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

Motion Picture & Television Imaging

Conversion of 10-bit Log Film Data

to 8-bit Linear or Video Data

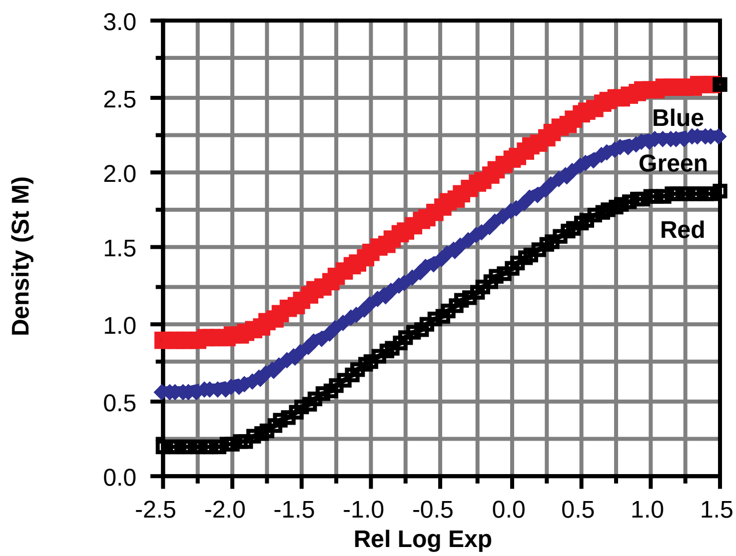
1.0 Film, Computer, and Video Images

1.1 Film Images

Film has traditionally been represented by a characteristic curve which plots density vs log exposure. This is a log/log representation. In defining the calibration for the Cineon digital film system, Eastman Kodak Co. talked to many experts in the film industry to determine the best data metric to use for digitizing film. The consensus was to use the familier density metric and to store the film as logarithmic data.

The characteristic curves for a typical motion picture color negative film are shown if Figure 1. The three curves represent the red, green, and blue color records, which are reproduced by cyan, magenta, and yellow dyes, respectively. The three curves are offset vertically because the base density of the negative film is orange in color (it contains more yellow and magenta dye than cyan dye).

Figure 1. Characteristic Curves for Color Negative Film



The next issue was calibration range. In order to provide as much creative freedom in the digital world as is possible in optical printing, it is necessary to digitize the full range of the original negative film. This allows the digital data to be "printed" up or down without compromise in post production. It also allows color grading decisions to be made in context with the elements of the final composite. The full dynamic range of a motion picture negative film can be captured in a 2.0 density range.

It is important to note that the original film captures more than what is displayed when it is printed and projected. This extra range or extended headroom can be used to capture specular highlights. Overexposure can also be used creatively by a cinematographer to alter the look of the image, increasing the contrast, cleaning out the shadows, and boosting the color saturation.

1.2 Computer Generated Images

Computer generated images (CGI) are traditionally created and stored as linear data. This means that the digital model is proportional to illumination levels in the physical world. The most common data storage format is 8 bits, although 16 bits is gaining more use as computational power increases. CGI images typically span the range from a nominal black at 0 code value to a nominal white at 255 code values. In general, there is no corellary to the extended range of film.

CGI images are typically displayed on CRT graphics display monitors with the gamma set to 1.7 (default). This compensates for the native gamma of the monitor (2.5), producing a displayed image with a gamma of 1.5. For comparison, note that the midscale gamma of a projected film print is also about 1.5.

