Preservation of Digitally Originated Motion Images on Film: An Integrated Systems Approach

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Abstract

As described in the Academy of Motion Picture Arts and Sciences publication, "The Digital Dilemma 2"[1], an abundance of digitally originated content intended for television broadcast, independent films and documentaries are at risk of being lost due to immediate financial concerns of production and distribution, the long term costs of continual digital migration, or even lack of awareness of the perishable nature of digital content. Various digital storage media become unreadable as hardware upgrades continue at a rapid pace, often without regard to backward reading capability. This class of content often cannot support the expense of either regular migration to newer media formats or preservation on higher cost black and white separation film. Film is the only proven archival medium for motion images without the need for migration, accordingly Eastman Kodak utilized a unique and full systems approach to develop a color asset protection film for this at risk class of content. This paper will focus on the development of this KODAK Color Asset Protection Film 2332 which utilizes common digital post production house devices to record and store digitally processed images for long term preservation. Discussion will focus on formulation considerations to deliver improved dark stability performance while maintaining a significantly reduced cost versus current archival films, system design considerations, color and image quality management, in addition to workflow proposals for present day quality check and future restoration strategies.

Introduction

As described in the Academy of Motion Picture Arts and Sciences publication, "The Digital Dilemma 2", an abundance of digitally originated content intended for television broadcast, independent films and documentaries are at risk of being lost. The reasons vary from immediate financial concerns of production and distribution, the long term costs of continual digital migration, or even lack of awareness of the perishable nature of digital content. Various digital storage media become unreadable as hardware upgrades continue at a rapid pace, often without regard to backward reading capability. This class of content often cannot support the expense of either regular migration to newer media formats or preservation on higher cost black and white separation film. Film is the only proven archival medium for motion images without the need for migration. Accordingly, Eastman Kodak utilized a unique and full systems approach to develop a color asset protection film for this at risk class of content. This paper will focus on the development of KODAK Color Asset Protection Film 2332 which utilizes common digital post production house devices to record and store digitally processed images for long term preservation. It will focus on formulation considerations to deliver improved dark stability performance while maintaining a significantly reduced cost versus current archival films, system design considerations, color and image quality management, in addition to workflow proposals for present day quality check and future restoration strategies.

Integrated Systems Approach

A customer focused systems approach for product development begins by identifying the customer needs in a manner that is relevant to each customer. In this case, a preservation media design needs to fit specifications of both customers and the film manufacturer. The ultimate or final customer is the content owner who could be a major studio with legacy television content, an independent creative who has but one digitally mastered copy of their work, a news broadcaster with years of digitally captured local or national events, or a documentarian. Given the nature of the content or the sheer volume of legacy content, utilizing either black and white separation or color intermediate film as a preservation media could be cost prohibitive. For this customer, a reasonable cost media with acceptable quality and longevity is a key deliverable. The second customer is the service provider, who in this case would be a motion picture post production facility. From the perspective of the post facility, this film product should fit well into their established work flow, including compatibility with existing recorders and scanning equipment. Product design must also include consideration of manufacturability. In order to offer a preservation film at a reasonable cost the components should be readily available and fit well into established manufacturing operations. A true systems approach takes all of the customers' needs into account in the product design and optimizes the final design to deliver the key deliverables to each customer.

At the first stage of product development, an assessment of available technologies and components that fulfill the customer objectives is made. The key to a successful systems design is a clear understanding of the customer. Eastman Kodak supplies a wide variety of negative, positive and intermediate films to the motion picture industry. Looking across the various platforms of existing technology, a wide array of components becomes available to choose from. As a starting point, the first focus is on the physical properties of this preservation product. A requirement from the post facilities, the actual users of this film, is that it transports through existing recorders and scanners without physical adjustments. The film most commonly used for recording is intermediate. This is a good place to start.

Physical Properties Considerations

KODAK VISION 3 Color Digital Intermediate Film 2254 is coated on 120 micrometer ESTAR base featuring a patented electrically conductive anti-static layer, a polymeric scratch resistant backing layer and a process surviving back side lubricant.

