ALEXA LogC Curve – Usage in VFX

REFERENCE MANUAL

Harald Brendel, 2 August 2012

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14-Jun-11	Harald Brendel	Initial Draft
14-Jun-11	Harald Brendel	Added Wide Gamut Primaries
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28-Mar-11	Harald Brendel	Clarified usage of color matrix
27-Jun-12	Harald Brendel	Added ALEXA WG to ACES matrix

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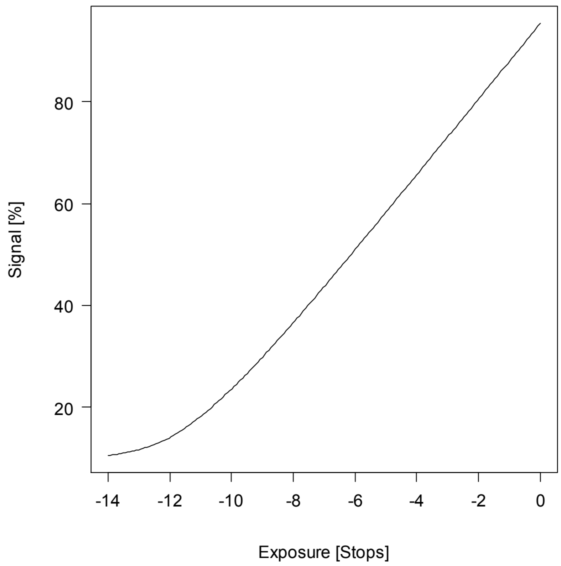
Introduction

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 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. The first and second release of the ALEXA camera firmware used a similar curve with a lower and variable gamma. The gamma changed from 0.54 at EI 200 to 0.49 at EI 1600, which is within the gamma range of contemporary color negatives.

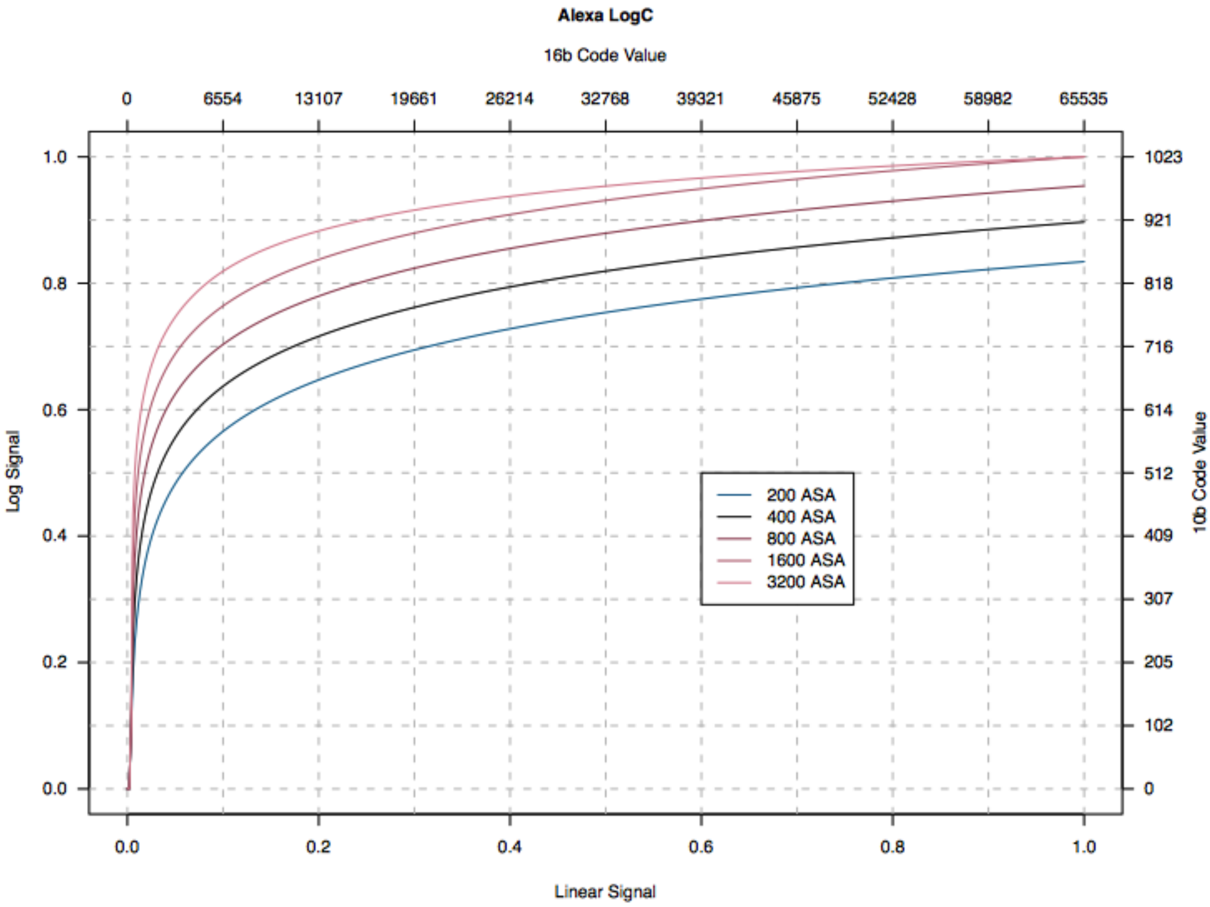
The Log C curve implemented in the ALEXA SUP 3.x adds the following features:

