

ALEXA Log C Curve

Usage in VFX

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Version	Author	Change Note
14-Jun-11	Harald Brendel	Initial Draft
14-Jun-11	Harald Brendel	Added Wide Gamut Primaries
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24-Feb-17	Harald Brendel	Remove LogCv2, clarify history
09-Mar-17	Joseph Goldstone	Make terminology consistent; modernize

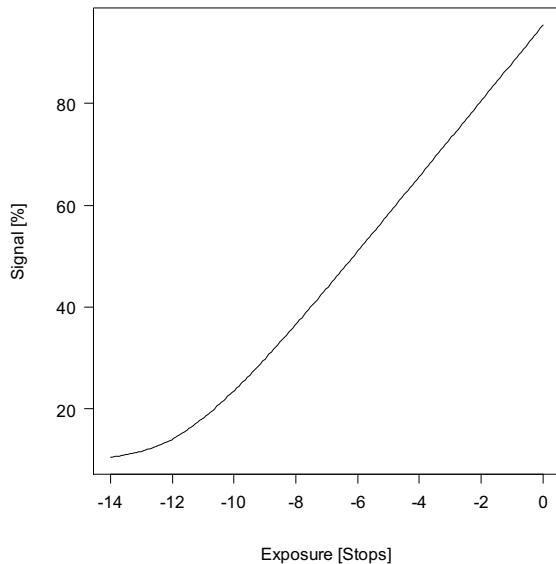
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Introduction

The Log C curve is a logarithmic encoding for images that is used in the ARRI ALEXA. The encoding has a grayscale characteristic similar to a scan from negative film. Because of the fundamental differences between digital cameras and negatives, the color characteristics remain different, though.

Logarithmic encoding means that the relation between exposure measured in stops and the encoded signal is linear (straight) over a wide range. Each stop of exposure increases the signal by the same amount. The slope of this part of the curve is called gamma. You see also the toe at the bottom of the curve. The toe occurs because the sensor cannot see low light levels with the same quantization as higher levels. The overall shape of the curve is similar to the exposure curves of film negatives.



This document describes how to handle Log C encoded images in a VFX workflow. In particular, it describes how to convert between Log C and a linear domain.

History

There are three versions of the Log C curve. It was first introduced with the ARRIFLEX D-20 and D-21. Version 3 [V3], the current version, has been used since 2011, when it was introduced in the SUP 3.0 release of the ALEXA camera's firmware. Log C V3 is also used in all AMIRA, ALEXA Mini, and ALEXA 65 cameras. Earlier versions, such as Log C V2, are only useful for vaulted captures from 2011 and earlier; please contact ARRI if you need information on dealing with Log C versions prior to V3.

