

Canon

WHITE PAPER

CINEMA EOS C300 & C500

CANON-LOG CINE OPTOELECTRONIC TRANSFER FUNCTION



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CINEMA EOS



Canon-Log Cine Optoelectronic Transfer Function

Abstract

Significant advances are being made in large format image sensor technology for digital motion image origination. In particular, sensor dynamic range is steadily increasing to a level where very wide exposure latitudes are now possible to achieve. Implementing capture of such a dynamic range within the confines of limited bit depth in RGB digital video recording calls for considerable care in structuring a nonlinear transfer characteristic that can successfully retain all of the tonal information delivered by the image sensor. This paper will discuss an optoelectronic transfer characteristic developed by Canon for the EOS C300 and EOS C500 digital cinema cameras that ensures effective management of wide dynamic range HD imagery.

1.0 Introduction

Contemporary digital motion imaging sensors can originate linear video signals having dynamic ranges in the vicinity of 72dB – requiring A/D conversion in the 12/14/16-bit range. Such a dynamic range exceeds that of most contemporary image displays. Achieving capture and presentation of an extended dynamic range entails re-scaling of the digital representation of the image sensor output. This will produce a video that will not be satisfactorily viewable on a video monitor. This issue was initially dealt with by Kodak’s development of their Cineon [1] system which produced a 10-bit logarithmic representation of the total dynamic range scanned from a negative motion picture film origination. This has become the core of the now widely used Digital Intermediate (DI) systems used for postproduction of motion film recordings.

Canon-Log is designed to reproduce the entire tonal reproduction range of which the Super 35mm CMOS image sensor (used in the EOS C100, EOS C300 and EOS C500 cameras) is capable. It anticipates a postproduction “finishing” process. This unique transfer characteristic acknowledges the desire of the cinematographer to make exposure decisions based upon the light meter techniques long employed in motion picture film imaging. In doing so, it disposes digital quantization bits in a manner that can ensure excellent tonal reproduction within both highlight and shadowed or darker regions of a given scene. Thus, Canon-Log protects the entire tonal reproduction range of the new CMOS image sensor by a transformation of the linear sensor output with this special logarithmic transfer characteristic. In turn, this enables systems such as Cineon to represent digitally originated imaging in a manner similar to motion picture film original negative transferred within the digital intermediate (DI) process. The Canon-Log transfer function is specifically intended to facilitate postproduction color grading processing. That process restructures a new digital representation that produces the final desired “Look” on a reference quality display monitor. This representation will optimize the final motion picture for a particular theatrical display (either positive print motion picture film or digital projection).

Challenges of Digital Motion Image Production

The digital motion imaging camera entails trade-offs between lens-camera sensitivity (its Exposure Index), camera dynamic range (Exposure Latitude), and camera signal to noise performance (level of “Graininess” in the image). For traditional video cameras, the camera sensitivity specification relates a scene illumination, a reference white within the scene, a setting for camera Master Gain, and a lens aperture setting that will produce a reference white video level – accompanied by the all-important signal to noise performance at those settings.

For example, in the case of the C300 camera, such a video specification is as follows:

With scene illumination of 2000 Lux at 3200 degrees Kelvin, a reference white of 89.9% reflectance, camera Master Gain set to 0 dB, Gamma and Detail enhancement switched off, the lens T-stop setting to produce 100 IRE of Luma video level on a waveform monitor is T-10, under which conditions the camera Luma signal to noise ratio is 54dB.

Imperatives of Digital Cinematography

In the motion picture film world, cinematographers are constantly aware of multi-dimensional aspects of the images they seek to record on the film negative. Scene illumination and specific creative aspirations for a given scene call for constant attention to imaging parameters such as those listed in Figure 1. These may vary significantly between different scenes within a given production.

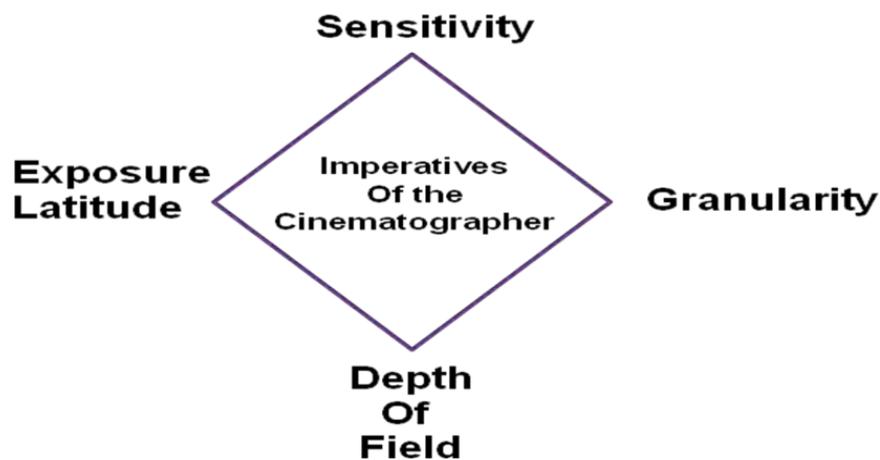


Figure 1 *Highlighting the principal imaging parameters requiring attention when shooting on motion picture film*

Oftentimes, restrictions encountered during actual shooting require downstream intervention in the film lab using chemical processing techniques [2]. For example, if a particular film emulsion having a specific exposure index (EI) must be shot at a higher EI (perhaps because of lower scene available illumination), then this can be compensated later in lab by using PUSH processing in the developer. This will increase image contrast but with an attendant increase in graininess. Conversely, if the film has been under-developed (perhaps in a specific quest to reduce graininess in a given scene) the film lab may resort to PULL processing.

In the case of the digital cinematography camera similar imaging imperatives prevail. But, there are real-time tools available in these cameras that allow more powerful trade-offs between the imaging parameters. Knowing the sensitometric characteristics of the digital camera affords the information necessary to the cinematographer to accomplish the requisite balance between those parameters. As one example, an especially useful trade-off can be made in terms of adjusting operational depth of field by manipulation of the lens aperture and the camera ISO setting. It is the thesis of this paper, however, that the all-important capture of these imaging parameters – most especially the maximum exposure latitude – is very dependent upon the characteristic of the nonlinear optoelectronic transfer function (EOTF) employed in the camera.

Figure 2 summarizes the operational controls available to the cinematographer in the Cinema EOS camera family. They can be collectively manipulated to achieve a desired depth of field and exposure of desired scene subjects, as well as optimizing exposure latitude in a manner that does justice to the highlight and darker regions of the particular scene being imaged. But, all of this information can only be originated in the camera digital domain and subsequently captured on digital recording medium if the all-important transfer function disposes the digital bit depth appropriately over that entire dynamic range.

