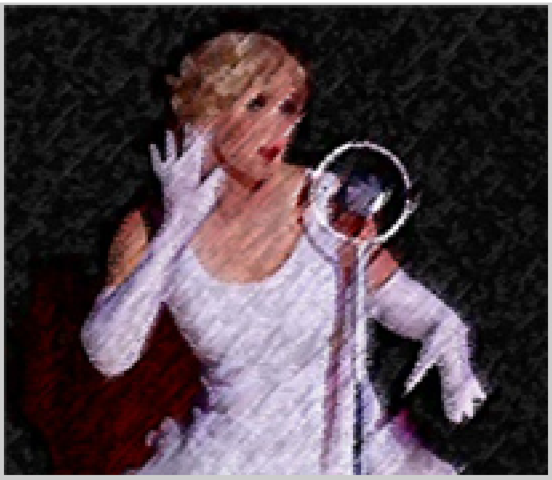
AMIA Tech Review

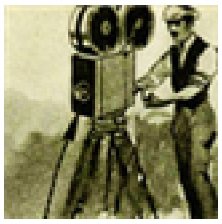
From the Association of Moving Image Archivists



From the Editor

Where is Lina Lamont When We Need Her?

Welcome again to the *AMIA Technical Review*. I want to thank the many readers who took the time to write to us with comments and suggestions. Without exception the comments have been positive and complimentary. Let me assure you that we'll do everything we can to insure a continuance of this reaction! MORE



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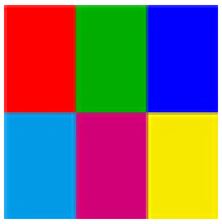

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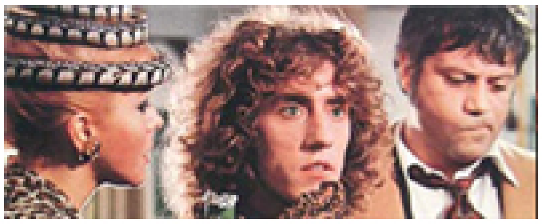
This fundamental change of technologies also has had a large impact on archives. . MORE



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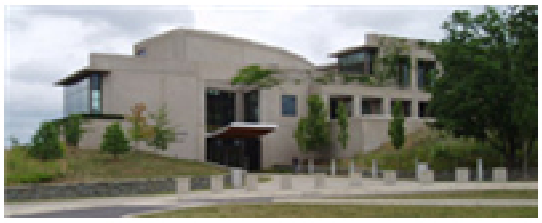

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The primary curatorial responsibility for the Library's 6.3 million piece collection of audio, moving image, and film materials. MORE

The *Visionary Archive* Process

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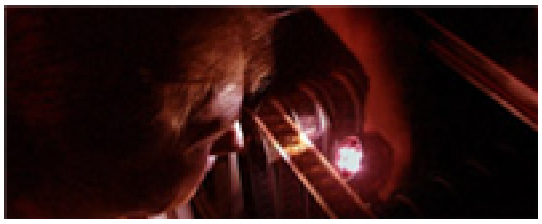

Legacy Optical Recordings: Then and Now

There is no book, no roadmap, no great guru to give a definitive answer and there are no test signals on the track leaders which can be measured to help in this matter... MORE

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CONTRIBUTING AUTHORS

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Ken Weissman
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Ralph Sargent
Sean McKee
Victor Panov

UPCOMING EVENTS Click for Details

October 4-8	ACVL Conference
October 15-18	FIAT Conference
October 26-28	SMPTE Tech Conference
October 27	. World Day for AV Heritage
November 2-6	AMIA/IASA 2010
November 3	The Reel Thing XXVI
February 2-4	AES Conference
April 9-14	NAB
May11-14 .	ARSC Conference

April Issue of AMIA Tech Review

AMIA Tech Review
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October, 2010.Volume 2

"Where is Lina Lamont When We Need Her?"

by Ralph Sargent

Welcome again to the AMIA Technical Review. I want to thank the many readers who took the time to write to us with comments and suggestions. Without exception the comments have been positive and complimentary. Let me assure you that we'll do everything we can to insure a continuance of this reaction!

Some suggestions have been made regarding proofing, grammar and spelling. These too have been taken to heart and we shall institute methods to improve in this area. However, I guarantee that undue emphasis on these points will not deter our getting the Tech Review to your eyes in a timely fashion. But to paraphrase what Lina Lamont once said with her usual brilliance, "If we bring a little ***tech*** into your humdrum lives, it makes us feel as though our hard work ain't been in vain for nothin'."

Moving on…

This issue has seven articles split between two general themes: 1) Casting an eye and ear on historic sound tracks; and 2) New facilities and practices, both analog and digital, in film preservation now and for the future. This last category includes a discussion of the Library of Congress' new Packard Campus technical facilities, an article on Digital Cinema technologies and the archivist, and two articles on color separation systems, one old and the other new. To help you out on these last two items, I've included a page from a book I wrote sometime back, "Preserving the Moving Image." It will give the reader a quick introduction to color separation systems and hopefully help you better understand both color articles. I hope you'll find all of the articles interesting and thought-provoking. Once again we invite you to send us your reactions and comments regarding this issue and ideas or whole articles for the future.

To paraphrase from my previous letter…

Those of you who feel you have appropriate material to contribute, please feel free to advise us via a thematic proposal or précis of your article. If accepted for publication, your articles should be received at the AMIA office no later than six weeks prior to next publication date. (Please email Laura Rooney at the AMIA Office for anticipated publication dates.) All articles or suggestions submitted are subject to review, condensation or augmentation and editing.

Publication of the AMIA Tech Review will be web-based in portrait format. The print version will be found as a PDF. Readers are encouraged to print whatever they wish ***for their own use***; however, all material shall remain the copyrighted property of The Association of Moving Image Archivists or respective copyright holders as indicated and may not be reproduced for any other use in any form without the prior express written permission of the Association or indicated copyright holder.

We encourage readers of the AMIA Tech Review to become members of ancillary trade associations such as the National Association of Broadcasters, the Audio Engineering Society, the Society of Television Engineers, the Society of Motion Picture and Television Engineers, etc. Cross-pollination of technical information is important and we strongly support it!

Finally, please let us know what you think. It never hurts to speak your mind in a civil and constructive manner. If there is some aspect of this publication you feel could be improved, please let us know. If there is something you liked, let us know. You get the idea….

Best wishes and see you in Philadelphia in November!

Ralph Sargent, editor

AMIA Tech Review
From the Association of Moving Image Archivists

October, 2010.Volume 2

Digital Cinema Technologies

From the Archive's Perspective

by Arne Nowak

Introduction

During the last few years digital technologies have gained much ground in production, editing, post-production and exhibition of cinematographic work. This fundamental change of technologies also has had a large impact on archives. On the one hand archives have very successfully implemented digital restoration and digital distribution of films on the internet or via DVDs, as well as to digital cinemas. On the other hand archives will have to adapt and change existing procedures or introduce new processes because they will be confronted with digital material for deposit that is not bound to a carrier medium, as is the case with film or video cassettes. Instead the images and sound will come to the archives in the form of digital computer files.

Digital cinema has evolved over the last few years, and even though various alternative systems and solutions are used in different parts of the world, most commercial productions in North America and Europe use a system that has its origin in the Digital Cinema Initiatives[1] (DCI). DCI was a joint venture of six major American film production companies which together worked out an open specification for a digital cinema system. Many parts of this specification have been adopted by SMPTE and also transformed into standards by the international standardization organization ISO.

This article is intended to give a basic introduction to the technologies and processes that are associated with the DCI / SMPTE digital cinema system. In the following sections I give an overview of the basic technologies that are used, describe important technical details of the Digital Cinema Package (the format that is delivered to the cinemas), point out how these packages can be produced and give some thoughts on implications of this system on archives.

[1] http://dcimovies.com/

Basic technologies and standards

The digital cinema system as it is used today in North America and Europe is defined by a set of SMPTE standards which are mostly based on the voluntary specification of the DCI. Currently, SMPTE standard documents exist and are effective for all essential parts of the systems. Ongoing work in standardization is mostly concerned with additional features and extensions such as the recently released additional frame rates document that introduces the possibility of other frame rates than the originally specified 24 and 48 FPS. Many of the SMPTE standards for digital cinema also have been adopted by the ISO in its technical committee TC36[2].

The SMPTE standards take care of different important technical aspects of digital cinema. A complete list can be found at http://www.smpte.org/standards/NumberIndex.pdf. The documents describe the D-Cinema Distribution Master (DCDM, SMPTE 428), D-Cinema Packaging (DCP, SMPTE 429), D-Cinema operations (including key management for encrypted packages, SMPTE 430) and D-Cinema quality for projection (SMPTE 431). All of these documents contain references to other standards from SMPTE, ISO and other organizations that describe certain technical details, and there exist also several SMPTE Recommended Practice documents for D-Cinema. The DCI Digital Cinema System Specification, which is available for download free of charge at http://www.dcimovies.com, contains very detailed descriptions of the technical aspects and serves as a good reference, since huge parts of this specification have been included in the SMPTE standards. The DCI Specification additionally contains very detailed information about all encryption and content security related aspects and serves as the operational guideline for the studios that are involved in the DCI.

All technologies that are used within the SMPTE / DCI D-Cinema system are openly available and can be used free of license or patent fees of any kind by all interested parties. This allows any person, company or organization to develop systems or software that comply with these standards. In fact, besides several commercial solutions to create Digital Cinema Packages (DCP), at least one free open source software implementation exists to do this.

The SMPTE / DCI D-Cinema system is centered on the DCP. This is the compressed format in which digital movies are delivered to the cinema and from which they are projected. D-Cinema is essentially a file and IT-oriented environment. The DCP is a set of files that contain images, sound, subtitles and additional files to control playback and optional encryption of the content. Images and sound are stored in separate files that are called track files and there is the possibility to divide a movie into several reels. That means the complete set of images and sound data and also subtitles are split into several files of arbitrary duration. The playback order is controlled by a Composition Playlist (CPL) that includes references to the image, sound and subtitle files. A DCP can contain more than one CPL. This makes it possible, for example, to create a multi-language DCP that contains only one set of image track files that are used for all language versions but several sets of sound track files, one for each language. Each CPL now contains references to the shared image track files and the sound track files for each language.

[2] http://www.iso.org/iso/iso_technical_committee?commid=48090

The following sections of this article give explanations of the technical details of a DCP, including encryption and access control, the mastering and creation of DCPs, and discuss the relevance of DCPs in film archives and implications related to their use as a deposit, exhibition and distribution format.

The Digital Cinema Package

Overview

The main intention of the DCP is to serve as a flexible and secure format for delivery and projection of digital movies on a very high quality level. The format takes a relatively simple approach to realize the required features. A DCP is essentially a folder on your hard disk that contains a set of MXF and XML files.

MXF stands for Material eXchange Format and is a so-called wrapper or container format similar to Quicktime .mov or Windows .avi files. MXF was developed by SMPTE and EBU for use in professional TV applications and is a very powerful but unfortunately also complex format. It can be used to store image or sound data (also called essence) and metadata. MXF itself is codec agnostic, which means that an MXF file can contain images or sound compressed using various systems or even uncompressed data in a single common file format. A simple internal MXF file structure and the wrapping process are depicted in Figure 1. The resulting MXF file on the right consists of a file header with metadata and the file body that contains the essence. In the DCP only very simple MXF files are used. These so-called “Operational Pattern Atom” files store either images or (multi-channel) sound data in each file. Only very rudimentary metadata is supported in the MXF files of a DCP. To reduce storage space and speed up transmission of DCPs the images are compressed using the JPEG 2000 codec, but at a very high quality level. Sound is stored uncompressed. Subtitles can either be stored as XML files that contain timed text or as subpictures. Timed text means that the subtitle texts are stored together with a time code that controls when the text appears on the screen in an XML file. The text is rendered and combined with the image in the projection system. A subpicture is pre-rendered image of the subtitles with transparency that is combined with the images of the movie at playback time. In this case the timing is also controlled by an XML file.

In addition to the files that contain the essence, several other XML files are contained in the DCP. The most important ones are the Packing List (PKL) that contains an inventory of all files that belong to the DCP and one or more Composition Playlists (CPL) that control playback of the essence in a DCP. The file names can in theory be arbitrarily chosen since all files are, during playback, referenced using internal identifiers (the so-called UUID) and not the file names.

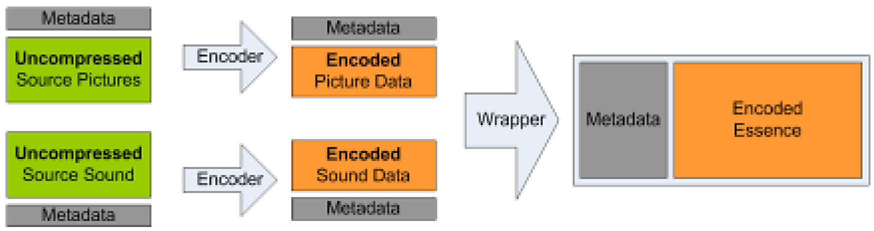

Figure 1 - Wrapping of images, sound and metadata into a single file

Images and sound

One of the goals of D-Cinema standardization was and is to ensure a high level of image and sound quality. This goal is reflected in the technical details of the standards such as image compression, spatial resolution and color fidelity.

In the standards two basic resolution containers are defined: 2K with 2048 x 1080 pixels and 4K with 4096 x 2160 pixels. Of course only a small number of movies are intended to be shown at the native aspect ratio of these containers which is 1.896:1. For other aspect ratios the resolution shall extend to the maximum of either the horizontal or the vertical resolution. In practice this means that a movie with an aspect ratio of 2.39 in a 4K container shall have an image resolution for the active pixels of 4096 x 1716, therefore filling the horizontal resolution of the container. It should be noted that the use of anamorphic projection lenses is explicitly not permitted in the standards which leads to the consequence that a CinemaScope movie may have a lower overall spatial resolution than other aspect ratios.

The primary frame rates that are supported by SMPTE / DCI D-Cinema systems are 24 FPS and 48 FPS. However, the standards have been extended[3] to support additionally 25, 30, 50 and 60 FPS. Other frame rates may follow but the basic requirement for D-Cinema equipment is to support 24 FPS and 48 FPS. So not all installed playback servers and projectors will be able to play at the extended frame rates.

The images are stored in the XYZ color space using 12 bits per component and per pixel and a gamma correction value of 2.6. XYZ is a device-independent color space that includes all possible colors in the visible spectrum. This makes it future proof in the sense that no changes to the format are necessary with the advance of technology in recording and projection. Since all projectors work in the RGB color space, a conversion has to take place during projection. The standards also define a minimum RGB color space for the projectors and include specifications for color accuracy and screen luminance.

At its original maximum resolution and 12 bits per component a single uncompressed 4K image needs roughly 39.8 Mbytes of storage space. This translates to a data rate at 24 FPS of 955.5 Mbyte/s or 7.6 Gbit/s[4]. Since this amount of data is too high to be handled in distribution to and projection in the

[3] see SMPTE 428-11-2009
[4] All data rates are given in power-of-ten units.

cinemas, compression has to be applied. Because natural images usually contain a fair amount of redundancy and also because the human visual system only has a limited sensitivity for certain image details, digital image compression can be applied to a certain amount without leading to a visible loss in quality for the audience. In the SMPTE D-Cinema system the JPEG 2000[5] compression algorithm is used for image compression. It is an intra-frame compression, which means that each image is compressed without looking at preceding images. JPEG 2000 is especially suitable for large resolutions at relatively high data rates and includes scalability features that are used in D-Cinema to simultaneously store 2K and 4K images in a single file. Simplified, a 4K image contains a 2K image plus the differences between the 2K and the 4K image. During playback of a 4K DCP a 2K projection system only reads and decompresses the 2K part of the compressed image and ignores the additional information for the 4K part. It is also possible to create 2K-only DCPs, and all playback server and projection systems, no matter if 2K or 4K, are required to support the playback of both 2K *and* 4K DCPs.

The maximum allowed data rate for the JPEG 2000 images in a DCP is 250 Mbit/s for both 2K and 4K DCPs. Practical experience shows that for natural images in the case of a 4K DCP only a relatively small percentage of the overall data rate is used to store the resolution difference between 2K and 4K. To achieve this data rate JPEG 2000 has to be used in its lossy compression mode. This means that image information is irretrievably lost during compression, but this happens in a way that the difference is usually unperceivable for a human viewer. If the data rate is set too low the images will first become blurry before more annoying compression artifacts become visible. Since JPEG 2000 does not use a block structure like MPEG-2 no blocking artifacts will occur. The critical data rate at which artifacts become visible strongly depends on the nature and technical details of the source images. In practice, data rates between 80 Mbit/s and 150 Mbit/s usually lead to acceptable results and often data rates significantly lower than the maximum of 250 Mbit/s are used to save storage space. At the maximum data rate of 250 Mbit/s a one hour movie would result in a DCP of around 115 Gbytes in size. In a DCP JPEG 2000 compression is normally applied using variable bit rates for each frame. This means that images with little detail–such as those that contain the closing titles on a black background—are compressed to very small files, while images with lots of fine details result in files as big as the maximum allowed size even if the average data rate of the complete movie is well below this limit.

