption and adequate management of encryption keys** can prevent digital content from being used. This is the purpose of most encryption or content protection solutions today.
- Analogue content theft is an issue in theatres. **Camcorder defeat technologies and fingerprinting** will respectively prevent a pirate from recording the movie from screen with a digital camera and will enable the origin of the piracy to be traced in the context of a forensic enquiry.

Those two types of solution are mandatory in digital cinema. The first type protects high-quality digital content from theft from the point where the content is produced up to the point where it is decoded for the projection. The second type takes charge of the content protection as soon as it has been played on a projector, where content is easily accessible for a pirate equipped with a camcorder.

8.2.2 Controlling the access to content

Setting Conditions for gaining access to content

A content protection system must not only be able to protect content against theft, but it must also give authorised users access to content. Distinguishing an authorised user from an unauthorised one is mandatory, as pirates will often try to access content, not by breaking its protection directly, but by trying to appear to the system as an authorised user.

Controlling the access to content in its simplest form will define who (or which device) will be able to access the content. Most content protection systems today also include the capability to define the conditions required to allow access to the content. These systems are often called Digital Rights Management (DRM) systems. A Digital Right is indeed a description of the conditions under which the content can be accessed. Example of such conditions are:

- a limited time window for accessing the content (e.g. three weeks),
- a minimum requirement on some device capabilities,
- a maximum number of accesses (absolute or per time window)
- the satisfying of some pre-conditions evaluated by the system.

The number or type of conditions is infinite. Practically, this number is limited, as business users have to specify for each set of conditions - some of them possibly in contradiction with each others - if the content can be accessed or not. This definition of the access policy is far from trivial.

Auditing the access to content

Another way to control the access to content is to record every access to this content. Content protection systems often integrate logging capabilities. A log is a record of the operations (content playout, rights modifications, etc.) performed on the system and the important system parameters (time, user performing the operation, etc.). Audits are the result of the analysis of logs into a more usable form.

Auditing those logs enables rights owners to know who accessed the content and when. Logging clearly does not prevent piracy. Combined, however, with 'fingerprinting' or 'watermarking' techniques, audit mechanisms can play a deterrent role, as it is then possible to track the origin of a pirated copy.

Often, the auditing mechanism is combined with the DRM system. Their interaction produces two advantages:

- the capability to define access rights based on audit information, for example so that a projection is authorised only if the previous projection was completed without interruption.
- the capability to detect tampering with the content protection system, by comparing the profile of the authorised accesses with the accesses that have been actually monitored.

Most DRM systems today integrate local or global logging features.

Balance between audits and constraints

The two previous sections demonstrated two very different policies regarding the protection of content in a business environment:

- The first one defines constraining rights to access the content. It is impossible to access the content in specific conditions if the user did not receive the rights to do it. This policy has the advantage of preventing unauthorised access to the content and then reducing the risk of piracy.
- The second one defines a secure logging and auditing system that enables content owners to check if the content was accessed according to the business agreements. This policy has the advantage of being more business-friendly, as users have a lot of freedom to access the content, within the legal agreements.

The Digital Cinema world is actually balancing between those two policies, the result being a mix of the two approaches. Studios and distributors have a preference for the first one, as they have better control of the use of the content. Exhibitors prefer the second one, as they have more flexibility to project their movies, and the risk of a black screen due to an issue in the transmission of specific projection rights is reduced.

This balance is a very sensitive subject in the Digital Cinema market. During the short history of Digital Cinema, the pendulum swung first towards the Constraint-Tight side, then went to the Audit-Only side, and is now oscillating between the two. Regardless of what is defined today, the future of the equilibrium will heavily depend on the way the business models evolve in Digital Cinema. A content protection system will be good for the digital cinema market only if it can support this ever-evolving move between the aforementioned policies.