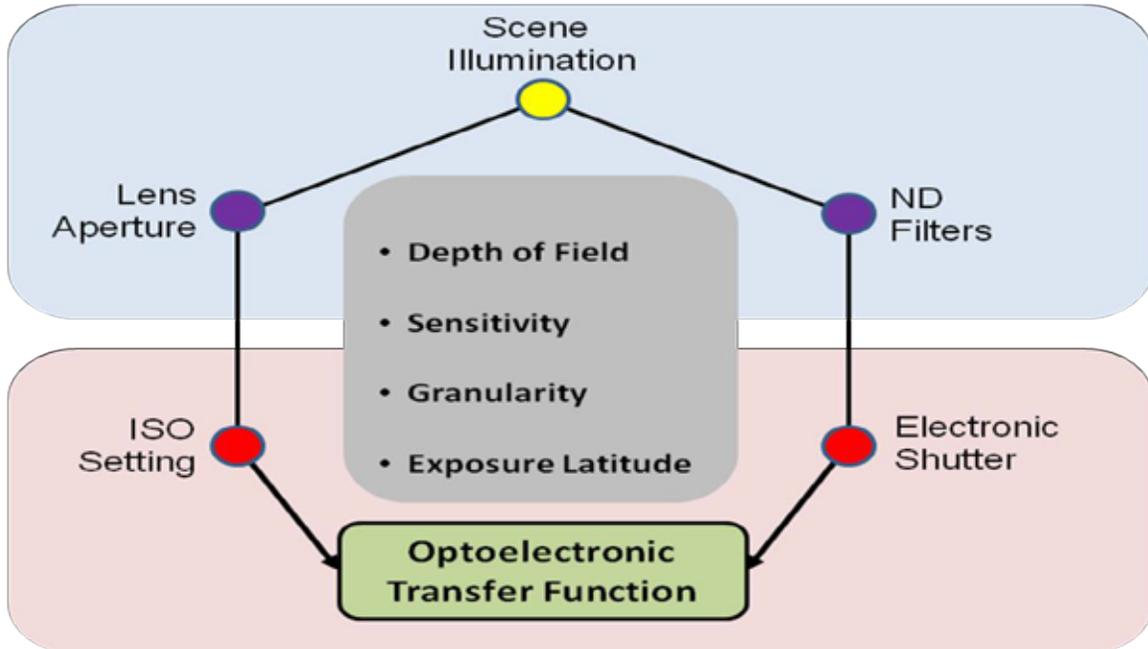


Figure 2 Showing on the periphery the contemporary controls available to the cinematographer in the Cinema EOS C300 and future EOS C500 cameras – while internally are shown the imaging parameters influenced by all of these controls

The characteristics of the CMOS image sensor in the C300 and C500 are such that the relationship between its Exposure Index (EI) measured in ISO units and its Exposure Latitude (dynamic range, which is measured as a percentage of scene illumination above that required for nominal exposure of the 18% gray chart) – are outlined in Table 1 below.

Table 1

Gain[dB]	-6	-	-3	-	0	0.5	1.0	1.5	2.0	2.5
ISO	320	400	-	500	640	-	-	-	800	850
Latitude [%]	300	378	424	476	600	636	673	714	756	801
Camera T-Stop (above 18% gray)	3.9	4.2	4.4	4.6	4.9	5.0	5.1	5.2	5.2	5.3

Priorities in Setting Camera Exposure

There are typically three separate shooting conditions:

1. Optimizing Tonal Reproduction under normal scene illumination
2. Lowering the Noise Floor for precision image reproduction (such as shooting green and blue screen)
3. Maximizing digital capture of Exposure Latitude for high dynamic range scenes

Priority 1 *Optimized Tonal Reproduction under Normal Scene Illumination*

The nominal sensitivity of the Cinema EOS cameras – with Master gain set to 0 dB – is ISO 640. At this setting, the dynamic range is optimized for excellent tonal reproduction over the nominal exposure range of black to reference white exposure. The camera has a dynamic range of 600% (or six times the level of reference white) at this setting – which, in cinematography terms, translates into 4.9 T-stops of latitude above the 18% gray reference level. Under this setting the camera can discern tonal gradations of 7.1 T-stops below the 18% reference neutral gray. The camera's Luma signal to noise is 54 dB. The question becomes how well the camera can reproduce this image sensor dynamic range in the digital domain.

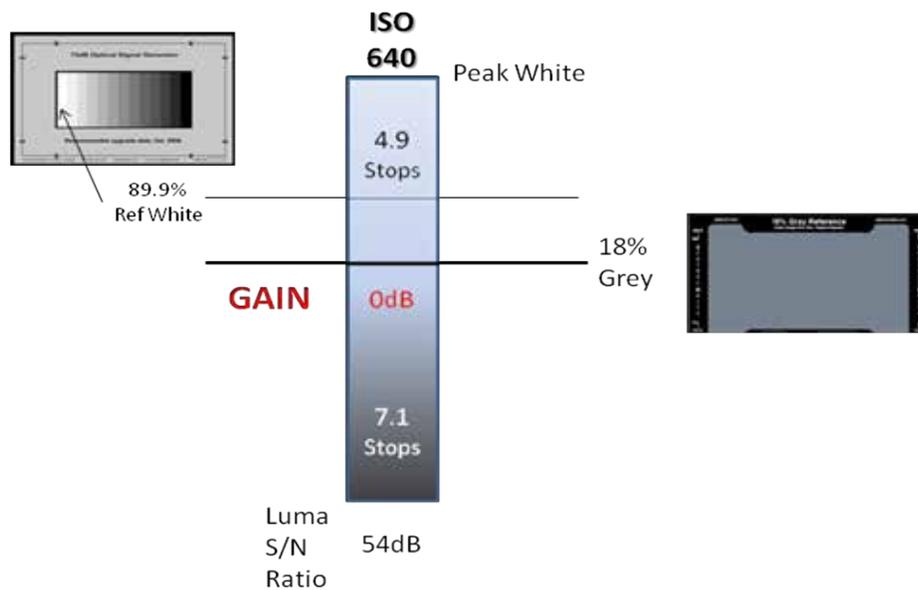


Figure 3 *Sensitometric characteristic of the C300 and C500 cameras at their 640 ISO reference rating*

Limitations of the Rec 709 Optoelectronic Transfer Function

The original SMPTE and ITU standardization work on HDTV video origination specified both an optoelectronic transfer function and a tristimulus color specification. The combination proved very successful in unifying HDTV origination around the world. However, the underlying philosophy was founded on traditional (and restrictive) video camera practices in terms of management of an extended dynamic range.

The transfer characteristic was confined within the boundaries of capped black video level and the chosen reference white level. As CCD and CMOS cameras evolved technologically, and as video techniques sought to adapt to practices of the motion picture film world, increasing attention was paid to extending the operating dynamic range of HD cameras.

The Rec 709 optoelectronic transfer function is specified as follows [3] :

$$V' = \begin{cases} 4.5L, & 0 < L < 0.018 \\ 1.099 L^{0.45} - 0.099, & 0.018 < L < 1 \end{cases}$$

