

Understanding Cineon

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Cineon Color Space

The Cineon file format was introduced by Kodak about 10 years ago as part of its electronic intermediate system for motion picture film. It was designed for what is essentially a closed loop system in which data from scanned motion picture images can be stored, manipulated and recorded back onto motion picture film. As a result a metric was chosen for the data which bears a direct relationship with the density of the negative. Traditional color management for motion pictures is based on measurement and control of negative densities. Densitometry or the measurement of densities for each color component of a negative or print is a well established technique used in quality control for the design and processing of negative and print stocks. (For a discussion of densitometry see *The Reproduction of Colour in Photography, Printing and Television* by Dr. R.W.G.Hunt, Tolworth, England: Fountain Press, 1987).

If the stored file values are indicative of negative densities, the film recorder can be calibrated to reproduce the densities of the original scanned negative. The ability to make a “digital dupe negative” which can be printed to yield a print which is indistinguishable from a print from the original negative is a basic design goal in an electronic intermediate system. Once this has been achieved you then open the door to all manner of computer manipulation of motion picture images.

Kodak designed their film scanner essentially to be a densitometer which takes 6 million density readings of each frame. Optical density is defined as $\text{Log}_{10}(100/\text{Transmittance})$ where Transmittance is percentage of light which passes through whatever is being measured. In this case Transmittance has a range of 0 to 100. It can also be expressed as having a range of 0 to 1.0 in which case the formula would be $D = \text{Log}_{10}(1.0/T)$.

Density is logarithmic. A density difference of 0.3 at any point on the scale represents a doubling or halving of the amount of light transmitted. This is an appropriate type of scale for analyzing the effect of exposure on film not only because the eye responds logarithmically to light but also because the light sensitive materials used in film also respond logarithmically to light. (Like the eye the ear responds logarithmically to stimuli and decibels are a similar logarithmic scale.)

If a scanner is calibrated to yield a value of 65535 on the open gate (i.e. there is absolutely nothing obstructing the path between the light source and the photosensitive array), and the response of the sensors in the array is absolutely linear, then the absolute optical density of anything inserted in the light path can be calculated very simply. The transmittance is equal to the yielded value / 65535 and optical density is $\text{Log}_{10}(1/\text{Transmittance})$.

The Cineon value range is 1024 steps where each step represents an increase in density of 0.002. An increment of 0.002 is a conservative choice which is well beyond the accuracy of most densitometers. It was chosen because of a desire to permit the file to encompass a density range of at least 2.0 and because it was felt that an 8 bit value with increments of 0.008 would be too crude. There was no incentive to use 9 bit values with increments of 0.004 since they are even more awkward for the computer programmer or the computer hardware than 10 bit values. Experience has shown that images using 8 bit Cineon values representing increments of 0.008 are often indistinguishable from full 10 bit Cineon images

once they have been recorded on film and printed onto print stock. Nonetheless the 10 bit standard has been embraced because it is a conservative choice that has headroom.

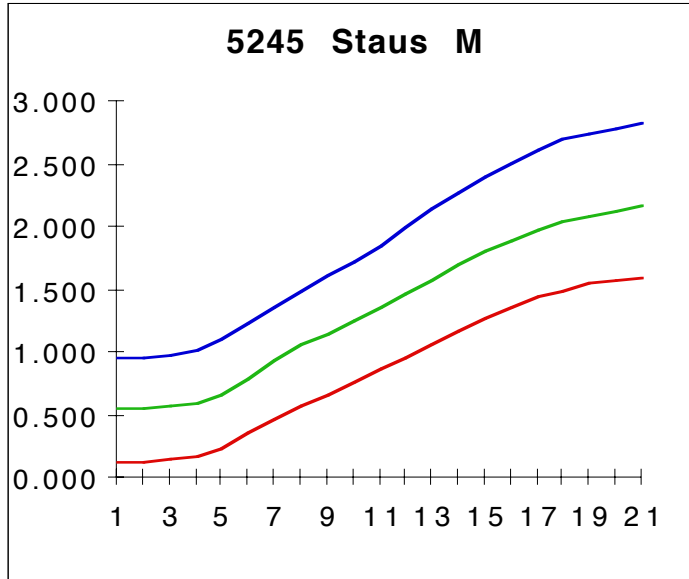
Cineon file values represent a range of relative densities, not absolute densities. The density range which it can encompass is 2.048 density units. An offset is employed to select the range of densities which are the most meaningful for motion picture negatives.

The Characteristic Curve

The image capturing capabilities of a particular film emulsion are described by its “characteristic curve.” This is a graph of Density vs. Log Exposure. A logarithmic scale of exposure is comparable to the f stop scale on a camera. On a camera each stop represents a doubling or halving of the amount of light striking the film. The range of exposures represented by the characteristic curve is relative to the minimal level of exposure which produces an effect. Generally the curve is based on 21 exposures in increments of 0.20 or 0.15. The range of negative densities in a typical characteristic curve for Eastman Color Negative 5245 is from 0.130 to 1.600 in the red layer 0.550 to 2.170 in the green layer and 0.950 to 2.823 in the blue layer.

X-Rite Status M of 5245-406 21 Step Full Frame Grayscale from Kodak

Rel Log E	Red	Green	Blue
0.00	0.130	0.550	0.950
0.20	0.133	0.557	0.960
0.40	0.140	0.570	0.980
0.60	0.170	0.590	1.030
0.80	0.240	0.660	1.110
1.00	0.360	0.783	1.237
1.20	0.470	0.930	1.370
1.40	0.580	1.057	1.500
1.60	0.670	1.150	1.610
1.80	0.770	1.257	1.733
2.00	0.870	1.360	1.850
2.20	0.960	1.470	1.993
2.40	1.060	1.583	2.140
2.60	1.167	1.693	2.280
2.80	1.270	1.807	2.413
3.00	1.360	1.890	2.520
3.20	1.440	1.970	2.610
3.40	1.500	2.040	2.700
3.60	1.550	2.093	2.753
3.80	1.580	2.137	2.793
4.00	1.600	2.170	2.823



An exposure range of 4.0 Log E means that the brightest exposure is 10,000 times brighter than the darkest exposure. In other words it represents an exposure range of $13^{1/3}$ stops. Traditionally characteristic curves were done with 21 steps at 0.15 intervals and they generally had a “toe” and “shoulder” which meant that the effect of the exposure was negligible beyond the range represented. More recently film stocks have been refined to the point where even the exposure range represented by 21 steps at 0.20 intervals does not exhaust the meaningful latitude of the film. The graph of the above curve indicates that it is just beginning to roll off at the top and the sensitivity of the film does in fact extend beyond this range.