On a side note, JPEG 2000 also supports a mathematically lossless compression mode that makes it possible to recreate the original image without any loss of information. This is not used in the DCP but may be useful for archiving high quality material.

Since a movie usually consists of several tens of thousands of single images, storing each compressed image in a single file on the hard disk would be complicated to handle and impose additional file management overhead. The solution is to put all image files into a so- called container or wrapper format. In the DCP the Material eXchange Format MXF is used for this purpose. An MXF file consists of a header section that in a DCP mostly contains technical details of the images and a body section that contains all images. In a DCP, sound and images are stored in separate MXF files.

[5] see ISO/IEC 15444-1:2004 and ISO/IEC 15444-1:2004/Amd 1:2006, http://www.iso.org/iso/catalogue_detail.htm?csnumber=37674

Sound data is generally stored uncompressed in a DCP and is also wrapped in MXF files. One sound track file can contain up to 16 discrete channels of audio which are typically used for multi-channel audio formats. Sound is sampled at 48 kHz or 96 kHz with 24 bits per sample. To handle multiple languages usually one sound track file exists per language, each of which can contain multi-channel audio data. Which sound track file and therefore which language is played is controlled by the Composition Playlist.

The package

The Digital Cinema Package is the entirety of all image, sound and subtitle track files, Composition Playlists, a Packing List, an Asset Map and an optional VolumeIndex. The functions of the track files have been discussed in the previous sections.

The Composition Playlist (CPL)[6] is a “self-contained representation of a single complete D-Cinema work, such as a motion picture, or a trailer, or an advertisement, etc.”[7] It specifies in which combination and order the assets (image, sound and subtitle track files) are played back to form this D-Cinema work. A DCP can contain more than one CPL and each track file can be referenced by more than one CPL. This makes it possible to create multi-language versions that reference the same picture track files but different sound or subtitle track files. It is even possible to create multi-language versions where some parts of the image differ for each language. To accomplish this it is necessary to put the differing scenes in separate image track files that can then be addressed by the appropriate CPL. Figure 2 gives a principle overview of the relations between CPL and track files.

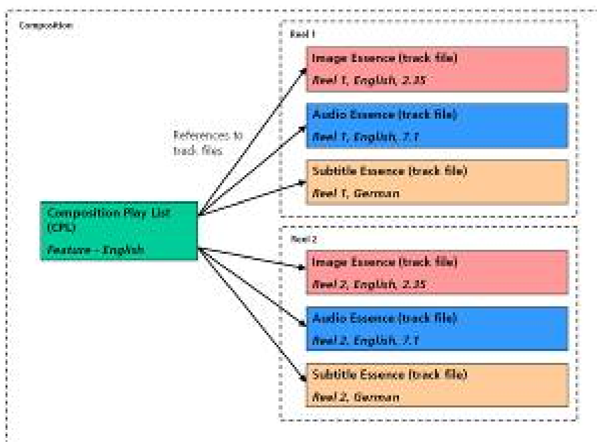

Figure 2- Relation between CPL and track files

The Packing List (PKL)[8] is an XML file that contains information about all files that belong to a DCP. The Packing List contains the identifiers of all assets in the DCP and includes further information regarding the issuer of the package, the system type that was used to create the package, etc. The PKL furthermore contains hash values for each asset in the package. Hash values or checksums are numbers of a certain length that are calculated from a file that is to be hashed and that can be used to identify

[6] see SMPTE 429-7-2006
[7] from SMPTE 429-7-2006, section 3
[8] see SMPTE 429-8-2007

manipulations or transmission errors. A playback server should recalculate the hash values from the asset files and compare them to those in the Package List to ensure the integrity of the package.

The Asset Map[9] describes the location of each asset on the storage media. It contains for each asset an entry that maps the UUID of the asset to a path on a file system. It is also possible to split assets that are too big for one single storage medium. In that case the asset map contains information of where to find all the chunks of one file on a multi-volume set of storage media. In that case the VolumeIndex[10] shall be used to identify each volume.

Encryption and access control

Encryption of a DCP is an optional possibility, but one that is used for most commercially distributed movies in order to enforce access control for the content. The DCI Specification contains many details of the complete access control and content security concept that encompasses encryption of the file in a DCP as well as mechanisms to ensure that only authorized playback systems are able to decrypt the content. The Specification also takes care of measures to prevent and detect manipulations of the playback systems. In this section of the discussion we will focus on the encryption and key delivery mechanism because this is the most important part for content producers and archives that receive encrypted DCPs.

The encryption-based content security and access control mechanism consists of two separate parts that are important here: 1) The encryption of the track files including digital signatures to ensure the authenticity of the CPLs and PKL and 2) The mechanism to deliver the cryptographic keys that were used to encrypt the track files to the playback system to enable it to decrypt and project the DCP. The encryption systems and algorithms that are used are standardized and have been commonly employed in information technology, encrypted emails, other documents and data for many years.

MXF track file essence encryption[11] makes use of the AES[12] system with 128-bit keys. AES is a symmetric encryption system, in which a single key is used both to encrypt and to decrypt a file. This means of course that if someone has the key that was used to encrypt a file he can also use it to decrypt the file. The conclusion is that the AES keys have to be kept secret and they should only be made available to the playback server systems that are authorized to decrypt and playback a DCP. Normally, the only point where these AES keys exist in plaintext is during production of an encrypted DCP. In a DCP each MXF track file shall be encrypted with its own key and with only one key per MXF track file.

Since the AES keys have to be kept secret they must be encrypted themselves before their transmission to the cinemas and to the D-Cinema playback servers. This is accomplished by using a second,

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[9] see SMPTE 429-9-2007
[10] see SMPTE 429-9-2007
[11] see SMPTE 429-6-2006
[12] Advanced Encryption Standard (FIPS 197), http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf

substantially different cryptographic algorithm called the RSA public key algorithm[13]. This is an asymmetric system. That means that a pair of two different keys is used: the receiver of an encrypted message holds a private key that must be kept secret and that is used to decrypt an encrypted message. The second key in the pair is the public key that is only used to encrypt a message but can not be used to decrypt it again. This asymmetric system makes it possible to send an encrypted message to a receiver without the necessity to arrange the secure exchange of a secret key.

In the case of a D-Cinema playback server the asymmetric key pair is created by the manufacturer of the server during production of the device. The private key is stored tamper-proof in a special hardware part of the server and there shall be mechanisms in place that ensure that the secret private key is automatically erased if someone tries to manipulate the system in any way. This means that not even the owner of such a server has the possibility of retrieving this private key. On the other hand, the public key that belongs to the private key of a playback server is available from the manufacturer or delivered together with the server, and this key is used to create Key Delivery Messages (KDM[14]) for DCPs that are specific for this server and that in turn contain the now RSA-encrypted, secret AES keys that were used to encrypt a DCP.

A KDM can contain the keys for one or more playback servers. It is also possible that a KDM might only contain the keys for one language version of a multi-language DCP while you would need another KDM to be able to playback another language. KDMs may also contain restrictions that define the time during which a DCP can be played back. In theory an end point very far in the future is possible. Additionally, hashing and signature mechanisms are in place to ensure authenticity of a KDM and to prevent manipulation of KDMs during delivery to the cinema. Figure 3 gives an overview of the encryption, key delivery and decryption process.

[13] see "PKCS #1: RSA Cryptography Specifications Version 2.1" By B. Kaliski. February 2003. RFC 3447, http://www.ietf.org/rfc/rfc3447.txt
[14] see SMPTE 430-1-2006

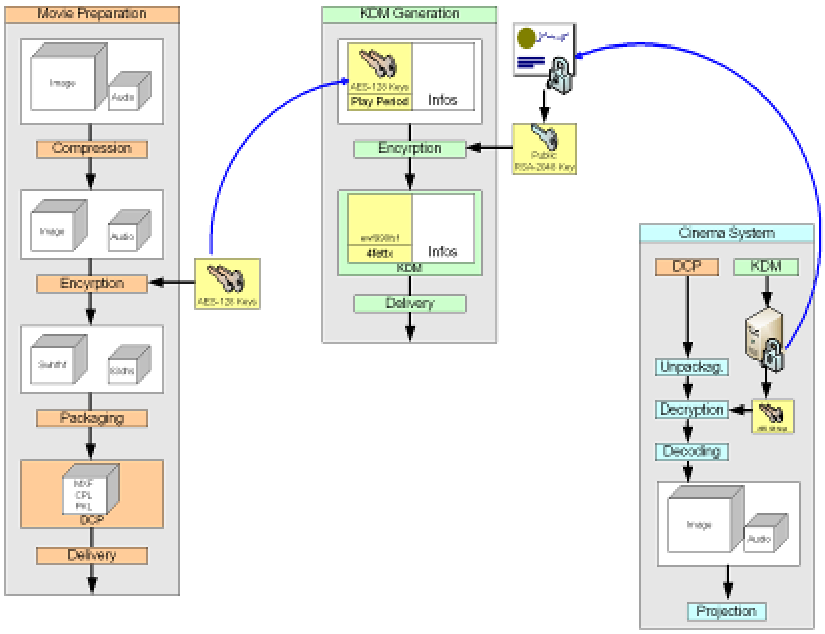

Figure 3 - DCP and KDM encryption process

The advantage of this two-stage approach is that a DCP only has to be encrypted once and not individually per cinema or per playback server. The connection to the playback servers is only created at the point where a KDM is created. Since each AES key has a size of 128 bits the size of a KDM usually is only a few kilobytes. Therefore a KDM can be easily and quickly created and also transmission of the KDM to the cinema can be achieved via email or small USB memory sticks.

Production of DCP

The production of DCP is a straightforward process that can somehow be compared to producing a video DVD. It usually consists of several steps:

1) Preparing the images, sound and subtitles;
2) Importing everything into the DCP authoring application;
3) Arranging the material in compositions that form the CPLs and setting general parameters; and finally
4) Starting the process to convert and compress, optionally encrypt, the images and sound data, create the MXF and XML files.

The result is a folder on a hard disk that contains the DCP and that can be copied to other media for transfer to the cinema.

Systems to create DCPs are available from different vendors like Doremi[15], Dolby[16], Fraunhofer IIS[17] and or the open-source Open Cinema Tools[18]. The software-only solutions from Fraunhofer IIS and the Open Cinema Tools run on any standard PC or Mac. However, it is advisable to use a fast multi-processor, multi-core computer with a fast and large hard disk system because JPEG 2000 encoding is a very complex process and especially because the source image files will be in most cases very large.

Most systems accept TIFF and DPX files as input for images and WAV files for the soundtrack. Most of the time it is not necessary to explicitly create the D-Cinema Distribution Master[19] (DCDM) that is mentioned in several SMPTE standards and is described as 16 bit TIFF files for images. The necessary conversion steps, like color space transformation to XYZ or scaling of the images, are often carried out during the encoding process and some systems even accept Quicktime .mov files as input formats.

In the case of creating an encrypted DCP, there are two basic possibilities: images and sound can be encrypted during the encoding and MXF wrapping process, or an unencrypted DCP can be created that is encrypted at a later stage. In both cases the authoring or encryption systems provide means to store the AES encryption keys for later use to create KDMs for the playback servers. The KDMs are typically created by an additional software system.

Archiving Digital Cinema

General considerations

The transition from film to digital cinema is going to have a very large impact on archives and there are positive as well as negative aspects connected to this process. On the one hand archives will have to cope with material that is going to be delivered in a wide range of digital formats, of which a Digital Cinema Package can be one. On the other hand digital technologies including the DCP provide efficient ways to publish and distribute archived material on different, and possibly very high, quality levels. Unfortunately, archiving of digital data follows very different principles compared to what film archives are used to. While quality degradation of the content over time can be reduced to zero as long as data is only copied but not converted during migration to new media, the loss in case of any errors at critical points in the complete system can be total.

The fundamental difference in archiving digital data compared to traditional films, books or similar materials can be found in the longevity of the storage media and the characteristics of degradation over time. Digital storage media often have a theoretical archival life of 15 to 30 years[20] according to the statements of the vendors. This is much less than what can be expected from traditional media like film. In practice this lifetime is reduced even more because of the strong risk of obsolescence of drives,

[15] see http://www.doremicinema.com/cinemaprods.html
[16] see http://www.dolby.com/professional/products/cinema/digital-cinema/scc2000.html
[17] see http://www.iis.fraunhofer.de/EN/bf/bv/cinema/dcpcreation.jsp
[18] see http://www.opencinematools.org/
[19] see SMPTE 428-1-2006
[20] see http://www.oracle.com/us/products/servers-storage/storage/tape-storage/029159.htm and http://nle.ch/dl/LTO.pdf

software and systems. A magnetic data tape in its best possible condition is worthless if the tape drive, the storage software and the computer systems that work with the drive and software are no longer available. Film can always be viewed, projected or scanned. Essentially, this means that in the digital world frequent migration processes are mandatory. If this migration is omitted because of lack of money or other resources or because of other external circumstances, there is a very strong risk of losing the collection. If a magnetic tape is discovered after 50 years in the attic it may be useless while film under the same circumstances may very well have lasted and can be of use.

Another important point for archives to consider is which digital formats to accept for deposit, especially where legal deposit rules are in force. DCPs are the digital equivalent to film prints that are delivered to the cinemas and the archives that accept film prints for deposit. The DCP may have a comparable quality level but most, if not all, DCPs of commercial productions will be encrypted. And while the quality level is already very high it probably does not match that of an interpositive because of the use of lossy compression. On the positive side, the amount of data encountered from a DCP can be handled in today's IT infrastructure without problems while uncompressed or losslessly compressed digital masters are still difficult to handle.

Encryption

While the image quality of a DCP that is deposited at an archive may be beyond that of a film print, encryption poses the most significant problem. As an archive element the DCP is only useful for the archive if it also holds the AES keys that were used to encrypt the image and sound track files. An encrypted DCP without keys is of no use at all because it can not even be played back. Also a DCP with a KDM for a specific playback server and projection system is only of very limited use for the archive. With a normal KDM the DCP can only be played back on the systems that are explicitly included in the KDM. This DCP can neither be converted to other formats for preview of long-term preservation nor can it be played back on other systems if the system the KDM was produced for is no longer serviceable. Also the time limit of the KDM may become a problem because the DCP can not be played back any more after the end date and time stated in the KDM.

Because of the high image and sound quality of a DCP and because of the fact that digital data is relatively easy to copy without any loss in quality compared to film, content owners are very reluctant to give unencrypted DCPs to archives. There are two important aspects to this practice. On the one hand content owners may fear that archives are not able to provide appropriate protection to the material on their premises. This problem can be solved by setting up suitable security measures that prevent unauthorized access of the material. On the other hand there is the risk of content theft during transport or transmission of DCPs to an archive. This can only be prevented by encryption. One possible solution could be to provide encrypted DCPs to archives and also delivery KDMs that can be used with special software to decrypt the DCPs in a secure and controlled environment on the archive's premises. This would secure the transmission but also give archives the possibility to take care of the long-term preservation of today's digital films for the future.

Playback of DCPs and other archival formats

Normally, D-Cinema playback servers and D-Cinema projectors are used to screen DCPs. These systems incorporate the security measures of the DCI Specification. Unfortunately, they are also expensive systems and oversized for many applications. Most especially the decoding of the JPEG 2000 compressed images in the DCP is a very demanding task that could in the past only be carried out in real-time by hardware decoding boards that use specialized integrated circuits. With the advent of more powerful personal computers and technologies like graphics accelerator boards that can also be used for other computationally complex tasks this has changed significantly. Today, it is possible to play back a 2K DCP on a PC equipped with a suitable graphics accelerator in real-time. And if it is not required to play the DCP in full resolution, a lower resolution preview can also be accomplished on a decent standard office PC[21].

Conclusion

Many digital technologies can be used to the advantage of film archives. They can simplify distribution and make sophisticated restoration processes for degraded film material possible. With the Digital Cinema Package there is also an efficient way to distribute archive films in a very high quality to digital cinemas. However, there are also negative sides. While it always has been possible to acquire release prints and store them for future generations, even without the consent of the content owner, this is now significantly more difficult if not impossible with encrypted DCPs. Archives not only have to take care of the specific properties of digital data and develop ways to store the data for a very long time frame. They also have to work out, in co-operation with the content producers and rights owners, how to preserve digital films and simultaneously satisfy the rights holders' needs for content security. This article describes only a very small part of the world of digital technologies for cinema. Traditional archives need to participate in these technological advances to be able to carry out their mission in the future.

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[21] see http://www.iis.fraunhofer.de/EN/bf/bv/cinema/dcpplayer.jsp

About the Author

Arne Nowak works as a project manager for digital film archives at Fraunhofer IIS in Erlangen, Germany. He received a degree in electrical engineering from Ilmenau University of Technology and started his professional career in 2002 with research work on digital TV production systems including file-based production and real-time graphics.

He joined Fraunhofer IIS to work on digital film archive systems in 2006. Since then he has been responsible for the development of a digital archive system's concept and architecture for which he led the user requirements analysis and coordinates the software implementation and testing. Arne Nowak also contributes to projects on digital post-production workflows, image compression and image processing. He is a member of SMPTE, FKTG and AMIA.