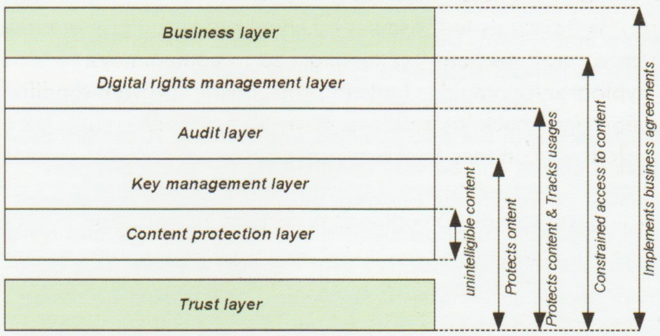
8.2.3 Enforcement of business usages

As soon as it is possible to define conditions on how the content can be accessed, and to control afterwards the actual access to the content, the full support of business agreements is no longer far away. As a consequence, some security systems also enforce or support business usages. Digital cinema is a business environment governed by oral or written contracts. Those contracts relate to the usage of the content itself, but also to some additional conditions. An integrated security solution may also include the supervision of the respect of the terms of a particular contract. While those elements are not directly related to the content, it indirectly influences the way the content is distributed or accessed. For this reason, security systems sometimes implement tools to model parts of those business agreements. For example, a distributor may require some exhibitors to provide full audit information while others may not have to do this. Or the same distributor may agree that an exhibitor benefits from a "No black screen policy" for its movies, while another distributor may not accept it. A third example is the capability for some theatres to pull projection licences from a distribution server automatically, while others may have to wait for the distributor to explicitly send them projection licences.

8.3 Elements of a security system

8.3.1 Overview

Generally a content protection system can be split into layers each with a specific purpose. The diagram shows an overview of those layers, focusing on the purpose of the layers and how they interact together to provide a complete content protection system. Except for the trust layer, which is pervasive to any system, all the other layers add a fundamental functionality to the system and need the layers that are below it. Every security system implements all the layers, but with some systems some of the layers appear in only a rudimentary form.



8.3.2 Physical security

Although discussion of anti-piracy measures often focuses on encryption measures, these techniques form only part of the overall solution. Inside the digital cinema playback system, the movie data cannot always remain encrypted, as it must be decrypted before the image can be decompressed ready for display. Although once decoded, the valuable image data is encrypted again before it is output from the playback system to the projector, other methods are needed to protect the data whilst it is being processed inside the playback system.

To prevent a pirate from opening the lid of the equipment and stealing the unprotected movie data inside, physical security can be used to prevent access to any parts of the circuit where value movie data is processed. Physical security stops a pirate from physically reaching the relevant parts of the circuit - for example by making it impossible to access the pins of the processing chips or the tracks carrying signals on the circuit board. Physical security measures can also include logging of attempts to disassemble or otherwise attack the unit. Current discussions suggest that in the future some major movie distributors may expect physical security in addition to encryption in order to protect movie content from piracy.

8.3.3 Design of a movie protection system

Detailing how to build a digital cinema protection system is too complex to cover in what is intended to be "A Guide for Early Adopters", and we have already seen that security is far more than a technical issue. However, some insights are provided below.

Encrypting a movie is equivalent to putting it in a safe box, locked with a padlock. Only people (theatres) having the padlock key are able to access the movie. Today, standardized encryption algorithms like AES can be used as a digital padlock. They are recognized as being unbreakable, provided the length of the key is larger than 128 bits. This does not solve the problem, however. Instead of finding a way to securely distribute a movie to theatres, we now have the problem of securely distributing a movie key to theatres. Back to the beginning? No. The main difference is that a key is far smaller than a full digital movie.

For small packets of data, powerful - but slow - cryptographic algorithms like RSA can be used to securely distribute movie keys to theatres. Unlike AES, those algorithms are asymmetric and enable to establish secure communications between entities that do not share the same secret upfront.

