Perceptually Uniform Grayscale Coding In the Panavision Genesis® Electronic Cinematography System

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Although it is fashionable today to deprecate many aspects of the NTSC television system such as interlace, limited color space, limited dynamic range etc. the 1953NTSC system was a masterful application of the limits of the technology available to the video engineers in the middle of the 20th century. The most important principle employed by the NTSC designers was that the camera's imaging parameters would be defined by the display parameters. This made perfect sense at the time since it ensured that the complex electronics would reside in the camera enabling greater simplicity and therefore lower cost in the display or television set. This principle persists to this day in many modern imaging systems that have nothing to do with television. **Why is this?**

The simple answer is that the response to change in light intensity of the human visual system is non-linear. The lightness response of the visual system is approximated by a power function with a 0.4 exponent. That is, an 18% gray card appears to the eye to be approximately half way between black and white.

$$\mathbf{Y^{x} = 0.18^{0.4} = 0.50 = 50\%}$$

By a happy coincidence, a CRT's response is also a power function with an exponent of approximately 2.5 requiring an input signal with an inverse value in order to output linear light

$$\mathbf{1/2.5 = 0.4}$$

Empirically an inverse value of **1/2.2 or 0.45** has been standardized as the average slope of the most recent incarnation of this video signal definition as incorporated in **ITU-R BT.709**. The basic gamma function embodied in this standard is almost identical to the original **1953NTSC** standard that required a camera output with the slope of a power function of **0.45**. This value is the reciprocal function of the CRT's gamma function modified to include a compensation for dark surround viewing.

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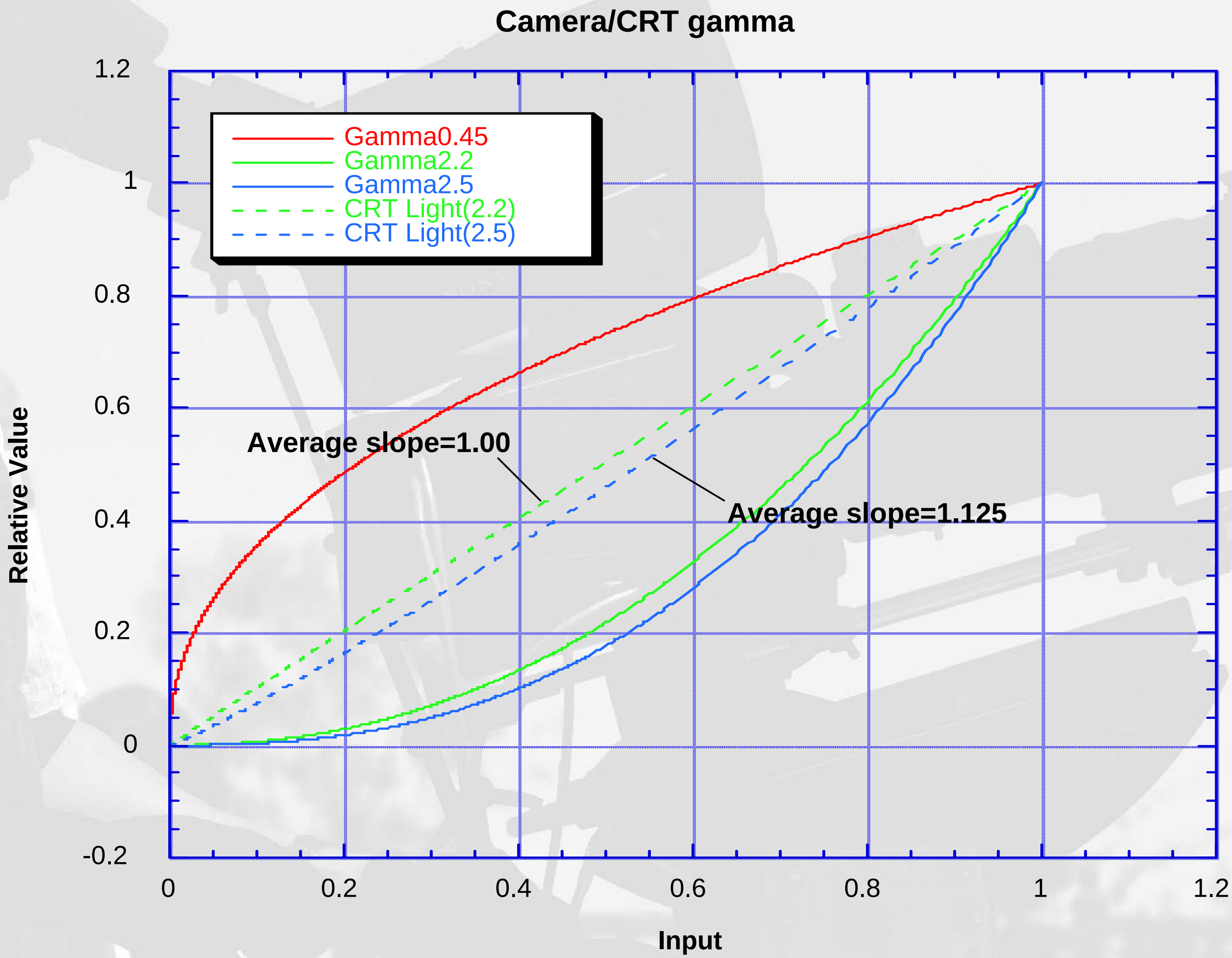