Terminology

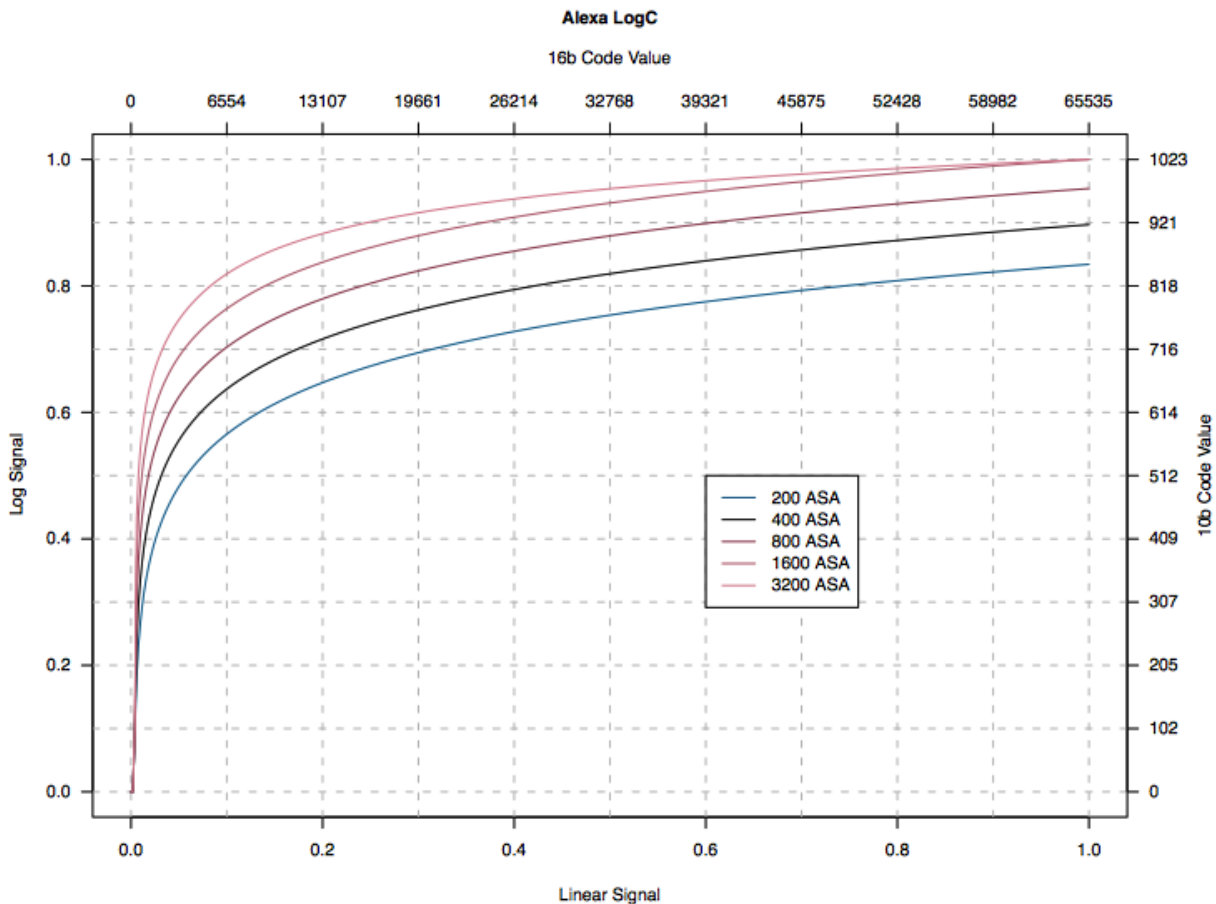
For brevity, this document uses four terms as shorthand for more comprehensive ones.

- It uses "Log C value" to mean a value between 0.0 and 1.0 representing a linearly normalized code value, thus avoiding distinction between 10-bit and 12-bit Log C encodings, both of which can be produced by ARRI cameras. (When an actual 10- or 12-bit code value is described, it uses "Log C code value".)
- It uses "sensor signal" to mean a value between 0.0 and 1.0 representing a linear normalization of the 16-bit code value (i.e. 0 to 65535) from the ARRI camera sensor. (When an actual 16-bit code value is described, it uses "sensor code value".)
- It uses "exposure value" to mean a relative scene exposure value. Relative scene exposure values are linear, and are "relative" to a theoretical perfectly exposed white card having a value of 1.0. Note that many objects, including specular highlights, pyrotechnics, etc. will have exposure values above 1.0.
- It uses "linear domain" to describe either sensor signals or exposure values, both of which are linear encodings of the captured scene.

Curve Characteristics

The Log C curve actually is a set of curves for different exposure indices. Each curve maps the sensor signal corresponding to 18% gray to the Log C value of 0.391, which is 400/1023.