Once you are able to distribute movie keys, you then have to add digital rights to those keys. Digital rights shall be authenticated, protected and tightly attached to content keys. Cryptography provides tools to protect, sign, prevent modification and check the safe reception of the digital rights. The same tools can also be used to protect and sign audit trails.

Now have we finished? No. One thing is lacking: trust. When you sign a contract with another person, you have to be sure it is the right person that signs the contract. Otherwise, the contract has no value. In the same way, to be sure that the keys you are using are actually tied to the right theatre (or projector), you need a trust infrastructure. This trust infrastructure can be based on people, on a certification authority, on shared secrets or on any other means that enable to establish this trust.

Now that you trust the person you are talking to, you can protect a content for this person only, define rights describing how to use the content, sign it and securely send it to the recipient. You have a security system!

This section oversimplifies the design of a security system. Actually this process must be executed in a very rigorous way in order to avoid creating a security hole due to a design flaw. This requires security experts because only one error may open a fatal hole in the whole system.

9 Alternative Content

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Alternative content is a perhaps somewhat pejorative term used to describe non-Hollywood content. John Fithian from the North American Exhibitors Association coined the term O.D.S, Other Digital Stuff. It can be describing anything from reasonably high-budget independent productions to a DV movie or even live transmission of, for example, a football match.

As there is a very wide variety of alternative content, some thought needs to be given to its distribution. If it is a movie or video production which is available some time in advance it is much better to process, compress and distribute as if it were regular D-cinema content.

So we will just consider the various types of alternative content and perhaps the best way to deal with them. One golden rule to remember is 'rubbish in means rubbish out'. What this means in practice is that some material will never look good due to the magnification factor of the big screen, but it may still be of significant interest and still be worthwhile to present. So let's look at typical origination formats and work out the best way to deal with them.

9.1 Film

If you have a piece of 35 or 16 mm film in due time then this can be taken to a transfer house for transferring from film to 1080p 24 (1080 lines progressively scanned, with 24 frames per second) or 2K.

Once transferred onto a format such as 1080p 24 it can be sent to a compression house for compression and packaging for distribution.

Today HDTV 24p technology is normally used, as it is very speedy and cost effective. If you have a larger budget you can scan at 2K (2048x1556), archive a copy and re-master to a 2048x1080 2K container or a 1920 x 1080 HD container.

To avoid scaling in the projectors the actual image might be for example 1920 x 818 (2.35:1 Aspect Ratio) for distribution or 1920 x 1038 for (1.85:1 Aspect Ratio).

The above applies to MPEG as a compression format. If an alternative compression system is used which has a container of 2048 x 1080 you may still wish to scale in post production rather than in the projector. The 2048 x 1080 format matches no film standard so there will always be a compromise. For example, 2048 x 871 for 2.35:1 or 1998 x 1080 for 1.85:1.

1.3K projectors can be served by the same masters but will need care in choice of the actual numbers used for distribution. Wide aspect ratios like 2.35:1 normally use an anamorphic lens on a 1.3k projector. Some have limited scaling capability. This may mean multiple inventory at the compressed file stage but at least means that Transfer, the most expensive part, is common to 1.3K and 2K compressed files.

This approach means you have plenty of opportunity to QA and clean up the content. It also means you can use the standard distribution channel and the operatives in the cinemas can deal with your programme as if it was regular content. The screen masking will be already set up to the standard aspect ratios.

9.2 HDTV

If it is an HDTV production then there may be some benefit in colour correction for the Digital Cinema projectors. In any case the Digital Cinema Projectors have look up tables for ITU 709 Colour space.

The compression houses will almost certainly take the HD tape format and compress it into the distribution format; as above it also means you can use the standard distribution channel and the operatives in the cinemas can deal with your programme as if it was regular content. The screen masking will be already set up to the standard aspect ratios.

A point to note with HD productions is that they may come in several flavours. 24p is the most Digital Cinema system friendly, but in Europe it will be quite common to use 1080i 50 (1080 lines interlace scanned, with 50 fields per second) for origination and in the US 1080i 59.94 or 720p 59.94.