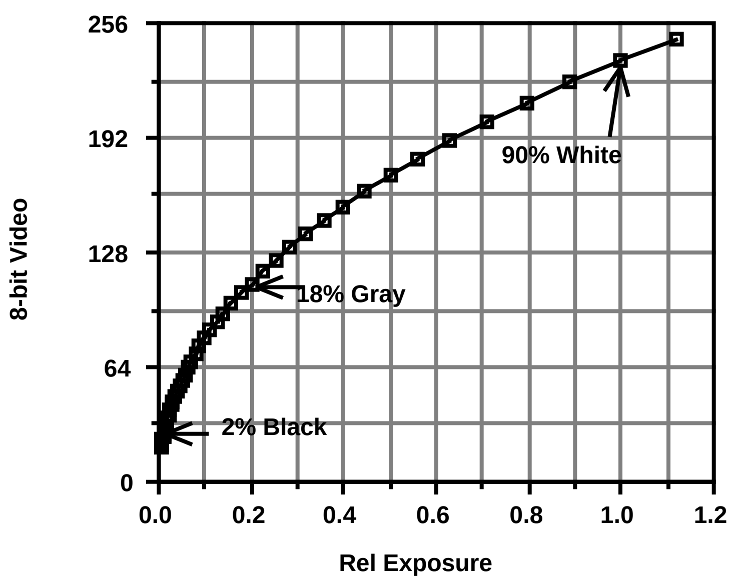
1.3 Video images

Digital video images are defined by CCIR 709. Video images are gamma corrected for display on a CRT monitor with this conversion specified by the following transformation. The video level (V') is scaled to put reference white at 235 and reference black at 16 code values, per CCIR 601.

$$V' = 1.099 * V^{0.45} - 0.099 \quad \text{for } 1 \geq V \geq 0.018$$

$$V' = 4.50 * V \quad \text{for } 0.018 \geq V \geq 0$$

Figure 16. Video Transfer Function



2.0 The 10-bit Digital Negative

The Digital Negative produced by the Cineon digital film scanner is a digital representation of a typical motion picture negative film. Since its introduction in 1992, the Cineon Lightning digital film scanner has set the standard for digital film conversion, with digital film scanning services provided by Cinesite in Los Angeles and London.

1.1 Full Latitude

The Cineon scanner is calibrated for a 2.048 density range: this allows it to capture the full latitude (density range) of the negative film with some margin at top and bottom. The scanner light source is balanced on film dmin, so that the resulting digital image will have a neutral color balance if the film was exposed at the correct color temperature. The Digital Negative includes significant headroom above the nominal white point to handle over-exposed negative films and scenes with wide contrast range.

1.2 10 bits

With 10 bits per color over a 2.048 density range, the resulting quantization step size is 0.002 D per code value. This is below the threshold for contour visibility, which insures that no contour artifacts (also known as mach banding) will be visible in images. Furthermore, having 10 bits rather than 8 bits allows the Cineon scanner to capture the extended headroom of the negative film.

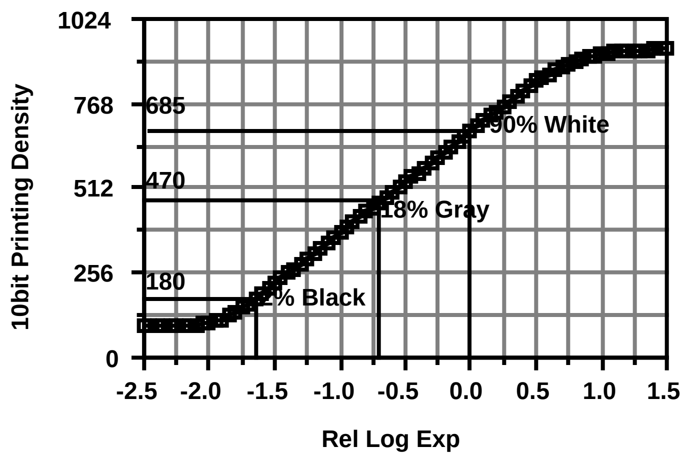
1.3 Printing Density

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.

1.4 Normal Digital Negative

The characteristic curve for the Cineon Digital Negative is shown in the following figure. For a normally exposed negative film, the 90% white card has a code value of 685, the 18% gray card has a code value of 470, and the 2% black card has a code value of 180. Dmin (~1% black) has a code value of 95. With the scanner balanced on film dmin, the three color records of the film can be represented by a single printing density curve.