The Cineon file value range is based on density above the minimum density for each layer. For the above curve this would be the following:

Status M Densities Above Dmin		
Red	Green	Blue
0.000	0.000	0.000
0.003	0.007	0.010
0.010	0.020	0.030
0.040	0.040	0.080
0.110	0.110	0.160
0.230	0.233	0.287
0.340	0.380	0.420
0.450	0.507	0.550
0.540	0.600	0.660
0.640	0.707	0.783
0.740	0.810	0.900
0.830	0.920	1.043
0.930	1.033	1.190
1.037	1.143	1.330
1.140	1.257	1.463
1.230	1.340	1.570

1.310	1.420	1.660
1.370	1.490	1.750
1.420	1.543	1.803
1.450	1.587	1.843
1.470	1.620	1.873

Printing Density vs Status M Density

In all cases the density range is less than 2.048, which is the range of densities which can be stored in a Cineon file. The density values represented in the Cineon file are not identical with density values as measured by a Status M densitometer. According to Glenn Kennel and David Snider, the principal architects of the Cineon System:

The Cineon digital negative is represented in printing density, which is to say, the density that is “seen” by the print film when the negative is printed with a standard illuminant. The illumination and color filters in the Cineon scanner were designed so that the effective spectral response of the scanner matches that of print film.

Although the specifications for filters for Status M (or Status MM) densitometry are designed to measure printing densities of negatives, film stocks have apparently changed sufficiently since the standard was adopted to require an adjustment represented by the following matrices which can be used to translate Status M densities to or from the Printing Densities on which the Cineon file system is based.

Printing Density to Status M Matrix

Red	0.9806	-0.0348	-0.0073
Green	0.0065	1.1191	-0.0601
Blue	-0.0132	0.0017	1.0297

Status M to Printing Density Matrix (Inverse of above)

Red	1.0197	0.0317	0.0091
Green	-0.0052	0.8933	0.0521
Blue	0.0131	-0.0011	0.9712

I confess I do not understand completely the significance of this conversion. I have used these calculations to correlate my densitometer readings to Cineon file values, but I do not know whether this matrix is actually used at some stage in the Cineon system. It may just be an indication of how the system was designed as a closed-loop system and only required when translating Cineon values to Status M densities, i.e. when moving from the closed system to the outside world.

Laboratory Aim Density (LAD)

Quality control in film labs uses a specific set of negative densities which are supposed to yield specific print densities when printed in a standard manner. These densities are the Laboratory Aim

Densities or LAD. They were first described by John P. Ptlak and Alfred W. Fleischer in a 1976 SMPTE paper “A Simplified Motion-Picture Laboratory Control Method for Improved Color Duplication.” (SMPTE Journal Vol. 85 No. 10 October 1976) The densities correspond roughly to an 18% gray, which was the traditional mid-density used in quality control. The choice of the Cineon file values which correspond to LAD is to some extent an arbitrary choice, but the de facto standard was established when Kodak’s Cinesite facility settled on 444, 444, 444 as the red, green and blue file values representing LAD density on the negative.

(Whether a negative with the actual Status M densities represented by these values would yield the proper densities on a print when printed at “standard” printer lights is an academic question. I am not convinced that they would, and for a time I calibrated our film recorder in such a way that Cineon values of 440, 401, 415 produced negative densities on 5245 of 0.80, 1.20, 1.60, which I believed to be LAD for camera negatives. I later realized that the important thing was to calibrate my film recorder in a way that was in sync with recorders at other facilities so that a Cineon file could be recorded on our recorder and printed in a way that represented what the same file would look like when it was recorded at a different facility.)

Once you have pegged the Cineon values for LAD to specific densities on the negative, it is a simple calculation to determine what negative density corresponds to any set of Cineon values:

$$\text{CineonValue} \times .002 = \text{PrintingDensity}$$

Convert PrintingDensity to StatusMDensity(AboveDmin) via matrix

$$\text{StatusMDensity(AboveDmin)} + \text{Dmin} = \text{ActualStatusMDensity}$$

This closes the loop for a given film stock and recorder. What comes out is a reasonable reproduction of what went in via the scanner. Depending on the stock used for recording and the type of film recorder, the actual densities of the digital dupe negative may differ considerably from those of the original, but this just means that each negative has to print at a different light. The resulting prints should be indistinguishable.

It is worth noting that these calculations should result in Dmin at a value corresponding to a Cineon file value of 95. For the reverse calculation it is necessary to use an offset of 95 to yield the proper Cineon value from a Status M density reading. The system was designed to put Dmin at 95 in order to allow room for “dark noise” caused by fluctuation in the actual value of Dmin. The amount of black noise varies for film stock to film stock but setting Dmin at 95 allows sufficient room for the stocks with the greatest amount of black noise.

Displaying and Converting Cineon Images

All of this tells you nothing, however, about how the image should look when viewed on a monitor. It also tells you nothing about how to convert a computer generated image into Cineon values for output onto film, especially if the computer generated image is going to be composited with a scanned film image.

Kodak addressed the first of these issues by developing lookup tables for the monitors used in the Cineon system, which was initially a complete turnkey hardware/software system. The monitors for the Cineon system were modified to increase their dynamic range (at the expense of tube life), and a

custom lookup table was developed which enabled them to display an adequate representation of the way in which the Cineon image would look on film. So far as I know the actual method by which this lookup table was developed has never been published, nor was it modified to reflect the change in print stocks with the introduction of the Vision stocks. I do not believe the monitor lookup tables can be derived from the published recommendations for converting Cineon to Video. Someone at OptiCal (now Color Vision) did once tell me that they were involved in the original monitor lookup table work for the Cineon system and their calibration program includes a Cineon lookup table. Since this monitor lookup table is such that the red, green and blue curves track throughout, I am skeptical of its accuracy. A graph of a “FiDO Video Shaper for ECP Match” for displaying printing density which I received from David Snider in November of 1993 shows three distinct curves each having a different gamma in the straight-line portion of the curve. I was never able to obtain the actual numbers underlying the graph nor do I know whether it was subsequently modified.

The published recommendations from Kodak for displaying Cineon files and for converting computer image files into Cineon files can be found in a paper by Glenn Kennel and David Snider entitled “Gray-Scale Transformations of Digital Film Data for Display, Conversion, and Film Recording” (SMPTE Journal, December 1993 page 1109). A refinement of these procedures was presented in a subsequent paper “Conversion of 10-bit Log Film Data To 8-bit Linear or Video Data for The Cineon Digital Film System version 2.1 July 26, 1995.” Both papers are available from Cinesite via their web page at www.cinesite.com. Both of these papers present a conversion method which assumes that neutral grays are represented by equal Cineon file values throughout the tonal range from black to white. In other words it ignores the fact that the emulsion layers in color negative have different gammas. If a neutral grayscale were photographed under the most exacting conditions imaginable and scanned on a Cineon scanner, the resulting file values in each layer would not be equal because the densities above D_{min} in each layer for each grayscale step would not be equal. Only the mid-gray or a LAD patch would produce equal red, green and blue values.