AMIA Tech Review
From the Association of Moving Image Archivists

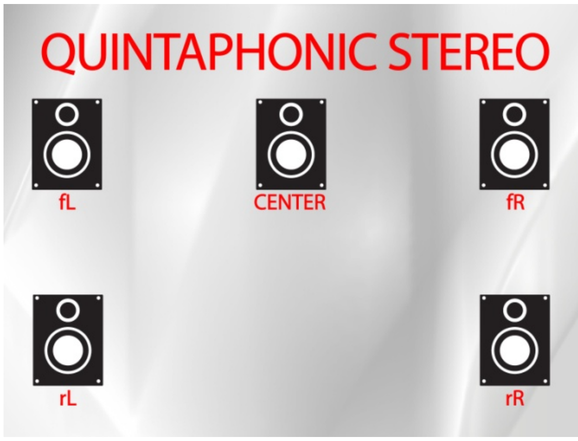
October, 2010.Volume 2

Tommy, Can You Hear Me?
The Quintaphonic Restoration of a "One Hit Wonder"

By Bob Heiber

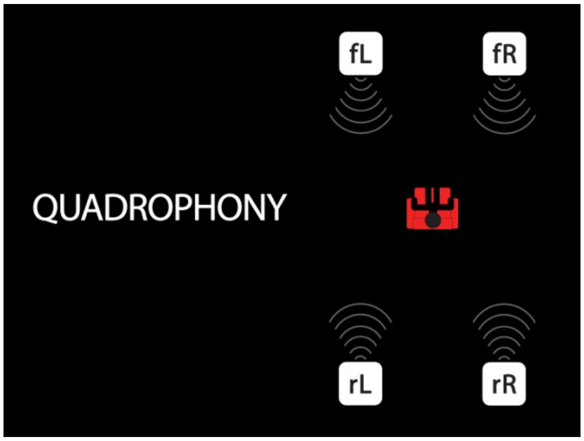
The old adage, "The more things change, the more they stay the same" could have been coined to describe the technical developments of multi-channel stereo for motion pictures. Today's warm embrace of 5.1 and 7.1 multi-channel surround stereo owes its existence to the pioneering motion picture stereo formats from as early as the 1940 release of *Fantasia.* However, over the years, most of these formats were either short-lived or unsustainable due to technical issues in presentation or equipment maintenance for exhibitors. The Quintaphonic stereo sound track for *Tommy* (1975) is one of these short-lived formats on the road of motion picture sound technology development.

The wizardry of *Tommy* extends beyond director Ken Russell's imaginative visuals and The Who's rock opera score for the distinction of introducing Quintaphonic Sound theatrically. Quintaphonic Sound, or "Sound in the Round," features 5 discrete channels.



Three speakers were behind the screen—left, center, right—and two speakers, also of equal fidelity, were in the left rear and right rear of the theater. This multi-channel stereophonic presentation was revolutionary in 1975, not for its multi-channel stereo capability but because it introduced the concept of matrixed stereo for motion picture sound tracks.

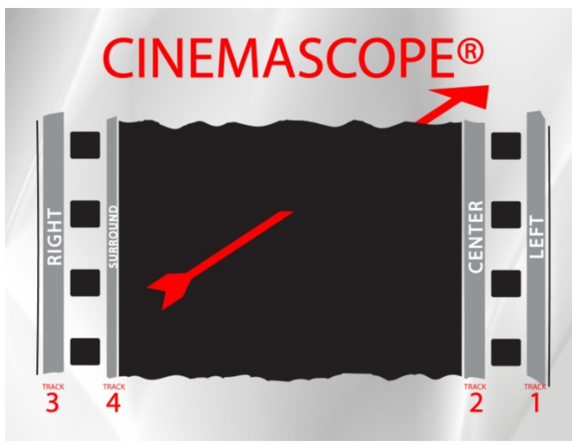
The concept of matrixed stereo was not new in 1975. Matrixed stereo tracks had been introduced in the early 1970s with the introduction of Quadrophonic (or Quadraphonic, either are correct) stereo for the record industry.



Quadrophonic, as the name implies, is a four-channel system with 4 speakers placed front-Left, front-Right, rear-Left and rear-Right (fL, fR, rL, rR). The format featured 4 speakers of equal volume and frequency response.

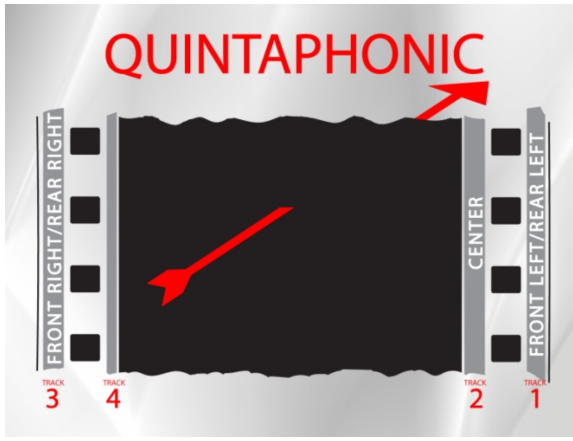
Early implementations of Quadrophonic presentations primarily used audiotape allowing for four separate channels to be recorded. However the record industry quickly adopted matrix technology, combining the 4-channels into 2-channels in order to produce a compatible 2-channel/4-channel stereo record. CBS Records was the first to produce a matrix, which it called SQ for Stereo Quadrophonic. Shortly thereafter, Sansui marketed the QS (Quadrophonic Stereo) decoder. The Sansui matrix, developed by Isao Itoh, was considered a superior version and was the choice for John Mosely and Keith Johnson, the developers of Quintaphonic stereo to bring 5-channel sound to motion picture audiences.

One shortcoming of Quadrophonic stereo presentations was the need for the listener to be at an equal distance from all four speakers, the "sweet spot," for the best stereo presentation. This is not hard to do in a living room for an individual listener. But for motion picture theaters with rows of seats stretched across the auditorium this would not be possible. However, motion picture mixers had already been mixing 4-channel stereo for CinemaScope® films since the early 1950s. CinemaScope stereo is different than 4-channel Quadrophonic.



In CinemaScope the speaker placement is: Left, Center, Right and Surround (L, C, R, S). The center channel speaker was critical to the motion picture sound experience, since a majority of the action on the screen happens in the center. Thus the center speaker "anchors" the mix and allows for audiences across the theater to hear the sound with a more or less equal experience.

Both Mosely and Johnson were familiar with CinemaScope stereo and had in fact decided that magnetically striped prints used for CinemaScope stereo sound could be used to exhibit Quintaphonic stereo too. However, the CinemaScope print has only 4 magnetic stripes and Quintaphonic stereo needed 5 separate channels. The pair cleverly employed the Sansui QS matrix to allow 2 of the magnetic stripes to carry a 4-channel Quadrophonic mix. The third track would carry the mono center channel to complete the 5-channel stereo presentation. Thus the final channel configuration for the Quintaphonic track of *Tommy* was left-Front/left-Rear, Center, right-Front/right-Rear.



Quintaphonic sound, however, was extremely short-lived because of the concurrent development of Dolby® stereo. Unlike Dolby® stereo tracks which could be recorded optically on motion picture prints, the Quintaphonic soundtrack was recorded on expensive 35mm magnetic-striped prints. Thus *Tommy* was the only film to be exhibited theatrically in 5-channel Quintaphonic sound.

For the preservation and restoration of *Tommy*, its unique stereo technology presented additional issues for element and technology research. In order have the most authentic Quintaphonic sound experience, Sony Pictures' Film Restoration department supplied fifteen sets of magnetic soundtracks—nearly 150 reels of 35mm magnetic sound—which were catalogued, inspected and evaluated for format and quality.

Though released in Quintaphonic sound, magnetic recordings for *Tommy* were also created in 4-track, L, C, R, S stereo, 2-track Dolby® stereo, and a variety of mono formats. To further compound the evaluation process, Quintaphonic sound used DBX® noise reduction while other sets used Dolby A encoding or no noise reduction at all. As was often the case with films made decades ago, many of the reels of film were not clearly labeled, so considerable time was spent in the studio to evaluate both the noise reduction systems as well as the Quintaphonic sound decoding.

Once the preferred 35mm magnetic Quintaphonic masters were identified, the tracks were processed with Sonic Solutions NoNoise® to reduce noise, distortion, dropouts, ticks, pops, etc., all problems common to older films. It should be noted that while many noise problems were addressed, great care was taken to not over process the track, so that the artistic integrity of the original mix could be maintained. Thus, the unusual characteristics of the original mix—close micing of the performers, instrument noise, active panning among the front and rear speakers—were carefully scrutinized to ensure that an overly sterile track was not produced.

Tommy is a 1970s rock opera. It does not fit the mold of a typical film soundtrack. Often, in place of representational sound effects (a real car or the actual ocean), synthesizers were used for an interpretational approximation. The mixing style varies from rather conventional to extremely wild, with exaggerated panning, phase shifting and very potent surround information. “Pinball Wizard” and “Acid Queen” demonstrate this to good effect.

Though the Quintaphonic stereo presentation of *Tommy* was a “one-hit wonder,” the groundbreaking technical developments it introduced–matrixed stereo sound tracks and dynamic surround mixing—are easily recognized as the foundations of our modern, multi-channel stereo experience. Fortunately the efforts of dedicated restoration and preservation executives and technicians have ensured the unique legacy of *Tommy* for future generations.

About the Author

Bob Heiber is Vice President Audio – Deluxe Digital Media, Chace Audio by Deluxe. Bob has been working in film sound preservation and restoration since 1990, when he joined Chace Audio. He is a member of AMIA, SMPTE, ARSC and the Academy of Motion Pictures Arts and Sciences. Bob has served on three National Panels for the Library of Congress and has spoken on film sound preservation, restoration and remastering at conferences and symposium around the world. Prior to joining Chace, Bob was a studio manager for Warner Bros. and an award-winning 16mm filmmaker in Chicago, Illinois.

Chace Audio by Deluxe is a well-known sound preservation company, located in Burbank, CA. Company projects include: ***Gone With the Wind, Patton, Close Encounters of the Third Kind, West Side Story*** *and many other motion pictures.*

AMIA Tech Review
From the Association of Moving Image Archivists

October, 2010.Volume 2

Film Preservation at the Library of Congress

Packard Campus for Audio Visual Conservation

By Ken Weissman

Protecting our moving picture collection assets and preserving "America's Memory" for future generations is the primary goal of the film preservation program at the Library of Congress. The Library has operated an in-house film preservation laboratory for nearly four decades. Founded in the early 1970's, the lab was originally located in the basement of the Library's Jefferson building on Capitol Hill. The lab relocated to Wright-Patterson Air Force Base near Dayton, Ohio in 1981, taking advantage of the close proximity of nitrate film vaults that the Library had operated on WPAFB since the late 1960s. The film lab closed in April of 2007 as staff began relocating to the Packard Campus for Audio Visual Conservation in Culpeper, Virginia about 70 miles southwest of Washington DC.

Main entrance to the Library of Congress' Packard Campus

The Library of Congress Packard Campus for Audio Visual Conservation has the primary curatorial responsibility for the Library's 6.3 million piece collection of audio, moving image, and film materials. Prior to the advent of the Packard Campus in 2007, the main focus of the film preservation program was the vast nitrate film collection, consisting of some 140 million feet of camera original negatives, original sound tracks, and projection prints dating back to the 1890s. With the new facility, the preservation focus has broadened to include all of the Library's film materials that are in need of preservation.

Just a few of the doors which lead to film vaults

Because of nitrate's nature to eventually deteriorate (sometimes in rather spectacular fashion), the content on all of the thousands of films in the Library's collection is at risk. But so are films that were made of cellulose triacetate, as anyone who has un-spooled a film suffering from "vinegar syndrome" can tell you.

The technical challenges of operating an archival film laboratory

As most of AMIA's membership is aware, cellulose nitrate is a flammable material, but it also happens to be a very high-quality and exceptionally clear plastic, making it ideal for projection. Film manufacturers struggled mightily to come up with a nonflammable substitute that could match the optical and physical performance of nitrate film. But until that new base was found, 35mm motion picture film was almost exclusively nitrate from the beginning of filmmaking. Nitrate film remained in circulation through the early 1950s in the US and as late as the early '60s in Eastern Europe, Russia and China. With the advent of cellulose triacetate, nitrate was phased out of use in the United States and Western Europe. Beginning in the 1960s film manufacturers in the US began manufacturing a limited number of emulsions on polyester base. As expertise with this inert product broadened, its use has been extended to many more film products, pushing triacetate-based materials into the minority in common laboratory applications. An archival preservation laboratory needs to be able to work with all three of these film types or even reels of film that combine these various bases. But this is just the beginning of the challenges that face a film laboratory specializing in the preservation and restoration of archival films.

The bulk of the nitrate-era films are black and white, so that has been our specialty. Chemical formulas have been tweaked from time to time, but the development process hasn't changed very much since it was invented.

A bevy of sparkling, new film processors

B&W film developing is as much art as it is science, which means that the final look of the print on the screen can be intentionally altered at the processing stage. The amount of time the film is in the developer and the temperature of the developer can be adjusted to compensate for the fact that we don't always have the luxury of an original camera negative as the source material when working on a preservation project.

Likewise the "copying" of old films to new stocks is not as simple as it sounds. There are many factors that can impact the quality of the final result, with shrinkage in nitrate and triacetate films being one of the most notable. It is a fact of life that shrinkage is unavoidable as these films age, but why does shrinkage matter?

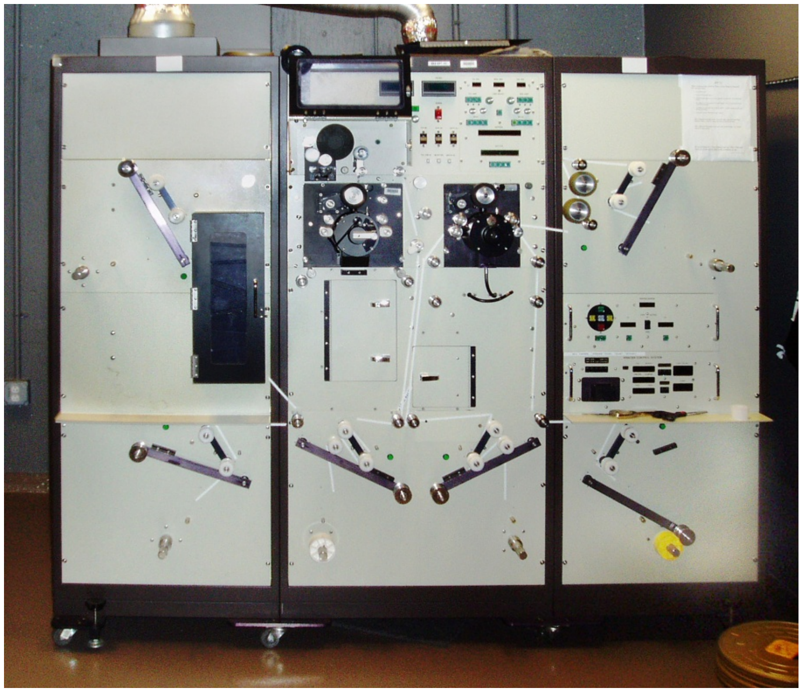
Stock makers perforate newly manufactured film to very rigid standards–accuracy is maintained literally to the ten-thousandth of an inch. Camera negative film perforations have a pitch (essentially the distance between them) of 0.1866” while print stocks are perforated to a pitch of 0.1870”. The 4 ten-thousandths difference enables the two films to be contact printed around the radius of a printing head, keeping the films in close contact with one another so that the image is as sharp as possible. The negative film or shorter pitched stock is on the inside of the radius, while the print stock with the longer pitch is on the outside. The slightly greater distance between the perforations allows the two pieces of film to remain in close contact during the printing process.

It was common for original era nitrate or acetate negatives to show shrinkage shortly after they were shot and processed of as much as 0.5%. But as nitrate film continues to age (and acetate film to a somewhat lesser extent), shrinkage can become more pronounced. Excessive shrinkage results in a loss of resolution, jitter, and/or general image instability and degradation when printed on machines designed to print fresh negatives. When source materials reach this stage of shrinkage, specialized equipment must be employed to produce duplicates which are acceptable.

Other challenges are associated with the amount of damage the film was subjected to over time. If the only remaining source material for a subject is a positive print, such prints frequently have been damaged to a greater or lesser extent by poorly maintained projectors upon which they have been run. In dry regions, static electricity can attract dirt to the surface of prints or negatives, where it may be embedded in the emulsion as the film was wound back up. These problems and defects can print through to new materials. Various pieces of equipment have been designed to help overcome these and other problems, including automated film cleaning machines to remove as much dirt as possible and wet-gate or full immersion printers to eliminate some surface defects, such as base scratches.

The introduction of wet-gate printers and immersion printers created a sea change in the world of preservation. They allowed laboratories to make fairly pristine copies from films that were otherwise horribly scratched. This is done either by applying or by immersing the film in a liquid–perchloroethylene, the same fluid used in dry cleaning–to temporarily fill in the scratches. When we look at films that were preserved prior to the wet-gate era and compare them with preservation work done from the same negative using wet-gates or immersion printers, there is often a remarkable difference.