- Soft-shoulder for exposure index settings greater than 1600 ASA.
- Fixed black level of 95/1023.
- Larger linear part of the curve, now covering a range of 9-10 stops.

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 encoded value of 0.391, which is 400/1023.

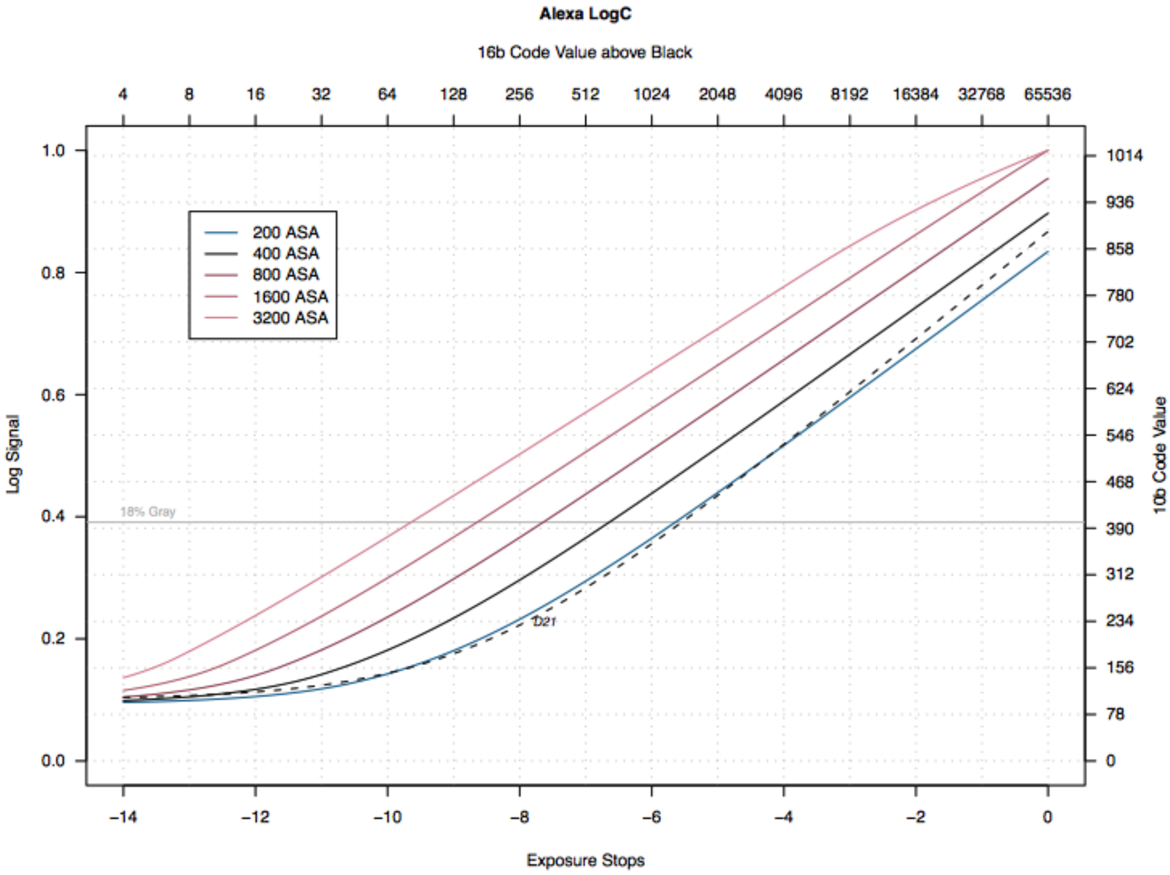
The following figure shows the ALEXA (SUP 3.x) Log C curves in a linear plot. The x-axis represents the signal of the camera sensor.