Both papers also posit a generic gamma for color negative film of 0.6 (or 0.61212, which is the value I had to use to reproduce the numbers in a spreadsheet in the earlier paper). None of the emulsion layers in any of the most common Eastman Color Negative stocks actually has a gamma of 0.6. *(Technically the term gamma is no longer used to refer to the shape of a film characteristic curve. Best Fit for Contrast is the preferred designation, and it is defined as the average slope of the curve from 0.2 above D_{min} to the density representing $+1.35 \log$ Exposure above that point. This amounts to the straight-line portion of the curve. The BFC for a typical sample of 5245 is 0.474 red, 0.592 green, and 0.627 blue.)*

The procedures recommended by Kodak are perfectly adequate for most purposes. They enable a desktop computer to display a reasonable approximation of what a Cineon file image will look like when it is recorded onto film, and they provide a means of converting Cineon images into files which can be recorded on video in the conventional manner. The limitations of the procedures only become apparent in critical applications where images are being created and composited for recording onto negative which is going to be intercut with similar scenes which have not been scanned and manipulated in the computer. Even in this case it is often possible to blend computer generated images into scanned

images while evaluating the results via a temporary conversion using the Kodak recommended procedures. What matters most in such cases is not exactly what how the image will look on film but how well the tones and colors of the synthetic elements match the tones and colors of the scanned image.

Why Bother Improving On This

Before I outline the approach which seems to me to be more accurate, it is worth explaining why the Kodak procedure is not good enough for our purposes. The simplest way is to look at images on the monitor to see the difference. I am hoping this document will be accompanied by an After Effects plug-in which will enable you to see the difference.

There are two main issues:

- 1) The gamma of the image as converted with the Kodak procedure is inaccurate and the result looks noticeably flatter. This is observable with the Marcie test image as well as most other images and has nothing to do with extended highlights. The look of the image is just not quite right. It is a pleasing look, and for transfer to video it may be preferable to make the image slightly flatter; but in terms of evaluating what the image will look like on film it is not as accurate as it could be. One can of course adjust the monitor until the contrast of the image seems right, but I am not satisfied that this is the best approach.
- 2) Colors will be slightly skewed in highlights and shadows because the gammas of the three colors are not right. This is less easy to see, but we have been able to see a difference in some images.

Note that these issues apply if the image is going to be sent to a service bureau for recording as well as if the images are going to be recorded in house. The whole point of this discussion is to enable the preview on the monitor to emulate as much as possible how the image will look when it is recorded on film. It assumes Cineon files will be recorded and printed in a “standard” fashion so that file values of 444,444,444 result in LAD densities on the print. So far as I know every service bureau uses this as their LAD target.

The Cineon Digital Negative

The document by Kennel and Snider describes the Cineon system in terms of a “Cineon Digital Negative,” which is “a digital representation of a typical motion picture negative film” produced by the Cineon digital film scanner. This digital negative is defined by five values:

- 1) 685 represents the density produced by “normal” exposure of a 90% white card
- 2) 470 represents the density produced by “normal” exposure of an 18% gray card
- 3) 180 represents the density produced by “normal” exposure of a 2% black card
- 4) 95 represents nominal D_{min} (~1% black)
- 5) The gamma of the straight-line curve for the first three points is 0.6 . This is not actually defined as such, but this is the figure that is used in all the conversion calculations. The slope derived by plotting the log of these reflectance values against the printing densities corresponding to these Cineon values is 0.608 and 0.615.

This digital negative is a convenient fiction for doing conversions to video, but it does not correspond to a real negative stock. With normal exposure a typical sample of 5245 with a Dmin of 0.16, 0.55, 0.95 will yield densities of 0.88, 1.36, 1.64 for an 18% gray card. (These are typical values provided by Alan Masson at Kodak.) Using the characteristic curve data I have for another sample of 5245 and adjusting for the difference in Dmin, my calculations indicate that a 90% white card would produce densities of 1.36, 1.904, 2.376 with the 18% adjusted to 0.85, 1.36, 1.64. Jumping through all the appropriate hoops I calculate that these densities when scanned will yield Cineon values of 750, 734, 795 for the 90% white card and 478, 473, 434 for the 18% gray. Further empirical testing under the most controlled conditions possible might improve the accuracy of these numbers, but I have had the negative for the 21 step grayscale scanned at Cinesite and also compared the density readings I get for it on our densitometer with the readings provided by Kodak with the film. I am satisfied that my calculations are accurate enough to serve as a basis for this kind of analysis unless there are mathematical errors somewhere.

What does this tell me? It tells me that if I shot a white card and a gray card under controlled conditions and had the scene scanned at Cinesite, the values I would get for each would not be 685,685,685 and 470,470,470. If Cinesite recorded the scans back onto 5244 and had it printed properly, the print would be identical to a proper print from the original negative, but using the recommended calculations to convert the scans for display on my monitor would not yield an accurate preview of the gray or the white. The white might seem to have an appropriate brightness relationship with the gray on the monitor because the white would be compressed or clipped, but neither would be neutral and both would be noticeably hotter than the 18% gray and 90% white in my computer generated element which I want to composite into the scene. So, big deal; I tweak the brightness and hue of the computer generated element until it blends into the scanned image.

While elements for a composite are still separate, color and tonal adjustments can be made to a computer generated image using all the conventional tools and/or corrections can be made to the Cineon version of the file. This ability to interactively correct and balance elements in a composite is one of the real beauties of the design of After Effects. I am convinced that it is essential to preview the file as accurately as possible, though, if the elements are being composited for recording back onto film. Even though I had written a custom plug-in for converting gamma-corrected Photoshop files into Cineon, some of the artists at Illusion Arts still used the Cineon Converter shipped with After Effects 5.0 to convert their paintings. We eventually had a problem with a painting which was being created in Photoshop, converted with the Cineon Converter and then recorded onto film from the Cineon file. There was a dramatic difference in the way the highlights in the sky looked on the monitor and on film, and only after we used the in-house plug-in to preview the file were we able to anticipate adequately how the painting would look on film after it had been converted to Cineon color for compositing with scans. We were recording this on our own film recorder, but I am convinced that the same difference would have been visible had we sent it to a facility for recording on a laser film recorder.

If I am trying to do overall digital color correction, I have an even greater challenge. The practical minded ex-optical-printer-operator-turned-digital-imaging-enthusiast will simply say, "Shoot a wedge

and make a pick.” “Shooting a wedge” is a traditional photographic color correction technique in which a sample frame is exposed 125 times with different color correction filters for each exposure. This is, in fact, something Illusion Arts still does. We have an After Effects project set up to shoot a sequence in which the Cineon values are adjusted in way that emulates the traditional wedge. If you don’t have an in-house film recorder or the budget for doing these kinds of tests at your service bureau, you might want a more reliable way to preview your scans on the monitor.

Extended Highlights

The main value of the Cineon file format is its ability to preserve the extended dynamic range of motion picture negative. If a “normal” scene is photographed with “proper” exposure, the extended range of the negative is probably not used. If a scene is “overexposed” or if it includes a wider than “normal” range of values such as an indoor scene with a window onto a bright exterior then the range of densities on the negative is probably greater than the range which can be reproduced faithfully on the print. In this case either highlight detail or shadow detail will be compressed into the shoulder or toe of the print curve. Altering the exposure of the print will shift the range of values which are faithfully reproduced in the print. You can print the scene for the interior or you can print the scene for the exterior outside the window; but you cannot have both “properly” represented. Either the exterior is going to look too bright or the interior is going to seem too dark. This characteristic is often exploited by cameramen who want a stage set to look “realistic” and light the backdrops beyond windows so that they “burn out.”