Figure 9. Cineon Digital Negative (Normal Exposure)



3.0 8-bit Linear Representations

Many software packages store images in an 8-bit linear representation. When importing Cineon 10-bit images it is necessary to convert the images to the appropriate 8-bit data representation.

3.1 8-bit Linear

If the software application is used with the display gamma of the graphics display monitor set to the default value of **1.7**, then the data representation is 8-bit linear. The graphics display monitor corrects for the gamma of the CRT display with a hardware look-up table (LUT) set to gamma 1.7.

3.2 8-bit Video

If the software application uses a display gamma of **1.0,** than the data representation is 8-bit video. In other words, the data has already been gamma-corrected for display on a video (CRT) monitor.

3.3 Keeping the most important 8 bits

In converting from the full-range 10-bit digital negative to a 8-bit linear or 8-bit video representation, the prefered method is to limit the density range that is translated to that of a normal exposure with scene contrast range of 100:1, or 6 2/3 stops. The resulting scene will have reasonable contrast when displayed on a standard graphics display monitor.

For a normally-exposed Cineon Digital Negative, a 90% white card will be recorded at a code value of 685. The Dmin of the film is set to 95, representing the blackest black that can be recorded (approx. a 1% black card). In converting from 10-bits to 8-bits, the range of code values from 95 to 685 are mapped to an output range of 0 to 255. In between these end points, it is necessary to implement the gamma correction that is described herein.

3.4 Densities above reference white

The densities above reference white (nominally a code value of 685) will be clipped in this process. Specular reflections in the scene that would be recorded above this point will be clipped. In addition, if the negative was overexposed, the reference white card itself could be recorded at a higher code value than 685. It is therefore necessary to specify the reference white code value in the scene before computing the conversion table.

3.5 Implementation of a soft-clip

Instead of a hard-clip above reference white, it is possible to implement a soft-clip that will compress highlight information and record it within the 8-bit range. This will be described herein.

4.0 User-specified Variables

4.1 Reference white

In order to compensate for overall negative exposure, the user must specify the code value of the reference white in the scene. The default value for a normal exposure is 685. If the negative is over-exposed, the true reference white in the scene may fall at a code value higher than 685. If so, this higher code value should be used.

4.2 Reference black

The default value for reference black is 95, which is the code value for Dmin in the calibration of the Cineon scanner. If the negative is over-exposed, the true reference black in the scene may fall at a code value higher than 95. If so, this higher code value should be used.

4.3 Display gamma

The gamma of the graphics display monitor must be specified in order to define the gamma correction applied to the data between reference white and black. The default value is 1.7, assuming 8-bit linear data. If the data is to be converted to video space, then the display gamma should be set to 1.0 because the video space representation assumes that the gamma correction has already been applied to the data.

4.4 Softclip

The softclip defines a compression (knee) function that covers a range from (n) code values below reference white to (4n) code values above reference white. The default value is 0, which corresponds to a hard clip at reference white. The maximum value is a softclip of 50 code values. The softclip should be used carefully, and only if you believe that there is important highlight information above reference white, as it non-linearly compresses highlight information.

5.0 Computing a Look-up Table for conversion to 8 bit Linear data

The following rules define the steps to compute the look-up table to convert 10-bit density data to 8-bit linear data. This look-up table is used for all three records. Color balance is achieved by subtracting an offset in density space before feeding the data into the look-up table. This look-up table is illustrated in Appendix A.

5.1 Determine the breakpoint for softclip

The breakpoint for the softclip function is determined by subtracting the softclip value from the reference white value:

Breakpoint = Refwhite - Softclip

The default value for Refwhite is 685, and the default value for softclip is 0 (softclip turned off).

5.2 Clamp black to 0

Output code values below RefBlack are clamped to a code value of 0 (no negative code values are permitted).

The default value for RefBlack is 95.