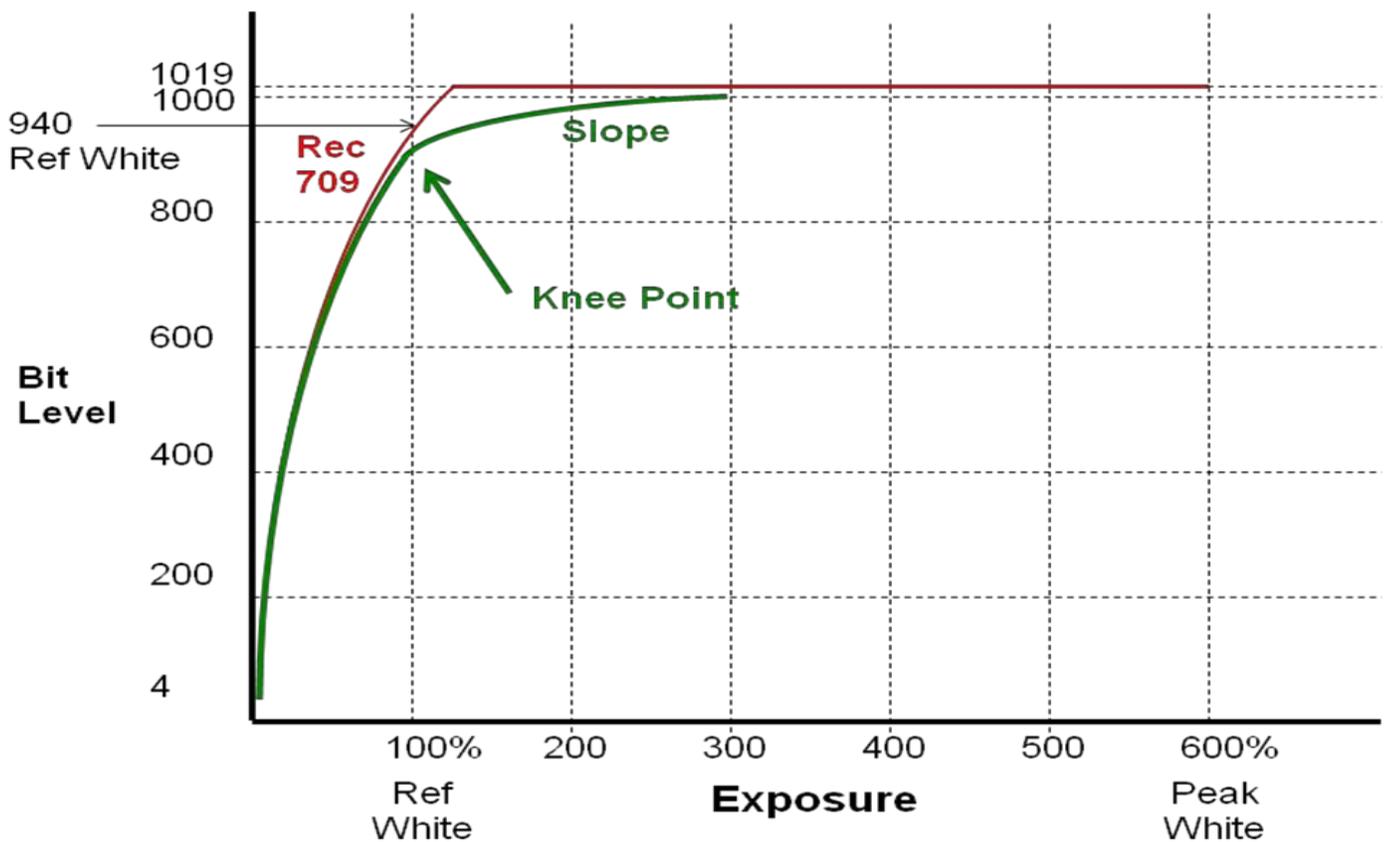


Figure 4 Showing the optoelectronic transfer function specified in ITU Rec 709 and a typical strategy adopted by HD camera manufacturers of adding a knee/slope control to try and manage information above the nominal 100% reference white level

Over the years, professional camera manufacturers have incorporated non-standard modifications to the standardized gamma functions in attempts to exploit the increasing dynamic ranges of the ever-evolving CCD and CMOS image sensors. These typically took the form of extensions to the gamma curves that usually terminated at nominal video exposure. New point gamma curves were added to the existing curve with onset points defined as “knee points” and the additional curves were termed “slopes” (which are variable) – as illustrated in Figure 4.

However, force-fitting these two curves together has historically been found to introduce artifacts in terms of colorimetric discontinuities when they are pushed to handle extreme highlights. Typically, they can operate satisfactorily up to perhaps a 300% overexposure.

Priority 2 Lowering the Noise Floor for Precision Image Reproduction

There are occasions when the highest possible signal to noise performance is required as a special priority – for example, when shooting blue or green screen. A setting between -3 dB and -6dB is commonly used for such shooting. At a -3dB setting the exposure index will be reduced to ISO 453, but the exposure latitude will be extended to 7.6 T-stops below the reference 18% neutral gray. This in-camera adjustment can be likened to the PULL adjustment long employed in motion picture film laboratories – and is outlined in Figure 5.

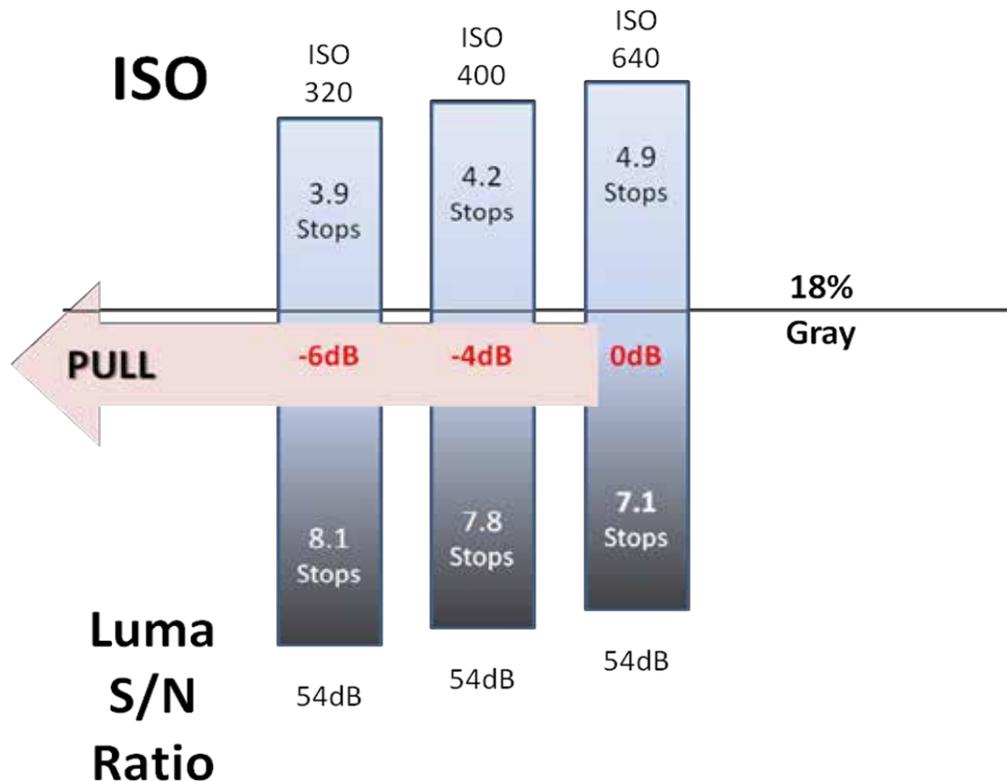


Figure 5 Showing the equivalent PULL process in a digital camera to extend the exposure latitude into the shadowed regions of the scene

When the Cinema EOS cameras are “Pulled” to ISO 320, they can reproduce a superb tonal gradation of more than 8 T-stops below the 18% reference gray. This can be of significant benefit in many green screen shootings where low noise and high detail in shadowed areas are important. The compromise, however, is that tonal reproduction above the 18% reference gray is restricted to less than 4-stops. Typically, scene lighting will be set to optimally accommodate this overall exposure latitude.

The overall sensitometric characteristics of the Cinema EOS cameras can be examined according to the graphical representation shown in Figure 6. Here both the equivalent Pull and Push controls are illustrated.