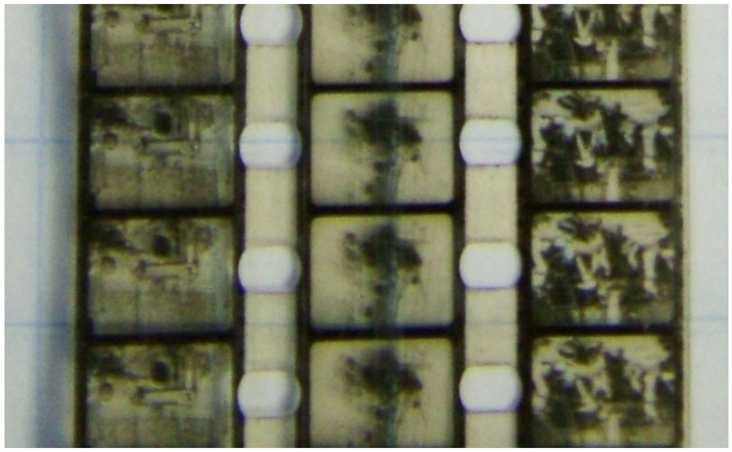
The Library’s film preservation laboratory has an interesting and diverse set of printers which it can use to preserve films in its collections. These include continuous-contact and step-optical printers, as well as several film scanners for direct-to-digital work.



A BHP Panel printer with dry printing heads installed

We have two BHP model 6127R continuous-contact full immersion printers, which are the workhorses of the film lab. The printers can be used for either 16mm or 35mm film and they can be run as full immersion or as dry printers, depending upon the project. In addition to the standard heads, we have a set of specially modified heads for handling shrinkage up to around 2.25% for 35mm film and over 1% for 16mm film. These printers run at varying speeds, from 60 feet per minute in wet-mode up to around 480 fpm in dry mode.

For films that have higher levels of shrinkage or exhibit other problems such as extreme brittleness, we can use one of our two step-optical printers: an Oxberry model 1500 or an ACME 105. The projector portion of the printers move the film one frame at a time, pause, and then the camera side of the printer re-photographs the picture onto the new film stock. These printers are much slower, running at up to 10 feet per minute at maximum speed.



A sample of an Edison Home Kinetoscope print

For the Oxberry printer we have a selection of dry and wet-gates with matching sprocket sets that enable us to print just about every gauge of film within the Library's vast collections. These include 8mm, S-8mm, 9.5mm, 16mm, 22mm Edison Home Kinetoscope, 28mm and various types of 35mm. This printer also features a variable pitch cam which allows us to adjust for shrinkage of the original. Some of the gates also allow additional adjustments; we seldom come up against shrinkage levels that are too high for us to transport.

We recently acquired an Oxberry Cinescan 4K step-optical film scanner that can also utilize the same wet-gates and sprocket sets, allowing us to go straight to digital files when needed, especially for use in restoration projects.

Preservation versus Restoration

For the most part the work being done at the film preservation laboratory comes under the definition of *preservation*. That is, we make as faithful a copy of the film that we have in our collection as we can. *Restoration* is a much more involved process beginning with answering the question: What is the right version of a given film to restore? There can be several different negatives and, especially as you get back to the 40s and earlier, there are few notes to describe what changes were made or why.

For example, we did a restoration of "Mr. Smith Goes to Washington" in 2002, and we were able to identify six different versions of the film, from roughly 119 minutes to 132 minutes. So, which one should be your guide? In our case, we chose to restore to the longest version. Based on research, including newspaper reports from the time, we became convinced that this was the version screened at the original premiere.

There are other more *technical* questions where the answer is not so easy. For example, what should we do if a film negative appears to have been underdeveloped? Clearly, there's art involved, so we must make a qualitative judgment as to whether this was intentional or merely poor lab work. If necessary, we can essentially force-process the master positive and to a certain degree adjust the gamma to make it more “normal.” But there are ethical decisions that have to be made: If this is the way it has always been seen even by the original audiences, what right do we have to change it?

Whenever we make decisions like this, we document our reasoning. I have no problem with people being critical of our approach. If someone were to provide evidence that we took the wrong approach, we can go back to the original and redo it with the new information–although, quite frankly, we don't get criticized very often, because our reasoning is usually pretty sound.

Paper Prints

We started as a photochemical laboratory and we are primarily one to this day. However it has only really been in the past half-dozen years or so that you could even begin a conversation that might convince “people-in-the-know” that preserving motion pictures might be done digitally. To test this approach we conducted a pilot digital project for a very special collection that we have in the Library of Congress: the paper print collection.

These paper prints exist because of an interpretation of the copyright law at the time that motion pictures were invented. That interpretation said that a motion picture film is simply a series of still photographs and therefore the still photographic copyright law applied. If you wanted to copyright a motion picture, you had to provide the Library of Congress two copies of the film, and they had to be on paper—***not film***. Thus a process was invented to literally create long strips of photographic paper, exactly the size of 35mm film stock. Contact prints from the original 35mm negatives onto those long strips of paper were then deposited with the Library.

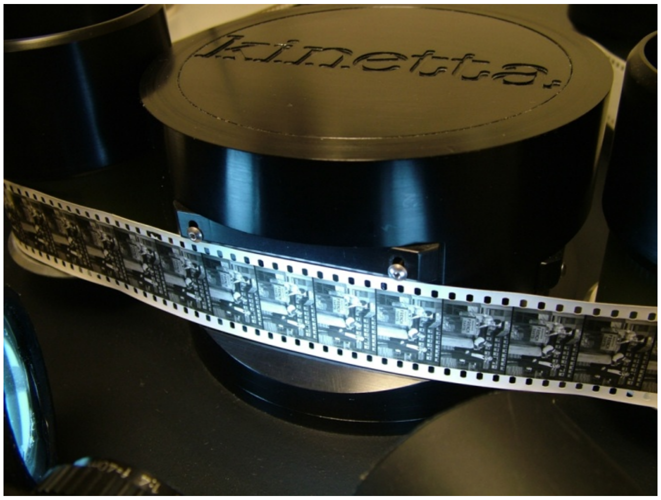
A paper print from a 35mm motion picture negative

There are over 3000 titles on paper within the paper print collection. These are some of the earliest films ever made, coming from the period of 1894-1915, the vast majority of which are from before 1912. Most of them are unique—no other copies of these films are known to exist. They represent the single largest collection of early motion pictures in the world and the Library is rightfully very proud of that collection.

The paper prints had been locked in a vault in the bowels of one of the library buildings–until rediscovered by librarian Howard Walls in the late 30s. Today the paper itself is still stable, but for the most part, you can't see the images very easily except by looking directly at the paper. Over the years there have been several projects to re-photograph the paper images back to film.

One of the first was by Kemp Niver and his company, Renovare. Niver took these 35mm prints (and there are some that are actually a larger gauge than that) and re-photographed them using a clever device that he built, printing to 16mm film. We have used various models of these Niver printers, including one where we replaced the 16mm camera with a 35mm camera in order to print back to 35.

All of the processes have been interesting and to some degree they've all been successful. However, for a variety of reasons, some of the images are alternately soft, fuzzy or very shaky, and up until now there has been no way to accurately register the images. In fact, we've concluded that in many cases the images weren't very well registered on the paper in the first place.



A paper print advances through a digital scanner

With today's technology, the obvious solution is to scan the images and then take advantage of digital processing to stabilize them, correct positioning and so on. Our first scans of the paper prints were 2K x 2K, which theoretically should have been good enough, but in some follow-up testing and subsequent analysis of the imagery, we think it might be better to go to 4K x 4K. But that's what a pilot program is intended to do—to figure out exactly how to do the job right. To date we haven't gone into a production mode due to some equipment issues, but we hope to implement a production work flow in the not too distant future.

Conclusion

The Library of Congress has been in the film preservation business for a very long time. With the advent of the Packard Campus for Audio Visual Conservation, the film preservation program enjoys a new facility in which to conduct its ongoing efforts. There are also plans for expanding the program's capabilities, such as color film developing and film sound re-recording. The future is bright with promise, and it will be interesting and exciting to watch it unfold, with more information to be presented in this forum. Stay tuned!

About the Author

Ken Weissman *has worked in film production and preservation for the past 31 years. He has worked for the Library of Congress since 1981. His career at the Library began in the Motion Picture Preservation Laboratory, first as a Film Preservation Specialist, then as Lab Supervisor. In 1995 he was named head of the Library's newly formed Motion Picture Conservation Center. Ken has directed the Library's restoration of such films as "Mr. Smith Goes to Washington," "The Maltese Falcon,""Where Are My Children?," "The Blue Eagle," "Big Fella," and most recently a restoration of Paul Robeson's "The Emperor Jones" under a grant from the National Film Preservation Foundation. For the past eight years he has been intimately involved in the design, construction, and commissioning of the film preservation laboratory located at the Library's state of the art Packard Campus for Audio Visual Conservation. The laboratory includes both traditional photo-chemical as well as digital DI workflows in order to preserve and make accessible the Library's massive film collection.*

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The *Visionary Archive* Process

By Sean McKee and Victor Panov

For decades color motion pictures have been archived for long-term storage using color separations which record each of the three primary colors on separate black and white films. Properly processed black and white silver-image film is well known to have a substantially longer shelf life than color film whose images are produced by fugitive dyes. Today, this traditional archival process is still used whether a movie was shot on film or with modern digital cinema cameras. In the case of stereoscopic 3D movies that contain left-eye and right-eye content, a total of six strips (three for each eye) have to be made for archival purposes. Ultimately, a future generation will be able to take these films and recombine them to view a full color movie.

No one will dispute that the making of separation positives is costly, and until recently these separations were still prone to age-related deficiencies associated with either nitrate or acetate bases. (Polyester based separation film exhibits a vastly more stable long-term geometry than either of its predecessors.) In any case it is possible that each strip of film with any of these bases may become physically distorted over time. If even one strip is warped or shrunken, the registration of the three color records will not line up, causing color fringing in the final combined color image. Recent advances in digital recombination of separations can correct this problem but certain facilities offering this service may charge an additional fee for its use.

The "Visionary Archive" process eliminates the need for a separate strip of film for each color record. By using proprietary software, a full color motion picture frame is digitally encoded into a specially designed multichannel color space. This creates a black and white version of the image to be recorded to a single strip of black and white film stock. Contained within this black and white image is the color information of all three color records, encoded using, for example, a RGB Intra-pattern mosaic. The process requires one-third the resources of the traditional method at both the recording stage and the re-scanning and recombining stage. No special color registration is required at all.

A further consideration concerns grain. Traditional 3-strip methods introduce three layers of film grain to the recombined image; "Visionary Archive" introduces one.

When an archivist wants to view an encoded film in full color, he or she will simply scan the one strip of black and white film using traditional film scanning methods and then process the image back to full color using an algorithm based on correlating information between the pixels. There are a variety of approaches which can be used to create a de-mosaic algorithm; the end user is not tied to any one de-mosaic solution.

To archive the image:

1. An image is divided into groups of NxM pixels (where N >0, M >0).

2. For each pixel in the group only one color value is kept and others discarded according to *some* rule. One example of such a rule is a mosaic pattern filter, where each group has size 2x2: one pixel keeps the red value, one blue and two others, green.

3. The resulting image is recorded on the medium. Because the image only contains a single value for each pixel it can be recorded on a broad range of media; the obvious choice for long term storage is black and white film. Each value for the pixel may be recorded in "analog" and/or "digital" form.

To reconstruct the image:

1. If the “encoded” image has been recorded on film, a single channel image is retrieved from the media using a common film scanner.

2. Using an algorithm based on correlating information between pixels, all missing values for each pixel are restored. As previously pointed out, the de-mosaic algorithm is commonly available for this purpose.

3. The image is converted back to the original color space.

Figure 1 – Source Image

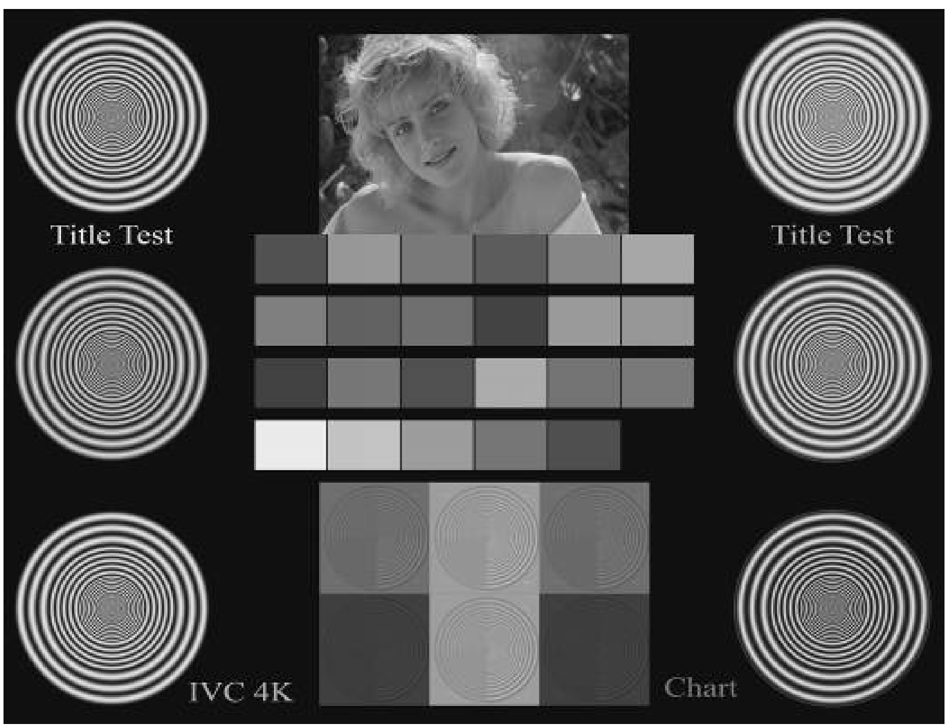


Figure 2 – Color space conversion & RGB Intra-mosaic pattern applied

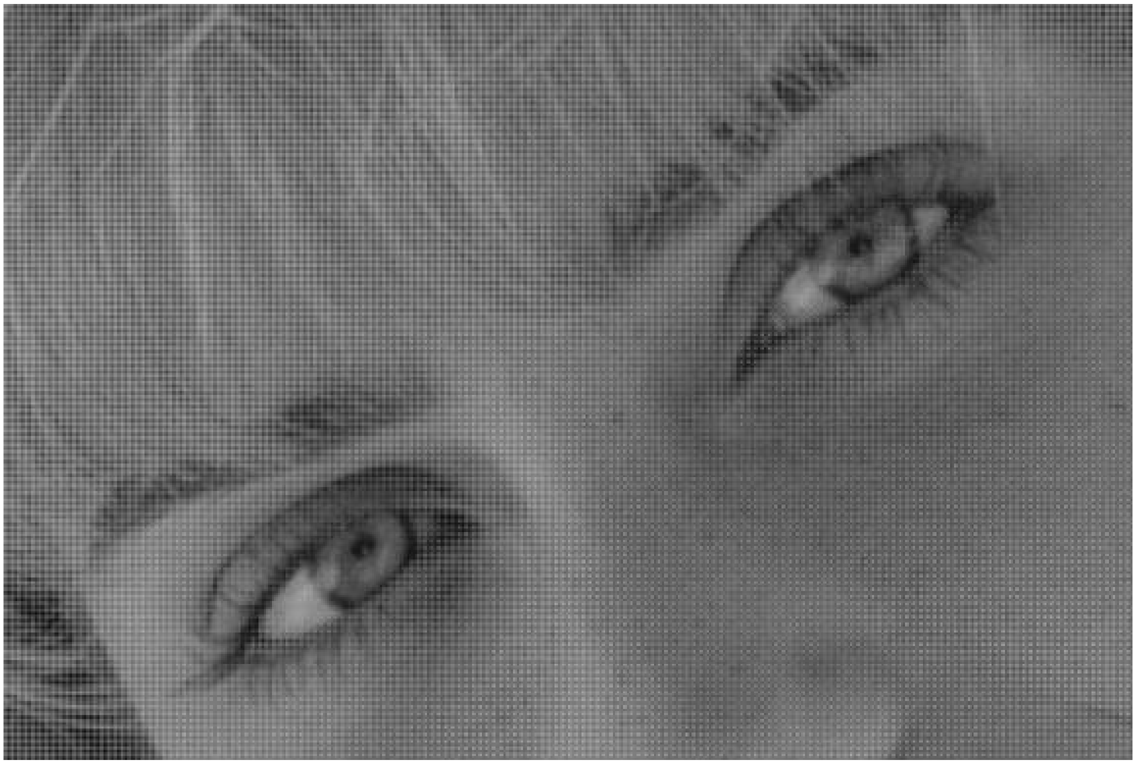


Figure 3 – Close-up of Mosaic Pattern

While reconstruction of the color image via this method has proved to be successful, various degrees of difficulty doing so were encountered in some footage. The extent of difficulty has been found to be related to the contrast of the image being recorded and scanned and the amount of grain in the resulting image. (Lower contrast makes it more difficult to recognize the Mosaic Pattern in the green color channel.)

The initial pattern was a four pixel square with GBRG arrangement. In order to guarantee a successful reconstruction every time, a new method was devised to place each of these unique color pixels/color records in its own quadrant of the film frame, as shown in Figure 4.

Using this geometry, a means of calibration and alignment has been devised to ensure pixel-accurate reconstruction of the image with no registration errors. A computer-generated, analog sine wave pattern based on prime numbers encompasses and represents each pixel in the recording. It is placed as a cross hair between the color channels and as an outline border around the whole frame (see Figure 5). By applying this method—as long as somebody can get the encoded film through a scanner, warped, shrunken or not—the “Visionary Archive” software will be able to recognize the alignment patterns and effectively de-warp an image to return it to the exact geometry it had when first recorded.