5.3 Compute a LUT between Refblack and Breakpoint

OUT = 10 ^ ((IN-Refwhite) * 0.002/0.6) ^ (Dispgamma/1.7) * Gain - Offset

where,

Dispgamma = 1.7 for linear data, and

Gain = 255 / (1 - 10 ^ ((Refblack-Refwhite) * 0.002/0.6) ^ (Dispgamma/1.7))

Offset = Gain - 255

5.4 Compute a Softclip above Breakpoint:

OUT = (IN - Breakpoint) ^ (Softclip/100) * Kneegain + Kneeoffset

where,

Kneeoffset = 10^((Breakpoint-Refwhite) *0.002/0.6)^(Dispgam/1.7)*Gain-offset

Kneegain = (255 - kneeoffset)/((5*Softclip)^(Softclip/100))

5.5 Clip white to 255

Output code values above 255 are clipped to 255.

6.0 Computing a Look-up Table for conversion to 8 bit video data

The following rules define the steps to compute the LUT to convert 10-bit density data to 8-bit video data. The approach is the same as the conversion to 8-bit linear data that is described in the previous section. The only difference is that the video data includes a gamma correction for display. This look-up table is used for all three records. Color balance is achieved by subtracting an offset in density space before feeding the data into the look-up table. This look-up table is illustrated in Appendix B.

6.1 Determine the breakpoint for softclip

The breakpoint for the softclip function is determined by subtracting the softclip value from the reference white value:

Breakpoint = Refwhite - Softclip

The default value for Refwhite is 685, and the default value for softclip is 0 (softclip turned off).

6.2 Clamp black to 0

Output code values below RefBlack are clamped to a code value of 0 (no negative code values are permitted).

The default value for RefBlack is 95.

6.3 Compute a LUT between Refblack and Breakpoint

OUT = 10 ^ ((IN-Refwhite) * 0.002/0.6) ^ (Dispgamma/1.7) * Gain - Offset

where,

Dispgamma = 1.0 for video data, and

Gain = 255 / (1 - 10 ^ ((Refblack-Refwhite) * 0.002/0.6) ^ (Dispgamma/1.7))

Offset = Gain - 255

6.4 Compute softclip above Breakpoint:

OUT = (IN - Breakpoint) ^ (Softclip/100) * Kneegain + Kneeoffset

where,

Kneeoffset = 10^((Breakpoint-Refwhite) *0.002/0.6)^(Dispgam/1.7)*Gain-offset

Kneegain = (255 - kneeoffset)/((5*Softclip)^(Softclip/100))

6.5 Clip to 255

Output code values above 255 are clipped to 255.

7.0 Computing a look-up table for converting 8-bit data to 10-bit film data

In order to import 8-bit data into the Cineon 10-bit database for manipulation or film recording, it is necessary to create a "normal" digital negative. In this case the only user-defined variable is the display gamma. The lookup table is illustrated in Appendix C.

OUT = 685 + log10 {((IN + Offset)/Gain) ^ (1.7/Dispgamma)} / (0.002/0.6)

where Offset and Gain are calculated as in section 5.3, using a
Refwhite = 685 and Refblack = 95.

This look-up table will create a normal negative density range that is a reasonable match for the displayed image when printed at standard printer lights.

It is not necessary to use the inverse LUT that was used to convert from 10 bits to 8 bits. Rather, it is better to use a standard LUT that reproduces the displayed contrast range and highlight compression. In other words, "what you see on the monitor is what you get on film", within the limits of an uncalibrated display.

8.0 Limitations of working with 8 bit data

In converting from 10-bit film data to 8-bit linear or video data, the extended range information above reference white is lost.

8.1 Limiting the Dynamic Range

In order to work within 8-bits it is necessary to limit the dynamic range of the scene, clipping (or rolling off) information above the nominal white point. This is not usually a problem in scenes with a contrast ratio of 100:1 or less, but it can be a problem with a high-contrast daylight exterior. It can also be a problem if the scene contains specular highlights, like reflections off water, glass, or chrome. These highlights will be clipped and may appear artificial.