Care is needed with this; the Digital Cinema projectors are Progressive Scan. They may have no means of accepting Interlaced formats. Interlace is a very old system for data reduction, it was invented for TV in the 1930s. At the time it was a very clever way to reduce the data rate by 50%. It has problems though, an interlaced image is scanned as two half frames called fields. This form of scanning originally called raster scan from the CRT days, captures the two half frames one after the other. With moving images the available vertical resolution is lowered and this can lead to alias, which manifests itself as flicker or jagged edges. From a mathematical point of view Interlace is very difficult to understand, this has led to a great many poor de-interlacing algorithms, particularly from the IT industry. So poor interlace has a bad name and progressive scanning is best, but it doubles the bandwidth requirement at the capture device and display. This is why 720 progressive has half the theoretical resolution of 1080 interlace. If the two fields in an interlaced picture are captured at the same time, just as they would be with Film or 24p then the system can handle a great deal more resolution in the vertical direction without artefacts.

This is one reason why 24p has become so popular in production and why HD Film Channels use 1080i, whilst Sports channels utilise the better motion rendition of 720p, even if it means throwing away half the resolution.

Back to the practical issues: Several of the Digital Cinema Projectors will run at frame rates from 23.97 frames per second to 96 frames per second, which is used for 3D. 720p 50 or 720p 59.94 are covered by the projectors' frame rate range but are less than half the resolution. This means that these sources need to be scaled up to use more of the projector display chip's area. If you don't do this you would end up with a small picture. Earlier 1.3K projectors have only Horizontal Scaling but no Vertical Scaling.

There are two approaches to this problem, send 1280 x 720 files if the destination projectors have scalers, or use alternative content input boxes at the projector to scale the incoming images to match the projector. This will need a break out from the secure path to the projector so may not be viable. Most external scalers do a good job on progressive sources but often make a poor job on Interlaced Images.

If the source is 1920 x 1080p 24 the 2K projectors can deal with this and the compressed file can be reconfigured to match the aspect ratio within the 1920 container. 1.3K projectors may only scale horizontally and may also use an anamorphic lens for some aspect ratios.

If the source is 1080i 50 or 1080i 59.94 there is a problem. The standards being proposed by Digital Cinema Initiatives only recognise 24fps or 48fps, which will be incorporated into the JPEG2000 compression system.

MPEG2 Compression recognises 1080i 50 and 1080i 59.94 but not 1080p 50 or 1080p 59.94.

MPEG AVC (Advanced Video Coding) recognises 1080p 50 and 1080p 59.94 but is so new that no equipment exists at these rates.

This means that the Interlace to Progressive scan conversion has to be made local to the projector. There are two main problems with this:

- **Security**: you have to break the secure server to projector path to go through the scaler.
- **Quality**: the external scalers are normally an afterthought and often have very poor de-interlacing algorithms in them.

Non Digital Cinema Large Venue Projectors are often better featured than Digital Cinema Projectors. They mostly have De-interlacers and scalers built in; be warned, however, the performance varies so the de-interlacing and scaling should be tested as part of any evaluation for non Digital Cinema Projectors.

9.3 SD Video

Only the best quality standard definition video images will have any chance of looking good on the big screen.
Again if possible it is better to get a transfer facility to up-con-

vert from SD to HD and compress at the best possible quality and then put the file into the standard distribution system. Some formats such as VHS will anyway benefit from a professional clean up and stabilisation before use, and in fact may not work locally due to tape transport stability issues.

9.4 Local insertion

This needs great care. It is possible to project from a DVD through a scaler box or from a live broadcast but the original pictures will be adjusted for domestic viewing environments.

Cinema environments are very different from domestic, and the calibration in the mastering process will need to be adjusted for Cinema use.

Experience at the Rezfest at the UK Digital Test bed suggests that each programme needs to be previewed in good time and the system adjusted accordingly.
The D-cinema system is generally well calibrated, but there is always the possibility of operator error, leaving in the wrong settings for the main feature.