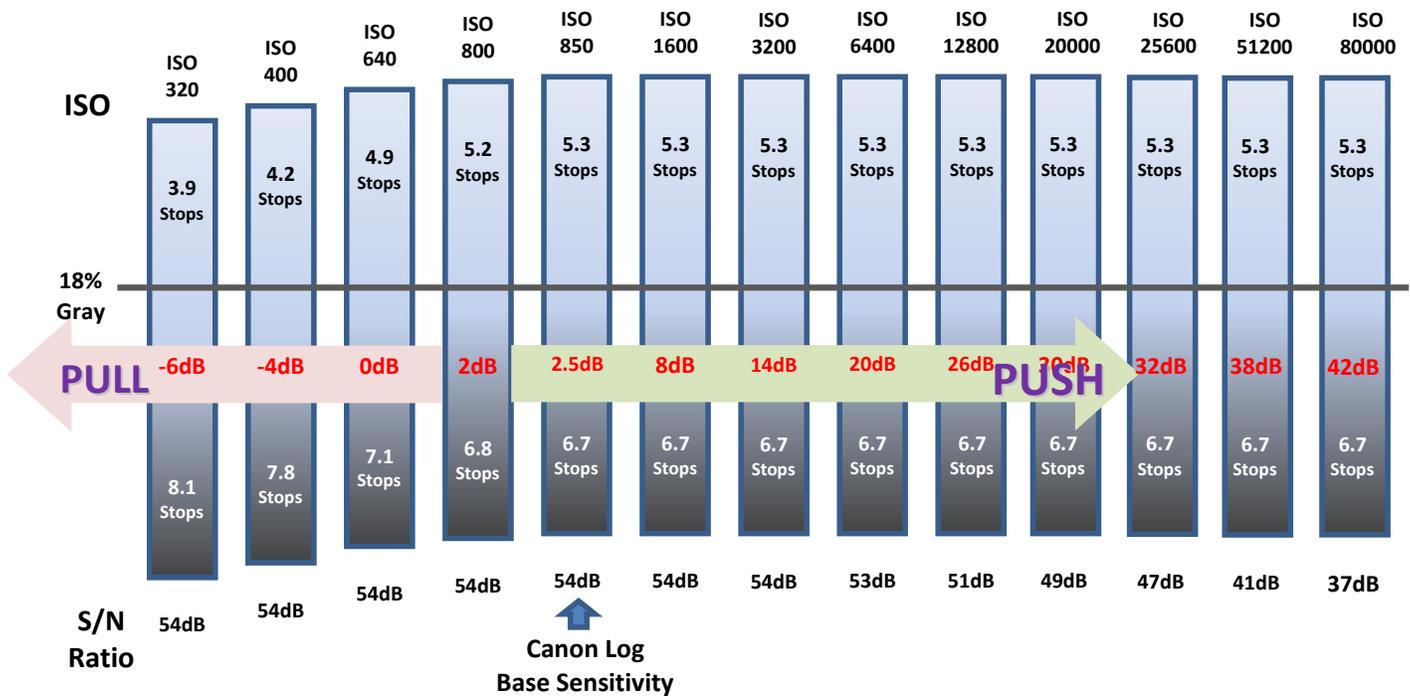


Figure 6 Showing the behavior of EOS C300 and C500 camera ISO settings, Luma exposure latitude either side of reference 18% gray, and Luma signal to noise

Priority 3 Maximizing Exposure Latitude for High Dynamic Range Scenes

When a scene having a very wide illumination range is encountered, the Cinema EOS camera's exposure latitude can be extended by raising Master Gain to 2.5 dB which will extend the camera's Luma dynamic range to a maximum of 800% above reference white level. At this gain setting, the equivalent exposure index now becomes ISO 850 and this affords some 5.3 T-stops of latitude above reference 18% neutral gray. This provides an additional degree of protection when dealing with extreme highlights – which can prove especially useful if light meters are not accurately calibrated. The tonal gradation still retains a generous 6.7 T-stops below the 18% reference gray level. Camera signal to noise remains 54 dB – because the signal to noise ratio of the video components at lower ISO settings is much higher than the 54dB cap imposed by the quantization noise of the final Luma 8-bit representation. What is especially noteworthy is that this total exposure latitude of 12-Tstops is preserved all the way up to the camera's maximum setting of ISO 20,000 with tonal gradation either side of 18% reference gray also remaining unchanged. Noise will progressively increase above ISO 3200.

Log Transfer Functions to Manage Wide Dynamic Range Video

In 1993 Kodak introduced a system concept intended to manage digital representations of wide dynamic range digital scanning of motion picture film negative program material. Kodak introduced the term Digital Intermediate (DI) with the introduction of their Cineon system, which included a digital film scanner (capable of scanning up to 4K resolution), a laser film recorder (also 4K recording), and Cineon software (which was supported by the Kodak digital imaging system). This system included scanning at the highest resolutions available, creation of digital data files, and final output recording back to film for theatrical distribution.

Subsequent to the Kodak developments a series of logarithmic image data specifications have been developed by various manufacturers of large-format single-sensor digital cine cameras:

Panavision:	Panalog system	
Sony:	S-Log system	[4]
Arri:	Log-C system	[5]

Canon has developed a logarithmic image data representation for the Cinema EOS cameras that is tailored to optimize the capture of the wide dynamic range of the CMOS sensor employed in these cameras. It does so from settings of ISO 850 all the way to ISO 80,000. This transfer function is labeled the Canon-Log characteristic. The transfer function is implemented on the high-bit depth RGB video signals. Subsequently, the recorded data will be processed – either in the linear domain or in a digital format having a greater bit depth. Canon-Log incorporates a lookup table (LUT) intended to facilitate the linkage between input and output in a manner that preserves that original wide dynamic range to the best degree possible. Below ISO 850 the exposure latitude favors the shadowed region below 18% reference gray.

Characteristics of Canon-Log

Canon's CMOS image sensor has a quite different light transfer characteristic to that of negative motion picture film. It has an essentially linear transfer characteristic – absent of “toes” or “shoulder” curves as found in motion picture film. Thus, the Canon-Log curve will differ significantly from the original log curve typically used in DI systems such as Cineon. An important aspect of Canon-Log is that it has been carefully designed to make maximum use of the available quantizing levels to accurately express the full dynamic range of the three Cinema EOS cameras.

Canon-Log is a perceptually uniform digital transfer characteristic that transforms – within the camera processing system – the high-bit depth per RGB color component linear output of the A/D converters into a quasi logarithmic nonlinear transfer function. In the postproduction domain Canon-Log can be transformed back to the linear domain to facilitate such digital processes as conversions to other transfer characteristics (such as Cineon) color matrix transformations, secondary color correction, luminance tonal adjustments, image compositing etc. This transformation enables wide dynamic range digital intermediate processes to be performed in linear light space with minimum quantization errors.

Mapping the High-bit Depth Canon Log to an 8-bit HD Digital Representation

The EOS C300 cinema camera was the first of a planned series of such cameras intended to collectively address the multiple levels of digital cinematography for moviemaking, documentary, television drama, television commercial production, and a range of corporate and government related productions. To expedite a timely entry to the marketplace the high-performance DIGIC DV III image processor and attendant 50 Mbps 4:2:2 MPEG-2 Codec (initially developed for the high definition small-format XF camcorder series) was deployed. Accordingly, the in-camera recording is constrained to the 8-bit depth specified by that MPEG-2 standard. In addition, the camera delivers an uncompressed 8-bit serial digital representation of the 4:2:2 video component set via the standardized HD SDI output port.

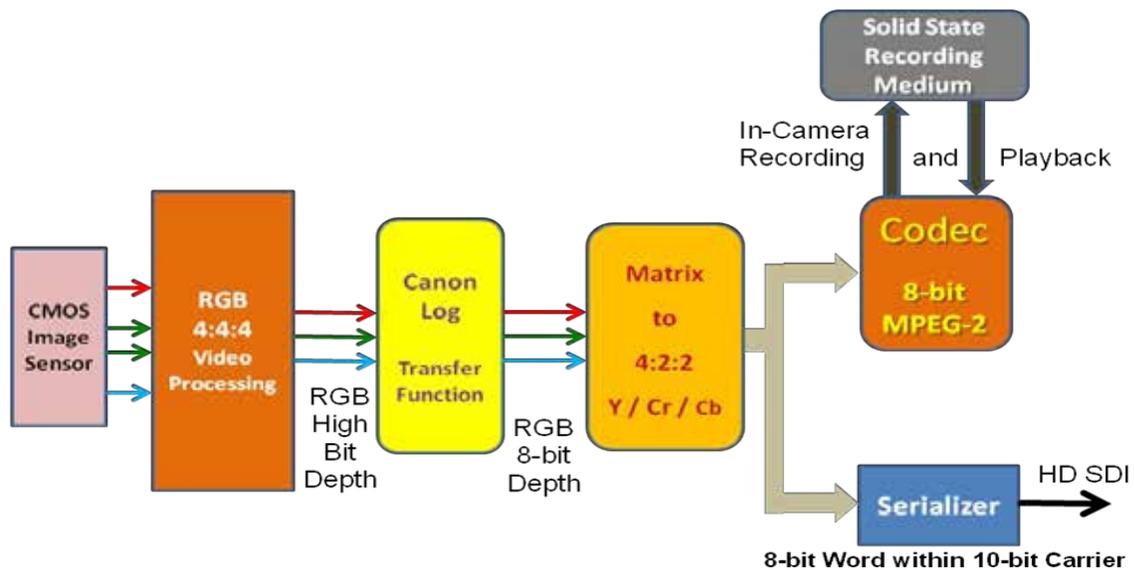


Figure 7 In the EOS C300 camera Canon-Log is implemented on high-bit RGB components and transformed to an 8-bit representation for in-camera and external recording

It is important to bear in mind that the HD SDI serial digital feed is an *interface signal* intended to facilitate connection to external system elements such as recorders, switchers, monitors etc. If the camera processing has been carefully implemented at a high bit-depth, then a conversion down to an 8-bit component set will lose very little of that processed image quality [6]. The HD-SDI serial signal is a ten bit word according to the SMPTE 292 M standards. Thus, the 10-bit serial signal constitutes a “carrier” for the 8-bit word that represents the actual 4:2:2 video output component set created in the C300 digital processing system. As such, when that serial video is processed within downstream 10-bit processing systems, it will fully maintain the high quality of the 8-bit information. If the video processing in the camera has been well-implemented at higher bit-depths (and appropriately rounded to the 8-bit representation) then the postproduction processes will not see much distinction from a full 10-bit interface. The Canon-Log curve was optimized for this 8-bit coding. This optimization reflected theoretical studies in addition to extensive subjective testing in collaboration with the major postproduction house Imagica Inc.