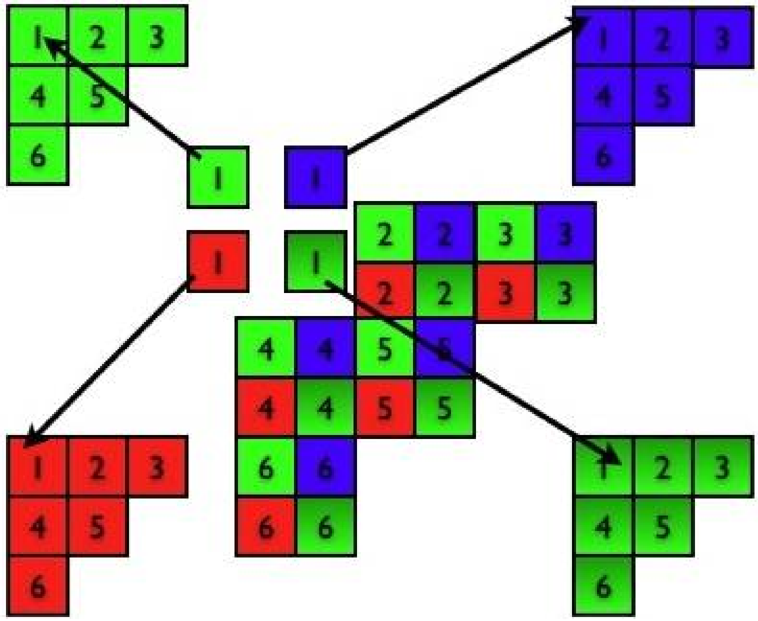


Figure 4 – Separating color channels from Mosaic pattern into quadrants

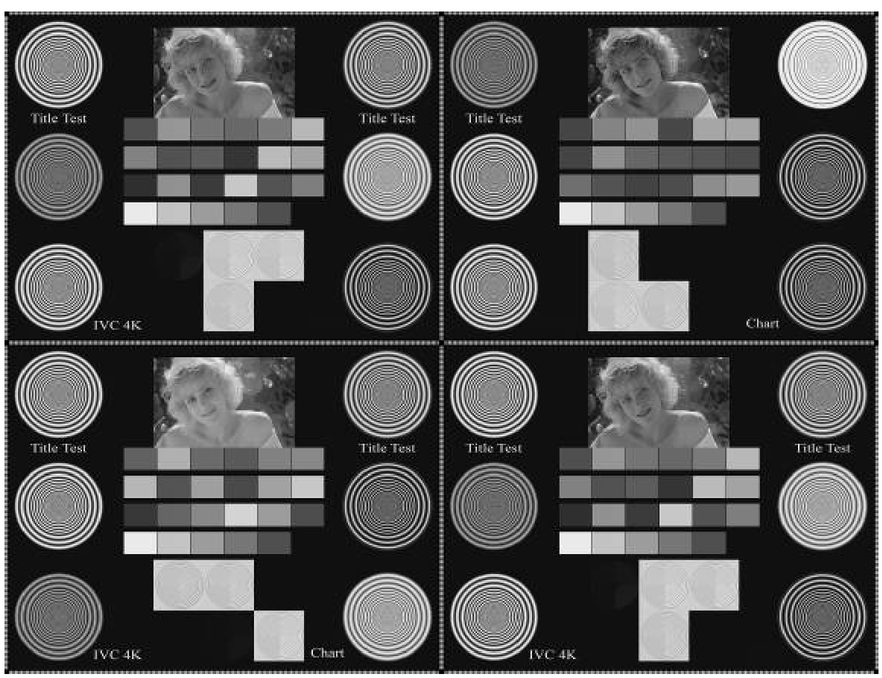


Figure 5 – Final image with alignment patterns, to be recorded to film

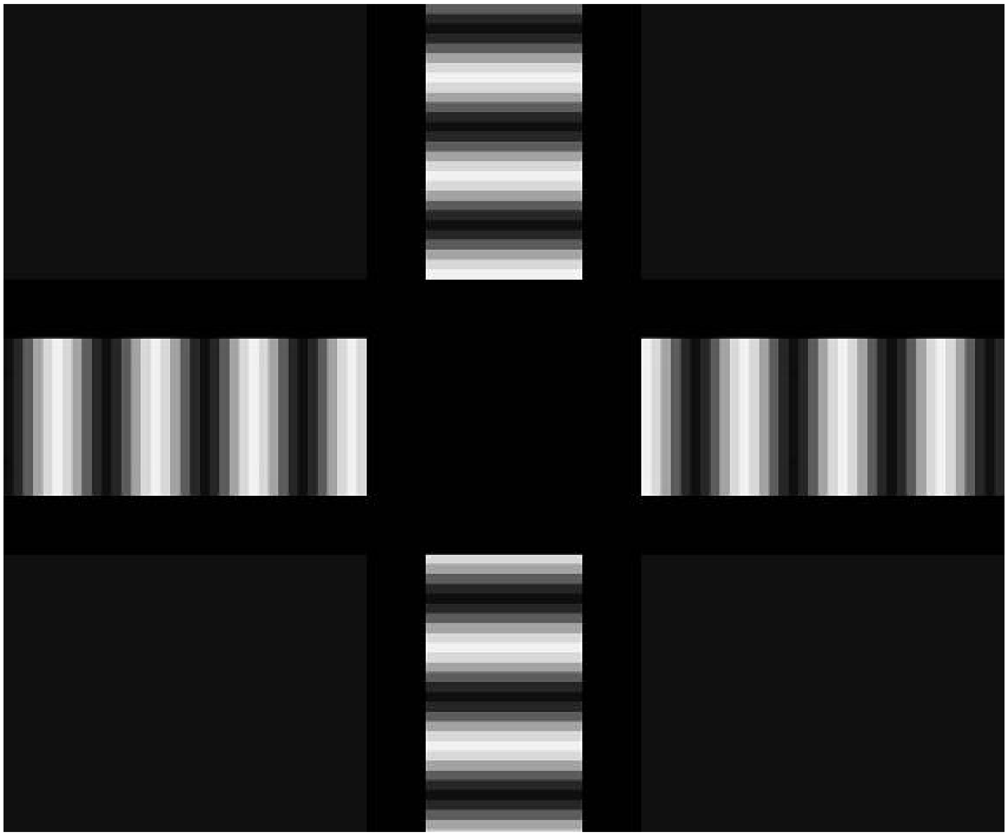


Figure 6 – Close-up of repeating calibration/alignment patterns

Field flatness and linear response are other concerns which have been addressed. It was observed that some film recorders or scanners would occasionally exhibit luminance differences across the frame. A grey bar and black and white patterns have been added to the encoded images to ensure consistent luminance, blacks, midtones and whites (Figure 7). By adding these additional calibration patterns, future generations will be able to get a much more accurate color representation of what the movie was intended to look like without the need for further color correction.

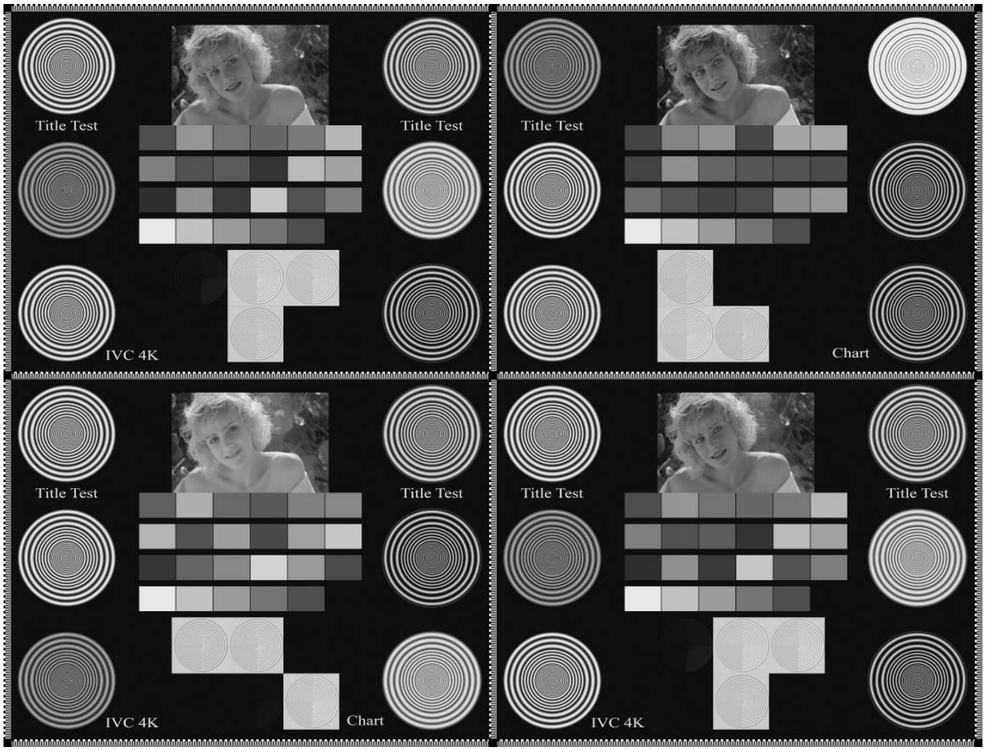


Figure 7 – Final Calibration Patterns

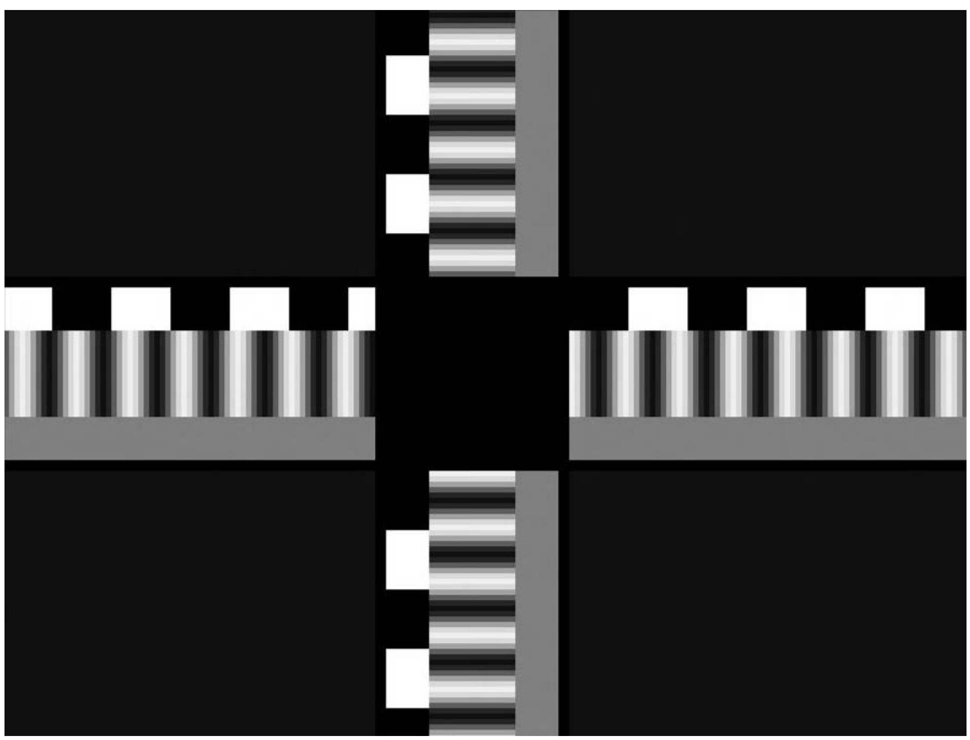


Figure 8 – Close-up of Final Calibration Patterns

For lower resolution images, such as High Definition or 2K, an RGB archive is achieved by recording to 4K, without the need for mosaic patterns, since the HD/2K canvas fits in to a quadrant of the 4K frame. The image will still reap the benefits of all the calibration patterns as described and since this method leaves open one of the quadrants, additional information—such as audio content, metadata, etc.—can be placed here.

In conclusion, the "Visionary Archive" process can reduce costs by using two-thirds less film stock, two-thirds less billable recording time and two-thirds less billable scanning time. Archival image quality benefits are achieved by eliminating color layer registration issues and image geometry/stabilization issues and by reducing media-related grain contribution to the final image. It is our plan to place a 'Rosetta Stone' at the leader of each film to explain the process, as well as make available free software and source code for image reconstruction purposes.

About the Authors

Sean McKee *is the Director of Restoration & New Technology for IVC (a Point.360 company), in Burbank, CA. In the past year, McKee and his team have developed a number of proprietary technologies for both the classic "movie/archival" and "current production" markets. The most recent being the "Visionary Archive" process detailed in the adjoining article. Other developments include Advanced Restoration Tools (A.R.T.) grain & noise reduction, best-in-class RAW camera image processing, automated color matching, a perceptually uniform color space, and other advanced algorithms/software. For 12 years prior, McKee was CEO of Screen Time Images, a Chicago based company specializing in film restoration, rights acquisition and distribution. McKee was the world's first user of the popular Revival film restoration system, and worked closely with da Vinci to develop the software. He has been featured in numerous interviews on national TV, radio and industry magazines.*

Victor Panov *is a key member of the Point.360 / IVC development team headed by Sean McKee. He is a theoretical physicist, and high level programmer. Prior to working with IVC / Point.360, Mr. Panov was part of the team at Motion Picture Marine that received a Sci-Tech Academy Award for camera stabilization hardware. He was a consultant to NASA JPL, creating communications hardware and software for picosatellites. Prior to that, Mr. Panov worked with Rockwell to design hardware and software devices for reliable wireless transmission. Before coming to America, Mr. Panov worked with the Kurchatov Institute of Atomic Energy of the Russian Academy of Science and the Institute of Molecular Genetics of the Russian Academy of Science creating software for finite element model visualization and processing, hardware oriented programming for video adapters for finite element model and data stereo visualization as well as 3-D stereo graphics software and GUI design.*

AMIA Tech Review
From the Association of Moving Image Archivists

October, 2010.Volume 2

Legacy Analog Optical Recordings: Then and Now

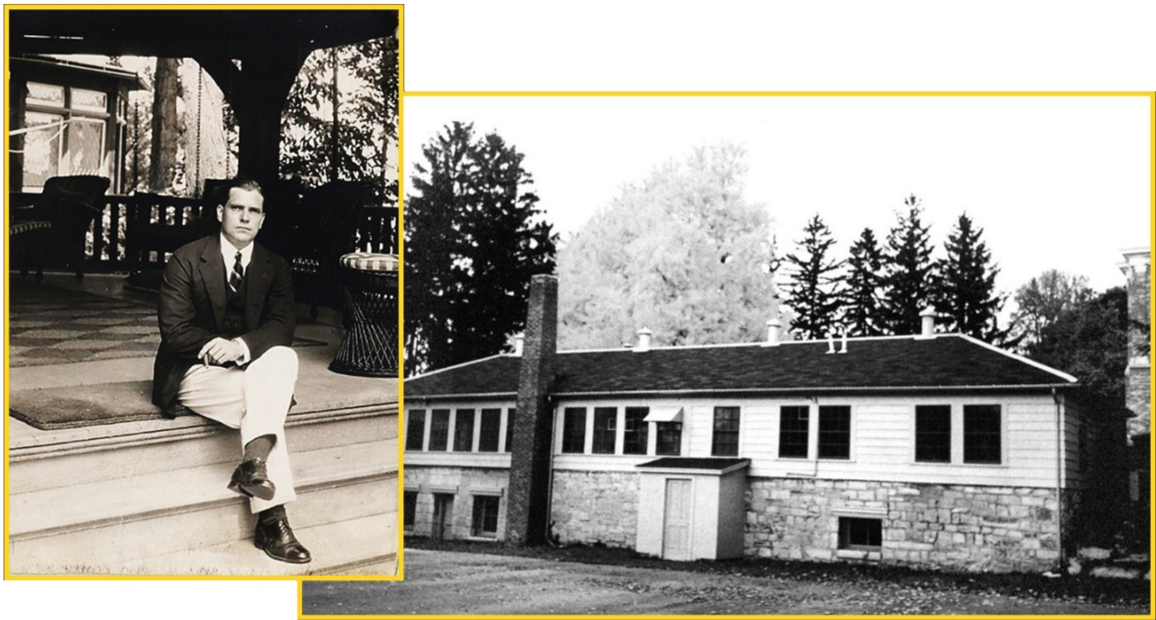
By Ralph Sargent

Some Background

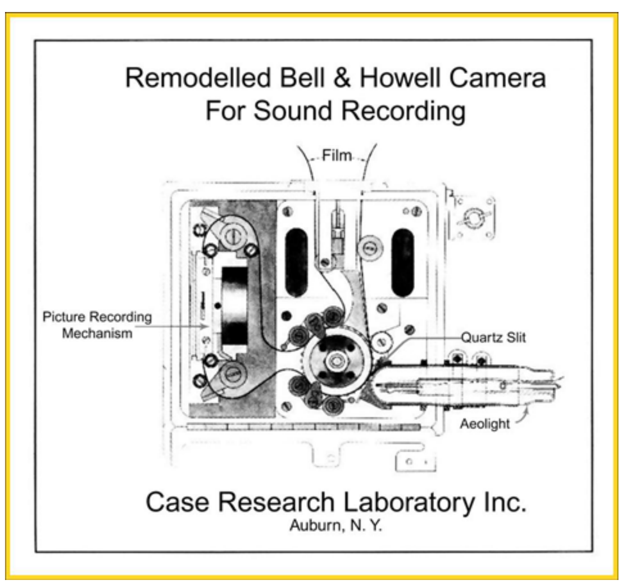
The success or failure of an analog optical recording system is totally dependent on the ***linearity*** of the medium upon which it is recorded. Of course a number of other factors will come into play when judging these systems, but all things considered, linearity must come first. Linearity is achieved in optical audio records by distortion and sensitometric analysis and adjustment of the interaction of the various electronic and photographic steps involved.