Having a curve in After Effects which emulates the characteristic curve of the print stock and an effect which can essentially alter the exposure of the print enables you to preview how the negative will look when it is printed at different exposures. To achieve this same result with the Cineon Converter would require adjusting both the black point and the white point by equal amounts and adding the right amount of highlight roll off. This could certainly be done, but it seems unnecessarily awkward given the simple nature of log color correction.

Previewing extended highlights as they will appear in a film print is possible using the highlight roll-off feature in the Cineon Converter. The only problem is that it is unclear exactly what setting represents the amount of roll off to be expected when the negative is printed and projected. This highlight adjustment may be more useful if the image is being converted permanently for use on video or as a means of correcting exposure problems which could not be handled during photography, but it is less useful as a preview of what the image will look like on film. A previewer built from film characteristic curves accomplishes this automatically.

Painting extended highlights is more of a problem. Tim Sassoon has explained how his company enables artists to use the extended dynamic range of the Cineon file format:

- 1) *Keep extreme highlights on a separate layer in Photoshop.*
- 2) *In After Effects put an adjustment layer between the all the background layers and the extreme highlights on top, and with levels, trim the output white. Then put the lin to log conversion white point up to compensate. In other words, it’s not that big a deal, just requires a bit of layer planning.*

As he sees it the problem has nothing to do with the Cineon Converter in After Effects but is rather a matter of the lack of a corresponding adjustment in Photoshop so that an artist can paint directly in log.

What we do at SFD is manipulate the white point on the preview layer to see how high white highlights are being painted. Export to owner is valuable here. We also typically set the lin to log conversion white point somewhat higher than default, like the 730's or so, to maintain a clean highlight. A slight compensatory gamma adjustment may be required...

The simplest solution to this is of course an arbitrary map which will permit the artist to preview a Cineon image (or at least an 8 bit version of the Cineon image) while he paints a layer in log space to be composited in After Effects. This requires a Cineon format plug-in for Photoshop which opens the file as 8 bit or 16 bit log and an arbitrary map for previewing Cineon images in Photoshop. These are fairly basic tools used at Illusion Arts which I am hoping can accompany this document. (Unfortunately all my plug-ins are Mac-only.) The main hitch with this is that the artist must remember to turn off the preview curve temporarily anytime he wants to sample a color from the Cineon image. It would be nice to be able to apply correction layers to 16 bit images in Photoshop, but creating elements in 8 bit log for compositing with Cineon scans in After Effects is a perfectly viable way to work.

Painting in log space may make some of the Photoshop tools respond in unexpected ways, but the difference will not be as dramatic as one might expect. There is a theoretical issue about doing color correction on gamma corrected images using tools designed for correcting strictly linear image values. Unless one is using the most advanced color management techniques available, the chances are good that working with "normal" images in Photoshop always means using linear tools on gamma corrected image data. Logarithmic Cineon image data is very similar to an image data with a gamma of 3.0 in terms of how it responds to mathematical manipulation.

It also seems to me that it should be possible to use the highlight roll-off feature of the Cineon Converter to permit artists to paint extended highlights in Photoshop. If there is a shop standard for the roll-off setting that will be used when converting from linear to log when the painting is composited with the Cineon scans in After Effects, then artists could paint in 16 bit linear color knowing that the upper portion of their tonal scale will be whiter than 90% white.

The greatest risk in painting extended highlights is probably the difficulty of anticipating how the extended highlights will print if the negative is printed darker than normal. Because extended highlights are compressed both in a preview on the monitor and in a normal print of the recorded negative, they will appear more neutral than they might actually be. If the scene is printed down sufficiently to bring the highlights below the shoulder of the print curve, any color imbalance will show up in the print. The only way to guard against this may be to preview the image as it will look if it is printed several stops darker than normal. The Printer Light plug-in which we use at Illusion Arts is designed to facilitate this.

Log Space Color Correction

There are also other issues associated with the use of Cineon files which are relevant to this discussion. One is the way in which color correction is done on the files. One of the advantages of

scanning film images and running them through the computer is that it opens up the possibility for all manner of color correction and tonal adjustment, just as the color corrector attached to a telecine enables video transfers of film to look radically different from a print from the negative. This is great, but there are also times when the goal with a scanned film image is to correct some defect or add some element without altering the basic look of the image at all. And there also may be times when the goal is to do only the kind of color correction to this scene that can be done in the lab to other scenes with which it is intercut.

The latter case is problematic with the set of tools included with After Effects, and it is the reason I wrote another plug-in for doing color correction in Cineon space. While it is theoretically possible to do appropriate log space color correction with the controls in the converter it is awkward. If you want to emulate the color correction that can be done when printing a negative in the lab, the way to do it is by adding or subtracting an offset to or from the Cineon file values. Increasing or decreasing Cineon values by a fixed offset is the equivalent of altering the exposure when the negative is printed. This is obviously a relatively straightforward plug-in, and the only hitch with the one I wrote is that it is designed for people with a film and optical printing background. It is set up to emulate literally the laboratory “color timing” process. A higher setting in the blue control actually makes the image more yellow and the increments of the control are designed to emulate the printer light settings at the lab (25 is normal and the range is 0 to 50; higher values make darker images).

Separating this kind of color correction from the previewing process enables us to produce color corrected Cineon files which are the equivalent of “timed” dupe negatives. They have color correction built into them, but it is only the kind of color correction that can be achieved in printing and could conceivably be applied to other shots which have never been scanned. This may seem esoteric, but it is really an essential ingredient in this kind of hybrid system where effects shots are digitally manipulated and put back onto film which has to intercut with the rest of the scene. Once we reach a point where the entire movie is digitized and manipulated, there may be no more need for this kind of digital correction.

Alternative Approaches

If one wants to achieve a more accurate representation of a Cineon image on a computer monitor, it is necessary to incorporate a characteristic curve for film. Right away this opens a can of worms. The problem is not only that every film stock has its own unique characteristic curve but that there is some variation within a given stock from one emulsion batch to another. The characteristic curve is also dependent to some extent on the way in which the film is processed. It is no wonder that Kodak shied away from publishing a procedure which uses film characteristic curves for converting Cineon values into other color spaces even though they managed a similar feat with their PhotoCD system.

The Kodak PhotoCD system includes a provision for loading Kodak “film terms” for a variety of Kodak film stocks. So far as I can tell these files are completely proprietary and not publicly documented in any way, but they seem to function as a type of device profile which permits the densities of the scanned film image to be interpreted in terms of a YCC color space which can then be used in normal color management processes. With reversal film stocks this process makes complete sense. The ideal

color temperature of the light for viewing or projecting a transparency is a known spec and Kodak knows the spectral transmission characteristics of the dyes in its film stocks so that a given set of red, green and blue densities can be translated into a device independent color space.

With negative film stocks it is not so simple because the “interpretation” of negative densities is something that happens when the negative is printed. There is nothing inherent in the negative to tell anyone what the color temperature of the light was that exposed the film or the relationship between the brightness of the original scene and the f-stop used for the shot. There is currently no ICC procedure for characterizing film negative stocks, although I gather there is a committee trying to get a consensus for a specification. Nonetheless the PhotoCD system does include film terms for negative stocks.

