Canon

WHITE PAPER

EOS C300 / EOS C300 PL

SENSITOMETRIC CHARACTERISTICS OF THE EOS C300 DIGITAL CINE CAMERA

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CINEMA EOS

Sensitometric Characteristics of the EOS C300 Digital Cine Camera

Abstract

Two separate white papers discuss technical details relating to a new 35mm CMOS single-sensor developed by Canon specifically for digital cine motion imaging. The excellent noise performance of the individual sensors coupled with its high saturation level produce a wide dynamic range of 73.5 dB for the green component, and 72 dB for the matriced Luma. It becomes the task of the camera digital processing system to implement a nonlinear transfer characteristic that can optimize the tonal reproduction of the nominally exposed portion of a given scene while also retaining as much detail as possible in the overexposed regions. It is the intent of this paper to examine the sensitometric characteristics of the EOS C300 cine camera

The on-board recording of the camera utilizes a high-performance 50 Mbps 4:2:2 MPEG-2 codec. This compression algorithm is constrained to an 8-bit depth according to this international standard. Accordingly, the matriced 4:2:2 components are converted to an 8-bit component set for recording

1.0 Introduction

Significant strides have been made in extending the performance capabilities of the new generation of large-format single-sensor digital cine camera and recorder systems. The technical evolution continues apace. Many variants, spanning an ever-broadening range in terms of image performance, operational features and interfaces, and pricing have appeared. To the cinematographer, the important attraction of these digital acquisition systems is their ability to use the existing global inventory of 35mm motion picture film lenses, to continue to exploit the creative use of the shallow depth of field. At the same time, new 35mm lenses — especially zoom lenses — are now being developed by all of the major optical manufacturers. As a major adjunct to the new EOS C300 cine camera system, Canon has developed two new zooms lenses (a wide-angle and a telephoto) and three new cine Prime lenses — all having full 4K optical performance in terms of MTF at picture center and extremities, well-controlled relative light distribution, and particularly tight control of chromatic aberrations. Such optical performance combines with the excellent 4:4:4 RGB video component set originated in the new image sensor to produce a high-performance final HD image quality.

Advances have also continued in nonlinear digital processing techniques to better emulate the extraordinary image capture range — long synonymous with 35mm motion picture film. In particular, the use of digital logarithmic optoelectronic transfer functions to optimally dispose the digital coding levels to ensure superb tonal reproduction of the primary scene content while also retaining important detail within overexposed portions of the scene has become the norm. The Canon EOS C300 camera combines such strategies with other innovations in RGB digital processing to produce very high RGB video quality.

2.0 Exposure Latitude of the EOS C300 Digital Cine Camera

Exposure Latitude [1] is a measure of the cine camera's ability to simultaneously reproduce detail in deep shadowed and highlighted areas within a single scene. In the moviemaking world, cinematographers are highly skilled in exploiting the generous exposure latitude of motion picture film to originate dramatic intra-scene contrasts for creative cinematic imagery. Exposure Latitude is usually measured in terms of the number of lens f-stops (with each f-stop representing a doubling or halving of light level projected on to the film plane) that can be faithfully recorded by a given film stock. It is the accepted practice by cinematographers to assign an 18% neutral grey card as the reference exposure with a film camera and to assess the film stock by the number of f-stops of latitude that is realizable above and below this reference.

In a separate paper [2] the noise characteristic and associated dynamic range of the new Canon CMOS image sensor was examined. This paper examines the deployment of this sensor within the new EOS C300 digital cine camera.

To fully capitalize on the 800% dynamic range of the CMOS image sensor and achieve a camera operational exposure latitude of the order of 10 to 12 F-stops a radical departure from the broadcast video gamma and associated knee curve is required for the cine nonlinear optoelectronic transfer characteristic. Canon has developed a special logarithmic transfer characteristic to do this. Its design entailed a careful mathematical analysis of possibilities followed by considerable subjective testing on real world images. A separate white paper will deal with the technical details this Canon-Log characteristic. Figure 1 is intended to convey the general concept behind this nonlinear transfer characteristic.