This would not be a sufficiently good reason to continue to use this fifty-year-old video standard were it not for an additional property of this gamma function:

Perceptual Uniformity

Because the inverse of the CRT’s gamma function is similar to the visual lightness response power function, data coded according to this function will make perceptually optimum use of available bit depth. However, tying the camera gamma to the CRT’s inverse gamma means, that the camera’s dynamic range and the CRT’s dynamic range are coupled. Although high performance monitor can have a measured 1000:1 contrast range, in a normal viewing environment, it is hard to exceed 100:1 due to the limitations of the light output of large CRTs

The 1953 NTSC standard continues to influence both the gamma function applied to what today are essentially linear camera signals and the parameters of the integral 3 x 3 matrix intended to match the camera's spectral analysis to the standard CRT phosphors. This strategy served the television industry very well for the first 30 years since there was no practical alternative to CRTs for displays and the various camera tube technologies from Iconoscopes to Saticons had a limited dynamic range that was easily accommodated by the display characteristics of CRT based televisions and monitors.

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With RCA’s introduction of CCD-1 in 1984, CCD imagers had come to television cameras. CCD’s would eventually have dynamic range capabilities that would exceed both the display dynamic range and the Rec.709 gamma function.

In 2005 Panavision and Sony introduced Genesis®, a Super35 sized CCD imager camera with a dynamic range six times greater than that accommodated by the nominal Rec. 709 standard . This camera is presently being used on a number of major feature films being shot in different parts of the world.

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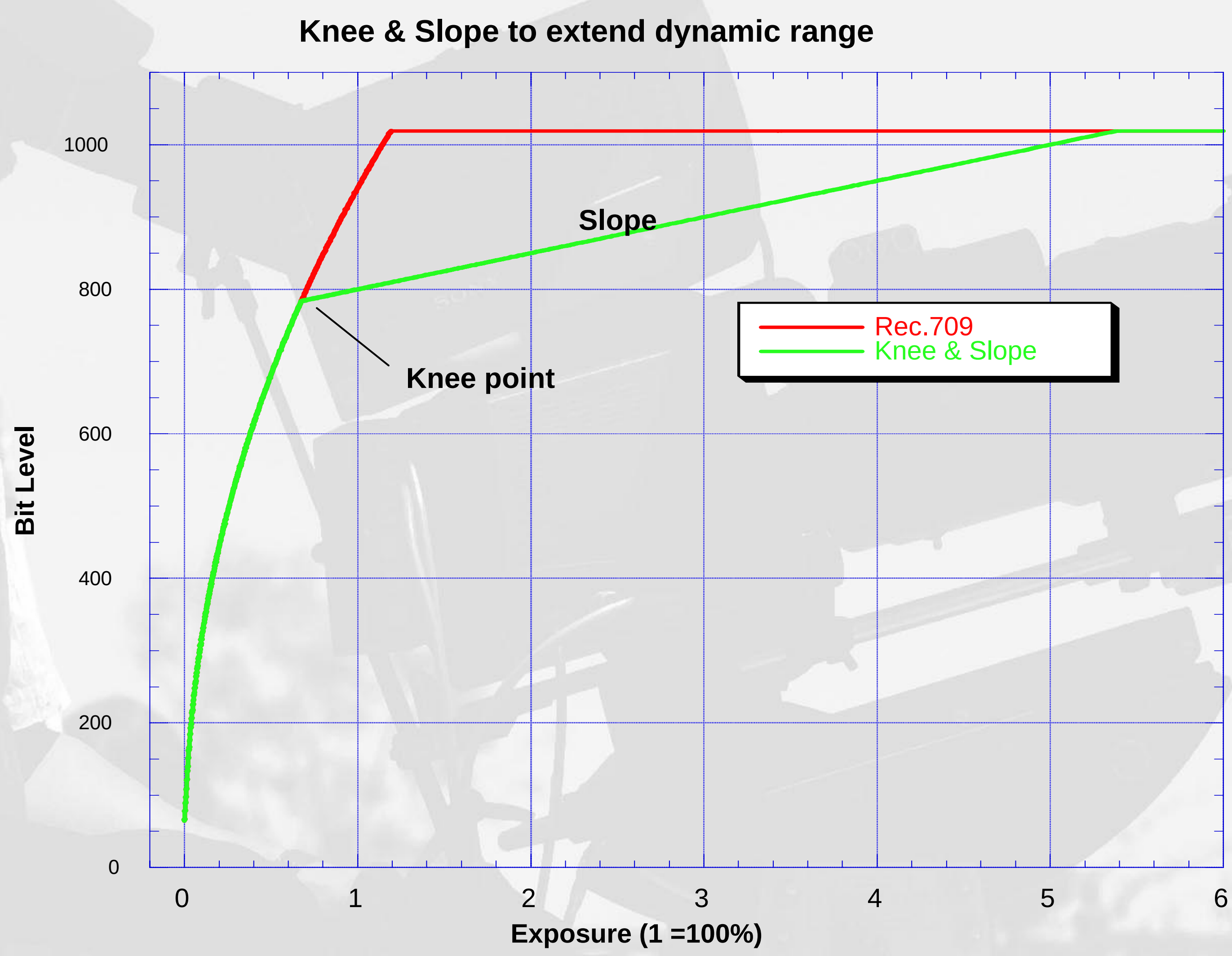
Genesis® is not intended for direct view on television. The Genesis® electronic cinematography camera must capture the greatest scene dynamic range possible, recognizing that the recorded image will undergo extensive post-production before conversion to a variety of release formats and color spaces from 35mm print film to video and Electronic Cinema.