8.2 Limiting the Artistic Flexibility

With the Cineon 10-bit density representation, the full density range of the film is digitized by the Cineon scanner. The Cineon workstation carries and processes the full 10-bits so the artist has as much freedom to "print up" or print down" the negative as he would in the traditional film printing world. No compromises or creative judgements need to be made at the time of scanning.

With an 8-bit representation, it is necessary to make some color correction decisions at the time of scanning. The scanner operator will decide which part of the scene to translate to 8-bits, cutting off the extended highlights or shadows which he decides are unimportant.

8.3 Introducing Contouring Artifacts

Reducing the density range when going from 10 bits to 8 bits is not enough to eliminate contouring artifacts. Even with scaling back the density range, the loss of two bits translates into approximately two times less precision. Fortunately, the natural film grain helps to conceal contouring.

For 8-bit video images (that have already had a 1.7 gamma correction applied), contouring is unlikely. However, for 8-bit linear images, contouring may be visible in the blacks when displayed through the gamma 1.7 look-up table.

Contouring is most visible in gradually shaded uniform areas, like the natural darkening of the sky on the horizon.

Appendix A. Lookup Table for Converting 10 bit Density to 8 bit Linear

(for display on a Graphics Display Monitor with Gamma = 1.7)

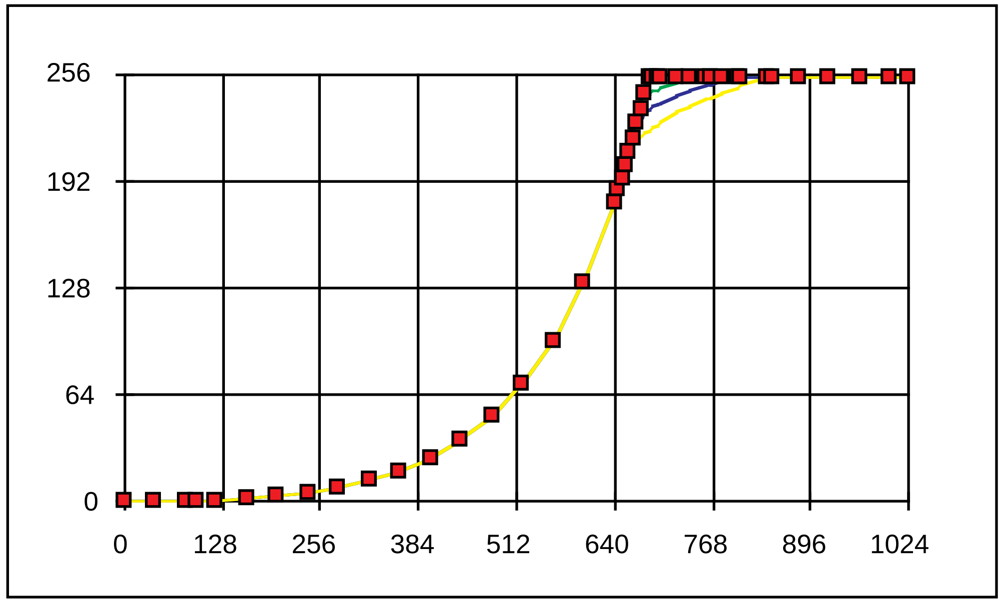
User Specified Variables:

RefWhite	685	685	685	685
RefBlack	95	95	95	95
DispGamma	1.70	1.70	1.70	1.70
SoftClip	0	20	30	40

Computed Scaling factors:

Gain	257.78	257.78	257.78	257.78
Offset	2.78	2.78	2.78	2.78
Breakpoint	685	665	655	645
Kneeoffset	255	218	202	187
Kneegain	0.00	14.60	11.79	8.19

10bDensity	8bLinear			
0	0	0	0	0
40	0	0	0	0
80	0	0	0	0
95	0	0	0	0
120	1	1	1	1
160	2	2	2	2
200	3	3	3	3
240	6	6	6	6
280	9	9	9	9
320	13	13	13	13
360	18	18	18	18