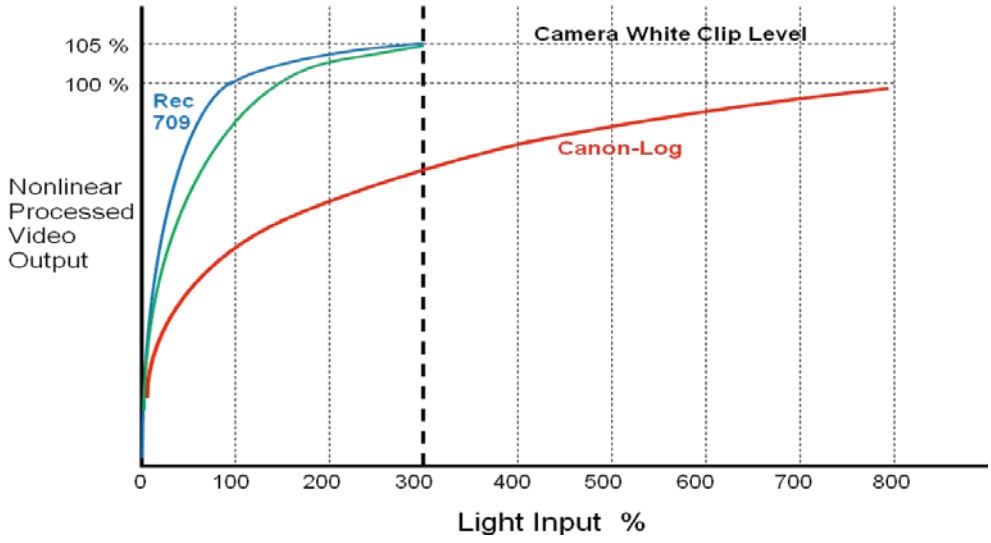

Figure 1 *Illustrating the concept of the Canon-Log curve specifically designed to fully utilize the 800% dynamic range capability for the CMOS image sensor in order to achieve wide exposure latitude in a digital cine camera*

As previously shown [2] the effective dynamic range of the green video component is 73.5 dB. This translates into a 12 f-stop range of exposure latitude as shown in Figure 2

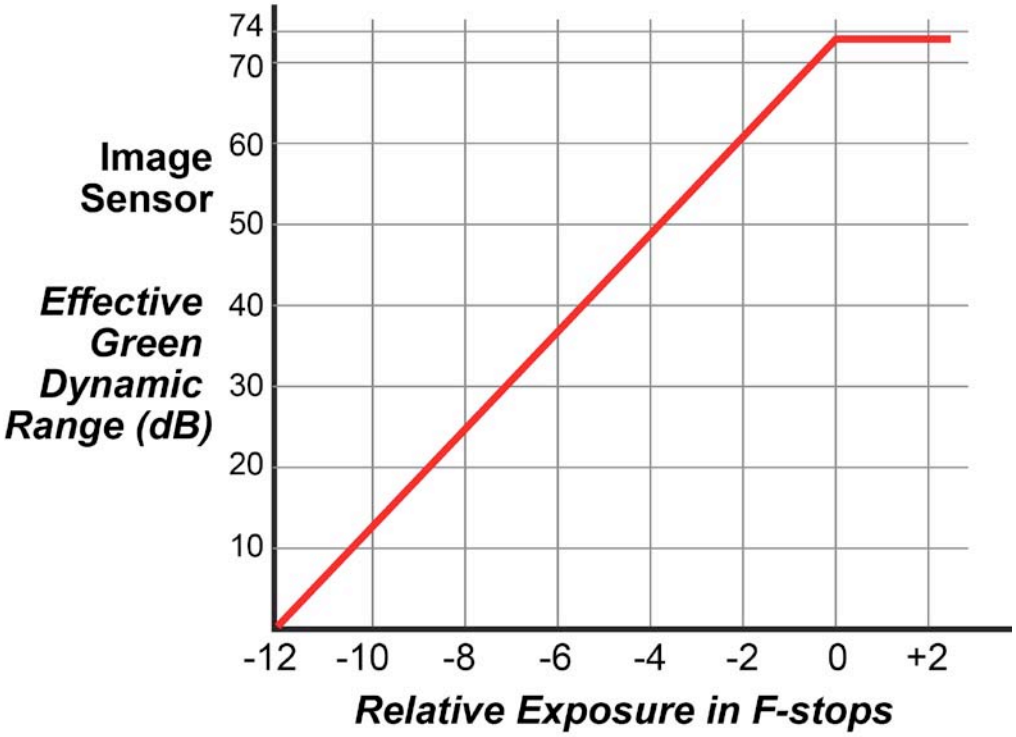

Figure 2 *Showing the relationship between relative exposure and the dynamic range of CMOS sensor's green video output*