An appropriate paradigm is the film camera negative that is capable of a much greater dynamic range that can be displayed by either print film or video displays.

For a number of years, video camera manufacturers have provided a non-standard extension to the standard video gamma function known as “knee” and “slope” control. The concept is that the basic 0.45 power function could be modified by creating a new point gamma function or slope that could be initiated at a particular video level or “knee point”. Unfortunately, this deviation from the 0.45 gamma function introduced an unpredictable change in the camera transfer characteristic that usually resulted in transitions in video levels that were often at the nominal skin tone levels and appeared unnatural


Knee & Slope to extend dynamic range
Bit Level
0
200
400
600
800
1000
0
1
2
3
4
5
6
Exposure (1 =100%)
Slope
Knee point
Rec.709
Knee & Slope

With the introduction of the Genesis® camera utilizing a large area array CCD with an expanded dynamic range, we realized that it was time to divorce image acquisition from the display

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The Genesis® camera incorporates a linear, 14 bit A/D converter, but the HDCAM-SR recorder can only support 10 bits per color. Linear quantization is perceptually inefficient and although the video gamma 0.45 power function results in a much better perceptual utilization of available bit depth than linear quantization the scaling of the video signal in the Rec. 709 standard only utilizes about 17% of the CCD saturation level to produce a 700 millivolt output. The maximum video output is limited to 760 millivolts, less than a 9% overhead; so defining an extended dynamic range must incorporate a re-scaling of the video signal such that the output of the camera will no longer be viewable on a standard monitor.

Others have faced this problem, Kodak developed Cineon™, a 10 bit quasi-log system that has become ubiquitous within the Electronic Cinema and Digital Intermediate post community.

Thomson developed Filmstream™ for their Viper camera.

Panavision has now developed yet another tool for Electronic Cinematography production and post-production.

May we introduce….

