WHITE PAPER

EOS C500 & C300

SENSITOMETRIC CHARACTERISTICS OF THE CINEMA EOS DIGITAL CINE CAMERA

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Sensitometric Characteristics of the Cinema EOS 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 sensor 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. A special logarithmic transfer characteristic optimizes the tonal reproduction of the nominally exposed portion of a given scene while also considerable retaining in the overexposed regions. It is the intent of this paper to examine the overall sensitometric characteristics of the EOS C500 and EOS C300 cameras. The C500 delivers 12-bit 2K/HD and 10-bit 4K/UHD to external recorders. The on-board recording of the cameras 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. The implications of this will be discussed.

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 and 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 Cinema EOS camera systems, Canon has developed five new zooms lenses (wide-angle and telephoto) and six 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. A new Super 35mm CMOS image sensor specific to digital motion imaging was developed in concert with these lenses which facilitated a higher degree of optimization of key imaging parameters such as sharpness and color reproduction.

Advances have also continued in nonlinear digital processing techniques to better emulate the extraordinary image capture range that has long been 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 Cinema EOS cameras combine such strategies with other innovations in digital processing to produce very high 4K/UHD/2K/HD video quality.

The sensitometric characteristic of a digital camera is a measurement of its overall reaction to the light projected by the lens into the camera. First and foremost are the specific characteristics of the image sensor itself. Closely allied with this is the subsequent digital processing within the camera and how it prepares the digital information for capture on a digital recorder – the objective here being to faithfully capture all of the core image performance parameters delivered by the image sensor.

2.0 Exposure Latitude of the Cinema EOS 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 T-stops (with each T-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 T-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 EOS C500 and C300 digital cine cameras.

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 T-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 deals [3] with the technical details this Canon-Log characteristic. Figure 1 is intended to convey the limitations of the television-centric ITU Rec BT. 709 optoelectronic transfer characteristic and the alternative advantages of the cinematic logarithmic transfer characteristic.

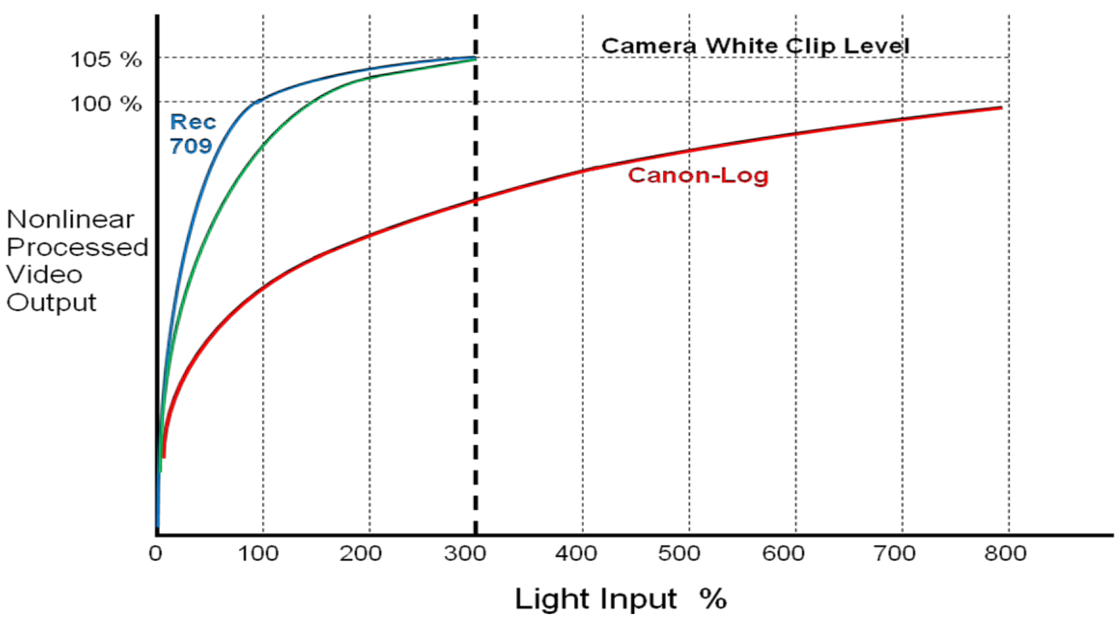

Figure 1 Illustrating the concept of the Canon-Log curve specifically designed to fully utilize the 800% dynamic range capability for the CMOS image sensor in order to achieve wide exposure latitude in a digital cine camera