ESTAR base is proven to be dimensionally stable which is a key deliverable for a preservation product. The anti-static layer eliminates electrostatic attraction of dirt particles. The very thin polymeric backing layer offers resistance to back side scratches and abrasions. It also contains process surviving matte to optimize winding and transport characteristics. This film base has a proven track record for problem free transport through all of the major recorder brands currently in use, making it a good choice for this product. Alternately, the ESTAR base used for KODAK VISION Color Print Film 2383 is also available for consideration for this new product. It has many of the same features described above. The ESTAR base is also 120 micrometers in thickness with process surviving anti static layer and a polymeric backing layer. The matte used for print film is larger and coated at higher coverage than intermediate because print needs to be durable through hundreds of passes through movie theater projectors. This asset protection film is not intended for projection, rather as a storage media. The larger matte beads used for abrasion resistance in print film could have a detrimental impact on the sharpness of the image as it is recorded onto the preservation film. Given these considerations, the optimum choice for this product is the currently available support designed for intermediate products.

Complimentary to the base side physical characteristics is the surface overcoat on the emulsion side of the film. There are multiple formulations to choose from which are currently manufactured. Each surface overcoat formula is optimized for best performance under the specific usage of the film. The formulation used for intermediate film will have characteristics that have proven transport reliability through current post facilities. The intermediate film surface overcoat is also designed to ensure smooth winding and roll integrity. It contains a lower level of matte compared to the surface overcoat used on print film which helps to maintain sharpness in the recording mode. Using a systems approach to product design, it is important to verify that various components interact yielding the desired performance. This is especially important with film products that must maintain physical integrity under high and low speed transport operations at a variety of ambient conditions. Since the intermediate surface overcoat has a proven track record for trouble free physical handling in combination with the base side backing layer, this is a solid choice for the overcoat formulation. Utilizing a currently available component is also positive for the manufacturer in order to keep cost down.

The next physical characteristic consideration is the perforation (perf) design. From the film manufacturer's perspective, the selection of perf format defines which film slitting and perforating equipment to use. Since intermediate film, which works well in current recorders and scanners uses a BH-1866 short pitch perforation, this again seems a logical selection. There would be no advantage, and most likely a trade off in transport performance in the post facility by using the print standard long pitch KS-1870 perf configuration. KODAK Color Asset Protection Film 2332 is designed to be processed in ECP-2D chemicals. Trade testing showed that BH-1866 perforation transport well through print processing machines.

Sensitometric Considerations

It is logical that components for physical characteristics of this preservation film be chosen based on intermediate film. The motion picture post production facilities have years of experience using intermediate film in their recorders and scanners. Intermediate film is a viable choice as a preservation film. It fulfills the specifications of both the content owner and post facility for longevity of over 100 years. The requirement that it does not meet is as a lower cost media. Due to the complexity of the film design and the relatively small volume of film that is produced, the manufacturing cost of intermediate film is much higher than that of print film. A new approach must be taken with components that can be obtained and coated at a lower overall cost. This brings the option of using motion picture print film components into the design space. The linear footage of KODAK VISION Color Print Film 2383 coated and sold is magnitudes larger than camera film and intermediate film combined. By design, print film has a lower unit manufacturing cost due to the sheer volume of film made. Component choices for emulsions and color coupler dispersions reflect the economy of scale that print film requires. Keeping in mind the requirements of both the content owner and post facilities, the next step in a system design approach is to examine the suitability of KODAK VISION Color Print Film 2383 components to fill the needs of this preservation film.