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PANALOG™

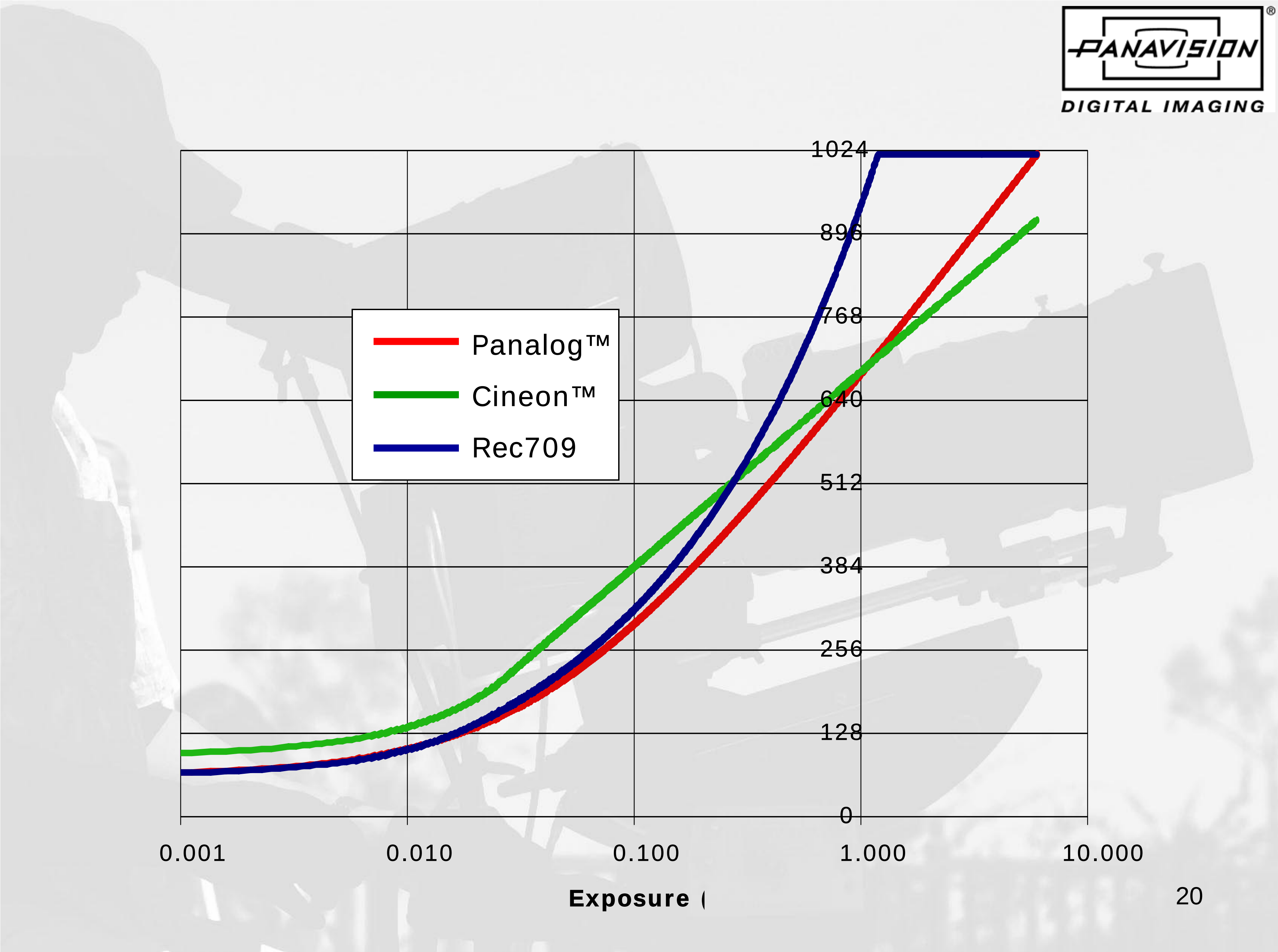
PANALOG™ is a perceptually uniform transfer characteristic that internally transforms the 14 bit per color linear output of the Genesis® A/D converters into a quasi-logarithmic 10 bit per color signal that enables the RGB camera signal to be recorded on 10 bit recorders including, but not limited to, the dockable HDCAM-SR1 portable VTR.

PANALOG™ can readily be transferred back to the linear light domain to facilitate post-production processes such as image compositing, color matrix transforms and other color corrections that are best done in the linear light domain.