The same is true for Satellite broadcasts of sports or cultural events. Test signals need to be transmitted in advance of the programme and the operators need training to know how to set the system for this content.

9.5 Audio

Lets not forget Audio. From film the Audio may need re-coding, it may only be stereo and it may be mastered for DVD in a Domestic environment. For any serious release you should consider re-mastering. At the very least it needs a careful QA check.

9.6 Mainstream Film

Today there are several methods in use for showing mainstream movies digitally, and the choice of workflow depends on the several factors, including,

- Production process - DI or Conventional
- Scanned Negative or Telecine
- Budget

As mentioned above the new way to post-produce a movie is using the Digital Intermediate process. To simplify this process it tends to follow the following workflow patterns:

9.6.1 Analogue DI

- Capture on 35mm Film
- Rough Colour Time
- Telecine for Dailies / Offline Edit
- Scan the negative @ 2K or 4K
- Generate CG Elements for compositing
- Online Edit (1k Proxy)
- Colour Time (Final) to projector / Set active projection area
- Render @ 2k or 4K
- Output to Digital Distribution
- Output to Film Recorder via Colour Cube

9.6.2 Analogue

The Alternative for conventionally produced movies is to take an answer print and follow the following process:

- Telecine Print Rolls
- Colour Time Roll to Roll (During Transfer or Post Transfer)
- Set active projection area.

9.6.3 Digital

- Capture on Digital Camera's HD Component, RGB, 10bit Log.
- Generate CG Elements for Compositing
- Offline Edit
- Online Edit
- Colour time to projector / Set active projection area.
- Output to Digital Distribution
- Output to Film Recorder via Colour Cube

Note that in the above simplified examples it is common for picture elements to bounce between HDTV equipment and file based Film Digital Processes.

As 2K (2048 x 1080) in raw form does not represent any currently used cinema aspect ratio it is reasonable to assume that mixed HD/2K operation will continue for some significant amount of time. The actual format used at any point in the chain will depend on the operation being carried out.

The proposed DCI system is designed to carry pictures with a wide Colour Space, large bit depth (12bits) and 2K or 4K resolution.

The DCI does not mandate that production or post production be carried out with these extended parameters. The intention of the DCI is to specify a system with a high level of performance and allow the Movie Producers to expand into the new parameters over time.

9.7 Bit Depth

File based systems can be used at any bit depth you wish although there is a trade off with time, which equals cost. 14 bit linear is a good target within the post process.

Bit depth is often mistaken as a measure of contrast - it is not. Bit Depth describes the number of levels that each pixel was sampled at. Bits are digital values of 1 or zero described in Binary Notation.

1 bit (0 or1) can describe Max and Min, representing 'full on' or 'full off'. The projection device sets the maximum contrast so a projector with, say, 2000:1 contrast ratio can be modulated from full off to full on by changing just one bit - the most significant bit. The additional bits fill in the middle range and set the granularity (the number of steps from on to off).
More bits are needed to preserve the qualities of the tones in the picture.
8bits (2 to the power of 8) has 256 discrete levels. Most TV recorders use 8 bits even if the rest of the plant is 10bit.

In reduced illumination on a large screen 8 bits is only marginally acceptable for good tonal reproduction, and posterisation may occur on faces or computer generated images.

A secondary consideration is that the bits are not applied to a linear signal. The output from the Digital Camera is subject to a non linear process called Gamma. This was invented for compensation of Cathode Ray Tube characteristics. Gamma also matches pretty well the characteristics of the eye so is still used, even though displays are now often linear. It gives a form of very efficient level compression.