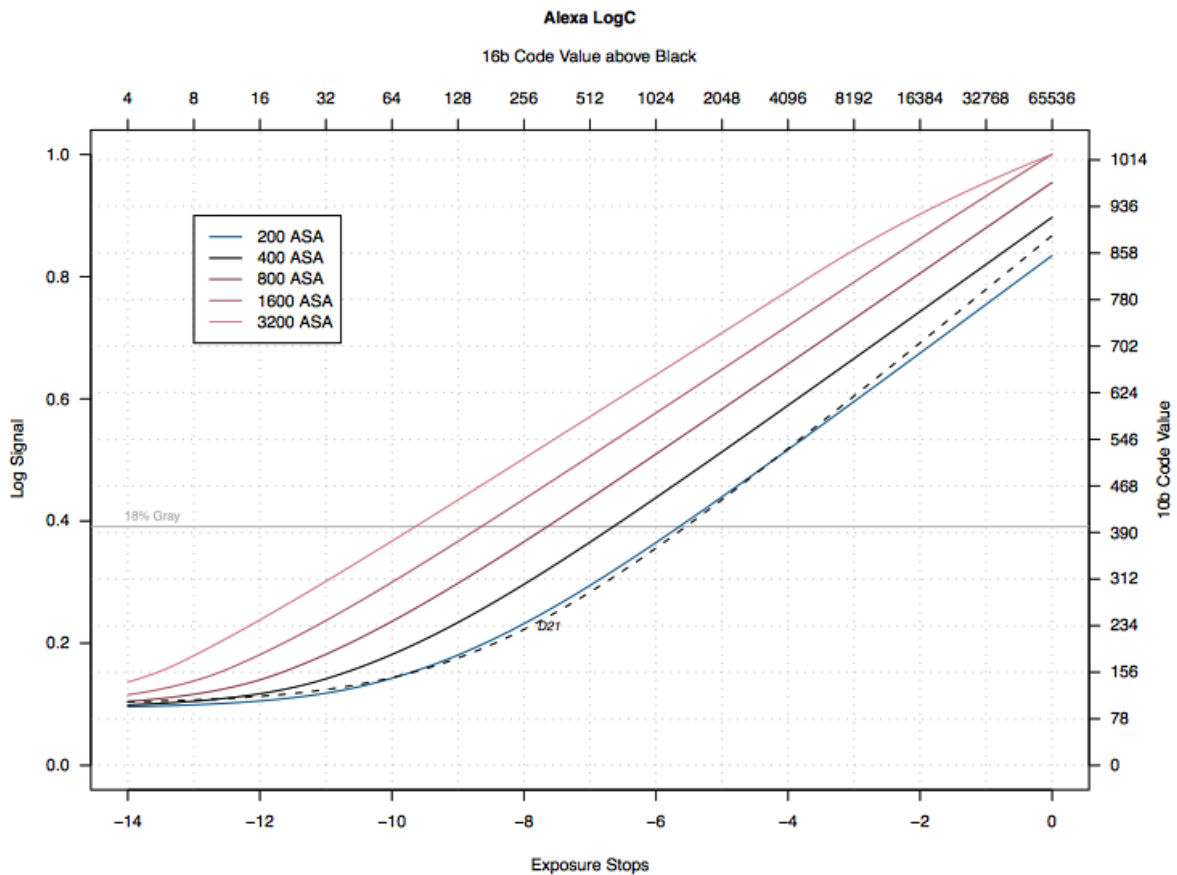
The following figure shows the Log C curves in a lin-lin plot. The x-axis represents the sensor signal.



The maximum value of the Log C curve depends on the EI value. The reason is easy to understand. When one steps down the exposure, by one stop for example, the sensor will capture one stop more highlight information. Since Log C values represents scene exposure values, the maximum value needs to be higher.

The curves for EI values above 1600 (including the shown curve for EI 3200) have an additional shoulder or roll-off built in to keep the maximum Log C code values within the available output range.

The following figure shows the curves in a log-lin plot. The x-axis represents the exposure measured in stops, relative to maximum exposure at the right end of the axis. In the linear part, the Log C curve has 73-78 code values per stop in a 10-bit encoding.



Conversions

ARRI provides lookup tables in different formats for the conversion between Log C value and sensor signal. Please go to http://www.arri.de/camera/digital_cameras/tools/lut_generator/lut_generator.html.

Alternatively, the formula described in the next section can be used for the conversion.

Formula

The encoding of linear data using the ALEXA Log C curves can be expressed by the following formula:

$$(x > \text{cut}) ? c * \log_{10}(a * x + b) + d : e * x + f$$

in which x denotes the linear-domain data, cut and a through f denote parameters and \log_{10} denotes the common logarithm. For a particular image being encoded, the values of cut and a through f will depend on two factors: which linear-domain quantity is being represented (sensor signal vs. exposure value), and exposure index (between 160 and 1600).

The appendix contains values of cut and a through f for all possible combinations of the above factors.