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

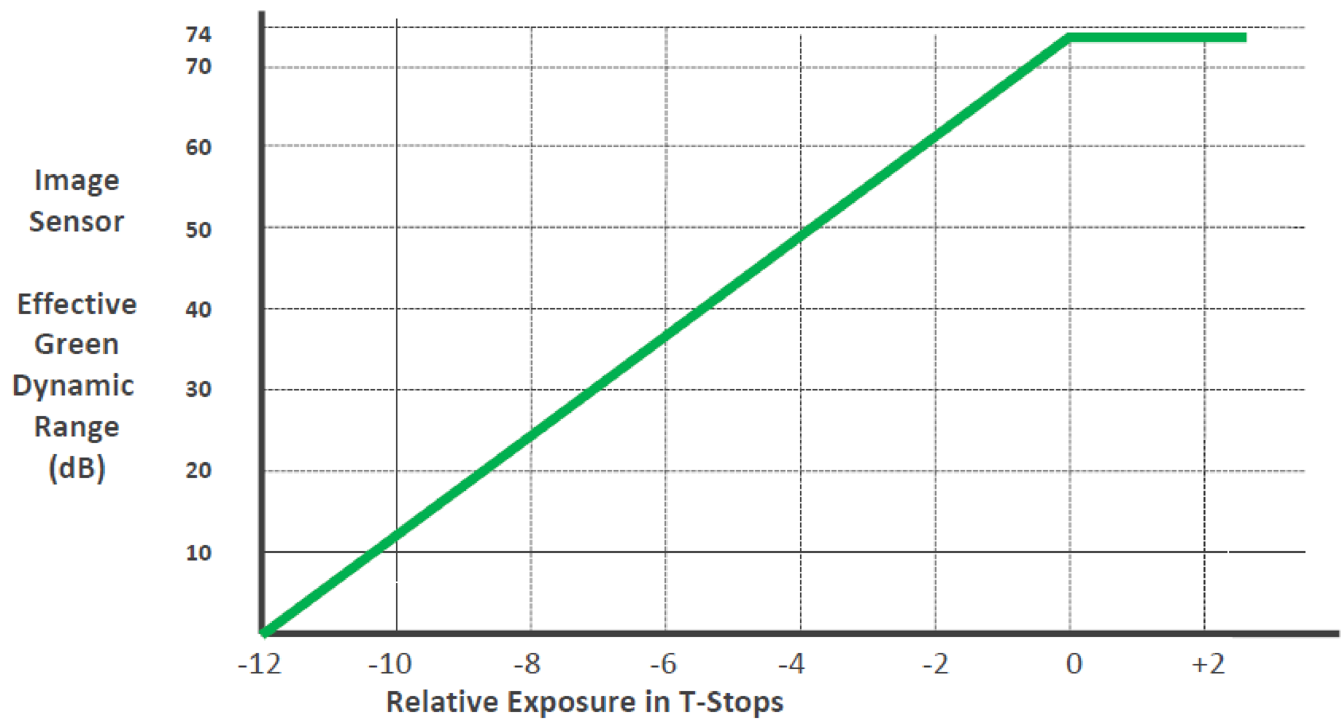

Figure 2 Showing the relationship between relative exposure and the dynamic range of CMOS sensor's green video output

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). Under those conditions, 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 C500 and C300 cameras have 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 four aspects of exposure:

- Scene illumination
- 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) [4] – 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 C500 and C300 cameras 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. It clearly shows the all-important disposition of the image sensor exposure above and below the reference 18% gray over the entire ISO range. Using this graphical representation the sensitometric performance of the EOS C500 and C300 cameras employing the new CMOS image sensor is summarized below.