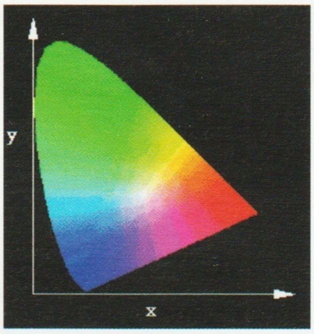
DCI specify 12 bits non linear. 12 bits = 4096 levels,
HD D5 and SRW Tape machines are 10 bit = 1024 levels.
Although wasteful of memory, 10 bits fit within 12.
If going from a higher bit depth to a lower one care is needed to prevent visible artefacts.

Rule of thumb is that an extra two bits are required to process in linear space. So 12bit Gamma space becomes 14 bits linear space.

9.8 Colour Space

Digital Cinema systems are expected to accurately portray the colours of 35mm Film. The commonly used HDTV colour space ITU709 does not have a wide enough colour space to represent Film properly. Due to this fact Texas Instruments developed projection technology with a wider colour gamut commonly called P3. This is specified using a Xenon light source.

Commercial reluctance from other projector manufacturers to utilise a proprietary colour space led to many discussions on what should be specified by the DCI. The result of the discussions was a System called Capital XYZ. This sounds complex but it is not in reality. Colour was described by the CIE, the International Commission for Illumination in 1931. The CIE invented a chart to show colours in graphical form.



This chart should also have a depth axis called Z.

In summary, the proposed DCI standards require the digital cinema system to be able to carry the full CIE XYZ coordinates. This extends beyond the visible spectrum, so each projection device will have a circuit to map from the CIE container to its own parameters.

The important point here is that the reference projector for mastering is using TI P3 colour space. If new technologies come along, like for example laser projectors, then the mastering reference will need to change.

10 From Analogue to Digital Cinema - Commercial Implications

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10.1 The Impact on the Business

The introduction of a radical new technology will affect any business. It will have an impact on the way business is done, and on the relative strength of the key players in the market. Their unique selling point, their products and the way they create value will be affected - and they might need to thoroughly re-engineer their entire business.

Something like this is likely to happen when distribution and exhibition of cinematographic content migrate from analogue to digital. Over the past decade, shooting and postproduction have already gone digital. When, over the coming decade, distribution and exhibition go digital, the impact will be felt by labs, post houses, distributors and exhibitors.

10.1.1 35mm, A truly global standard

Before we dive into speculations on how the digital technology will affect the business of labs, distributors and exhibitors, it is probably worthwhile dwelling a moment on the still reigning 35mm standard.

The 35mm standard was invented and accepted worldwide well before the second world war, and even though the capture, storage and rendering of the sound have since changed significantly, the basic 35mm standard for moving images has not changed at all for nearly a hundred years. Very few businesses can display this sort of stability. In fact, 35mm film is a truly global, open standard. One can take a 20 year old 35mm projector from one corner of the Earth, move to a completely different country, plug it in - and it works. Who can say the same for a computer, or a piece of software?

Nobody "owns" the 35mm standard. And there is no patent or software licence involved in using a 35mm projector.

This open, global 35mm standard - and its extraordinary stability - have made it possible for films to travel all over the world. As long as the film is on 35mm, it can be screened anywhere, in any country. There have indeed been a number of obstacles to the free circulation of cinematographic content, but technical barriers, patents, licence fees and incompatible systems have not hindered the circulation of films.

We should do out best to make it stay that way, even in the digital era.

10.1.2 Changing the business

On a more practical level, how will the huge technological transformation, described in this "EDCF Guide for Early Adopters", affect the business of distributors and exhibitors? At this early stage in the migration from analogue to digital, nobody can answer this question. However, it might be useful to pinpoint some of the key commercial implications of the new technology, and to highlight areas where further investigation is needed. But, be warned, the following is not a list of answers or a guideline on how to navigate securely through a troubled market place. It is, on the contrary, and for the benefit of European labs, distributors and exhibitors, a list of areas for further inspection.