The decoding of ALEXA Log C values into linear-domain data can be expressed by the following formula:

$$(t > e * \text{cut} + f) ? (\text{pow}(10, (t - d) / c) - b) / a : (t - f) / e$$

The above formulas can be easily implemented in programming languages like C or as expressions in software systems like *Nuke*.

Application in VFX

In VFX, the image data is usually round-trip converted. Log C images are converted to exposure values for use in 3D or compositing and converted back to Log C.

Apply the transform described by the second formula to Log C-encoded images from ARRI cameras. In most cases you will want to use the parameters for conversion into exposure values.

The composited image may be converted back to Log C by using the first formula. Use the parameters based on the same EI value in both directions.

While the exact values of the parameters depend on the exposure index, this level of precision may not be needed for many applications. We suggest to use the parameters for EI 800; this is what pre-OpenColorIO [OCIO] versions of Nuke do, for example.

For images actually encoded with EI values from 200 to 1600, the maximum deviation in exposure value between the formula's results for EI 800 and the formula's results for the actual EI will be less than 10% for tonal values up to scene white.

When higher precision is needed, and the EI is less than or equal to 1600, use the parameters for the actual exposure index; this will return a result that is extremely accurate for all EIs below 1600, and for EI 1600 up to a Log C value of about 0.8 (corresponding to an exposure value of about 10.0). At EI 1600, above Log C values of about 0.8, the error in calculated exposure value increases somewhat, eventually producing about a 3% difference from its true exposure value.

The EI value is included as metadata in QuickTime™ and MXF. ARRI distributes a small app that can extract the metadata. The EI is also included in the header of ARRIRAW files and will be displayed by the ARRIRAW converter (ARC) and other applications that support the ARRIRAW format.

Handling of Black

When Log C values are converted to sensor signals, black (corresponding to zero exposure) will be represented by the value 256/65535. This sensor signal black level is the mean of all pixels. Because of read-out noise, single pixels may be above or below this value. The standard deviation of the read-out noise is approximately 2.5 sensor code values meaning that the offset of 256 is more than high enough to encode the full noise amplitude (usually one assumes a range of three times the standard deviation or ± 8 code values).

Using the parameters for exposure value will map the black value, as expected, to 0.0. With the noise, however, some pixels will come out as negative exposure values. When those values cannot be preserved and one does not want to clip them, a small offset of 8/65535 should be added to the sensor signal. This is equivalent of adding flare to the image data. The amount of flare expressed relative to the scene white will vary with the exposure index. It ranges from 0.1% (for EI 200) to 0.8% (for EI 3200).

The flare should be subtracted before the images are converted back to Log C.

Colorimetric Information

ALEXA (SUP 3.x) Log C encodes image data in a wide gamut RGB color space that is detailed at the end of the Appendix. There are two ways to display Log C encoded images. The first approach is based on tone-mapping and is what the camera does internally to generate a video image. The full dynamic range of the camera is non-linearly compressed into a display signal. This approach attempts to create a preferred reproduction of the scene.

The second approach is to invert the Log C curve obtaining scene linear data. This data is then scaled such that the exposure value of a white diffusing reflector is 1.0. ALEXA wide gamut RGB values are converted into the display's RGB values and corrected for the non-linearity of the display ("gamma correction"). This approach attempts to create a colorimetric reproduction of the scene, but exposure values above 1.0 may be clipped in display.

Conversion in Combination with Tone-Mapping

Lookup tables for the tone-mapping can be downloaded from the ALEXA LUT generator (see below). After tone-mapping the RGB values may be converted into color spaces commonly used in digital post production.

The matrix for conversion from tone-mapped ALEXA wide gamut RGB to the RGB color space defined by ITU Rec. 709 is given below.

1.485007	-0.401216	-0.083791
-0.033732	1.282887	-0.249155
0.010776	-0.122018	1.111242

For conversion into the P3-DCI color space¹ the following matrix is used.

1.296541	-0.194182	-0.102359
0.019844	1.224098	-0.243942
0.031999	-0.036114	1.004115

The matrix above includes a chromatic adaptation transform to the DCI white point. If the projector is set up for a D65 white point or if no chromatic adaptation transform is desired, the following matrix can be used.