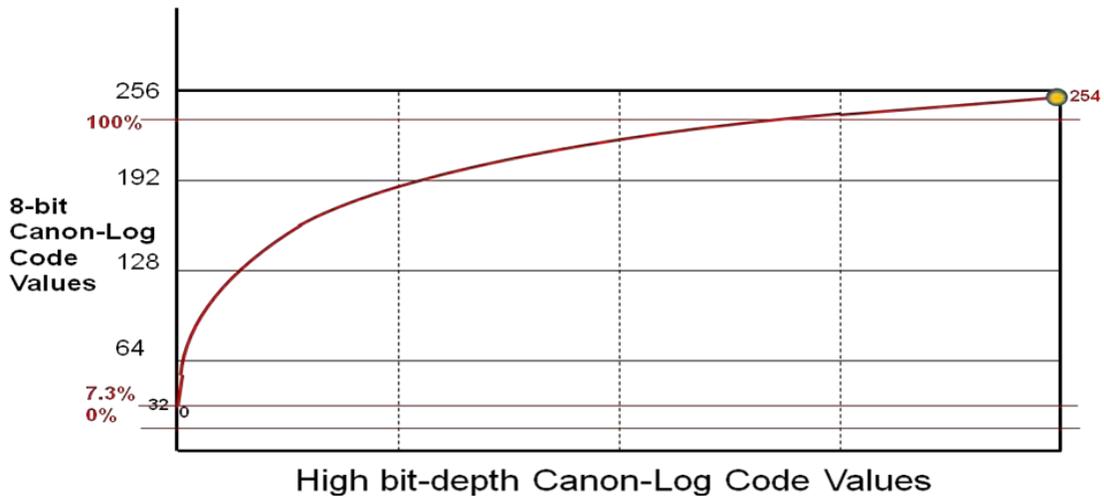


Figure 8 Showing the transformation characteristic that converts the high-bit RGB video from the image sensor to an output video 8-bit representation

Figure 9 shows the mathematics underlying Canon-Log curve and defines the 8-bit code values assigned to primary points along that curve: points related to the maximum reflectance level, the reference white level, the 18 percent gray level, a two percent and zero reflectance level. The information supplied here should aid in the design of a conversion to Cineon or alternatives.

$$y_{\%}(x_{\%}) = 0.529136 \times \text{Log}_{10}(10.1596x_{\%} + 1) + 0.0730597$$

$$-0.0452664 \leq x_{\%} \leq 8.00903$$

$$-0.0684932 \leq y_{\%} \leq 1.08676$$

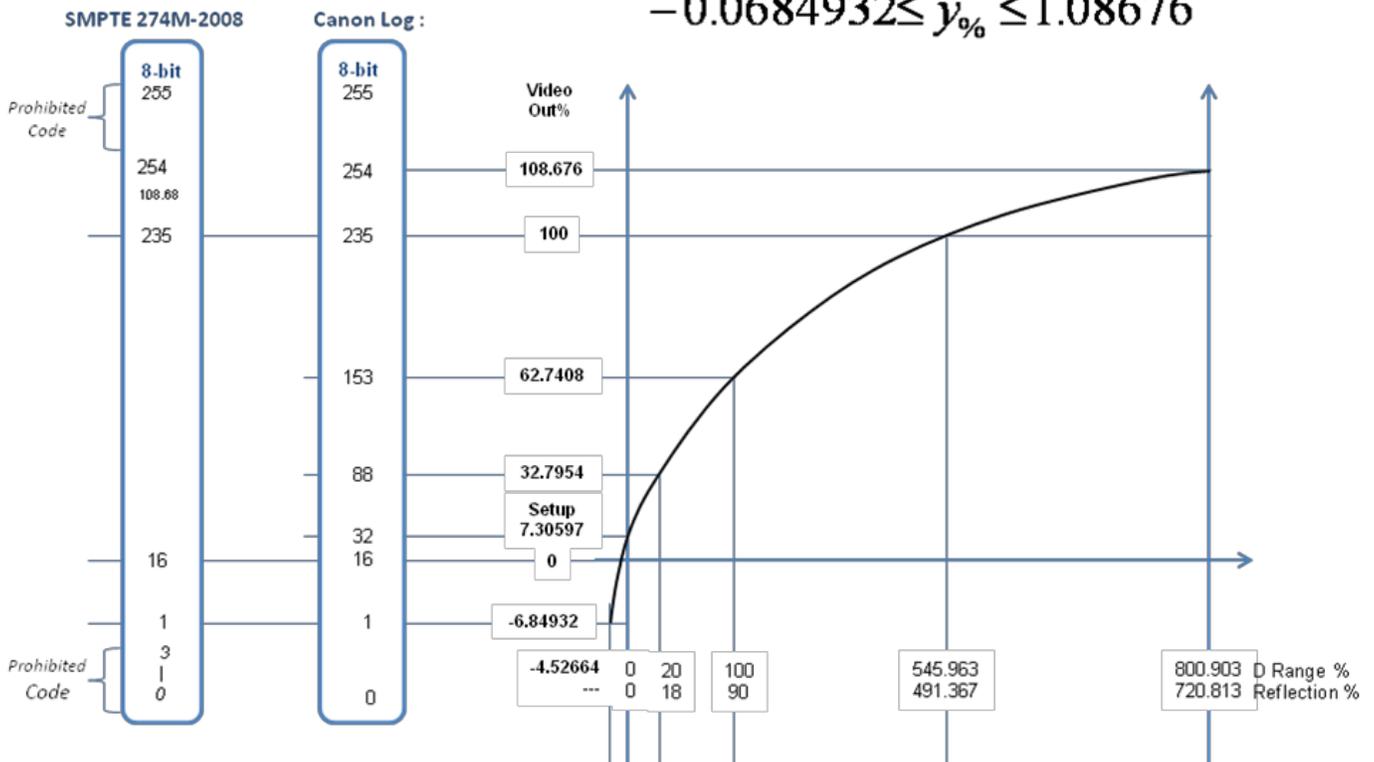


Figure 9 Canon Log transfer characteristic for an 8-bit output of the EOS C300 camera

The EOS C500 camera delivers a high quality uncompressed 10-bit 4K or UHD video output as a unique RAW file for external recording. In order to ensure faithful capture of the full 12 T-stop exposure latitude of the image sensor, and to lower the total data payload to be recorded, the RAW 4K video is nonlinearly processed according to Canon-Log. An alternative mode of operation of the camera originates 2K or HD as uncompressed RGB 4:4:4 video components at 10 or 12-bits at high frame rates – and, these too, are processed with Canon-Log.