10.1.3 D-cinema: a new product?

For the exhibitor, this is the fundamental question: Is D-cinema a new product, or is it just a new, behind-the-scenes, technology to deliver the same, well-known product? If D-cinema is a new product, then it should be marketed as such, priced as such, and it will inevitably compete with the "old" products, namely the 35mm screening. If D-cinema is not a new product, but simply a new way of delivering the well-known screening of a film in a theatre, well, then there is no new thing to market, to sell or to price. And the customers shouldn't really care about it.

On the other hand, if D-cinema is a new product, then it might hold the promise to grow the market, or to capture market shares from existing products. It might be priced differently, and it might prove to be an important competitive advantage for those exhibitors who make the transition first. There is additional incremental revenue to be generated.

If D-cinema is a new product, distributors might decide to offer the old and the new products alongside, i.e. the same title on 35mm and on digital, but priced differently, and in competition. To do this, however, the exhibitor will need to be very clear about the new D-cinema product's unique selling point, and then translate this into an efficient marketing strategy.

10.1.4 The risk of not having one standard

The DCI D-cinema specifications will soon be ready, and they will now take the international standardization route, in this particular case through the SMPTE, and then on to the ISO. The DCI specs are the result of a long and thorough process, initiated and carried forward by the seven US majors from Hollywood, although with significant input from Europe. The specs, however, might be seen as American, and there is probably still a risk that some territories will not see the DCI D-cinema specs as the obvious, global and open standard to take over from the 35mm standard for distribution and exhibition of cinematographic feature film worldwide. The cinemas and the audience will be the first victims of any such "war on standards".

Given that some 70% of feature films screen in Europe come from America, the European distributors and exhibitors will obviously have to adhere to the DCI specs when showing Hollywood content. But will some territories be tempted to create their own digital standard for their own films? Or will some distributors and producers be tempted to opt for a different standard for - let's say - documentaries?

Cost could be a driving force, since the equipment to run a DCI D-cinema compatible theatre is still considerable.

But the players on the European market - let alone the governments and other institutional bodies - should carefully consider the risk of creating a European market place where different types of films are shown on different - and cheaper - types of E-cinema equipment, either based on the nationality of the film, or based on the genre. Cheaper E-cinema equipment most often translates into a lesser quality, and if national films, non-US feature films, plus documentaries, are screened on this type throughout Europe the audience will notice. The audience will notice that non-US content does look quite as good on the screen. That the experience of going to the cinema, i.e. the large screen, the sound, and the extraordinary sharpness and quality of the image, is still true for Hollywood content, but not quite so for other types of films. Playing this card might give the US majors - and their films - an overwhelming competitive advantage, to the detriment of European films.

10.1.5 Advertising

Speaking of content, what will happen to advertising? Traditionally, the pre-show advertising is screened from the same 35mm projector as the feature film. But this is beginning to change in some countries, where ads are now being screened on E-cinema projectors.

It is probably still too early to tell which technology and which business models will win when it comes to pre-show advertising. On a commercial level, it should be noted that digital screening of ads introduces a new flexibility, where content - ads - can be targeted precisely at specific customers segments, e.g. a set of ads for each feature film, or a specific set of ads - in a specific sequence - for the Matinee show, and a different one for the younger audience at the 8 pm screening on the Friday night. This will effectively be a new product, and therefore priced differently.

10.1.6 The DCI D-cinema specs are nearly ready, but what about the hardware?

When looking at the DCI D-cinema standard, one must remember that though these specifications indicate how the digital film should be stored, encrypted, secured, compressed and finally screened, the specs do not indicate what the actual hardware to do this job should look like. The specs do not indicate if films are to be moved around on small hard discs, on tapes, or by satellite. Or indeed the shape and size of any such tapes or hard discs. This will be handled by the companies who produce the hardware, and they will probably strive to impose their own DCI-compatible hardware on the market. In other words, cinema owners will be offered different types of hardware, from competing manufacturers, probably all claiming to the DCI D-cinema compliant. But are these different pieces of hardware compatible? Will it be "plug-and-play"?

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