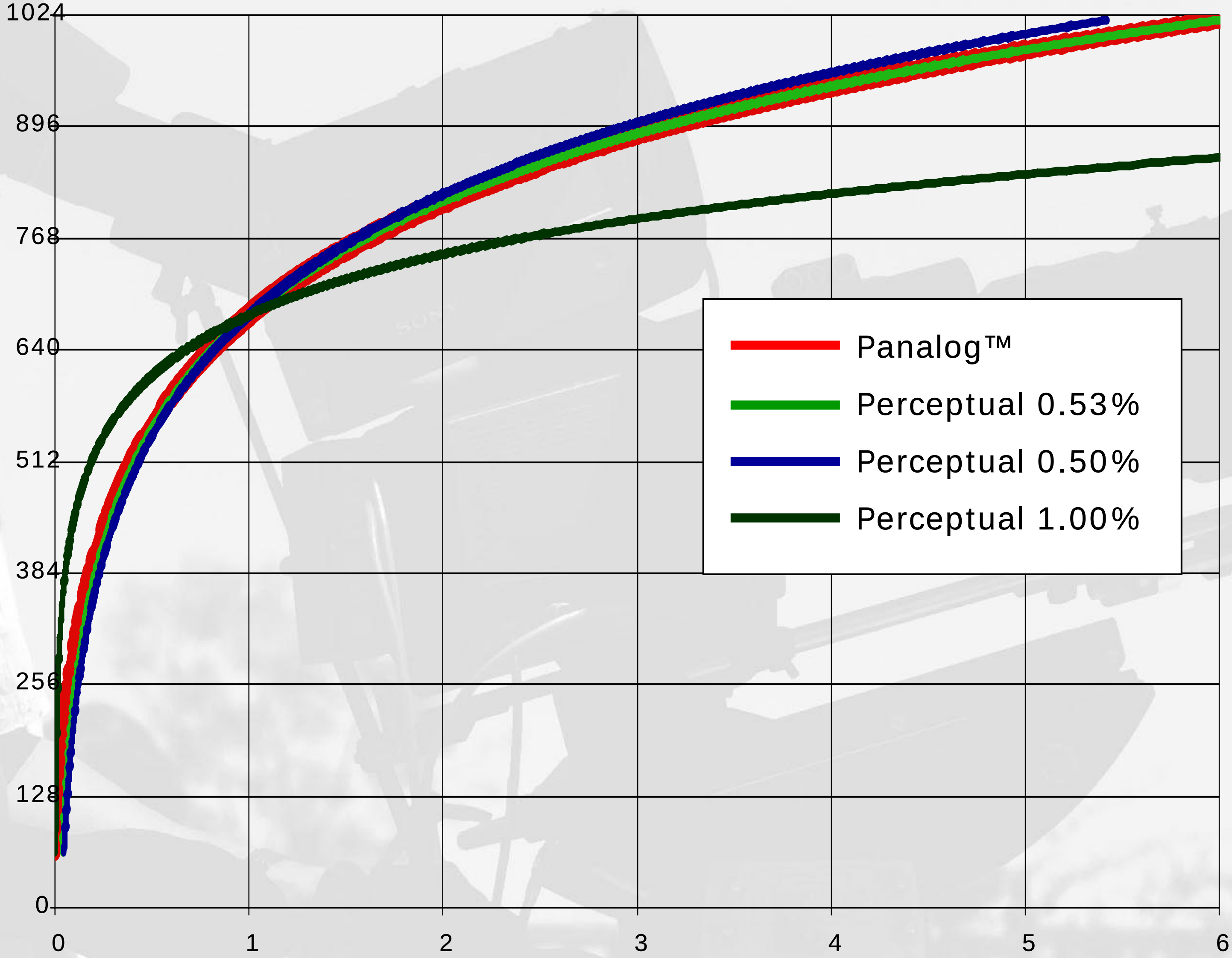
PANALOG™ data, without any transformations being necessary, can also be processed through existing telecine type color correctors.

PANALOG™ LUTs and transformation data will soon be freely available and downloadable from the Panavision web site

The following graph shows PANALOG™, Rec.709 and Cineon™ in Log_{10} space. Cineon™ is included because a number of post facilities have attempted to use this familiar toolset. Although it is relatively simple to convert PANALOG™ to Cineon™, this will result in a reduction of the number of data levels available due to the indeterminate dynamic range of Cineon™ data. An important aspect of PANALOG™ is that it makes the maximum use of the quantizing levels available to express the full dynamic range of Genesis®.