Figure 10 The EOS C500 camera is a digital 4K/2K camera delivering an uncompressed RAW signal in the 4K mode and RGB component video for the 2K/HD mode

$$y_{\%}(x_{\%}) = 0.529136 \times \text{Log}_{10}(10.1596 x_{\%} + 1) + 0.0730597$$

$$-0.0452664 \leq x_{\%} \leq 8.00903$$

$$-0.0684932 \leq y_{\%} \leq 1.08676$$

Not used: 1017-1019 (10bit) 4065-4079 (12bit) code

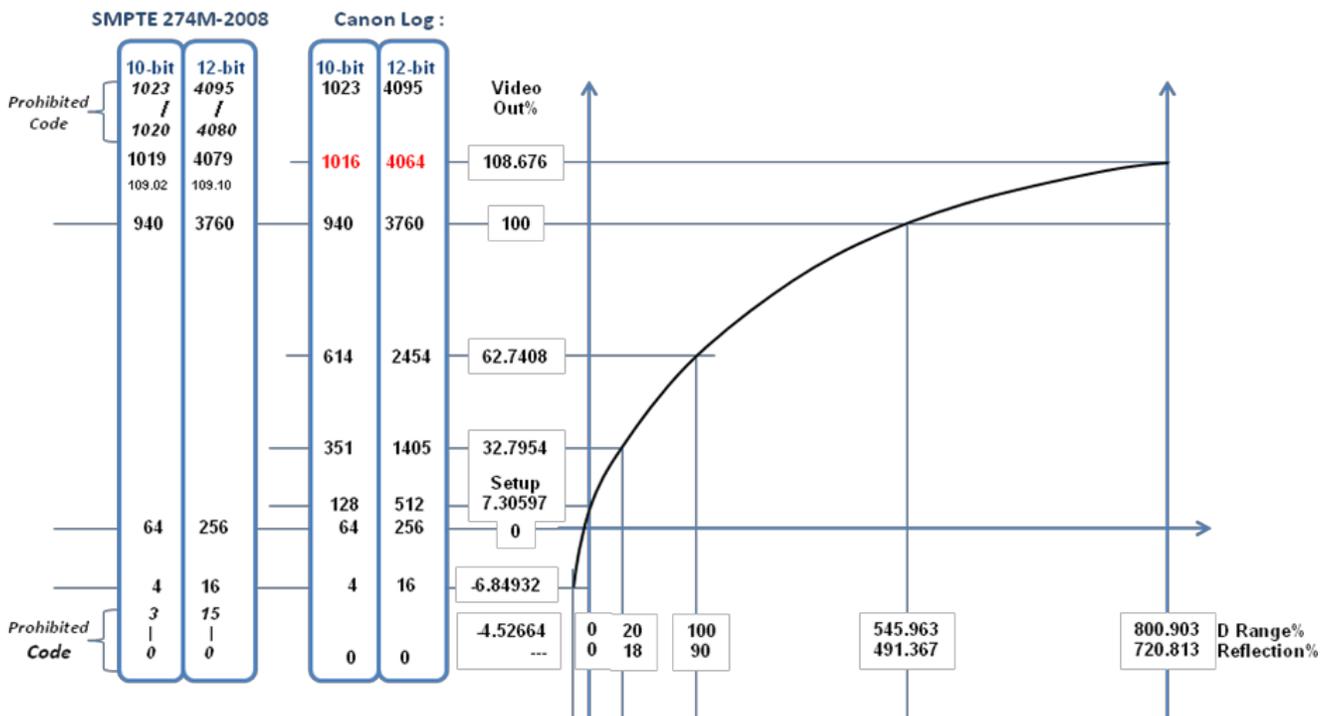


Figure 11 Transfer characteristic for the 10-bit and 12-bit outputs of the EOS C500 camera. This information will aid the design of conversion from Canon-Log to linear or other spaces.

Comparison of Canon-Log and Cineon Log

All of the various logarithmic transfer functions are typically 10-bit representations delivered as HD-SDI interfaces from the various camera outputs. To facilitate comparison of the Canon-Log characteristic with other established Log curves the 10-bit transformation is shown in the table below – relating the scene gray scale reflectances with code values and video levels

Table 2 Canon-Log Code Values

Reflectance (%)	Code Value	Video Level (IRE Units)
0	128	7.3
2	169	11.9
18	351	32.8
90	614	62.7
720	1016	108.7

As one example, the associated optoelectronic transfer functions for Canon-Log and Cineon-Log are compared below in Figure 12

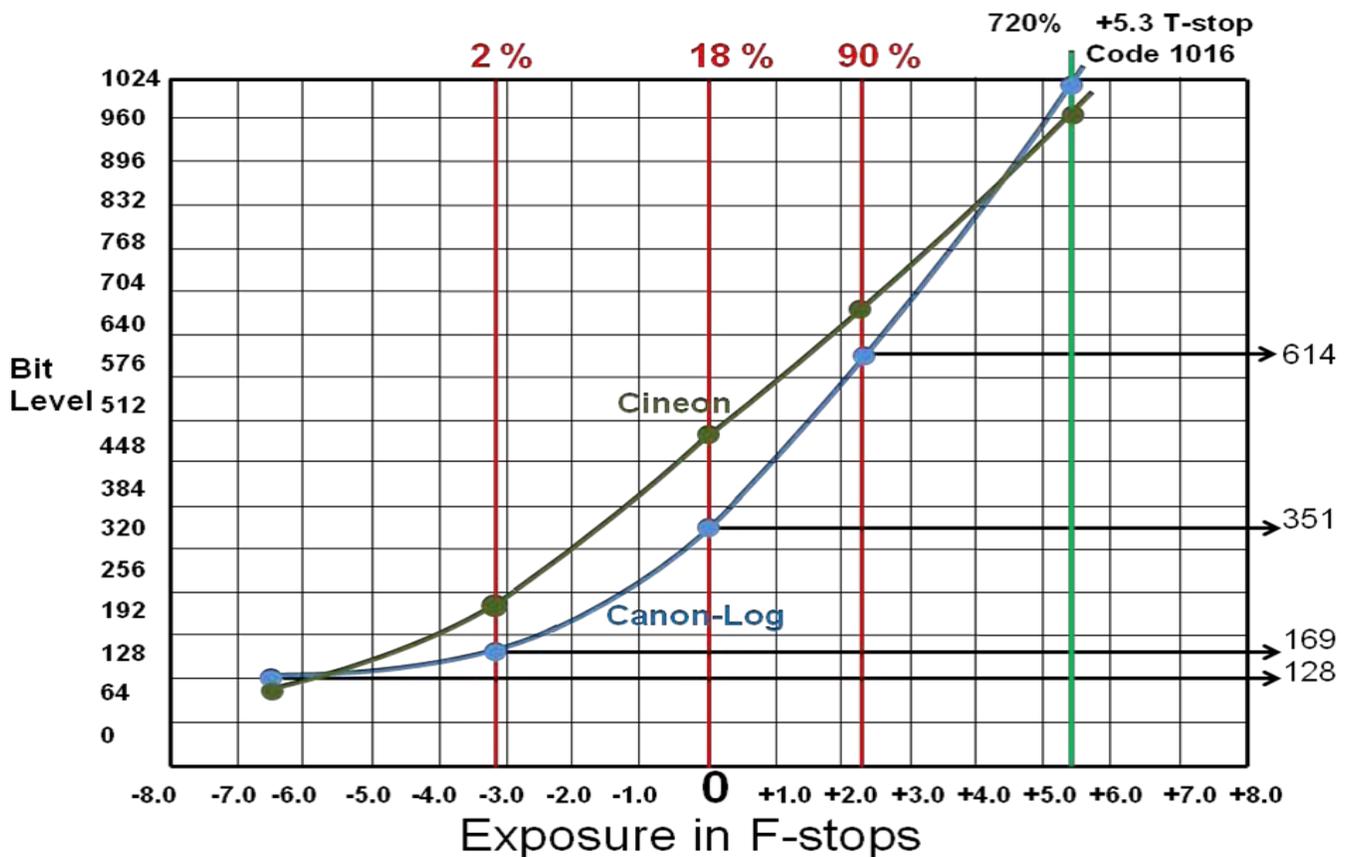


Figure 12 Optoelectronic Transfer Functions – showing the Canon-Log characteristic in the 10-bit domain to allow direct comparison with Cineon Log characteristic