The growing concern about digital storage is the rapid and continual upgrades to equipment and the loss of backward compatibility. Even if the content is successfully preserved digitally, it is possible that the content cannot be retrieved due to lack of reading capability. Migration to newer formats can be very costly at each step. The objective of using film for preservation is to avoid that ongoing cost, labor and possible degradation of quality through migration by allowing the content owner to store with confidence of integrity for an acceptable length of time. The goal for KODAK Color Asset Protection Film 2332 is to provide a minimum of 100 years thermal dye stability. If this new film is to use economical print film components, then thermal dye stability needs to be addressed. KODAK VISION Color Print Film 2383 is designed to be physically robust through the release printing and exhibition workflow. It must maintain its integrity through high speed printers in a dry, preprocess state. Print film must be robust in the wet state to survive high speed processing and drying. Finally, print film must also be resistant to scratches and pressure it is exposed to during high speed exhibition projection. The coupler dispersion formulations for KODAK VISION Color Print Film 2383 are optimized to provide a film structure for these strenuous physical situations. The thermal stability of such a design, however, does not meet the requirements for this product.

The system requirements for a preservation film are very different from an exhibition film. By removing the formulation constraints that high speed printing, processing and projecting impose, a new design for the coupler dispersion becomes possible. The limiting dye for thermal stability in print film is cyan. Kodak material scientists re-optimized the cyan coupler dispersion for this preservation film with alternate coupler solvents compared to those used for the print product. This unique dispersion offers increased thermal stability, which is a key deliverable. The trade off is that the resulting sensitized package is less robust to the physical stress applied in theater projectors, with transport speeds of 24 frames per second. Since the preservation film is not intended for projection, this is a logical trade off to make. The resultant stability of the limiting cyan dye is greatly improved. Arrhenius testing was conducted to provide an extrapolated estimate of the time lapse before a 10% loss of dye density at a starting density of 1.0 Status A would occur. The data in Figure 1 shows these results for the new KODAK Color Asset Protection Film 2332 as well as for KODAK VISION 3 Color Digital Intermediate Film 2254, another film in the KODAK Asset Protection Platform.

	Stored at 21C (70F)		Stored at 7C (45F)	
Record	2332	2254	2332	2254
1.0 Above Dmin (NEUTRAL) Years to 0.10 Density Loss				
Red	25	>100	>100	>100
Green	>100	>100	>100	>100
Blue	68	>100	>100	>100
1.0 Above Dmin (SEPARATION) Years to 0.10 Density Loss				
Cyan	23	>100	>100	>100
Magenta	>100	>100	>100	>100
Yellow	>100	86	>100	>100
Dmin - Years to 0.10 Density Gain				
Red	>100	>100	>100	>100
Green	>100	>100	>100	>100
Blue	>100	77	>100	>100

Figure 1. *Arrhenius data*

By design, KODAK VISION Color Print Film 2383 has a density to exposure contrast ratio of approximately three to one. This relatively high contrast, compared to camera original and intermediate films, provides for excellent theatrical viewing. The dynamic range in a dark viewing environment affords the audience optimal image quality. However, this contrast position is too high for easy calibration in recorders and scanners. The equipment used in post facilities are designed for use with low contrast films and prove hard to calibrate with a print like contrast ratio. Kodak formulation engineers considered both the product performance requirements as well as ease of manufacturing in the design of a lower contrast product based on KODAK VISION Color Print emulsion components. A maximum density of 2.5 Status A was set as an aim. The formulation engineers then modified the formulation, without significantly altering the starting components or coating operation. The end product results maintain the economy of using print components as well as fitting into the current manufacturing workflow. Figure 2 below compares the density to log exposure relationship of KODAK Color Asset Protection Film 2332 to KODAK VISION Color Print Film 2383.