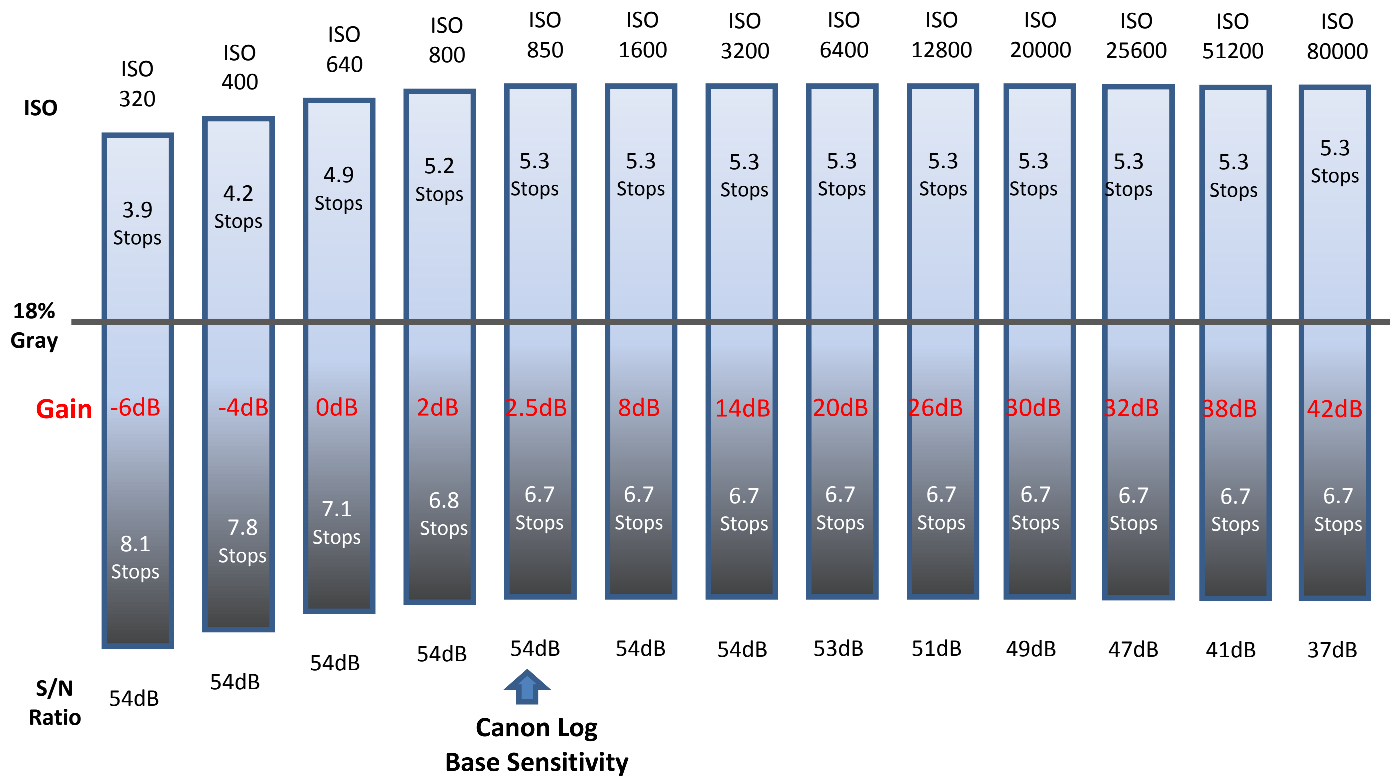

Figure 3 Showing the overall sensitometric behavior of the cinema EOS cameras. This allows assessment of the exposure latitude behavior (with respect to the reference 18% gray) with ISO setting while correlating this with the Master Gain setting and associated Luma signal to noise

4.0 ISO Setting Control in Cinema EOS Cameras

The Super 35mm CMOS image sensor developed by Canon is novel in that the gain control system used to alter the camera ISO settings is embedded within the image sensor itself – prior to the on-chip A/D conversion system. This analog gain control is a key element within the overall amplification architecture of the sensor. When scene illumination is low the gain is raised and this tends to maintain an approximately constant signal level going into the A/D converters. In combination with some other on-chip strategies (the dual photodiodes within each individual Photosite used for the Auto Focus feature is also a key contributor to lowering the image sensor noise level) the excellent preservation of constant exposure levels above and below the reference 18% gray with increasing ISO settings is ensured.

5.0 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 [5] 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.

Kodak 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 C500 / 300 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 FILMSTOCK
- 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]*

Note that the Cinema EOS cameras at ISO 12,800 have a granularity (noise) level equivalent to that of the high-speed film EXR 5290 (ISO 500). 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 many producers using the EOS C300 and C500 cameras that there is an “organic” look to this noise which they feel is different to what they had traditionally noted in video cameras.

While noise is clearly very visible at the highest ISO settings it does exhibit a randomness that is evocative of the grain in relatively slow-speed motion picture film. Up to ISO 12,800 the subjective appearance of the noise is remarkably benign. For a given scene illumination this does facilitate creative flexibilities in controlling depth of field by playing settings of lens aperture versus ISO gain with still acceptable noise levels. A further feature of this image sensor is that fixed pattern noise (FPN) is virtually invisible even at the highest ISO settings..

6.0 The C500 Camera in both 4K and 2K Mode

The C500 and C300 (and the C100) all use exactly the same 4K CMOS image sensor that has been described in a companion paper [2]. As shown in another paper [3] these cameras all have total exposure latitude of 12 T-stops. It is important that the video processing that prepares both the 4K RAW data stream (when the C500 is selected to originate 4K) and the 2K video component set protects that full range of exposure. As shown in Figure 4 the image sensor always delivers the four 2K components described in those two papers. The Canon Log transfer characteristic is applied to all four components to preserve the 12-stop exposure latitude. In the case of 4K these components are structured into RAW file clips that are then multiplexed into a singular 10-bit RAW out data stream from the camera (10-bit bit depth is necessary to have the RAW signal stay within the data rate constraints of the 3G SDI output interface standard.