EOS C300 Cine Production using in-Camera Recording

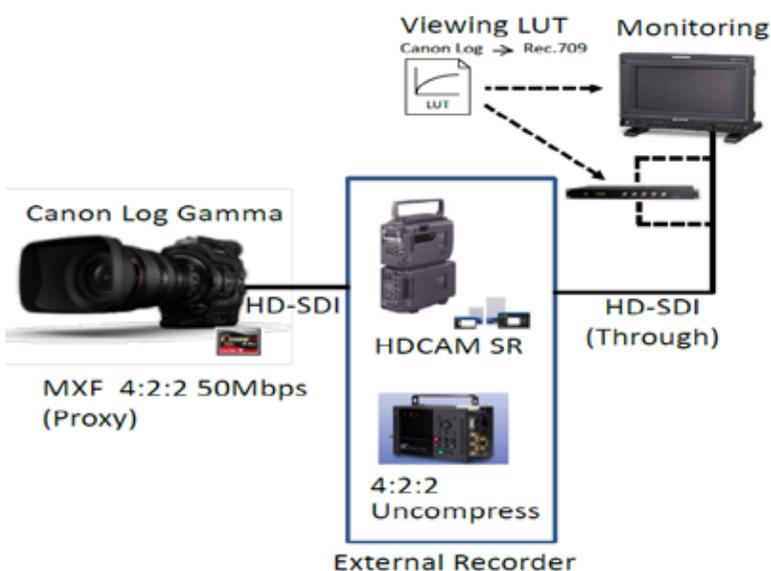
When the C300 is set to the Canon Log mode both the compressed video being recorded on the internal Compact Flash cards and the baseband HD video output via the HD-SDI port have this same transfer characteristic. When viewing Canon-Log coded images – that are intended for theatrical release *via film projection* – on a studio HD reference monitor, the display LUT that is applied should emulate the contrast range and colorimetry for film cinema within the boundaries of that display.



When viewing Canon-Log coded images – that are intended for theatrical release *via digital cinema projection* – on a studio reference monitor, the display LUT that is applied should emulate the contrast range and colorimetry of that digital theatrical display within the boundaries of the reference monitor.

Figure 13 Primary Canon-Log video is recorded in-camera while the baseband video output via HD-SDI is used for on-set monitoring

EOS C300 Cine Production using External Recording



In this scenario, the MPEG-2 50 Mbps video recorded in-camera is used as a proxy to facilitate later off-line editing, while the primary recording is the camera 8-bit baseband Canon-Log video fed via HD SDI to an external tape-based or tapeless recording system.

Figure 14 Compressed HD recordings within the C300 are proxies to support on-line editing of the primary uncompressed video recorded externally on a baseband recording system

The Postproduction Process

Here it is assumed that the video in Canon-Log mode has been recorded on an external high-end recorder (tape-based or tapeless) and that the MPEG-2 files recorded in-camera are used as proxies for off-line editing. During that process, a viewing LUT converts the Canon-Log to Rec 709 for viewing purposes. Separately, during the on-line conform and color grading, a LUT is used to transform the Canon-Log to Cineon Log space.

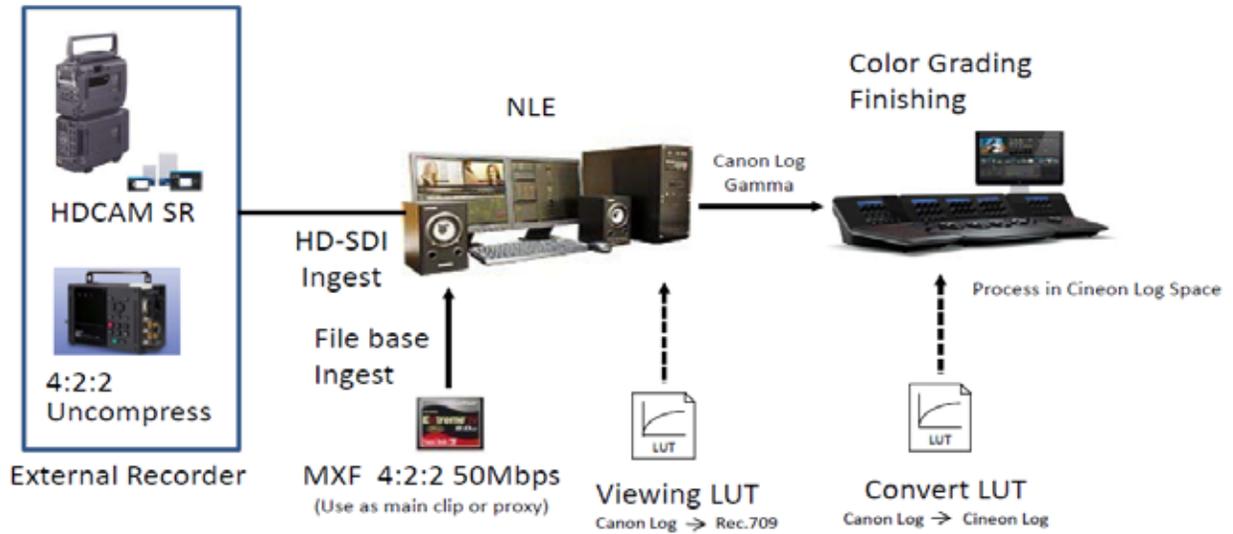


Figure 15 Showing postproduction of the recorded baseband signals while using the in-camera compressed recordings as proxies for the off-line editing

EOS C500 Cine Production using External Recording

The EOS C500 camera applies the Canon-Log nonlinear transfer function to the 4K RAW video it creates and also to the 2K RGB video component outputs, to reduce the data payload.

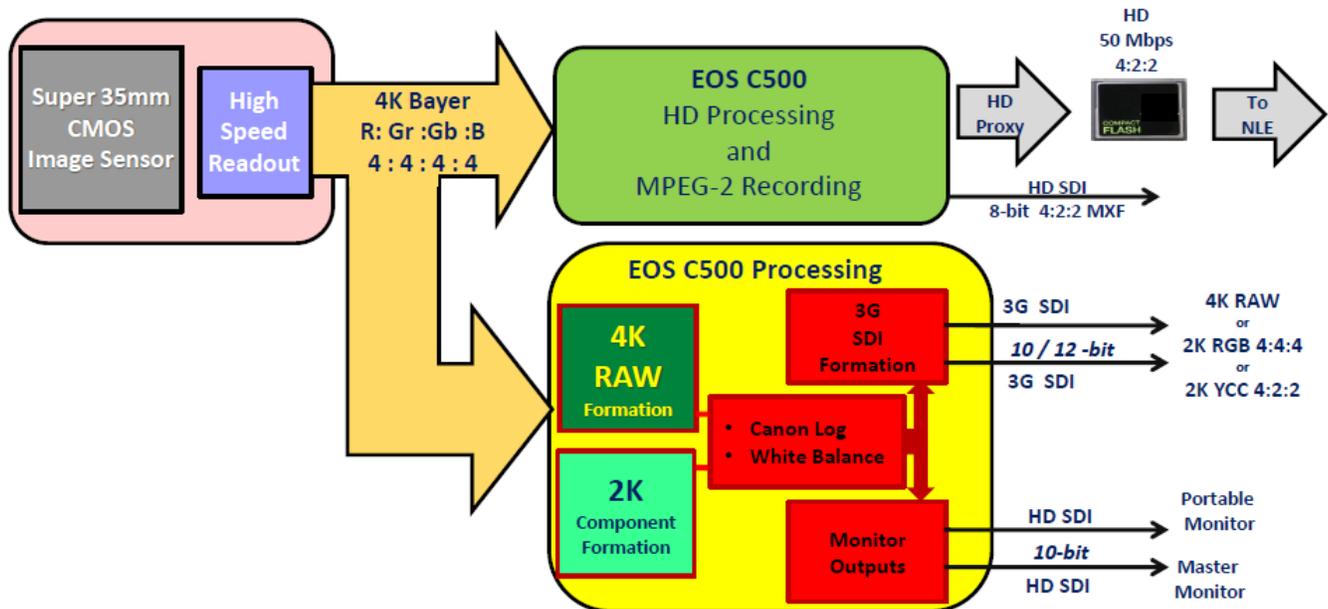


Figure 16 Canon-Log is always applied to all of the uncompressed video outputs of C500