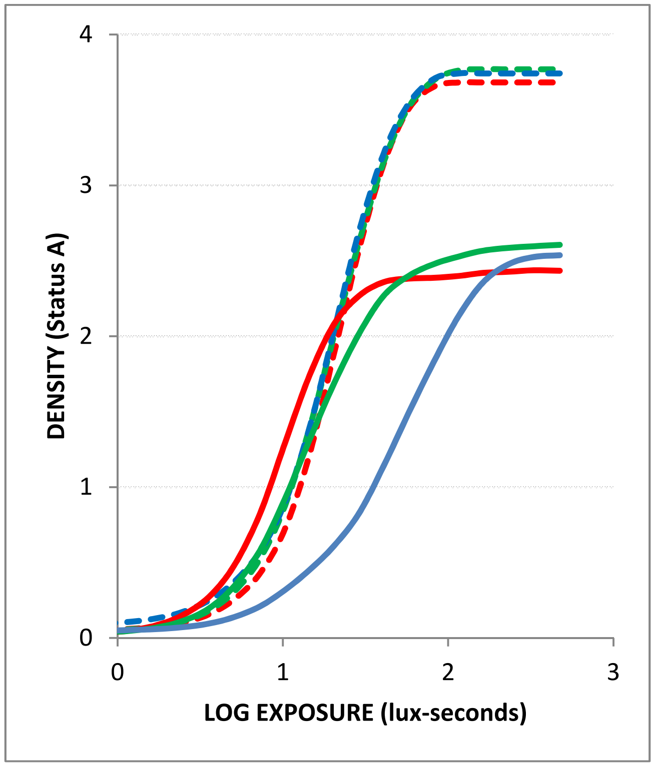

Figure 2. *Sensitometric Comparison*

Customer Verification

The new product design is now ready for the customer verification step. This is a critical facet for systems design. Once the development engineers feel that each customer's requirements have been addressed, it is essential to verify that the resultant product design is feasible. A manufacturing trial is used to confirm that aims can be achieved and that the manufacturing process is robust. Samples of the new product design are made available to the post production facilities. It needs to be confirmed that this product will fit into their workflow easily and without calibration or transport failures. The value proposition also needs to be marketed to the intended end customer, the content owner. During the verification phase, it became apparent that an adjustment was needed to the product so that it would be easier to calibrate. The blue speed was too fast for laser recorders. Even at the lowest laser power setting, it was difficult to achieve an acceptable calibration position for the blue layer. A significant amount of yellow absorber dye was added to the product to slow the shoulder speed down to a position that is more compatible with laser recorders. KODAK Color Asset Protection Film 2332 is truly a hybrid product that utilizes appropriate components from two film types to meet the objectives of two customers as well as the manufacturer.

Post Production System Considerations

Facilities that are familiar with recording onto other films will likely have no issues using this product, but since this film is intended to be used for asset preservation, there are a few systems considerations that should be accounted for.

The premise of how this film (or any other asset protection film) is simple on the surface - record out a sequence of images to the film with the intention of at some future time being able to scan or telecine transfer this film and produce digital images that are the same as the original images.

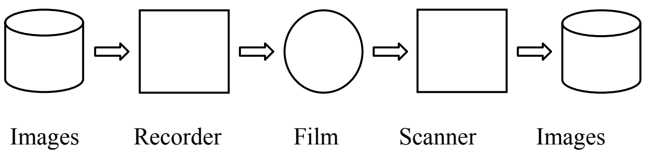

Figure 3. Workflow Diagram

Since this film will be used as a scan only film, there is no real need to have the high density capability of 2383 print film, so this film was designed to reach roughly 2.5 Status A density above Dmin. Most recorders allow for a density aim that is often a linear relationship between the given code values and density on film. We have found that using an aim in the range of 2.0 to 2.3 is likely the preferred recorder calibration position. The exact value will be a balance between the capability of both the intended recorder and scanner (or telecine). The recommended density range provides for a 0.002 to 0.00225 density per code value relationship. Higher density ranges will produce a preservation element that might be difficult to fully capture on a scanner. Going lower than this may reduce the signal to noise ratios unnecessarily.

Without the requirement to print the resulting film for final viewing, it is suggested that the three color channels have the same density aim. This is different from intermediate films which often use different aims for the red, green and blue records.

This film is not like color intermediate film in terms of color cross-talk. The three color records of print film are not as independent from one another as intermediate films. This means that changes to one of the color records will impact the other two color records to some degree. After building the first set of 1D calibration LUTs, the tone scale calibration may not be quite as good as one would like. Figure 4 shows the tone scale error after a single pass calibration. Here the green and the blue records have more error than desired.