10bDensity	8bLinear			
400	26	26	26	26
440	37	37	37	37
480	51	51	51	51
520	70	70	70	70
560	96	96	96	96
600	131	131	131	131
640	180	180	180	180
645	187	187	187	187
650	194	194	194	202
655	202	202	202	207
660	210	210	221	211
665	218	218	226	214
670	227	238	229	217
675	236	241	231	219
680	245	243	233	221
685	255	245	235	223
690	255	246	236	224
695	255	247	238	226
700	255	248	239	228
720	255	251	243	233
740	255	253	247	237
760	255	255	250	241
765	255	255	250	242
780	255	255	252	245
800	255	255	254	248
805	255	255	255	249
840	255	255	255	254
845	255	255	255	255

10bDensity	8bLinear			
880	255	255	255	255
920	255	255	255	255
960	255	255	255	255
1000	255	255	255	255
1023	255	255	255	255

Appendix B. Lookup Table for Converting 10 bit Density to 8 bit Video

(for display on a Graphics Display Monitor with Gamma = 1.0)

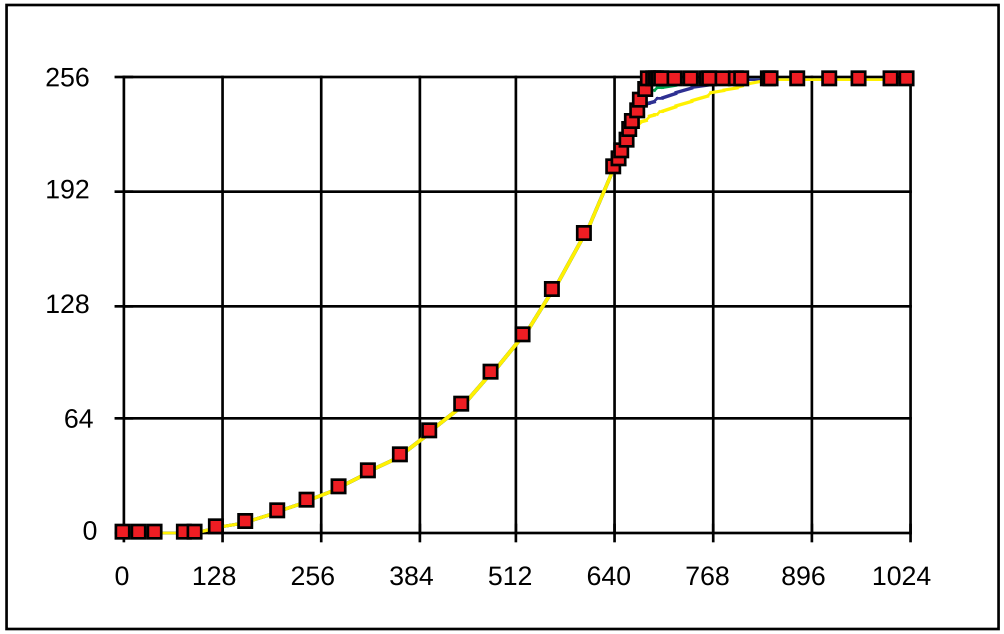
User Specified Variables:

RefWhite	685	685	685	685
RefBlack	95	95	95	95
DispGamma	1.00	1.00	1.00	1.00
SoftClip	0	20	30	40

Computed Scaling Factors:

Gain	274.10	274.10	274.10	274.10
Offset	19.10	19.10	19.10	19.10
Breakpoint	685	665	655	645
Kneeoffset	255	231	220	210
Kneegain	0.00	9.42	7.72	5.44

10b Density	8b Video			
0	0	0	0	0
20	0	0	0	0
40	0	0	0	0
80	0	0	0	0
95	0	0	0	0
120	2	2	2	2
160	7	7	7	7
200	12	12	12	12
240	18	18	18	18
280	25	25	25	25
320	34	34	34	34