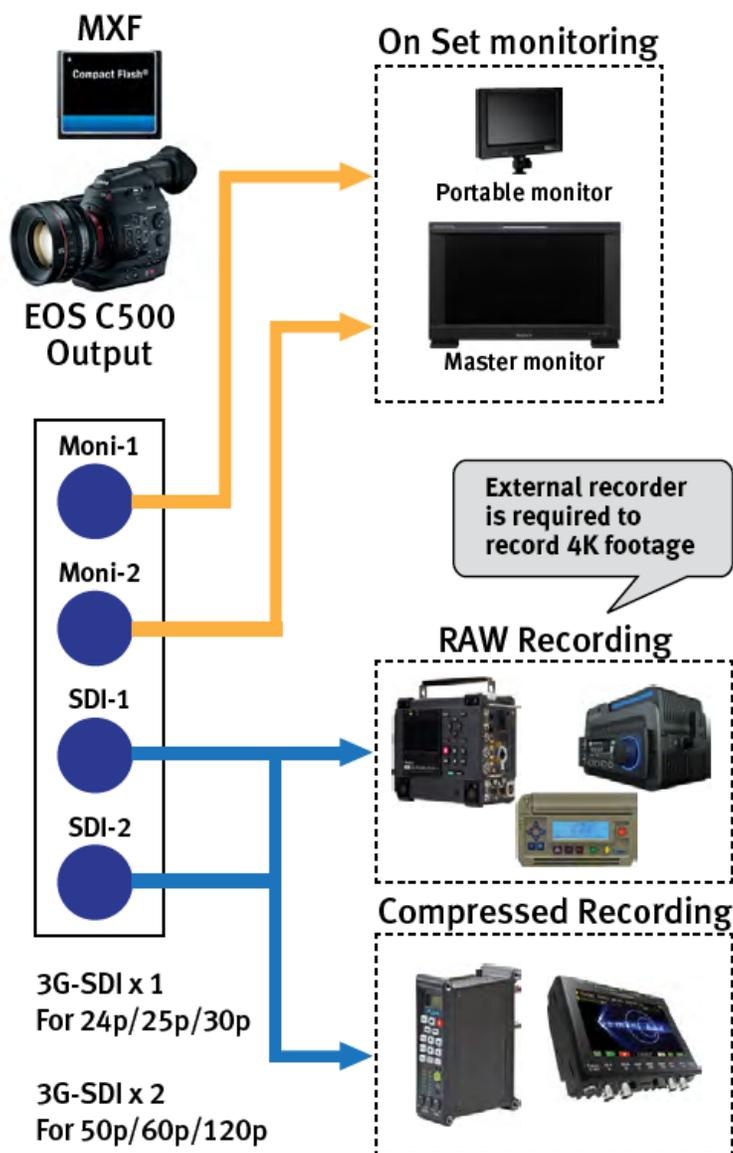


Figure 17 *The uncompressed 4K RAW is sent via 3G SDI interfaces (according to the SMPTE 425M-1: 2011 serial interface standard) to external recorders while the monitoring video is output via HD-SDI interfaces*

Processing Canon-Log Coded Images within a Postproduction Workflow

If the Canon-Log coded representation is converted to DPX Log File for a particular postproduction process it must employ an Input Conversion Transform (ICT) to readjust its nonlinear transfer characteristic to be compatible with the specifications pertaining to that color grading system. Canon Cine-RAW Development Application software has been developed to support this ingestion and transformation. It is anticipated that various third party options will become available to accomplish the same task.

When shooting with the EOS C500 the monitoring outputs always deliver an HD rendition of whatever format is being originated in the camera – via two HD-SDI ports. In structuring this 10-bit monitoring video, a rudimentary de-Bayer is done in the case of 4K origination, and in the downconversion to HD a LUT can be selected that converts the video to conform to Rec 709. At the same time, the C500 is recording HD proxy files (as 50 Mbps 4:2:2 MPEG-2) on the internal Compact Flash memory cards.

Canon is collaborating with a number of international manufacturers of solid state recording systems for the C500. Some recorders do not compress the camera output data while others do so. Some convert the Canon RAW files to their own unique recording file formats. Some de-Bayer within the recorder and provide 4K output video via multiple SDI interfaces.

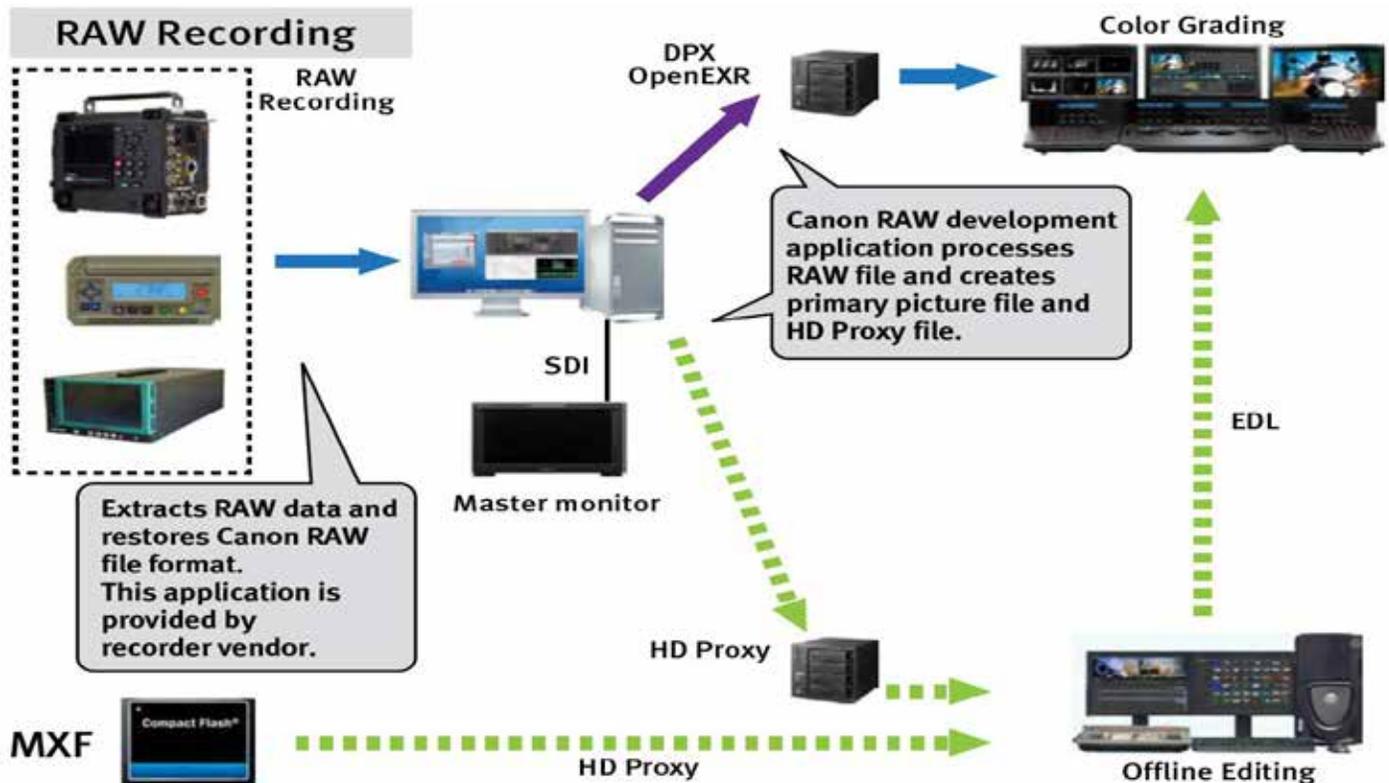


Figure 18 *Generic postproduction process entailing processing to convert Canon-Log to whatever space (Linear, Cineon etc) pertains to the particular finishing and color grading system being employed*

Summary

This paper has outlined the basics underlying a special optoelectronic transfer function that can be invoked in the EOS C300 and EOS C500 cinema camcorders for digital acquisition of motion imaging material.

The resulting digital video images are intended to support postproduction processing using techniques akin to those employed for film-originated material in a digital intermediate system. The transfer function is quasi-logarithmic and its design took careful consideration of the remarkable noise and dynamic range characteristics of the unique Super 35mm CMOS image sensor used in both cameras. The Canon-Log curve implements an optimized allocation of quantization levels that ensure faithful reproduction of both the shadowed regions and the overexposed regions of a specific scene.

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