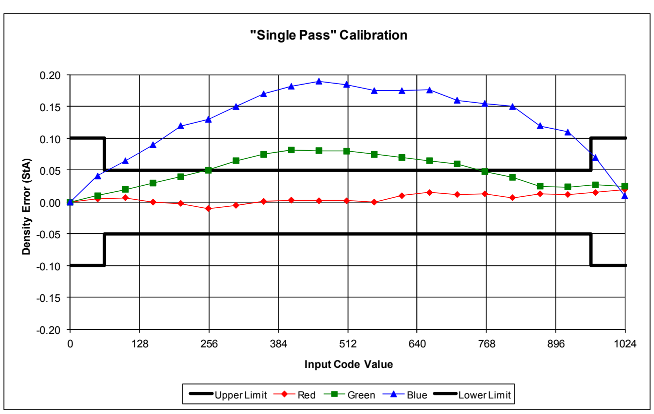

Figure 4. *Single Pass Calibration Results*

To achieve more acceptable results, it will likely be needed to build a second set of calibration LUTs off of the first set. The following plot (Figure 5) shows the results from a double pass calibration. Now all three colors are within the desired tolerance.

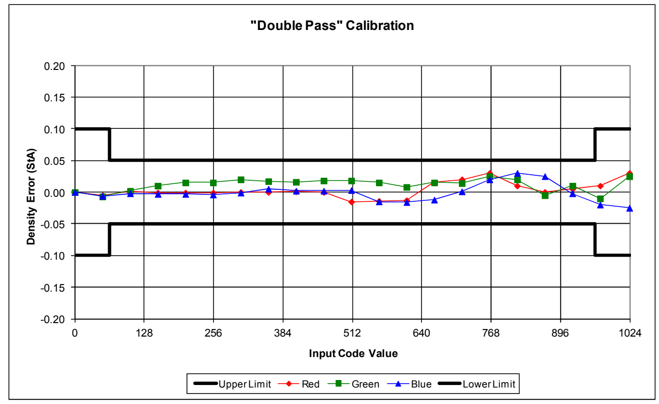

Figure 5. *Double Pass Calibration Results*

Another consideration that should be taken into account is how the film will be used in the future and what can be done during the recording to make the subsequent scanning easier and more accurate. Recording out test images with tone scale and color patches and some supporting metadata as part of each roll, will give a good starting point for the scanner operator. An example of one such image is shown in Figure 6.

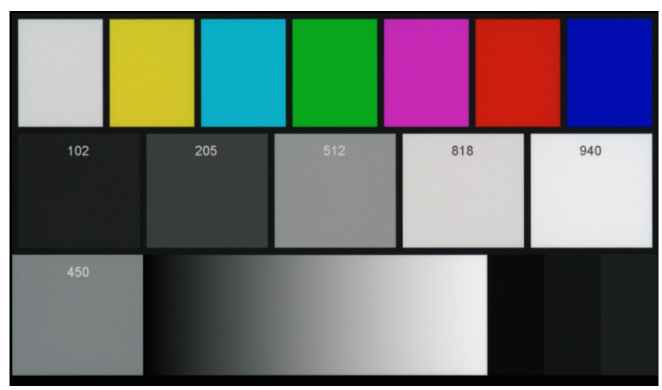

Figure 6. *Sample of Calibration Target*

When a roll of this film is pulled from storage at some future time, the scanner or telecine can be setup to the target. The added benefit of this approach is that if the film has faded some amount during storage, simply setting up the scanner will correct for any of the dye loss.

It was found that during the testing of this film, a skilled colorist was able to creatively transfer the film and produce images that looked quite good. However, if one wants to perform a more objective, mathematical approach, it may be appropriate to include a more elaborate set of color patches. With these patches and the metadata which identifies the original code values, it is possible to create a color transform that can be applied to the scanned images which further corrects the images back to their original look. We found using a large grid of color patches (4913) at the head of each roll, along with the metadata for each patch; we were able to produce a 3D look up table that restored the images back to the original very well. Since people in the future will not have the advantage of what the original looked like, providing additional patches and information can give them an advantage over the pure subjective approach.