One story about the development and refinement of the PhotoCD system is relevant to a consideration of alternative approaches to the translation of Cineon color. Initially the approach taken was to interpret the film densities in terms of the original scene brightness values. These values could then be translated into appropriate values for display on the computer monitor so that what was displayed was a representation of the original scene. What this did was to make an image from Ektachrome look just like an image photographed on Kodachrome. Photographers complained because the PhotoCD system removed the “look” of the film. They chose one stock over another because they wanted a certain look and the PhotoCD scan removed that look. As a result Kodak refined the system by permitting it to retain the characteristics of the particular stock used to shoot the scene.

For several years my own attempts to develop an alternative system for translating Cineon images was hampered by the fact that I did not have characteristic curve data for the print stock. The only alternative was to interpret the negative densities in terms of the exposure in red, green and blue which would yield those densities based on the characteristic curve for the negative stock and to reconstruct the original scene brightness values. At first I devised lookup tables for translating each of the different film stocks that were used to shoot the scenes we worked on. Eventually I concluded that this was counterproductive and based all the conversions on the curve for 5245, which was the stock we used in our film recorder. If the system acts as though all the scenes were photographed on 5245, then the characteristics of the other film stocks will be preserved. The “original” scene which is reconstructed in the translation is the scene as photographed. Interpreting a scene shot on 5293 as though it were shot on 5245 means that the “original” scene is not the real scene but an hypothetical scene that would yield these densities if it had been photographed on 5245. Recording these densities back onto 5245 in the film recorder will yield a scene which “looks” as though it were photographed on 5293.

This approach does incorporate the different gammas for each emulsion layer in the negative, but it does not address an even more complex issue which is color crosstalk and the interimage effects which are designed into camera negatives. The nature of negative camera stocks is such that altering the exposure of one layer can alter the density of the other layers. (See Hunt pp. 278-281 for a discussion of inter-image effects) A full discussion of color crosstalk and interimage effects is beyond the scope of this memo, and I do not pretend to understand it completely. I have done some experiments with the Solitaire film recorder to track the effects with an idea of eventually creating a 3 dimensional lookup table which could deal adequately with color crosstalk. I initially assumed the crosstalk was a function of the

film recorder, but I discovered that it is designed into the emulsion for 5245 as a means of controlling saturation. What surprised me most was the fact that increasing exposure in one layer beyond a certain level can decrease densities in other layers.

The net effect of this is that the “meaning” of a density in one layer of a camera negative can not be fully interpreted without reference to the densities of the other two layers – if one is seeking to reconstruct the original scene, or if one is trying to control a film recorder. Fortunately neither is really the goal of the present discussion. What you want to see on your monitor is the scene as photographed not as it “really was.” Ideally you want to see the way it will look on the theater screen when the movie is properly projected. The only way to achieve this is to incorporate a characteristic curve for the print stock as well as the negative.

Intermediate Stocks vs Camera Negative Stocks

One of the most significant features of the Cineon system is that its film recorder was designed to record onto an intermediate or duplicating film stock rather than a camera stock. The main differences between intermediate stocks and camera stocks are that intermediate stocks can have much finer grain because they can be much less sensitive and that they are designed to have a gamma of 1.0 with no color crosstalk or inter-image effects.

5244 Sensi Strip 1/24/97			
Status M Densities			
Rel Log E	Red	Green	Blue
-2.00	0.12	0.58	0.68
-1.85	0.13	0.60	0.71
-1.70	0.16	0.63	0.74
-1.55	0.21	0.67	0.79
-1.40	0.29	0.74	0.87
-1.25	0.39	0.84	0.98
-1.10	0.51	0.97	1.12
-0.95	0.65	1.11	1.27
-0.80	0.80	1.26	1.43
-0.65	0.95	1.42	1.58
-0.50	1.09	1.57	1.74
-0.35	1.24	1.72	1.90
-0.20	1.39	1.87	2.05
-0.05	1.53	2.02	2.21
0.10	1.68	2.17	2.36
0.25	1.82	2.32	2.51
0.40	1.95	2.45	2.65
0.55	2.08	2.58	2.78
0.70	2.18	2.67	2.88
0.85	2.26	2.77	2.96

Plotting the above values as density above D_{min} will show clearly how well the three layers track with each other. It will also show how straight the overall curve is. When using an intermediate stock in the traditional way for duplicating negatives it is possible to expose the intermediate stock through the negative in such a way that all of the densities in the negative are positioned in the straight line portion of the curve for the intermediate stock. This means that the relationships of all the densities

on the original negative can be preserved in the intermediate without any further compression caused by a toe or shoulder in the curve.

The same thing applies when digitally recording onto intermediate stock. There is no need to compensate for non-linear portions of the original negative's characteristic curve. Values from the scanner can be recorded back onto the intermediate stock with appropriate offsets yielding a negative which can be printed to produce a print which is indistinguishable from a print of the original negative.

Print Stock Characteristic Curves

Motion picture film stocks are designed as a system and the characteristics of the print stock are tailored to the characteristics of the negative stocks which will be printed on them. Since all the negative stocks are designed to be similar enough to be intercut in a single movie, they all designed to print on the same stock. This is one reason why the Cineon concept of a single model for a "digital negative" is viable. The densities of the negative will determine the exposure of the print stock and the relationships between all the densities in a given image will determine the look of the image on the print. If you know what the densities will be on the print, you know what the image will look like when it is projected. The densities of each color layer in the print at any point determine how much light for that color will hit the screen at that point.

When Kodak released their Vision print stocks, I was able to obtain characteristic curve data for each of the new stocks. There are two principal print stocks in use: 2383 and 2393. They differ primarily in terms of the "depth" of their blacks and the saturation of the colors.

2383 Print Stock			
	Status A Densities		
Rel Log Exp	Red	Green	Blue
2.291	4.1365	4.2060	4.1740
2.141	4.1310	4.2020	4.1585
1.991	4.1205	4.2010	4.1335
1.841	4.0925	4.1695	4.1015
1.691	4.0120	4.0835	4.0380
1.541	3.8420	3.9030	3.9240
1.391	3.5495	3.6020	3.7155
1.241	3.0990	3.1515	3.3105
1.091	2.4910	2.5680	2.6625
0.941	1.7705	1.9095	1.9250
0.791	1.0980	1.3035	1.3090
0.641	0.6260	0.8295	0.9290
0.491	0.3690	0.5040	0.5245
0.341	0.2260	0.2915	0.3380
0.191	0.1415	0.1685	0.2200
0.041	0.0925	0.1055	0.1410
-0.109	0.0675	0.0810	0.0940
-0.259	0.0570	0.0685	0.0740
-0.409	0.0540	0.0600	0.0685
-0.559	0.0520	0.0540	0.0655
-0.709	0.0500	0.0500	0.0600

2393 Print			
	Status A Densities		
Rel. Log Exp	Red	Green	Blue
-0.709	0.050	0.050	0.070
-0.559	0.054	0.055	0.075
-0.409	0.056	0.059	0.079
-0.259	0.064	0.070	0.084
-0.109	0.075	0.082	0.100
0.041	0.099	0.107	0.146
0.191	0.140	0.166	0.220
0.341	0.225	0.293	0.339
0.491	0.379	0.508	0.528
0.641	0.647	0.837	0.834
0.791	1.091	1.289	1.309
0.941	1.718	1.865	1.970
1.091	2.504	2.555	2.780
1.241	3.308	3.305	3.623
1.391	4.049	4.038	4.352
1.541	4.590	4.656	4.925
1.691	4.898	5.076	5.183
1.841	5.065	5.306	5.308
1.991	5.159	5.421	5.372
2.141	5.230	5.496	5.382
2.291	5.260	5.524	5.386

The density of the print stock translates into the brightness of the screen and the exposure is directly related to the density of the negative which is being printed. Connecting these two curves enables you to interpret the densities of the negative in terms of brightness of each color on the screen.