3.0 Sensitometric Characteristics

The traditional broadcast video specification for lens-camera sensitivity is measured by the lens aperture setting in F-stop required to achieve 100 IRE units of Luma when the system is imaging a reference white chart having 89.9% reflectance under 2000 Lux of 3200 degree Kelvin illumination (with Camera Master Gain set to 0 dB, Gamma switched off, and all image enhancement switch off). The amount of electronic noise in the image is another important issue closely allied with this sensitivity specification because of its bearing on dynamic range.

Under these conditions, the EOS C300 camera has a reference sensitivity rating of F-10 and a Luma signal to noise ratio of 54 dB.

However, in digital cine imaging the cinematographer is constantly cognizant of three aspects of exposure:

- Lens aperture
- Sensor sensitivity
- Shutter speed

Both aperture and shutter control how much light comes into the camera. How much light is actually required is determined by the sensitivity of the image sensor. The cinematographer has considerable experience in operating "blind" with motion picture film imaging — where he mentally envisages the transfer characteristic of the specific film stock he is using — while making adjustments to lighting, exposure, and shutter to ride up and down that characteristic dependent upon the scene and the desired "look". These practices instinctively transfer to the operation of a digital cine camera.

In digital cinematography, the camera operational sensitivity is measured as an Exposure Index (EI) [3] — formerly quoted as an ASA speed, but today more usually expressed as an ISO speed. The established practice within the motion picture film community (and increasingly with digital cine) is to measure the ISO value using a light meter and a neutral gray card of 18% reflectance. There is a recognized method of calculating the reference ISO speed rating of the digital cine camera that corresponds to the above video sensitivity specification [4].

For the EOS C300 camera the nominal rating of its exposure index at 0 dB master gain is specified to be 640 ISO for a picture capture rate of 23.98 Hz using an equivalent 180-degree shutter.

Overall subjective image quality is bound up in the three key image sensor parameters of sensitivity, signal to noise, and dynamic range. Their combination is often termed the Sensitometric characteristic of the camera system. Dynamic range of the image sensor is a variable with ISO speed — this, because of noise in the dark areas of a scene and clipping in the highlight areas (due to sensor well-saturation). For the reference 640 ISO setting of the EOS C300 camera, and using the Canon-Log nonlinear transfer function, the gain calibration of the camera system is such that at 0 dB Master Gain setting, correct exposure of the 18% gray card will afford 4.8 stops of exposure latitude above that exposure and 7.2 stops of latitude down into the dark region.

If the Master gain is raised by 2.5 dB then the noise floor is amplified, but the lens setting can be readjusted for an ISO 850 setting to restore the correct 18% gray card exposure — under which condition the overall effective dynamic range is increased from 600% to 800 %. This raises the exposure latitude to 5.3 stops above the 18% exposure level affording a higher degree of protection of the capture of scene's brightest highlights. This is sometimes termed the "Push Process" in cinematography.

The cinematographer is constantly preoccupied with exposure and optimizing the exposure latitude according to scene illumination and the content of a particular scene. They instinctively and diligently pay close attention to exposure latitude in both the dark and overexposed portions of a scene. Accordingly, they are much more interested in the overall sensitometric characteristics of the digital camera.

A novel method of portraying the behavior of camera Luma exposure latitude and noise over a range of ISO speeds was recently proposed [5] and Canon supports this methodology. Using this graphical representation the sensitometric performance of the EOS C300 camera employing the new CMOS image sensor is summarized below.