Historically speaking, there have been three principal ways of recording optical tracks for motion pictures and each is inextricably linked to sensitometry for freedom from distortion and efficient utilization of the chosen method. Two of these three methods are distinctly different ways of producing Variable Density recordings and the third is Variable Area recording. This article will discuss each of these methods and then present experiential techniques for producing modern prints for restoration applications and archival storage.

The Case Variable Density recording system, “Toe Recording”



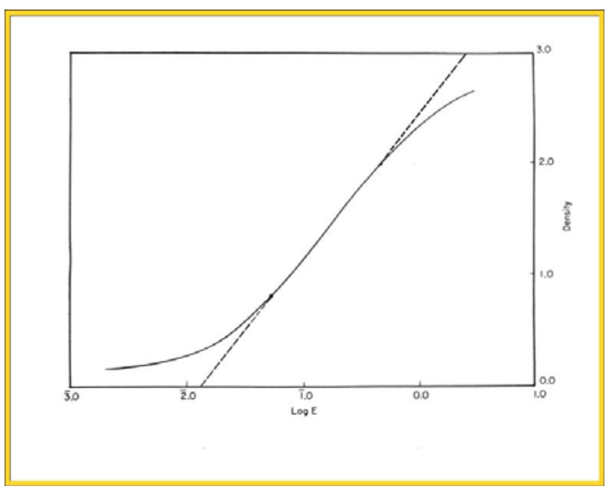
If you take a trip to Auburn, New York and visit the Case Research Laboratory you’ll have a chance to examine a highly modified Bell & Howell 2709 with an Aeolight recording tube, positioned to expose a variable density optical soundtrack on film as it traveled on the camera’s main film sprocket having already passed the picture exposure gate. Both the modifications to the camera and the Aeolight were the brainchildren of Theodore “Ted” Case.



Aeolight was a recording device which depended upon a modulated, ionized gas to produce various intensities of light which were an analog of the original sound. However, an Aeolight was not a very powerful instrument. It could not produce enough light to place optical recordings on the portion of the characteristic curve which eventually became “home plate” for variable density recordings made with Electrical Research Products, Incorporated’s (ERPI’s) Western Electric recording equipment. Case and his assistant, Earl Sponable, later Chief Engineer for 20th Century-Fox, envisioned single system recording to be their method of choice. (“Single System” utilizes a camera which records both picture and sound simultaneously on the same film.) Case’s camera became the parent of the newsreel camera of the '20s through to the '60s and it truly was the great-granddaddy of the Auricon camera, the 16mm workhorse of early television news.

You might think that Case and Sponable’s development is an odd way to begin an article on sound recording systems, but figure this: millions of feet of film were shot and recorded with “Toe Recordings.” Remember the early Fox sound feature, “Sunrise”? Well, that’s a toe recording made with an Aeolight. Remember all those Fox Movietone Newsreels from the '20s and early '30s? Aeolight! The fact is that Fox-Case single system style cameras went around the world to record events that otherwise would be silent clips today. For studio production however, single system cameras quickly gave way to double system equipment, with separated but interlocked recorders and cameras.

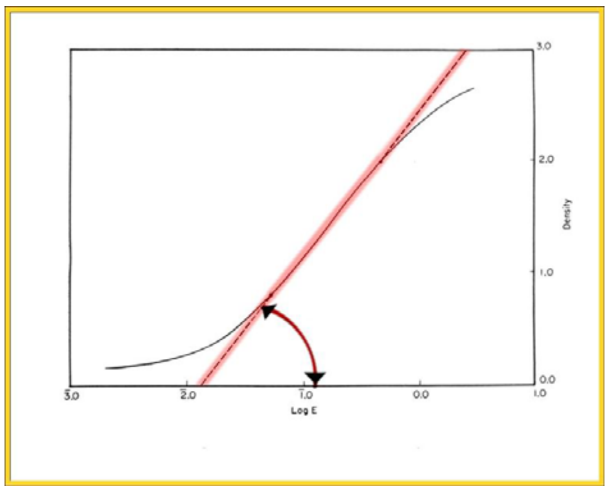
Exactly what is a “Toe Recording?”



Pay attention to the classic H&D curve above. Its purpose is to tell us how a piece of film–in this case an idealized black and white print stock–reacts to various levels of exposure to light.

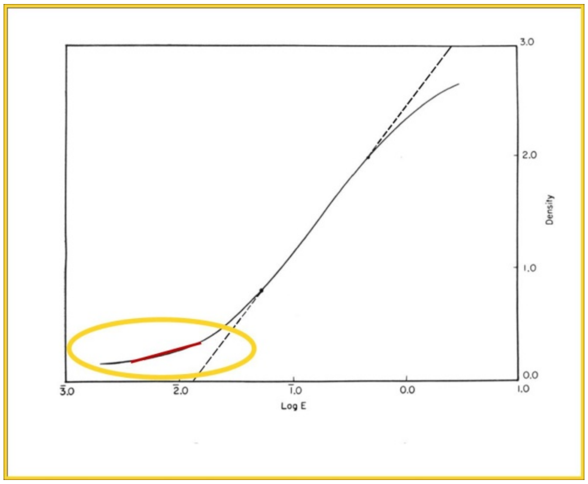
The right vertical side of the chart, from bottom to top, represents ascending density. The bottom line, looking left to right, shows increasing amounts of exposure. The curved lowest part of the graph is referred to as the “toe,” the straight mid-section is called the “straight-line” and the top curved portion is called the “shoulder.”

(So you have a touchstone for what this means, keep in mind that a normal print “gamma” for black and white is 2.40. This number is derived by extending a line down from the “straight-line” portion of the curve (the dashed line) to a point where it intersects the exposure or horizontal line at the bottom of the chart. By measuring the tangent of the angle of the intercept, we derive a numerical value for “gamma,” or as people unfamiliar with “film-speak” might say, “contrast.” See the curve below.)



(Today most of the calculations involved in deriving gamma are done in a computer, which spits out a graph of the characteristic curve and gives you a gamma upon which you make decisions related to how the film will be developed. Back in the `20s all of these calculations were carried out by hand and judgments about exposure and electrical setup of a recording chain were also carried out by ***listening and trial and error***.)

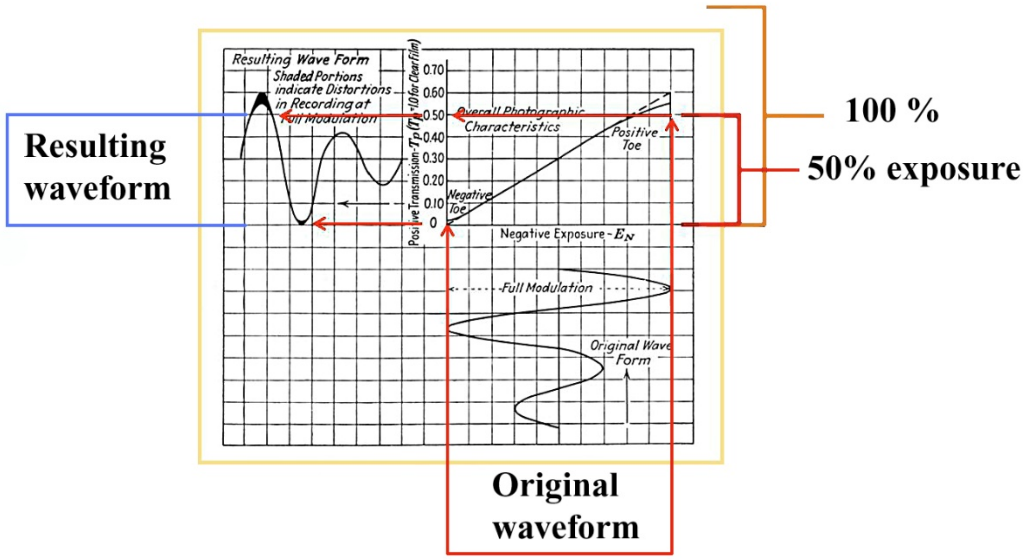
One thing Case discovered really early on was that–as I previously mentioned–his Aeolight couldn’t put out much in the way of exposure with then current films. To get as much photographic “speed” as possible, he used positive film and then played a trick on it. This was by any other measure a method to capitalize on gross underexposure. Here’s what he did:



If you examine the H & D curve again very carefully in the toe region, you'll see that there is a portion of it which—for practical purposes—is straight. If the developing is particularly vigorous, as would be the case with Kodak's D-16 or similar developing formula, the toe portion of the characteristic curve could be exaggerated and brought to its own gamma of 1.0; or to put it another way, it could be completely linear. This meant that the negative could be played directly and not sound terrible, and if the print made from such a track was carefully exposed so that it too fell on the print's toe-region straight-line, it could be reproduced with the maximum volume possible for its day with the least amount of *intrinsic* distortion. I'm using the word "intrinsic" because when toe recordings were in vogue, intermodulation distortion analysis hadn't yet been invented as a control method for variable density recording and probably wouldn't have amounted to much in the analysis of toe recordings anyway.

Be that as it may, toe recordings were certainly the mainstay for Fox features until 1932 with shorts and newsreels continuing as Aeolight recordings for some time afterwards. You should be aware of some of the audio specifications of toe recordings so that as I discuss the two other alternatives, you'll understand why the Aeolight and its toe recordings did not survive as the method of choice at this major studio indefinitely.

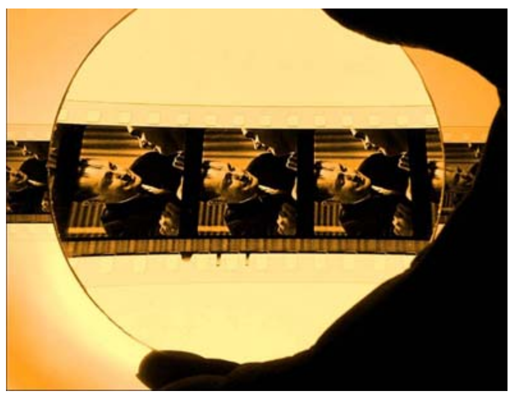
Because the light produced by the Aeolight was a glow-discharge similar to a neon light, like a neon light it required a polarizing potential which caused the ionization of the internally contained helium gas. It was this polarizing potential too which was modulated with the audio signal to produce the recording on film.



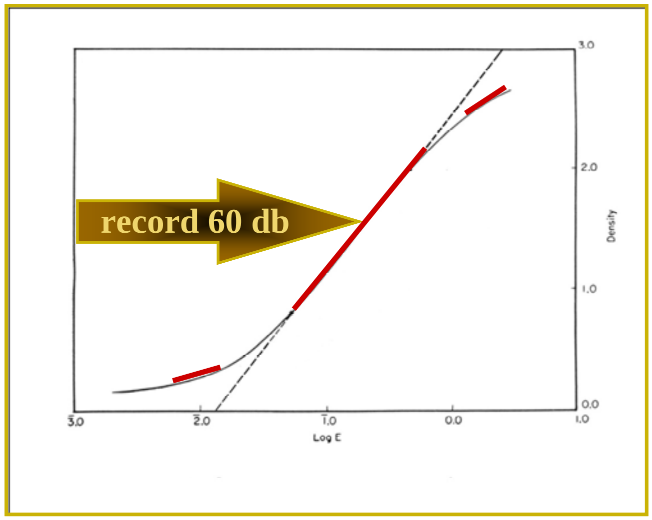
In the days before anyone had conceived of noise reduction methods, the unmodulated value for the polarizing potential was set at 50% of the available exposure range. This meant that the loudest typical cycle of sound could dip down to just above the point where the gas would fail to remain ionized and, on the positive excursion, the linearity of the record would be just below the point of onset of severe distortion. Exceed these two extremes and the recordings would not be acceptable. This led to a limited dynamic range for toe recording of approximately 30 dB. Even if the Aeolight could get brighter, the characteristic curve would prevent it from being useful! Compare this to the average range of a recording made by either Western Electric or RCA equipment of about 54 dB! There is quite a difference. Further, since both the negative and a print made from it were operating at the extreme bottom of the characteristic curve, there was no room to make use of any sort of noise reduction system that depended on exaggerating the negative's minimum density. You can't make something that's already transparent any more so!!!

Look at the soundtrack on the above sample of a Toe Recording. By definition these recordings were “thin” or lower in print density than those made by competing systems and therefore were subject to higher than normal wear-related noise as prints were repeatedly projected and rewound, projected and rewound, etc. On the good side, Aeolight recordings had relatively flat frequency response for the day, roughly 50 to 6000 Hz with no recording preemphasis. Slippage in the positive printing process probably brought the high-frequency response down 6 dB or so at 5 kHz and even more at 6 kHz. Even so, the audience of the day probably heard sound that was on the tinny side, given the extremely bumpy speaker response curves common at that time. But all in all, what the audience heard was not that much different from those made by other contemporary recording systems. But this situation did not last for long….

The Western Electric Variable Density Recording System



A more robust variable density recording system was that developed by Edward Christian Wente of Bell Telephone Laboratories in 1922. The equipment was sold under the name "Western Electric" and marketed and licensed to the motion picture community by Electrical Research Products, Incorporated, otherwise referred to as “ERPI.” Unlike Case recordings, which depended on the Aeolight to be an audio-modulated variable light source, Western Electric recorders used a light valve which modulated a fixed external light source, and that light source could be as bright as necessary to produce whatever level of exposure might be required of it. In other words, Western Electric's modulator ***did not*** serve double-duty. This separation of functions made the system highly adaptable as track requirements, film stocks and processing constituents changed over the years. What made the Western Electric system succeed where Case failed? The answer lies in where the Western Electric recordings lie on the sensitometric curve!

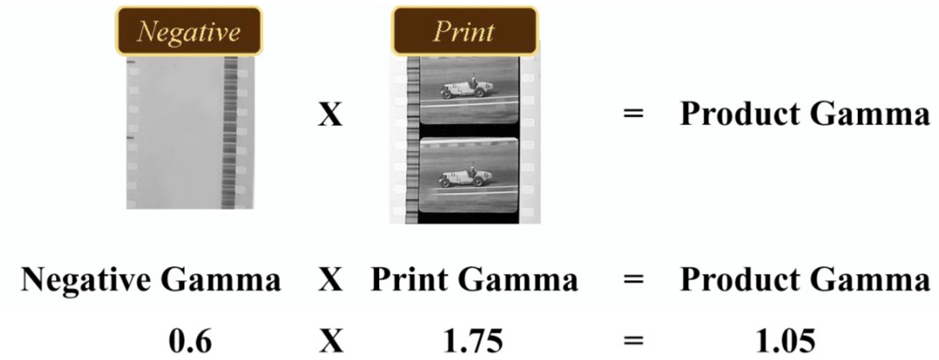


If we go back to the classic H&D curve, we'll see that in fact there are three straight line portions. The toe and shoulder portions each have a short straight line while the classic, long straight-line has the greatest amount of real estate for placing a variable density audio recording and getting the most out of it; this is precisely where the Western Electric system put its recording.

Compared to the Case system, the Western Electric system had the potential to record a far wider dynamic range. Early experiments proved that this value was somewhere close to 60 dB; compare that to Case's 30 dB and it's not much of a horserace. But from a practical day-to-day standpoint the early utilization of the W-E system was limited to a range of 40 dB or so, and this was because of two reasons: first, strictly mathematical calculations of product gamma throughout the photographic process could not dynamically model the total distortion characteristics of the process; and second, noise reduction techniques had yet to be invented or applied to it. Techniques for coping with both of these early weak spots were rectified in the early and mid '30s. Even so, the W-E system WAS better than the Case system from the get-go and had the potential to get MUCH better. On the other hand, the Case system had nowhere to go.

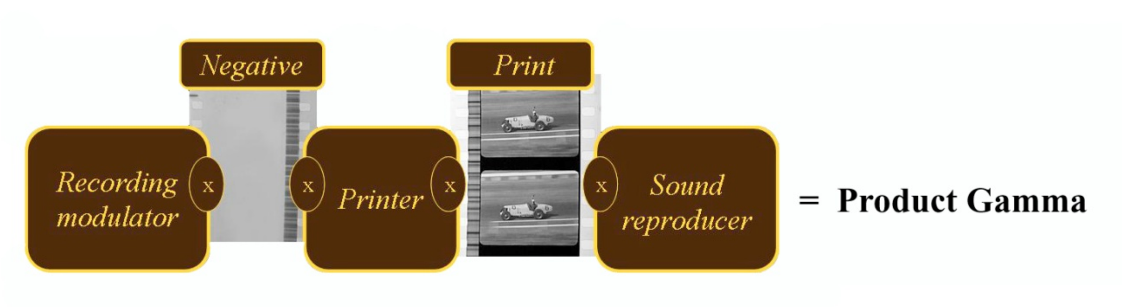
From a purely business standpoint, the Case system was owned by Fox and had to be licensed by them. The Western Electric system on the other hand was available to anyone who had the bucks to buy the system and pay the license fees to ERPI to use it. Now, if you owned another studio, whose recording equipment would you buy: one supplied and controlled by a competing studio or one supplied by an "independent" non-competing source?