There is some crosstalk in the color of these print stocks, but I believe it is negligible.

Combining these curves can provide the theoretical basis for creating a monitor lookup table or an arbitrary map for previewing the image in Photoshop or After Effects. The main limitation is the fact that the brightness range of a movie screen is greater than that of a computer monitor. I have not researched and quantified this to my satisfaction yet, but I believe it is noticeable.

There are two alternatives for displaying the image on the monitor. The brightness ratios in the print can be preserved by displaying only a portion of the total brightness range on the monitor, or the entire brightness range of the print can be mapped onto the available brightness range of the monitor. The latter choice seems more reasonable to me. The result is that the tonal range of the image is somewhat compressed and this may mean that gradations in extreme highlights or shadows will be not be discernable on the monitor. I believe it is more noticeable in the shadows where the blacks can appear a bit crushed. This is more of a problem in dark images with important detail in extreme shadow areas and with monitors which have more noise in their blacks.

Connecting the curves for the negative and the print requires that some density on the negative be pegged to some density on the print. The obvious point to connect the two is the Laboratory Aim Density. This also provides a simple connection to Cineon file values since it has already been determined that 444,444,444 will represent LAD density regardless of what the actual densities on the recorded negative will be. The normal LAD point for print stock is a Status A density of 1.09,1.06,1.03. (Status A or more precisely Status AA density is the filter specification for measuring densities of films

intended for viewing rather than printing.) The ideal film lab is set up in such a way that printing a negative with LAD density onto a print at printer lights in the middle of the scale (usually 25,25,25 on a scale of 0 to 50) will produce a print density of 1.09, 1.06, 1.03. This means that the “normal” interpretation of Cineon file values of 444, 444, 444 will be a brightness of a LAD patch projected on the ideal theater screen:

LADscreenBrightnessRed = $1 / (10^{1.09}) = 0.0813$ or 8.13% of brightness of screen with open gate in projector

LADscreenBrightnessGreen = $1 / (10^{1.06}) = 0.0871$ or 8.71% of brightness of screen with open gate in projector

LADscreenBrightnessBlue = $1 / (10^{1.03}) = 0.0933$ or 9.33% of brightness of screen with open gate in projector

The brightest possible screen corresponds to minimum density achievable in the print stock. We could use the Dmin from the characteristic curve (0.05,0.05,0.06 for 2383), but it probably make more sense to use the print density corresponding to the maximum density achievable in our negative. With negative Dmin placed at a Cineon value of 95,95,95 and LAD at 444,444,444; my calculations indicate that the maximum density possible in the hypothetical camera negative will be Status M densities of 1.737, 1.885, 1.830. Exposing the print stock normally through these densities will yield print densities of 0.056, 0.056, 0.067. These correspond to a screen brightness of 87.9%, 87.9% and 85.7% of the brightness of the screen with no film in the gate.

Similar calculations can be made with the minimum density on the negative which in our case is set to 0.15, 0.55, 0.95. The resulting maximum density for the print is 3.6602, 3.5495, 3.5843, which correspond to a minimum screen brightness of 0.022%, 0.028%, and 0.026% of the brightness of the screen with no film in the gate. This is not the maximum density achievable with the print stock, but it is the maximum density which is achievable when printing our hypothetical negative normally.

When making a monitor lookup table or an arbitrary map for previewing Cineon images, you need to factor in the gamma for the monitor. The brightness values calculated above are linear brightness levels in the strict sense of linear. (When some people distinguish between “log” and “linear” values sometimes what they are calling linear values are really gamma corrected values of the sort normally associated with video images.) At Illusion Arts our monitors are calibrated to a gamma of 2.2 and the Cineon Preview Map which should accompany this paper is designed for our monitors.

The only monitors we have that come with a utility which permits me to load an arbitrary curve into the video card are our Barco monitors. I generated a lookup table and did some limited testing on the Barco monitors to see if it was accurate; but I have not really pursued the idea of monitor lookup tables because I think the adjustment layer in After Effects is a much more effective tool for previewing Cineon images via a lookup table.

The following table is a sampling of the lookup table for previewing a Cineon image as a 16bpc gamma corrected image with a listing of most of the parameters involved in the calculations. I am hoping the full lookup table as an Excel spreadsheet will accompany this document. The best way to explain exactly how this lookup table is generated is probably with the code that did it. I shall append

the most relevant portions of the code for this at the end of this document. The functions for using the characteristic curve data to get the exposure which produces a given density or vice versa are calls to interpolation routines using spline based interpolation. I have not bothered to include this code. The most arcane part of it is the calculation of the offset which is applied to the Cineon values before they are translated. This offset results from the fact that my hypothetical digital negative differs from the one described Kennel and Snider and my conclusion that the choice of 444 as the Cineon value corresponding to LAD is a convenient, but somewhat arbitrary choice. My whole approach to this was initially based on the need to record Cineon files onto 5245 camera negative rather than 5244 intermediate stock and a desire to set up a system where my output printed at 25-25-25. I also wanted a negative which would yield something like the original Cineon values if it were scanned in the same way as the original or which would print at the same light as the original negative. (Negatives recorded at Cinesite do not print at 25-25-25. They generally print at something like 32-33-21. It is common practice in making intermediate negatives to have them print at a higher light than the original, but these printer lights imply to me that the LAD patch on a Cinesite negative does not have the densities normally associated with a LAD patch on 5244 (1.15, 1.60, 1.70). Scanning these LAD densities assuming a typical Dmin for 5244 of 0.12, 0.58, 0.68 should yield Cineon values of 554, 638, 615 if 95 still represents the value for Dmin.)