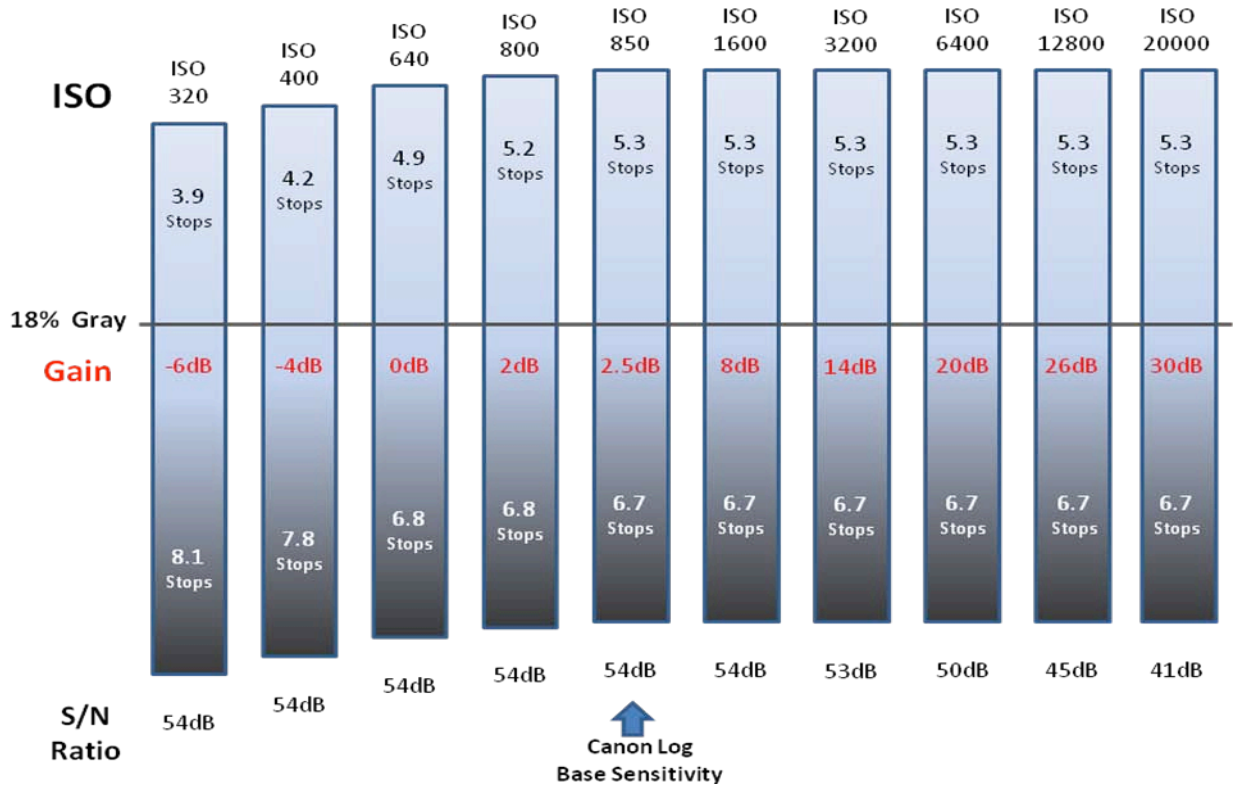

Figure 3 *Showing the overall sensitometric behavior of the EOS C300 camera. This allows assessment of the exposure latitude behavior (with respect to the reference 18% gray) with ISO setting while correlating this with the Master Gain setting and associated Luma signal to noise performance.*

4.0 8-bit MPEG-2 Codec

The video components within the EOS C300 camera are processed at a high bit-depth for Green, Red and Blue. This allows excellent nonlinear processing of the video that ensures a superb tonal reproduction over the nominally exposed range (that is, from reference white down to capped black level — which defines the formal contrast ratio of the camera). A contrast ratio in excess of 500:1 is achieved. In addition, this bit depth has sufficient overhead to handle overexposed signals. When the camera is set to 850 ISO and the Gamma transfer function is switched to Canon-Log an 800% overexposure is achieved — which translates to the camera being able to capture an Exposure Latitude of 12 f-stops.