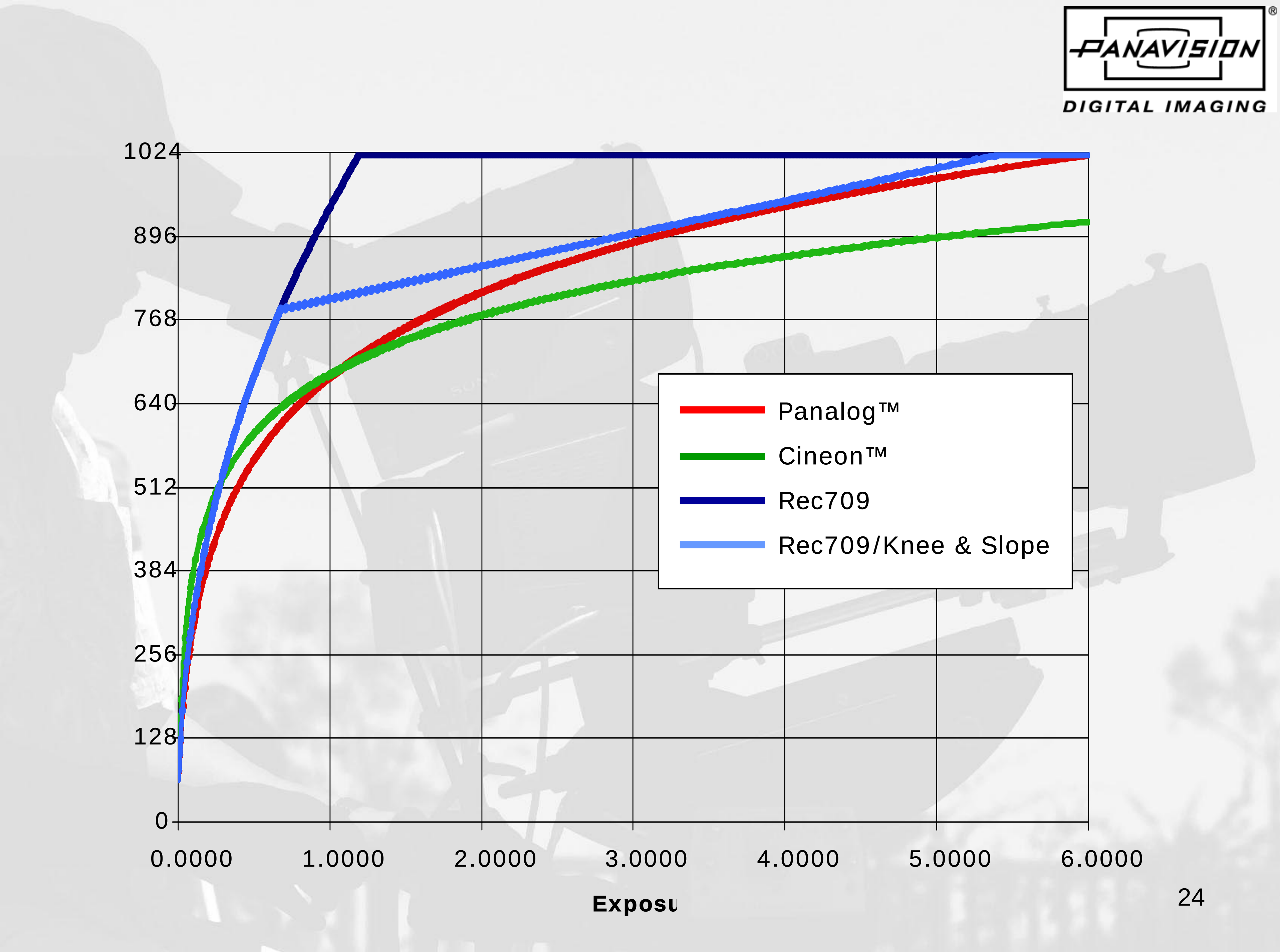

PANAVISION
DIGITAL IMAGING
1024
896
768
640
512
384
256
128
0
Panalog™
Cineon™
Rec709
0.001
0.010
0.100
1.000
10.000
Exposure (

The next graph shows PANALOG™ (this time with linear axes) overlaid with several perceptually uniform curves. The 0.53% increment is the best fit to PANALOG™.



1024
896
768
640
512
384
256
128
0
0
1
2
3
4
5
6
Panalog™
Perceptual 0.53%
Perceptual 0.50%
Perceptual 1.00%

The next graph shows PANALOG™, Rec.709, Rec.709 with knee and slope and Cineon™, again in linear space. Due to its lower slope, Cineon™ has fewer code values therefore poorer quantizing than PANALOG™ applied to Genesis®’ dynamic range.