Let's stay with the early days of the Western Electric system for just a few moments more. Wente's theory of laboratory processes for variable density of this kind states that if the negative and positive gammas together produce a product gamma of 1.0 or thereabouts, the result will be a "distortion free" recording and reproduction of the original sound.



But how would you arrive at what was a true or real system-wide gamma of 1.0? Early literature indicates values used for these calculations to be a negative gamma of 0.6 and a positive gamma of 1.75. Multiplying both together yields a product gamma of 1.05. The unmodulated negative track exposure of 50% valve opening would produce a density of 0.6 above base and residual fog. The positive track density for the same unmodulated negative spot would be 0.5. Allowable error was 20%.

But simply knowing each film's gammas and densities does not bring into the mix all of the principal factors which affect distortion in the variable density process. Look at this:



At the very least the recording modulator has its own optical gamma or "flare factor," the negative certainly has its own gamma, as does the printer used to make the print, the print itself and the projector's sound reproducing optics. Each of these must be taken into mathematical consideration if you stand a prayer of getting anywhere close to a truly representative product gamma for the whole chain of events!

But, hold on! One other thing must be added to the mathematical soup literally and figuratively. Belying the underpinnings of Wente's theory of a simple product gamma of unity for negative and positive was this: the law of reciprocity states that exposure = intensity x time. However, for recording slit heights of .0001 inches or less, the exposure times during recording of the track negative become less than 1/20,000 of a second at 90 feet per minute of film travel. In this case the recording film no longer follows the law of reciprocity and simple math will not give us a reliable prediction of what's going to happen with negative densities.

How do you get around this mathematical "gotcha?" The answer was found in these three main areas: one, the introduction of sound recording films especially constructed for variable density recording; two, the introduction of intermodulation distortion analysis equipment to the setting and control of the total recording, laboratory and reproduction process and the removal of the uncertainties due to the effects of reciprocity law failure; and three, the introduction and complete adoption of noise reduction means.

Points You Should Know

Intermodulation distortion is the primary distortion characteristic associated with incorrectly manufactured variable density positive prints. Mathematically, it is an extremely complex distortion based on the nonlinear transmission of two or more frequencies, resulting in the generation of both sum and difference components between each of the original frequencies. Since common audio in a motion picture is rarely as simple as two pure tones, the complexity of the resulting undesirable components can quickly overwhelm a simple math description of the offending signals. However, the invention of intermodulation distortion analysis equipment literally took the guesswork out of the process of setting correct exposure and developing conditions for both negative and positive track.

One other thing happened with the changes I've just mentioned. Up to this point (the early '30s) a considerable amount of negative and positive developing had been controlled by eye without regard to sensitometry.

The recording of sound tracks forced the developing and printing processes of laboratory work into the age of objective science. Some might lament the loss of artistic control in this regard, but no one can argue with the resulting dependability and repeatability of the results.

Later Developments

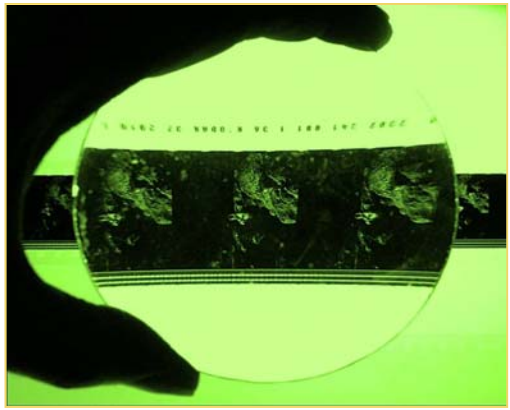
As the era of, “Gee whiz, the screen talks…” gave way to the era of, “We gotta make this sound better,” experience and technical analysis honed the craft in many areas. Newer, simpler modulators were designed that had higher flux levels which could be driven with more modern, low distortion amplifiers. Simpler, more direct optical and mechanical designs let the useful upper frequency range be extended from 5 kHz to 8 or 9 kHz offering a more lifelike, realistic recording. This simplification also allowed a wide variety of ribbon configurations and applications. Noise reducing circuits increased the apparent signal-to-noise ratio by 6 to 10 dB, and some studios, notably led by MGM and Columbia, added frosting on the cake with the introduction of “squeeze track” which varied the width of the recorded track to increase or decrease its playback volume at the discretion of the mixer.

A squeeze track negative and a positive print from it

Finally, in the mid-forties, push-pull recording was widely adopted as the preferred method for pre-release tracks. Push-pull made it possible to significantly reduce residual distortion in these recordings, making for quieter, cleaner mixes and producing a significant improvement in the quality of sound heard in theaters.

All in all, careful control of the process from beginning to end produced variable density optical recordings which came very close to those produced by magnetic means, which were beginning to be introduced in 1947 – but this is a big topic for another time. Let's finish the story of optical with a discussion of Variable Area.

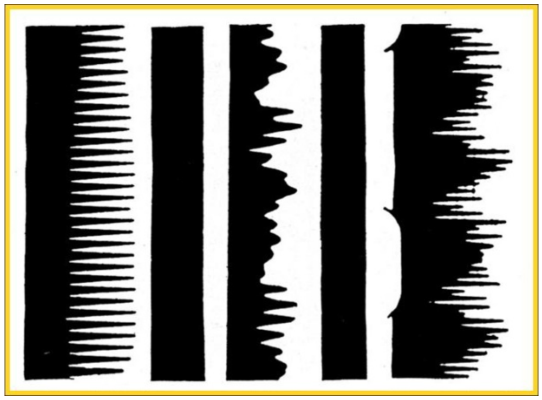
Variable Area and the RCA Recording System



Developed in the early and mid '20s by Charles Hoxie of General Electric, variable area recording under the name of "Pallophotophone" languished from GE's disinterest for some time before David Sarnoff of RCA came knocking. Sarnoff was motivated by his distaste for AT&T's domination via ERPI and Western Electric of the motion picture theatrical sound recording field with its variable density recording system; he, and therefore RCA, wanted into the game.

At its peak, quite literally ERPI ***did*** have most of the studios under contract. Even as early as the late '20s only a few studios were available to a potential competitor. Along with General Electric, RCA's then parent company, and Westinghouse, Sarnoff struck out on a path to build his own theater chain and the studio facility to feed it, using of course the now renamed RCA Photophone equipment.

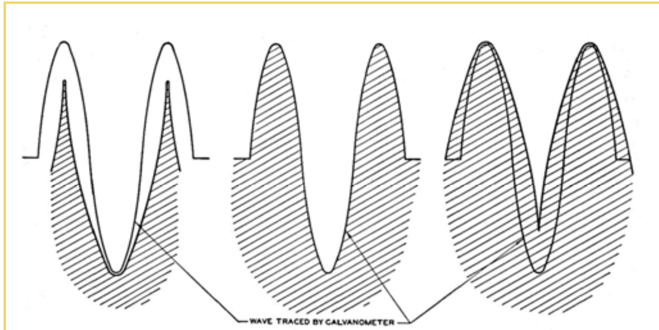
On the theatrical side RCA bought the 100 or so theaters of the dying Keith-Albee-Orpheum vaudeville circuit and began equipping them with motion picture projectors and RCA sound equipment. On the studio side, RCA bought up Joe Kennedy's Film Booking Office of America studios (nicknamed FBO) and joined it with several other smaller film-producing operations, renaming the conglomeration RKO, for Radio-Keith Orpheum or Radio Pictures. The physical location of the new studio remains today where it always was: on the corner of Melrose and Gower, now a part of the Paramount lot in Hollywood.



Examples of unilateral Variable Area Recordings

Variable Area recording was the antithesis of everything Variable Density. It used (and still does use) high contrast, high density recording materials upon which a theoretically perfect photographic record of a moving light-stop edge or edges is exposed. To be more specific, in the earliest unilateral non-noise reducing systems, with no audio applied, the resulting track was half black and half clear. As audio was applied, the dark edge would oscillate in accordance with the waveform of the sound and the excursions of the waveform would increase or decrease depending on the strength of the applied signal. 100% modulation meant a signal amplitude just at the point of touching the extremes of the physical track width, with abrupt distortion beginning just beyond 100% modulation. From a practical standpoint, "maximum or 100% modulation" was defined as 1 dB into "clash" or the point where excessive distortion began. This extremely loud signal was rarely encountered in early release tracks even though automatic equipment such as "brick-wall limiters" did not exist at that time. The danger of severe distortion from over-modulation in production tracks was seriously discouraged by management!

There is one fly in the ointment of theory vs. reality: namely, no photographic material is capable of an immediate and instantaneous transition from total transmission to total density. If you were to take a microdensitometer and scan across such a transition, you would always find a slope between one state and the other. In the case of variable area recording, this slope is called ***image spread.*** Image spread and its effects on variable area recording may be more easily understood by examining the following illustration of three perfect sine waves as traced by the galvanometer.



under-exposure *correct exposure* *over-exposure*

All three thin-line traces are "perfect" in shape when laid down by the recorder; but when you examine the photographic record produced by under-exposure, correct exposure and over-exposure, shown here as the diagonal hash marks, you'll see that, in the case of the underexposed, silver image on the left there are gaps between its image and the original exposure. Likewise, the over-exposed silver image on the right shows density ***exceeding*** what should be—in other words, the ***image has spread***.

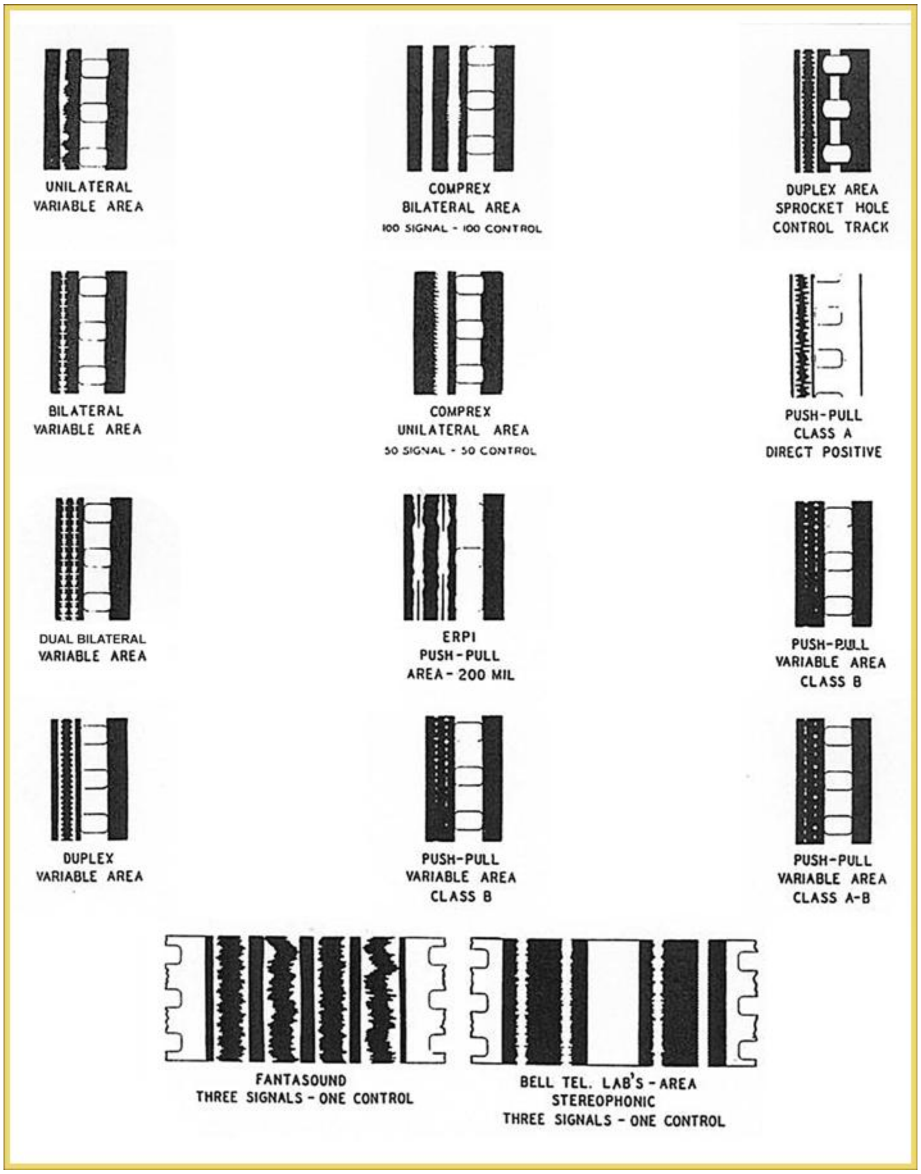
Of course I'm writing of a two-part system of recording: the original sound track negative and the print from it. To produce a final recording which has no distortion, the image spread of one film must be counteracted by the image spread of the other. But how do you select what the exposure and developing conditions of the track negative should be when the gamma of the positive print is fixed by the requirements of picture content and track density is set by technicians who like to keep track specifications constant from one show to the next?

In the early years of Variable Area recording the only answer to the preceding question was to resort to ***listening and trial and error***—a system which once again could only approximate what the correct negative exposure might be, not deliver a finite yet simply arrived-at and ***accurate*** answer.

The answer came in 1936 or thereabouts, with a system of electronic cross-modulation distortion analysis suggested by G. L. Dimmick and brought to fruition by J. O. Baker and D. H. Robinson, all of RCA. This type of distortion measurement system made setting both the exposure and development of a given negative track emulsion easy and predictable and took into account the entire chain of events from recorder to film to reproducer. It is still the dominant means of accomplishing this end today.

More Points You Should Know

Unlike peak distortion produced by exceeding 100% modulation of the system, cross-modulation distortion exists in negatives as a natural product throughout the recorded signal, whether loud or soft. In the 1950s, efforts were undertaken by RCA to build a cross-modulation compensator to reduce the inherent distortion in direct positive, one-step recordings which of course were functionally negatives. The technique involved the intentional pre-distortion of the recorded signal in a manner such that it would counteract the anticipated image spread occurring in processed film. Such a system was instituted in a number of recording chains for 16mm use, but was not widely adopted by the 35mm studio industry. However, the same conceptual approach may be applied ***after*** a conventional negative has been made to allow its direct playback with a considerable reduction in distortion. Modern digital techniques have made this approach more useful.



Many variations of the appearance of the track itself have occurred since the original simple unilateral configuration. The above chart shows a variety of pre-1948 track configurations. Unilateral transformed to dulateral to bilateral, then dual-bilateral to multi-bilateral with as many as 13 or more individual area tracks packed into the same space as unilateral. What was the point of all of this? Most of the changes you see here were made with the view of sidestepping non-uniform illumination and poor azimuth in early or poorly maintained reproducers.

As in the case of Variable Density recording, Variable Area recording benefitted greatly from the application of noise reduction techniques produced by the addition of side-shutters, which blocked out the otherwise wide open areas of track unused during silent or quiet effects or speech.

Finally, as in Variable Density, push-pull recording offered a whole new dimension of lower distortion and noise with broader, more easily attained recording conditions for the technicians producing these recordings in the late 1940s.

How do you print Legacy Optical Track Negatives today?

There are no easy answers to this question. There is no book, no roadmap, no great guru to give a definitive answer and there are no test signals on the track leaders which can be measured to help in this matter, but there are a few good guideposts to observe, and here they are:

Know the history of the films that were used

Become familiar with the history of the system with which you are working. A lot can be gleaned by learning the characteristics of and developing suggestions given by data sheets of the various films which were used at the time a given film was made.

Learn the science of the recording systems

Immerse yourself in the science of the recording systems used to produce a given type of track.

Know what can be expected from a certain era of track

Know the time spans within which a particular type of track was made and what the realistic expectations are for a given era's product.

Learn to recognize what type of track each recording system makes and each system's typical distortion characteristics

Understand and learn to recognize what dominant type of distortion is typical for a given system and know what you can do to influence and minimize that type of distortion. To wit:

Toe Recordings

For Toe recording: Be aware that not only was Toe Recording used for early sound newsreels and some features, but that it was also used for a great many direct positive kinescope recordings of television shows from the mid-1940s through to the late-1950s. This also holds true for Kodachrome Commercial prints with sulfide tracks during the same period. On the other hand, Western Electric style (NOT Toe Recording style) Variable Density single-system recording was commonly used for many negative kinescope recordings intended for conventional printing to positive films. Adjust your thinking accordingly.

Western Electric (Westrex) Variable Density Recordings

For Western Electric (Westrex) Variable Density Recordings: Learn what intermodulation distortion sounds like. In the simplest sense, it's this: "Where low frequencies chop holes in high frequencies." This usually means run a series of exposures of a relatively loud music section (usually main titles) and listen carefully how bass notes influence high strings. If you hear holes in the string sound which correspond to what's happening in the bass line, you've got intermodulation distortion. Select the exposure which has the least of this effect.