Cineon	Gamma	Gamma	Gamma				
File	Corr.	Corr.	Corr.				
Value	Red	Green	Blue		Red	Green	Blue
0	0	0	0	Cineon LAD	444	444	444
31	0	0	0	Negative Dmin	0.15	0.55	0.95
63	0	0	0	Calculated LAD	440	401	415
95	0	0	0	Cineon Dmin	95	95	95
127	460	6	171	Offset	99	138	124
159	741	507	642	Negative LAD	0.8	1.2	1.6
191	1041	910	1057	LAD Dens. Above Dmin	0.65	0.65	0.65
223	1414	1353	1597	Print LAD	1.09	1.06	1.03
255	1909	1926	2310	LAD Print Exp	-1.5020995	-1.5712544	-1.6089593
287	2575	2691	3336	Neg. Dmax (Cineon)	1.7374274	1.8847592	1.830016
319	3524	3769	4684	Print Dmin	0.05566403	0.05557045	0.06679197
351	4835	5170	6359	Print Max Trans	0.87970278	0.87989237	0.85744846
383	6525	6982	8332	Print Dmax	3.66019787	3.5495317	3.58428534
415	8745	9175	10233	Print Min Trans	0.00021868	0.00028214	0.00026044
447	11336	11673	12001	Brightness Range:	0.87948411	0.87961023	0.85718802

479	14125	14397	14325	Max Brightness Range	0.87961023
511	17000	17141	17459	Monitor Gamma	2.2
543	19667	19803	20476	InverseGamma:	0.4545
575	21882	22353	22549		
607	23863	24631	24148		
639	25555	26629	25712		
671	26940	28223	27038		
703	28187	29526	28246		
735	29200	30485	29289		
767	30065	31186	30179		
799	30780	31618	30898		
831	31347	31891	31454		
863	31808	32121	31839		
895	32141	32286	32076		
927	32396	32438	32233		
959	32574	32564	32295		
991	32687	32674	32347		
1023	32766	32768	32386		

Color Management Issues

Perhaps the biggest long term issue with Cineon is that it uses a color space that is not compatible with ColorSync and color management with ICC profiles. Once there is an agreement on the definition of a profile for a negative film stock, it will be possible to incorporate Cineon color space into an overall color management system. For now I believe the only way to use color management tools with Cineon files is to create a profile for an output device that combines conversion to Cineon and recording via a specific recorder. This would presumably require converting Cineon scans into a device independent color space for working on the images and then back into Cineon space for output. I'm not sure this is really the most efficient way to work with scanned motion picture footage. Encouraging Photoshop to expand the 16 bit per channel capabilities is more urgent than trying to incorporate Cineon conversion into a color management system in After Effects.

I am not that familiar with the inner workings of ColorSync or the specifications for a color profile. I assume a color profile can define a curve with an arbitrary number of points as part of the definition of a color space. This is the biggest problem with doing conversion to and from Cineon correctly. A single mathematical formula or algorithm does not suffice to define the characteristic curve

of a film stock. It requires sample points on a curve and a method of fitting a curve to data. While the characteristic curve for a given film type varies in manufacture from emulsion batch to emulsion batch, I believe the general shape of the curve is consistent enough to justify using the curve of a particular emulsion as the basis for a conversion procedure. The key to this is the fact that Cineon values of 444, 444, 444 are a de facto standard for LAD and the target densities for LAD on print stock are well established. This means that variations from one emulsion batch to another either in negative or print will all come out in the wash. If the film recorder is recalibrated for each negative batch the LAD density on the output negative can be consistent. Laboratory quality control procedures take care of the variations in print stock emulsions as well as is feasible in the real world.

Appendix: Source Code Extracts

```
// Generate Cineon to 16 bit Lookup Table

OSErr LutMeister::MakeCineonLUT(void)
{
    double  redLADexp, greenLADexp, blueLADexp;
    double  redMaxTrans, greenMaxTrans, blueMaxTrans;
    double  redMinTrans, greenMinTrans, blueMinTrans;
    double  redMaxDensity, greenMaxDensity, blueMaxDensity;
    double  redMinDensity, greenMinDensity, blueMinDensity;
    double  redRange, greenRange, blueRange, theRange;
    double  redPrtExp, greenPrtExp, bluePrtExp;
    double  redExposure, greenExposure, blueExposure;
    double  redNegDmax, greenNegDmax, blueNegDmax;
    double  inverseGamma;
    long    redValue, greenValue, blueValue;
    long    redOffset, greenOffset, blueOffset;
    double  redLAD, greenLAD, blueLAD;
    long    counter;
    long    tempLong;
    Density mDensity;
    Density pDensity;
    Density negLAD;
    LongTableEntry cineonLUT[1024];
    Calculations *calculations;
    OSErr   err = noErr;

    // This is all based on the assumption that
    // Status M 0.80, 1.20, 1.60 prints at 1.09, 1.06, 1.03 Status A
    // And a hypothetical camera negative Dmin of 0.15, 0.55, 0.95

    // In other words it assumes that the LAD exposure of the print
    // is 0.65 above negative Dmin (Status M) in each color

    // The Calculations structure is a hack to save a spreadsheet
    // of all the parameters rather than just the lookup table

    calculations = (Calculations *)NewPtr(sizeof(Calculations) * 1024);
    if (!calculations) return memFullErr;

    redLAD =
    greenLAD =
    blueLAD = 444.0;

    // Calculate LAD offset based on characteristic curve of negative
    // In other words how far is 444 from the value that would result from scanning
    // an actual LAD patch of 0.80, 1.20, 1.60
    mDensity.red = 0.80 - 0.15;
    mDensity.green = 1.20 - 0.55;
    mDensity.blue = 1.60 - 0.95;
    StatusMtoPrintingDensity(&mDensity, &pDensity);
}
```

```

// Convert this printing density to Cineon value and offset to put Dmin at 95;
redValue = (long)(500.0 * pDensity.red + 0.5) + 95;
greenValue = (long)(500.0 * pDensity.green + 0.5) + 95;
blueValue = (long)(500.0 * pDensity.blue + 0.5) + 95;

redOffset = redLAD - redValue;
greenOffset = greenLAD - greenValue;
blueOffset = blueLAD - blueValue;

// Incorporate Dmin adjustment in this offset
redOffset += 95;
greenOffset += 95;
blueOffset += 95;

inverseGamma = 1.0 / 2.2;

// Calculate relative log exposure of print for LAD values

redLADexp = thePrintCurve->GetExposure(1.09, 1);
greenLADexp = thePrintCurve->GetExposure(1.06, 2);
blueLADexp = thePrintCurve->GetExposure(1.03, 3);

// 2: Calculate print Tmin
// Based on range above LAD for maximum Cineon densities
// Maximum Cineon density above Dmin = (1023 - 95) * .002 = 1.856 above Dmin converted to Status
M
// Need to adjust maximum density with offsets

pDensity.red = (double)(1023 - redOffset) * 0.002;
pDensity.green = (double)(1023 - greenOffset) * 0.002;
pDensity.blue = (double)(1023 - blueOffset) * 0.002;

PrintingDensityToStatusM(&pDensity, &mDensity);

redNegDmax = mDensity.red; // status M density above Dmin for maximum possible density
greenNegDmax = mDensity.green;
blueNegDmax = mDensity.blue;

pDensity.red = (redLAD - (double)redOffset) * 0.002;
pDensity.green = (greenLAD - (double)greenOffset) * 0.002;
pDensity.blue = (blueLAD - (double)blueOffset) * 0.002;

PrintingDensityToStatusM(&pDensity, &negLAD); //negLAD is status M above Dmin

//Exposure is relative to exposure for LAD
redExposure = redNegDmax - negLAD.red;
greenExposure = greenNegDmax - negLAD.green;
blueExposure = blueNegDmax - negLAD.blue;

redPrExp = redLADexp - redExposure;
greenPrExp = greenLADexp - greenExposure;
bluePrExp = blueLADexp - blueExposure;