The Red, Green, and Blue video signals are subsequently matriced to formulate the Luma video component and the two color difference signals according to the 4:2:2 coding structure, preparatory to being compressed according to the MPEG-2 422 Profile @ High Level international standard. This standard stipulates an exclusive 8-bit depth. Accordingly, the fully processed 4:2:2 video components are rounded to an 8-bit depth before being sent to the compression engine. This process loses very little of the careful management of the nonlinear transfer function performed (as described above) on RGB at the higher bit depths.

The serial representation of the uncompressed 4:2:2 component set is structured from the parallel 8-bit component set and is fed to the camera's HD SDI on a standardized 10-bit carrier interface allowing parallel outboard recording to be implemented if desired.

6.0 Perspective on Luma Signal to Noise Performance

In terms of a contribution to overall image quality, electronic noise is difficult to quantify — it is best assessed by viewing actual captured imagery. Just as in motion picture film imaging, the image quality troika of exposure latitude, sensitivity (ISO speed) and noise (or "grain" in the case of film) needs to be collectively assessed over a range of images.

In an important technical paper [4] an Eastman Kodak team made a very interesting comparison between 35mm motion picture film and an HDTV camera. They examined the various imaging attributes and attempted to correlate the two media. Their most interesting analysis attempted to find a way to compare electronic noise in the HD camera with the granularity characteristic of motion picture film. They discussed their methodology for formal measurement of film granularity and the subsequent technique they used to convert this to an equivalent video noise (this being an unweighted r.m.s noise level in a 30MHz bandwidth in dB below reference video white level). They used the green record on two very popular film stocks — available at that time — the EXR 5245 and EXR 5296 and compared the converted noise levels with that of the green HD video.

Using this technique the EOS C300 camera performance is compared with those two film stocks in Table 1.

Table 1

MASTER GAIN SETTING (dB)	EXPOSURE INDEX (ISO)	SIGNAL to NOISE (dB)	35mm MOTION PICTURE FILM STOCK
- 6	320	54	
- 3	400	54	
0	640	54	
+2.5	850	54	
+8	1600	54	
+14	3200	53	
+20	6400	50	
		49	EXR 5245 (EI 50) *Ref [4]*
+26	12800	45	
		44	EXR 5296 (EI 500) *Ref [4]*

This comparison is intended to put perspective on noise/grain in imagery. Various new film stocks have appeared since the publication of the original Kodak paper that unquestionably

exhibit improvements in their granularity characteristics. What is of significance, is that the cinematographers and film producers were never as acutely sensitive to this image artifact as say, broadcast engineers for their high-end studio cameras. The presence of grain was such a fact of life, that it is still spoken with admiration as constituting one important component to the oft-described "organic" look of film.

The 54dB Luma signal to noise is subjectively invisible on a high-performance large HD display (under normal setup) at the 640 ISO exposure index setting. As the ISO setting increases the noise does finally become visible. It has been commented by the early producers using the EOS C300 that there is an "organic" look to this noise which they feel is different to what they had noted in other video cameras. While still too early to properly quantify what this might be, it is a fact that the new Canon image sensor is devoid of any visible fixed pattern noise (even at the 20,000 ISO setting) and the visible noise does have randomness that is evocative of the grain in relatively slow-speed motion picture film.

7.0 Conclusion

An important new 35mm single image sensor has been developed. It offers video imaging attributes reflective of the most contemporary in CMOS imager technology, and has elevated HD digital motion imaging to a plane that offers a viable creative alternative to 35mm motion picture film.

REFERENCES

[1] Dr. R.W.G. Hunt "*The Reproduction of Color in Photography Printing and Television" Fountain Press, 1975 Pages: 167 — 184*

[2] L. Thorpe, Canon, *"New 35mm CMOS Image Sensor for Digital Cine Motion Imaging"* Canon White Paper, November 2011

[3] Fujifilm Team, "*New Fujicolor High-Speed Negative Film and Fujicolor Positive Film"* J.SMPTE, July 1985, p: 735-742

[4] G. Kennel et al of Kodak, *"A Comparison of Color negative Films and HDTV Cameras for Television Program Production"* SMPTE J., May 1991

[5] Hans Kiening, "*4K and Beyond — Comparing Digital Camera Performance: Part II"* SMPTE J., May/June 2011