RCA Variable Area Recordings

For RCA Variable Area Recordings: Learn what crossmodulation distortion sounds like. Typically excessively sibilant dialogue will be an obvious tipoff. Rough sounding speech surrounded by a rattling effect or grating characteristic that is not natural is what you're listening for. Run a series of test prints of a sequence of dialogue containing lots of "Ss" at various exposure levels and select the exposure with a minimum of this distortion.

Other Manufacturers' Equipment... Time Marches on!

Bear in mind that manufacturers other than RCA or Western Electric made optical recording equipment, for example: J. A. Maurer, W. A. Palmer and Bach-Auricon. Also, remember that Western Electric (Westrex) equipment, patents and designs were folded into Photophone in the 1980s and that the bulk of Variable Area recorders in use today either were Variable Density machines by Western Electric to begin with or are modern clones of the Western Electric design, set up to produce Variable Area tracks using light valves, not galvanometers.

Brush up on your knowledge of photographic processing

Know your way around photographic processing and recognize what you can and can't do by careful manipulation of gamma and exposure.

Examine the original carefully!

Carefully examine your incoming track negative and look for the following tips: Is the negative notched, indicating that it should be timed or graded to match levels or scene-to-scene changes? Is the negative composed of pieces of both Variable Area and Variable Density recordings? Should these sequences receive different exposures? Many labs today are not equipped to time or grade sound tracks and/or don't care.

Relax, this is not rocket science....

Finally, I recommend that, if you're faced with material with which you are not familiar, take a deep breath, do your homework, approach the work systematically and you will not be disappointed with the results. Remember that the work you do in fact includes not just the protection of the images we cherish but the sounds that accompany them. The future will thank ***you*** for them.

About the Author

Ralph N. Sargent III received his B. A. in radio, television and motion pictures from the University of North Carolina, Chapel Hill in 1964. He earned his M. A. in motion pictures from the University of California, Los Angeles and joined the technical staff of UCLA's Motion Picture Division of the Theater Arts Department following graduation in 1965. In 1968 he was appointed a lecturer at UCLA teaching both technical and production courses.

Sargent formed Film Technology Co., Inc. in 1971. The company has grown to become one of the premiere restoration laboratory facilities in the United States serving both film, video and sound clients throughout the world.

Sargent is the author of "Preserving the Moving Image" published by the National Endowment for the Arts and the Corporation for Public Broadcasting, 1974. He was a contributing editor and advisor for the National Film Preservation's publication, "The Film Preservation Guide: The Basics for Archives, Libraries and Museums," 2004. He is a life member of the Society of Motion Picture and Television Engineers and a member of the Association of Moving Image Archivists. He has contributed lectures and presentations to both organizations touching on a wide variety of technical devices and techniques of interest to the field.

In less directly related fields, Sargent is a past chairman and honorary life member of the Los Angeles Theatre Organ Society and a producer of numerous silent film scores and theatre organ recordings. He is also a member of the Society for Astronomical Sciences and an astrophotographer whose deep space photographs have appeared in Astronomy Magazine.

AMIA Tech Review
From the Association of Moving Image Archivists

October, 2010.Volume 2

Introduction to "A New Colored Movie Process"

The following article comes from the May, 1923 issue of "Science and Invention" published by Hugo Gernsback. Gernsback is well known to older readers as the publisher of numerous magazines having to do with science and generally aimed at the amateur science enthusiast. He was also one of the first to produce a string of magazines which published science fiction stories; his contributions in that field were so highly regarded that he is commonly spoken of as "The Father of Science Fiction." Be that as it may, a number of his magazines dealt with non-fiction descriptions of bold, new inventions of his day. He too was a prolific inventor who, at the time of his death in 1967, held more than 80 patents.

"A New Colored Movie Process" describes a system of 2-color cinematography which this writer has never seen described before, whether from P D. Brewster or anyone else. In it Brewster lays out two significant suggestions which the astute reader will quickly see are the basis of the Technicolor 3-strip camera: a half-silvered prism beam splitter and two separate gates, one for each color. The rest of the process follows fairly conventional 2-color procedure.

The reader is invited to seek out a copy of "Colour Cinematography" by Major Adrian Bernard Klein, published by American Photographic Publishing Co., 1940 for a comprehensive description of both 2-color and 3-color photographic systems up to that time. Considerable space is given to 2-gate and 3-gate beam-splitting cameras, but only the merest suggestion is made of using a 2-gate variety for 2-color movies as proposed by Brewster in this article! After all, it turned out that there were far simpler ways of deriving 2-color negatives without using a special camera, to wit: bi-pack negative pairs in a standard camera which reindexed the lens focus position back by .005 inch (the thickness of the front film's base). Enough said! Read on, dear reader!

A New Colored Movie Process

THE production of perfect colored motion pictures is claimed by Mr. P. D. Brewster, an American inventor, who has been interested in motion picture work for several years. His experiments in colored photography have extended over a period of more than nine years, and he has at last perfected a system which he claims is as near perfect as it is possible for a colored picture to be. In a recent interview with the writer, Mr. Brewster exhibited several still views taken by essentially the same process as he uses in his moving pictures. The tones and shades of colors in these photographs were a revelation. Detail was perfect, and the colors blended into one another in a most remarkable manner.

In explaining his process Mr. Brewster explained that one of the main features was the special light-splitting combination of prisms. This device consists of two triangular prisms. On the face of one of them is a checkerboard effect composed of minute silver squares alternating with transparent squares. The two prisms are placed together face to face, so that the silvered surface, when viewed from the end of the square block thus formed, runs diagonally across it from corner to corner.

The action taking place in connection with these two prisms, may be plainly seen in the accompanying illustration. The light from the subject being photographed enters the lens, which, of course, is equipped with the usual shutter and diaphragm, and proceeds through the side of one of the prisms. When it strikes the silvered face, it is split up; that part of the light which falls upon the silvered squares being reflected at right angles to the original beam and passing through a blue-green filter, is focused upon a film which registers the intensity of the red shades of light. That part of the light which is not reflected passes on through the prisms and after passing through a red filter, gives the image upon a film which receives the picture in tones of blue-green.

Because of the fact that only one lens is used in taking these films, any stereoscopic or blurring effect is eliminated. Mr. Brewster also has done away with the difficulty usually encountered in photographing flesh tints. In the first attempts at color photography, the hands and faces of the actors were reproduced in a sickly brown shade. This new process, however, does not have this drawback, and in the photographs shown to the writer by the inventor the flesh tints were exceedingly well registered. A section of colored positive films showed very fine color values.

After the two negative films mentioned above have been exposed and developed, they are both printed simultaneously upon opposite sides of a positive film, which is sensitized on both sides. This is made possible by means of a chemical which renders the film opaque, until it is run through the developer where the chemical is eliminated. In the printing process as well as in the exposure of the negatives, the films are all kept in synchronism by means of specially designed but relatively simple apparatus, which we will not attempt to describe here.

The two sides of the positive film are treated, so that in the final process they will be color-sensitive to orange-red on one side and to blue-green on the other. The blue-green negative is exposed on the orange-red side of the positive, and the red negative on the blue-green side of the positive. The accompanying illustration shows the degree of shade obtained with two negatives as well as on the two sides of the positive, when a strip containing red, white and blue squares is photographed.

In 1, the red photographs transparent on the blue-green negative, the white very dark, and the blue semi-transparent. In 2, the red is semi-transparent, the white very dark red, and the blue transparent. When these are printed on their respective sides of the positive, the results shown in 3 and 4 are obtained. In 3, the red shows very dark orange-red, the white transparent, and the blue a medium shade of orange-red. In 4, the red comes out a medium shade of blue-green, the white transparent, and the blue a dark shade of blue-green. When these are super-imposed upon each other, the true colors will appear. This is rather hard for the layman to understand at first, but if he will take a piece of red celluloid and a piece of blue celluloid, and place them over each other, and look through the combination, he will find that the resulting color will be entirely different than either the original red or blue.

After the printing the positive goes through the developing, fixing and washing baths, and is afterwards carried to a bleaching solution which renders the emulsion susceptible to certain dyes. The sides of the film are then separately treated with certain dyes, and after drying are ready for projection.

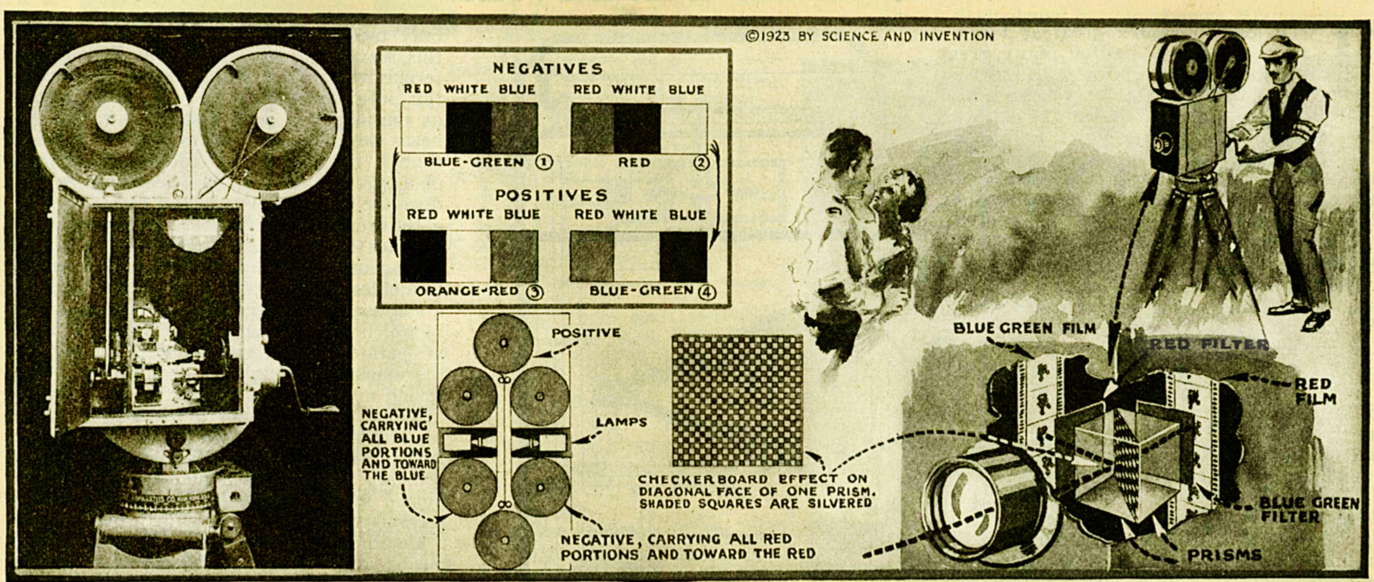
This film can be used in any standard projector without any adapters of any kind.

For various kinds of photography there are three series of negative films with corresponding positive films used. For outdoor work where foliage and bright colors are paramount, the negative films are light sensitive to blue-red and yellow. For studio work they are sensitive to red and blue-green, while for scenes where sea and sky predominate, they are orange and blue. Of course the filters used are of the color to which the film is sensitive.

Mr. Brewster at present is talking photographs with this method and is exhibiting them in a private studio in New York City. He expects, however, to have his processes developed to such an extent that his work will be commercially available in a very short time.

The many advantages of colored motion picture photography are at once obvious. The value of the more elaborate productions being shown before the public today, is sometimes seriously detracted from because of the inability of the pictures to faithfully reproduce the colors of the various parts of the sets. For instance, the writer was quite disappointed when viewing a motion picture recently which was highly exploited by the press agent. The entire production was very elaborately assembled, and some wonderful old masterpieces used in adorning the walls of various scenes. Because of the black and white reproduction, however, the color values of these pictures were lost, and the effect was not even comparable to what it would have been if some system of colored pictures were used, such as Mr. Brewster's.

This value of such colored effects in scenic productions can be very easily imagined. The difference between a standard motion picture of, for instance, the Grand Canyon of Colorado, and one of the same scene taken in colored movies is almost unbelievable.



The Left-Hand Photograph Shows an Interior View of the Camera Used in Taking the Brewster Colored Movies. The Four Figures in the Upper Center Show Diagrammatically How Various Colors Photograph on Both the Positive and Negative Films. Directly Below This is Shown the Method of Printing the Positive Film from the Two Negatives. In the Lower Right Hand Corner Will Be Seen a Diagrammatical View of the Camera Used in This Process. Standard Motion Picture Films Are Used and the Light is Filtered Through the Color Filters Shown. The Film in Back of the Blue Green Filter Registers the Red Color Values, and That in Back of the Red Filter Registers the Blue-Green Color Values.

AMIA Tech Review
From the Association of Moving Image Archivists

October, 2010.Volume 2

A Quick Tutorial on Color Separation Systems

There are two basic approaches to the creation of color separation records for archival storage. The first relies on the separation of the color information into its primary records as totally separate frames. These frames can be isolated to separate rolls of film representing red, green, and blue, or they can be placed sequentially upon a single roll. Many designs exist for the place of these *total* frames on film of varying gauges.

The second approach to color separation depends upon subdividing the original image into a finite number of analytic units and recording these units, within one frame, on a space-sharing basis. This is the essential idea underlying such systems as Kodak Keller-Dorian Kodacolor and Agfa Lenticular color processes. These obsolete systems are severly limited in their horizontal resolution and suffer from inherently poor efficiency.

A derivative of the second approach is typified by systems such as ABTO and RCA Focused-Image Holography. Both of these systems depend not only upon space-sharing for the storage of color information, but also upon the angular displacement of the subdivided records to create a diffraction grating. By such techniques, separate records can be integrated within the space normally reserved for one record; then, separated by the use of spatial filters.

A proposed modification of the ABTO system, for archival applications, would use a grating encoder of 200 lines per millimeter. Coupled with a high resolution microfilm, such as Kodak's AHU microfilm, such a record would be of sufficient resolution to meet Archival Category One.

In RCA Focused-Image Holography, the diffraction grating is produced by the use of lasers. This technique, when coupled with certain elements of RCA's HoloTape system, offers an extremely attractive solution to many of the existing archival problems; the final archival image would be in terms of a nickel strip, which could be used to emboss vinyl replicas, or make ordinary color prints.

Such applications of ABTO and RCA focused-image holography techniques are still experimental, and have not been applied to the 35mm motion picture field. At the present time, the only systems which can fulfill the requirements for Category One archival materials are those based upon the classic methods of full-image color separation. The question then remains how to obtain the most efficient use of materials and techniques at hand for the production of such separations.

70MM SPECIAL COLOR SEPARATION SYSTEM

The 70mm special color separation system, as proposed by Linwood Dunn of Film Effects of Hollywood, is a coalescense of traditional color separation theory and practice put into a form which allows optimum compaction of the various picture and sound records.

Three color separation images are oriented side by side on a four-sprocket 70mm frame. Four-sprocket pull-down has been chosen since it makes possible efficient 1:1 contact printing of the sound track. The picture images are printed by optical means 18% smaller than the standard 35mm format. Equipment would be specially designed to allow wet-gate printing of the original film, through special optics which would expose the three separation images simultaneously. Sound track printing could also be handled on the same machine. Retrieval would be accomplished in the same manner as exposure, but in reverse, combining the three images by superimposition through their respective narrow-band color separation filters.

The major advantages of the 70mm special color separation system are:

1) The 70mm film specifications, the emulsion coating, and the processing are all standard.

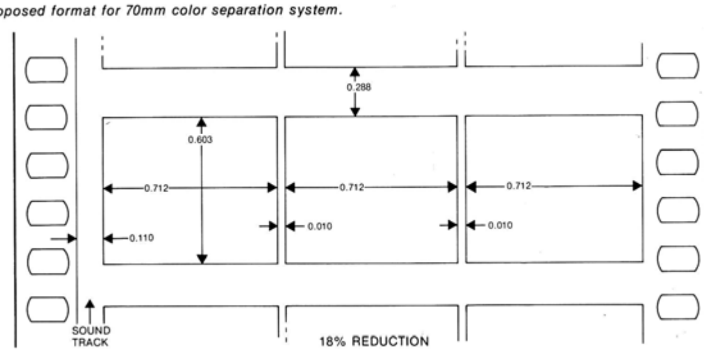
2) The images are almost their full size. Comparing the resolution of separation raw stock against that of the camera negative film, reduction of image size of 18% followed by a subsequent enlargement should produce little, if any, loss of picture information.

3) The increase in bulk, over a conventional color composite print held for storage would be less than 25%, if the separation film is manufactured using a three-mil polyester base. If manufactured on a four-mil polyester base the increase would be roughtly 35%. In either case, when the 70mm color separation film is compared for bulk against comparable records on separate strands of conventional film, the reduction in bulk would be significant.

4) The single film format will obviate the image shrinkage, distortion and general instability of three-strip systems. Also, with all of the picture and sound information on one film, there is no chance of loss of one of the film units, or of mis-synchronization.

This proposed system is a straightforward approach to the problem—giving due consideration to resolution, placement, maximum utilization of the material, volume, and cost. For all practical purposes, the techniques employed are proven and reliable. To put such a technique on a production line basis would require only the construction of high-speed equipment, and not the development of new, basic technology.

Proposed format for 70mm color separation system.



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Published by the National Endowment for the Arts and
The Corporation for Public Broadcasting, 1974