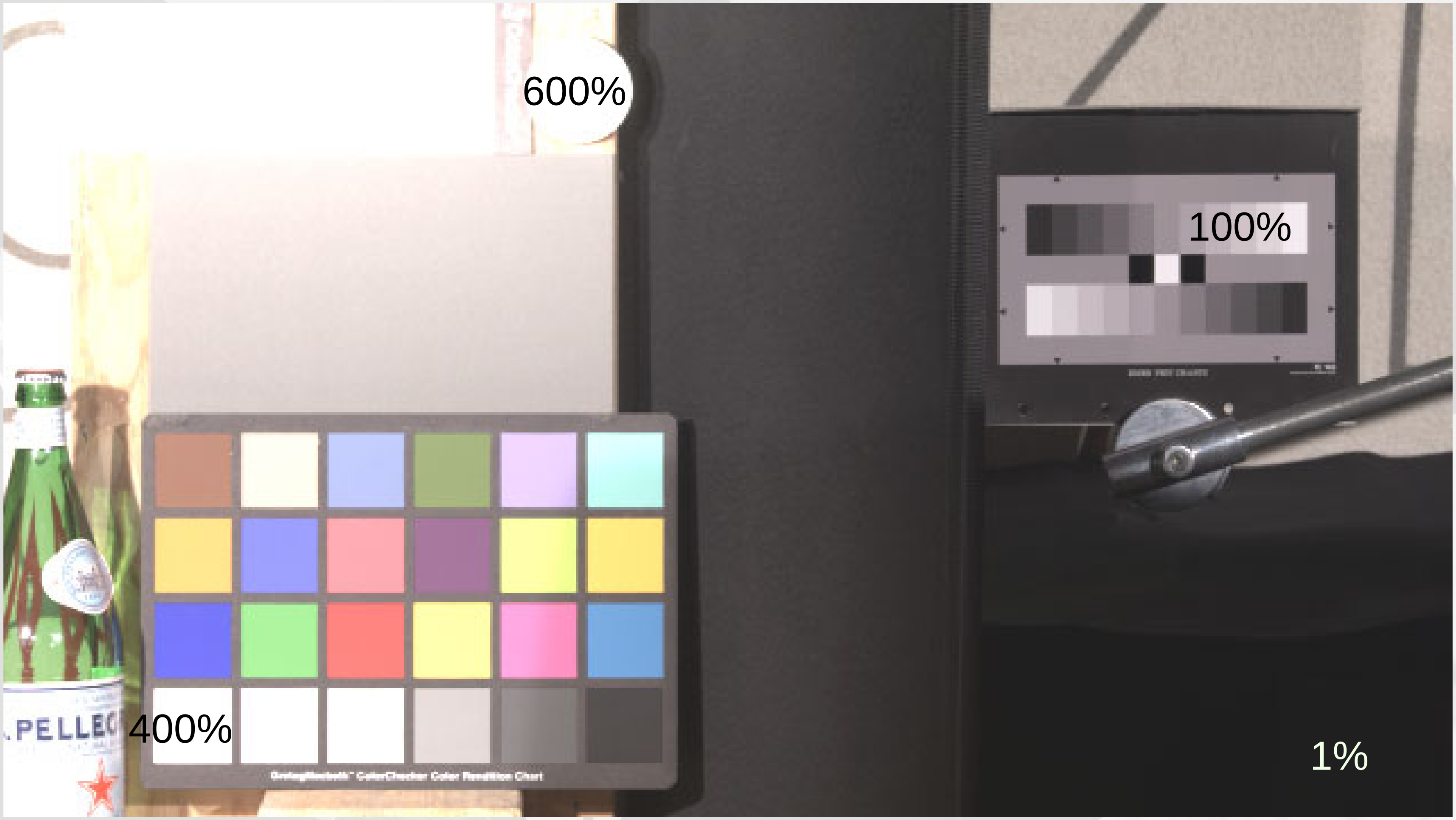

PANAVISION
DIGITAL IMAGING
1024
896
768
640
512
384
256
128
0
0.0000
1.0000
2.0000
3.0000
4.0000
5.0000
6.0000
Exposu
Panalog™
Cineon™
Rec709
Rec709/Knee & Slope

The following slides are Genesis® frames from a high dynamic range image. The percentage numbers are linear reflectance values. The 600% is five stops over 18% gray, 1% is four stops under 18% gray.

Slide A is the unprocessed PANALOG™ output of Genesis®
Slide B is a normal Rec. 709 image
Slide C is processed through the Panavision Display Processor. The Display Processor enables the cinematographer to modify the transfer characteristic for display purposes only.
Slide D is PANALOG™ converted to linear light space scaled to display 600% dynamic range.
Slide D is PANALOG™ converted to linear light space with scaled to display 100% dynamic range.