Figure 7 shows an example of the color reproduction capability of this film when properly used. The plot shows the color information collapsed down into a 2-D plot. Neutrals are in the center of the plot, and highly saturated colors are around the outside. Brightness is perpendicular to the page. The black dots represent the color position of all the sample color patches, with the larger colored squares representing the six primary and secondary colors.

The lighter gray squares represent the color gamut of the raw telecine scans. This indicates a desaturated look to the images. After applying the 3D LUT to the images, the color gamut is stretched out to nearly the full gamut range of the source images, identified by the red diamonds. The tone scale of the images is also corrected with the use of the 3D LUT.

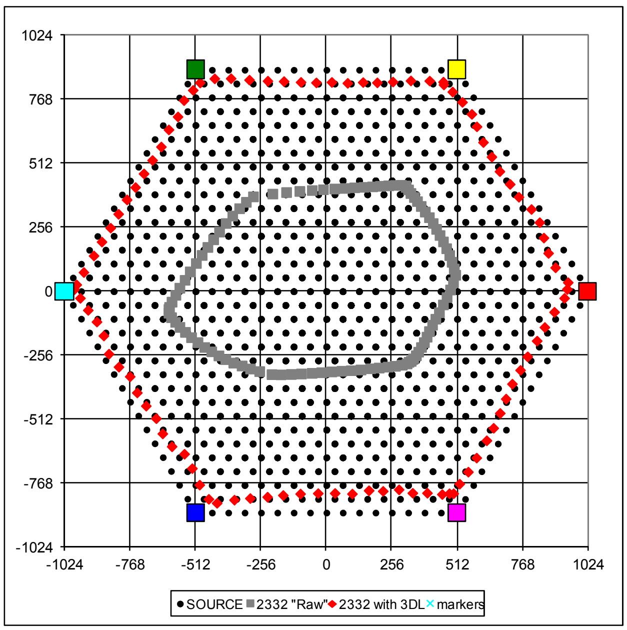

Figure 7. Color Gamut of Scanned back image both with and without 3DLUT applied

Conclusions:

KODAK Color Asset Protection Film 2332 is a good example of product development using a full systems approach. A unique customer need was identified that is not currently supported with an appropriate product offering. Digitally originated content intended for television broadcast, independent films and documentaries are at risk of being lost. Even some film originated content that was not conformed on film, could also at risk. An economical film offering that has been designed to fit the needs of each customer provides an elegant solution to potential loss of valuable content. Using the long existing model of storing motion images on a film base product is a timely solution to this digital dilemma. KODAK Color Asset Protection Film 2332 has a work flow design that includes processing the film in the present, removing the concern of process availability in the future. Film images are also human readable, supporting the argument that film storage is "future proof". Motion picture post production facilities are currently equipped to record digitally originated content onto a preservation media such as KODAK Color Asset Protection Film 2332 now with chemical processing available and appropriate storage available. The risk of losing valuable content forever can be easily and economically resolved by acting now by utilizing the appropriate film preservation media.

References

[1] "The Digital Dilemma 2 Perspectives from Independent Filmmakers, Documentarians and Nonprofit Audiovisual Archives," The Academy of Motion Picture Arts and Sciences, Science and Technology Council, (2012)

Authors' Biographies

Cindy Fitzgerald joined Eastman Kodak in 1979 with a Bachelor's of Science degree in Chemical Engineering from Clarkson University. She has held various positions in the research and development community, specializing in new product development with an emphasis on fulfillment of customer needs while insuring robust manufacturing performance. Cindy has held technical leadership roles for numerous professional photographic paper programs, motion picture print programs and most recently was the technical project leader through the development of KODAK Color Asset Protection Film 2332.

John Rutter has a M.S. in Electrical Engineering from Rochester Institute of Technology. John has worked at Eastman Kodak for 32 years. He has worked in a variety of roles from R&D to product development and project management. For the past 20 years he has primarily worked on scanning and recording technology for the motion picture industry including the Cineon products. For the past several years, John has helped teams develop new films specifically for preservation and archival.

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