When the C500 is in its 2K (or HD mode) the two green components are summed and the set of output RGB 444 components are streamed out at a 12-bit depth. Thus the 2K/HD mode of operation provides both excellent tonal reproduction and a superb color reproduction – both of which become highly beneficial when the images are being manipulated in postproduction.

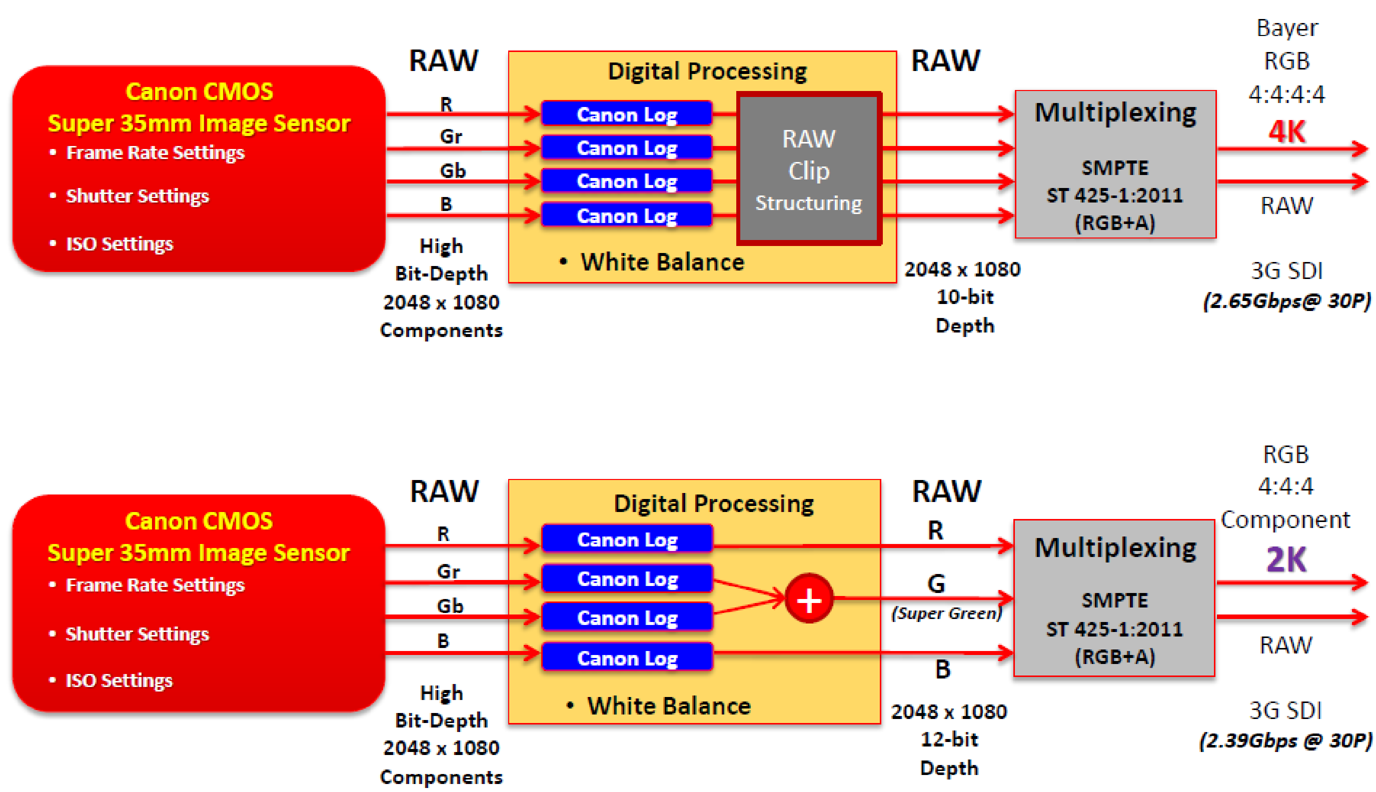

Figure 4 Showing a simplifies rendition of C500 signal processing for 4K and 2K operation

7.0 On-Board Recording with the 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.

8.0 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 the highly flexible sensitometric controls have 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, May 2014

[3] L. Thorpe, Canon, "*Canon-Log Cine Optoelectronic Transfer Function:*
Canon White Paper, May 2014

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

[5] 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