1.213079	-0.098707	-0.114372
0.014386	1.230503	-0.244889
0.030442	-0.021558	0.991116

After converting to the display's RGB space the data needs to be gamma corrected. The presumed nonlinearity of the displays associated with the color space defined by ITU Rec. 709 is given by ITU Rec. 1886. The presumed nonlinearity of the displays with P3 primaries (no matter which white point is chosen) is a pure gamma function with a gamma of 2.6.

Note that the 3D lookup tables offered at

http://www.arri.de/camera/digital_cameras/tools/lut_generator/lut_generator.html combine all of those steps (tone-mapping, color conversion, gamma correction) in one LUT.

Linear Conversion

For display of linear data without tone-mapping it's recommended to calculate conversion matrices from ALEXA wide gamut RGB to the target color space based on the information given in the appendix.

For example, the matrix for conversion from linear ALEXA wide gamut RGB into ITU Rec. 709 RGB is

1.617523	-0.537287	-0.080237
-0.070573	1.334613	-0.26404
-0.021102	-0.226954	1.248056

Comparing this matrix with the one given above, you may recognize that the latter generates less saturated RGB values (smaller values along the main diagonal). That deviation from the correct conversion is done to compensate for the increase of saturation produced by the tone-map curve.

¹ This refers to the minimum gamut of the reference projector as specified in SMPTE RP 431-2.

Appendix

ALEXA (SUP 3.x) Log C Curve

The parameters in this section apply to all images recorded with ARRI digital cameras released after 2011, and to pre-2011 “Classic” ALEXA cameras using SUP 3.0 or more recent firmware. Thus beyond the Classic ALEXA, this includes the AMIRA, ALEXA XT, ALEXA SXT, ALEXA MINI and ALEXA 65, no matter what their firmware version was when the images were created.

The following table lists the Log C values corresponding to sensor signals representing no exposure (black) and sensor saturation (a sensor signal of 1.0) depending on the selected EI. Note that the Log C values for black level are constant in Log C V3.

ASA	Black	Clipping Level
160	0.0928	0.8128
200	0.0928	0.8341
250	0.0928	0.8549
320	0.0928	0.8773
400	0.0928	0.8968
500	0.0928	0.9158
640	0.0928	0.9362
800	0.0928	0.9539
1000	0.0928	0.9711
1280	0.0928	0.9895
1600	0.0928	1.0000
2000	0.0928	1.0000
2560	0.0928	1.0000
3200	0.0928	1.0000

Use the parameters in the following table for conversion between Log C values and sensor signal.

EI	cut	a	b	c	d	e	f	e*cut+f
160	0.004680	40.0	-0.076072	0.269036	0.381991	42.062665	-0.071569	0.125266
200	0.004597	50.0	-0.118740	0.266007	0.382478	51.986387	-0.110339	0.128643
250	0.004518	62.5	-0.171260	0.262978	0.382966	64.243053	-0.158224	0.132021
320	0.004436	80.0	-0.243808	0.259627	0.383508	81.183335	-0.224409	0.135761
400	0.004369	100.0	-0.325820	0.256598	0.383999	100.295280	-0.299079	0.139142
500	0.004309	125.0	-0.427461	0.253569	0.384493	123.889239	-0.391261	0.142526
640	0.004249	160.0	-0.568709	0.250219	0.385040	156.482680	-0.518605	0.146271
800	0.004201	200.0	-0.729169	0.247190	0.385537	193.235573	-0.662201	0.149658
1000	0.004160	250.0	-0.928805	0.244161	0.386036	238.584745	-0.839385	0.153047
1280	0.004120	320.0	-1.207168	0.240810	0.386590	301.197380	-1.084020	0.156799
1600	0.004088	400.0	-1.524256	0.237781	0.387093	371.761171	-1.359723	0.160192

The parameters are inserted in the conversion formula:

```
lin2log(x)
(x > cut) ? c * log10(a * x + b) + d : e * x + f
log2lin(t)
(t > e * cut + f) ? (pow(10, (t - d) / c) - b) / a : (t - f) / e
```

Refer to the main text for more explanations.

Use the parameters in the following table for conversion between Log C values and exposure values.