```

```

// Characteristic curve yields density for given exposure
redMinDensity = thePrintCurve->GetDensity(redPrtExp, 1);
greenMinDensity = thePrintCurve->GetDensity(greenPrtExp, 2);
blueMinDensity = thePrintCurve->GetDensity(bluePrtExp, 3);

// Convert Print Tmin into transmissiveness (i.e. screen brightness)

redMaxTrans = 1.0 / (pow(10, redMinDensity));
greenMaxTrans = 1.0 / (pow(10, greenMinDensity));
blueMaxTrans = 1.0 / (pow(10, blueMinDensity));

// Need range from Tmin to Tmax for calculations

// Find Print Dmax and Tmin corresponding to negative Dmin (0.15, 0.55, 0.95)
// i.e. the thinnest possible negative yields the densest possible print
// and the darkest possible screen
// Note this will not necessarily be the maximum density the print stock is capable of
// as indicated in the characteristic curve because the negative is being printed in such a way
// that its Dmin does not get positioned all the way at the top of the print curve

//Exposure is relative to exposure for LAD
redExposure = 0.0 - negLAD.red;
greenExposure = 0.0 - negLAD.green;
blueExposure = 0.0 - negLAD.blue;

redPrtExp = redLADexp - redExposure;
greenPrtExp = greenLADexp - greenExposure;
bluePrtExp = blueLADexp - blueExposure;

// Characteristic curve yields density for given exposure
redMaxDensity = thePrintCurve->GetDensity(redPrtExp, 1);
greenMaxDensity = thePrintCurve->GetDensity(greenPrtExp, 2);
blueMaxDensity = thePrintCurve->GetDensity(bluePrtExp, 3);

// Convert Print Tmin into transmissiveness (i.e. screen brightness)

redMinTrans = 1.0 / (pow(10, redMaxDensity));
greenMinTrans = 1.0 / (pow(10, greenMaxDensity));
blueMinTrans = 1.0 / (pow(10, blueMaxDensity));

redRange = redMaxTrans - redMinTrans;
greenRange = greenMaxTrans - greenMinTrans;
blueRange = blueMaxTrans - blueMinTrans;

// Use the greatest range for all three colors ?????
theRange = MAX(redRange,greenRange,blueRange);

for(counter = 0; counter < 1024; counter++)
{
    // convert file value to printing density
    // pd * 0.002 = Cineon 10 bit value

```

```

// always need to offset to put LAD at 444 and Dmin at 95

calculations[counter].redValue = counter - redOffset > 0 ? counter - redOffset : 0;
calculations[counter].greenValue = counter - greenOffset > 0 ? counter - greenOffset : 0;
calculations[counter].blueValue = counter - blueOffset > 0 ? counter - blueOffset : 0;

pDensity.red = (double)calculations[counter].redValue * 0.002;
pDensity.green = (double)calculations[counter].greenValue * 0.002;
pDensity.blue = (double)calculations[counter].blueValue * 0.002;

// convert printing density to status M density

PrintingDensityToStatusM(&pDensity, &mDensity);

// Beware of negative Status M density values
calculations[counter].redNegDensity = mDensity.red > 0.0 ? mDensity.red : 0.0;
calculations[counter].greenNegDensity = mDensity.green > 0.0 ? mDensity.green : 0.0;
calculations[counter].blueNegDensity = mDensity.blue > 0.0 ? mDensity.blue : 0.0;

// convert status M density to print exposure via print LAD exposure

calculations[counter].redExposure = calculations[counter].redNegDensity - negLAD.red;
calculations[counter].greenExposure = calculations[counter].greenNegDensity -
negLAD.green;
calculations[counter].blueExposure = calculations[counter].blueNegDensity -
negLAD.blue;

calculations[counter].redPrtExp = redLADexp - calculations[counter].redExposure;
calculations[counter].greenPrtExp = greenLADexp - calculations[counter].greenExposure;
calculations[counter].bluePrtExp = blueLADexp - calculations[counter].blueExposure;

// convert print exposure to print density to print transmission

calculations[counter].redPrintDensity = thePrintCurve-
>GetDensity(calculations[counter].redPrtExp, 1);
calculations[counter].greenPrintDensity = thePrintCurve-
>GetDensity(calculations[counter].greenPrtExp, 2);
calculations[counter].bluePrintDensity = thePrintCurve-
>GetDensity(calculations[counter].bluePrtExp, 3);

calculations[counter].redPrtTrans = 1.0 / (pow(10, calculations[counter].redPrintDensity));
calculations[counter].greenPrtTrans = 1.0 / (pow(10,
calculations[counter].greenPrintDensity));
calculations[counter].bluePrtTrans = 1.0 / (pow(10,
calculations[counter].bluePrintDensity));

// convert print transmission to monitor value

calculations[counter].gammaCorRed = pow((((calculations[counter].redPrtTrans -
redMinTrans) / theRange),inverseGamma);
tempLong = (long)((32768.0 * calculations[counter].gammaCorRed) + 0.5);

cineonLUT[counter].red = tempLong;

```



```

        calculations[counter].gammaCorGreen = pow(((calculations[counter].greenPrtTrans -
greenMinTrans) / theRange),inverseGamma);
        tempLong = (long)((32768.0 * calculations[counter].gammaCorGreen) + 0.5);

        cineonLUT[counter].green = tempLong;

        calculations[counter].gammaCorBlue = pow(((calculations[counter].bluePrtTrans -
blueMinTrans) / theRange),inverseGamma);
        tempLong = (long)((32768.0 * calculations[counter].gammaCorBlue) + 0.5);

        cineonLUT[counter].blue = tempLong;
    }

// WriteTextLUT(cineonLUT, 1024L, theCineonLUT);
err = WriteCalculations(calculations, cineonLUT, 1024L, theCineonLUT);
WriteArbitraryMap(cineonLUT);

return err;
}

void LutMeister::PrintingDensityToStatusM(Density *pDensity, Density *mDensity)
{
    mDensity->red = pDensity->red * 0.9806 -
                    pDensity->green * 0.0348 -
                    pDensity->blue * 0.0073 ;

    mDensity->green = pDensity->red * 0.0065 +
                    pDensity->green * 1.1191 -
                    pDensity->blue * 0.0601 ;

    mDensity->blue = pDensity->red * -0.0132 +
                    pDensity->green * 0.0017 +
                    pDensity->blue * 1.0297 ;

}

void LutMeister::StatusMtoPrintingDensity(Density *mDensity, Density *pDensity)
{
    pDensity->red = mDensity->red * 1.0197 +
                    mDensity->green * 0.0317 +
                    mDensity->blue * 0.0091 ;
    pDensity->green = mDensity->red * -0.0052 +
                    mDensity->green * 0.8933 +
                    mDensity->blue * 0.0521 ;
    pDensity->blue = mDensity->red * 0.0131 -
                    mDensity->green * 0.0011 +
                    mDensity->blue * 0.9712 ;

}

```