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 the Log C output represents scene exposure values, the maximum value needs to be higher.

The curve for EI 3200 has an additional shoulder or roll-off built in to keep the maximum code values within the available output range.

The following figure shows the curves in a logarithmic plot. The x-axis represents the exposure measured in stops. 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 and linear camera 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 > cut) ? c * log10(a * x + b) + d: e * x + f
```

in which `x` denotes the linear data, `cut` and `a` through `f` denote parameters and `log10` denotes the common logarithm. For a particular image being encoded, the values of `cut` and `a` through `f` will depend on three factors:

- `version of Log C encoding (SUP 3.x or SUP 2.x)`
- `type of linear data (normalized sensor value or relative scene exposure factor)`
- `exposure index (160 to 3200 for SUP 3.x, 160 to 1600 for SUP 2.x)`

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

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

```
(t > e * cut + f) ? (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* or *Shake*.

Application in VFX

In VFX, the image data is usually round-trip converted. Log C images are converted to linear exposure 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 the ALEXA. In most cases you will want to use the parameters for conversion into a relative scene exposure factor.

The composite 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. For images actually encoded with EI values from 200 to 3200, the maximum deviation from the true linear value will be less than 10% for tonal values up to scene white.

When the higher precision is needed, use parameters for the actual exposure index. The value is included as metadata in QuickTime™. ARRI distributes a small app that can display the metadata. The EI is also included in the header of ARRIRAW files and will be displayed by ARRIRAW converter (ARC) and other applications that support the ARRIRAW format.

Handling of Black

When the Log C data is converted to linear sensor data, black (corresponding to zero exposure) will be represented by the value 256/65535. This sensor 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 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 linear scene exposure will map the black value, as expected, to 0.0. With the noise, however, single pixels will come out as negative 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 relative scene exposure factor. 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. There are two ways to display Log C encoded images. The first approach is based on a tone-mapping and is the same way as the camera generates 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 value and corrected for the non-linearity of the display ("gamma correction"). This approach attempts to create a colorimetric reproduction of the scene.

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 into ITU Rec. 709 RGB 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 DCI P3 color space[1] 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 P3 white point. If the projector is set to a D65 white 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.

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). This deviation from the correct conversion is done to compensate for the increase of saturation produced by the tone-map curve.

ALEXA (SUP 2.x) Log C encodes image data in a raw camera RGB color space, which requires the use of different color matrices than those used for ALEXA (SUP 3.x) Log C. Please see the appendix for the corresponding matrix values.

Since the ALEXA (SUP 2.x) color conversion happened before the tone-map operation, there is no difference between a tone-mapped and a linear approach.

Film Style Matrix

As of SUP 3.x, the ALEXA offers an optional film style matrix that can be applied to Log C images so that they more closely match the look of scanned negative film. This matrix can be used when the images are color corrected with a print film emulation LUT as done in the conventional DI workflow.