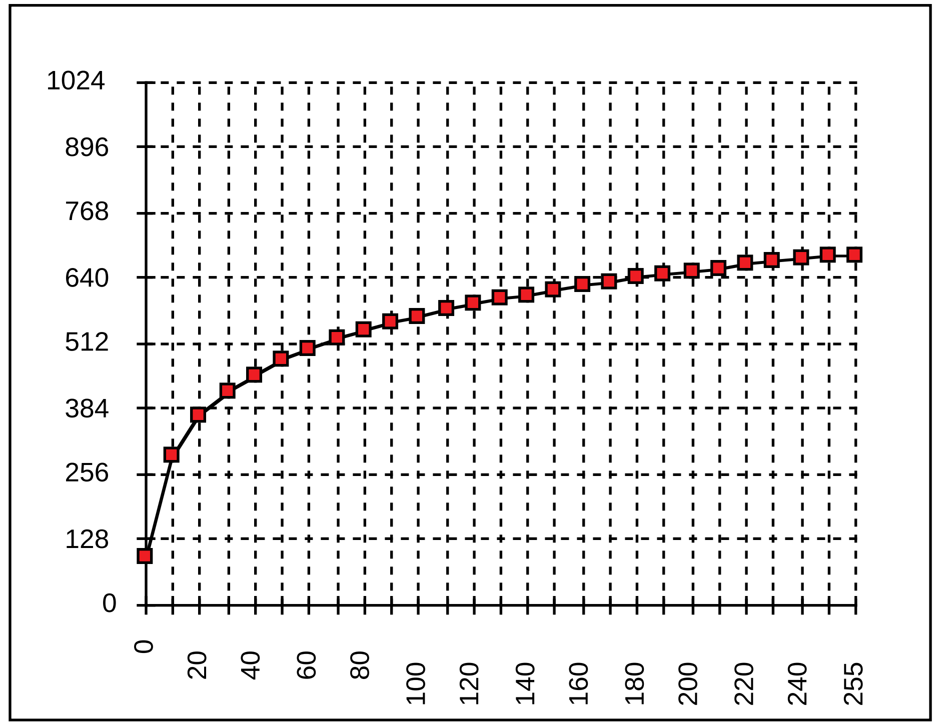
10b Density	8b Video			
360	44	44	44	44
400	57	57	57	57
440	72	72	72	72
480	90	90	90	90
520	111	111	111	111
560	137	137	137	137
600	168	168	168	168
640	205	205	205	205
645	210	210	210	210
650	215	215	215	220
655	220	220	220	223
660	226	226	233	226
665	231	231	236	228
670	237	244	238	229
675	243	246	239	231
680	249	248	241	232
685	255	248	242	234
690	255	249	243	235
695	255	250	244	236
700	255	251	244	237
703	255	251	245	237
720	255	252	247	240
740	255	254	250	243
760	255	255	251	246
765	255	255	252	247
780	255	255	253	248
800	255	255	255	251
805	255	255	255	251

10b Density	8b Video			
840	255	255	255	255
845	255	255	255	255
880	255	255	255	255
920	255	255	255	255
960	255	255	255	255
1000	255	255	255	255
1023	255	255	255	255

Appendix C: Lookup Table for Converting from 8 bit Linear Data
to 10 bit Film Density Data

User Specified Variables:	
RefWhite	685
RefBlack	95
DispGamma	1.70
SoftClip	0
Computed Scaling factors:	
Gain	257.78
Offset	2.78
Breakpoint	685
Kneeoffset	255
Kneegain	0.00

8bLinear	10bDensity
0	95
10	294
20	369
30	416
40	451
50	478
60	501
70	520
80	537
90	552
100	565
110	577
120	588



130	599
140	608
150	617
160	625
170	633
180	640
190	647
200	654
210	660
220	666
230	672
240	677
250	682
255	685