Genesis® camera Panalog™ output

Slide A



REC. 709 clipped at 109%

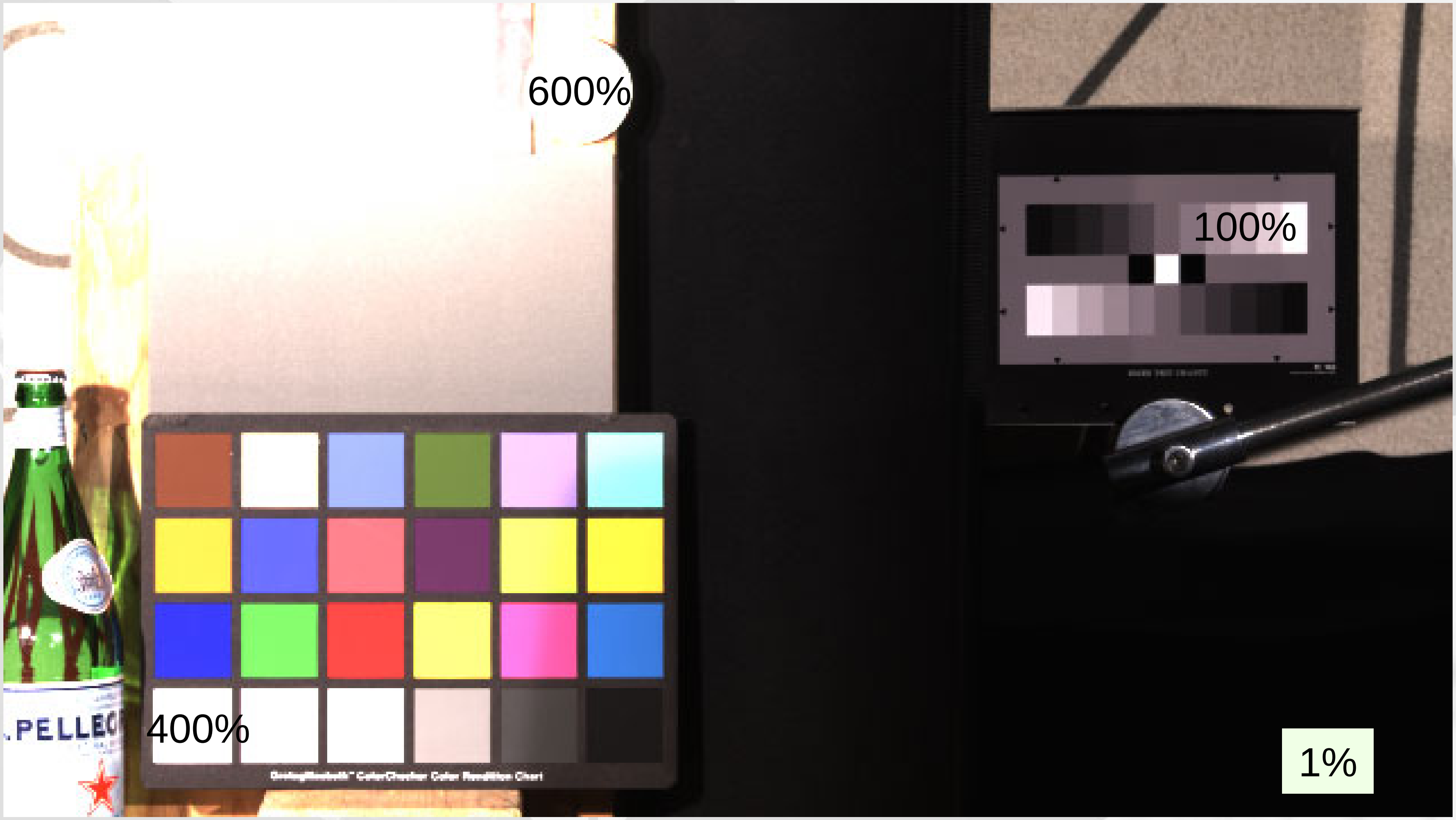
Slide B

REC. 709 Through Panavision Display Processor (soft clip)

Slide C

Panalog™ to linear light. 600% dynamic range scaled to monitor output

Slide D



Panalog™ to linear light. 100% dynamic range scaled to monitor output

Slide E

In conclusion, PANALOG™ is a perceptually uniform transfer characteristic that is designed to replace Rec. 709 gamma in high dynamic range digital cameras such as Genesis®.

PANALOG™ separates the display function from the camera processor and therefore requires an external device such as the Panavision Display Processor to be introduced between the camera and the display.

PANALOG™ enables wide dynamic range Digital Intermediate processes to be performed in linear light space while minimizing quantizing errors.

PANALOG™ data can also be processed in standard telecine color correctors without the need for custom LUTs.