EI	cut	a	b	c	d	e	f	e*cut+f
160	0.005561	5.555556	0.080216	0.269036	0.381991	5.842037	0.092778	0.125266
200	0.006208	5.555556	0.076621	0.266007	0.382478	5.776265	0.092782	0.128643
250	0.006871	5.555556	0.072941	0.262978	0.382966	5.710494	0.092786	0.132021
320	0.007622	5.555556	0.068768	0.259627	0.383508	5.637732	0.092791	0.135761
400	0.008318	5.555556	0.064901	0.256598	0.383999	5.571960	0.092795	0.139142
500	0.009031	5.555556	0.060939	0.253569	0.384493	5.506188	0.092800	0.142526
640	0.009840	5.555556	0.056443	0.250219	0.385040	5.433426	0.092805	0.146271
800	0.010591	5.555556	0.052272	0.247190	0.385537	5.367655	0.092809	0.149658
1000	0.011361	5.555556	0.047996	0.244161	0.386036	5.301883	0.092814	0.153047
1280	0.012235	5.555556	0.043137	0.240810	0.386590	5.229121	0.092819	0.156799
1600	0.013047	5.555556	0.038625	0.237781	0.387093	5.163350	0.092824	0.160192

It's not possible to express the Log C V3 function for EI values greater than 1600 in the compact formula. At EI 1600 there is a very small difference between the maximum value of the Log C function used in the camera and the formula provided in this document. The maximum value of the Log C curve using the parameters for EI 1600 will rise just above 1.0. Those values should be clipped to 1.0.

Example: How to configure Nuke to work with Log C data.

This example assumes that you are using Nuke in its pre-OpenColorIO configuration. This corresponds to using the 'Nuke' setting for color management in Nuke's Project Settings' 'Color' tab. If you are working with a monitor that supports multiple color spaces, it assumes you have set that monitor for 'Rec. 709'. This example also assumes you are working with DPX files.

The following can be added to the Nuke `init.py` file. It uses one of the LUTs downloaded from http://www.arri.de/camera/digital_cameras/tools/lut_generator/lut_generator.html. With this setup, you can convert ALEXA Log C data into exposure values for compositing, while displaying the data in exactly the same way as did the video output of the camera.

Note that the LUT file's path will differ on your system.

```
# ViewerProcess LUTs
nuke.ViewerProcess.register("AlexaV3Rec709", nuke.createNode,
("Vectorfield", "vfield_file
/mnt/libs/nukelib/luts/AlexaV3_EI0800_LogC2Video_Rec709_EE_nuke3d.cube
colorspaceIn AlexaV3LogC"))
```

When reading in a DPX image, the Colorspace in the Read node should be set to 'AlexaV3LogC'. Do NOT use the default setting ("Cineon"). Be sure that the viewer process installed by the `init.py` file ('AlexaV3Rec709') is selected. This choice will emulate the clean, uncorrected look that was seen on set. As an alternative to the viewer 3DLUT you can use the ALEXA wide gamut to Rec 709 conversion matrix and apply a gamma correction to the "normal" range (from 0.0 to 1.0) of your scene data. This results in a linear representation of the scene, but will clip all highlight information and will not match the look that was seen on set.

ALEXA Wide Gamut RGB

A digital camera does not have RGB primary colors like a monitor. ALEXA Wide Gamut RGB is based on virtual primaries optimized for the encoding of the color data generated by the camera.

The chromaticity coordinates of the primaries and of the white point are given in the table below.

	x	y
Red	0.6840	0.3130
Green	0.2210	0.8480
Blue	0.0861	-0.1020
White	0.3127	0.3290

The ALEXA Wide Gamut RGB to CIE 1931 XYZ conversion matrix is

```
0.638008  0.214704  0.097744
0.291954  0.823841 -0.115795
0.002798 -0.067034  1.153294
```

The inverse matrix for conversion from XYZ into ALEXA Wide Gamut RGB is

```
1.789066 -0.482534 -0.200076
-0.639849  1.396400  0.194432
-0.041532  0.082335  0.878868
```

The matrix for conversion from ALEXA Wide Gamut RGB to ACES RGB is

```
0.680205  0.236137  0.083658
0.085415  1.017471 -0.102886
0.002057 -0.062563  1.060506
```