Another white paper by ARRI, "ALEXA Color Processing", explains the use of this optional matrix in more detail.

For VFX work or if the matrix has been applied unintentionally, its effect can be removed by applying the inverse matrix.

0.806165	0.168534	0.025301
0.091228	0.765221	0.14355
0.092241	0.251418	0.656341

It may have to be applied again for a round-trip conversion.

1.271103	-0.284279	0.013176
-0.127165	1.436429	-0.309264
-0.129927	-0.510286	1.640214

[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 images recorded with an ALEXA having firmware 3.0 or higher.

The following table lists the black and clipping level in the ALEXA (SUP 3.x) Log C signal depending on the selected EI. Note that the black level is constant in this version of the Log C curve.

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 ALEXA (SUP 3.x) Log C signal and normalized 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 ALEXA (SUP 3.x) Log C signal and linear scene exposure factor.

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 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.

The following two lines can be added to the Nuke `init.py` file. It uses expression for EI 800 and 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 LogC data into linear scene exposure while displaying the data in exactly the same way as the video output of the camera.

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

```
#custom input/output LUTs
nuke.root().knob('luts').addCurve("AlexaV3LogC", "{ t > 0.1496582 ?
(pow(10.0, (t - 0.385537) / 0.2471896) - 0.052272) / 5.555556 : (t -
0.092809) / 5.367655 }")

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

There will be three options after installation.

1. A new "AlexaV3LogC" choice when specifying a read node's colorspace. Select this choice when reading ALEXA Log C (SUP 3.x) data. Do NOT use the default setting ("Cineon").
2. A new "AlexaV3LogC" choice when specifying a write node's colorspace. Select this choice when writing ALEXA Log C (SUP 3.x) data. Do NOT use the default setting ("Cineon").
3. A new "AlexaV3Rec709" choice when designating a Viewer Process for a Viewer. Selecting this choice will emulate the clean, uncorrected look that was seen on the 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.

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 primary and the white point is 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
```

ALEXA (SUP 2.x) Log C Curve

The parameters in this section apply to images recorded with an ALEXA using SUP 2.x (or earlier) firmware.

The following table lists the black and clipping level in ALEXA (SUP 2.x) Log C signal depending on the selected EI.

EI	Black	Clipping Level
160	0.1083	0.8110
200	0.1115	0.8320
250	0.1146	0.8524
320	0.1181	0.8743
400	0.1213	0.8935
500	0.1245	0.9121
640	0.1280	0.9320
800	0.1311	0.9494
1000	0.1343	0.9662
1280	0.1378	0.9841
1600	0.1409	0.9997

Use the parameters in the following table for conversion between ALEXA (SUP 2.x) Log C signal and normalized sensor signal.

EI	cut	a	b	c	d	e	f	e*cut+f
160	0.003907	36.439829	-0.053366	0.269035	0.391007	45.593473	-0.069772	0.108362
200	0.003907	45.549786	-0.088959	0.266007	0.391007	55.709581	-0.106114	0.111543
250	0.003907	56.937232	-0.133449	0.262978	0.391007	67.887153	-0.150510	0.114725
320	0.003907	72.879657	-0.195737	0.259627	0.391007	84.167616	-0.210597	0.118246
400	0.003907	91.099572	-0.266922	0.256598	0.391007	101.811426	-0.276349	0.121428
500	0.003907	113.874465	-0.355903	0.253569	0.391007	122.608379	-0.354421	0.124610
640	0.003907	145.759315	-0.480477	0.250218	0.391007	149.703304	-0.456760	0.128131
800	0.003907	182.199144	-0.622848	0.247189	0.391007	178.216873	-0.564981	0.131312
1000	0.003907	227.748930	-0.800811	0.244161	0.391007	210.785040	-0.689043	0.134494
1280	0.003907	291.518630	-1.049959	0.240810	0.391007	251.689459	-0.845336	0.138015
1600	0.003907	364.398287	-1.334700	0.237781	0.391007	293.073575	-1.003841	0.141197