Canon

WHITE PAPER

EOS C300 MARK II

IMAGE PERFORMANCE ENHANCEMENTS IN THE EOS C300 MARK II

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CINEMA EOS

Image Performance Enhancements in the C300 Mark II

Abstract

The original EOS C300 digital cine camcorder employed an innovative new 4K UHD Super 35mm CMOS image sensor developed by Canon [1]. The readout system dissected that 4K sampling into four parallel HD components. The summation of the two green components reduced aliasing that, in turn, supported a higher Luma MTF [2]. The new C300 Mark II preserves these basic strategies but within a totally new 4K CMOS image sensor design. The new camera is intended to significantly extend the overall image performance of HD beyond that of the C300 while further supporting the alternative 2K cinema format. A 15-stop dynamic range is provided by a new photodiode design that simultaneously lowers the noise floor while elevating the saturation level – offering excellent HDR functionality. The separate video components are processed in a quite different manner than those of the original C300 – utilizing a novel sample rate conversion system to further reduce aliasing and provide a more benign appearance to noise within the formulated 2K / HD RGB 444 components. Picture capture rates have been extended to a maximum of 120 fps progressive. The camera can manage a far greater range of scene Illuminance levels by deployment of a choice of 5 separate ND settings and a greater range of ISO sensitivity settings. Finally, unlike the C300, the new C300 Mark II also originates a choice of high performance UHD or 4K cine video – constrained, however, to a maximum picture capture rate of 30 fps progressive. This white paper will outline the advances made in image origination and processing in the C300 Mark II and their contribution to the enhancement of overall image performance. A separate white paper discusses in detail the more powerful on-board recording options in the new C300 Mark II [3].

1.0 Introduction

The C300 gained a reputation for high performance imagery – a testament to the excellent performance of the 4K image sensor developed by Canon. That camera was, however, largely television-centric in that it exclusively originated 1080-line HD from that single 4K image sensor and recorded this on-board as 8-bit YCrCb 4:2:2 via an MPEG-2 50 Mbps codec at frame rates up to 30fps.

It is clear that both digital cinematic technology and creative aspirations have been moving into higher realms. The need to advance beyond the constraints of 8-bit depth and harness the far greater flexibilities of 10 and 12-bit in support of creative postproduction processes cannot be ignored. A choice between RGB 4:4:4 or YCrCb 4:2:2 video components is deemed highly desirable to cover a wider range of origination possibilities. Higher frame rates are also sought.

A totally new 4K image sensor has been developed that can be switched between 4K (with a 17:9 aspect ratio) or 4K UHD (with a 16:9 aspect ratio) to support origination for digital cinema or for broadcast television. The camera outputs can be selected from a choice of four digital sampling structures – two for cinema 4K or 2K [4] and two for television UHD [5] or HD [6] – all having been standardized by SMPTE. The central design goal was to offer a substantial extension of the 2K / HD options beyond the HD-only capability of the C300 while also adding a modest 4K / UHD capability (that was totally absent from the C300). The C300 Mark II offers a choice between HD or 2K – as RGB 4:4:4 components at either 10 or 12-bit at frame rates up to 30fps, or alternatively, YCrCb 4:2:2 at 10-bit with frame rates up to 120fps progressive. It further can be switched to deliver 4K / UHD 10-bit YCrCb 4:2:2 at frame rates up to 30 fps progressive.

2.0 HDR Origination – New Super 35mm CMOS Image Sensor

It has been almost four years since the original C300 was introduced to the worldwide marketplace. The novel CMOS image sensor specifically developed for that camera has served unusually well over those years – and continues to do so. But, Canon R&D never stops and a totally new generation CMOS Super 35mm image sensor is the heart of the stunning imagery of the C300 Mark II. Further innovations within the second generation proprietary photodiode design in combination with on-chip noise cancellation technology have simultaneously lowered the noise floor and elevated the saturation level of the charge well. In addition, a totally new microlens design heightens the efficiency of light direction onto the individual photodiodes – a combination that achieves a more than two-fold increase in effective sensor dynamic range. This provides a definitive ***15-Stop*** dynamic range capability in this new cinematography camera. The more controlled noise floor allows the ISO range to be extended up to ***ISO 102,400.*** The Luma signal to noise ratio is a superb 67dB over a range of ISO settings.

In the original C300 image sensor there were two fast readout modes – one, at 1/60 sec progressive and another at 1/120 sec interlace. The new image sensor in the C300 Mark II has a single readout capability of up to 1/120 sec progressive – further reducing rolling shutter skew effects.

3.0 Totally New Video Processing

Every core element within the overall C300 Mark II system entails entirely new advanced video processing that elevates the overall performance of the 2K / HD video component sets very significantly above the single HD component set of the C300. The image sensor is new. The main video processing is new – accomplished by deploying two powerful Digic DV5 processors compared to the single Digic DV3 processor of the C300. And finally, the codec that powers the on-board recording is also new – in the form of the formidable new XF-AVC [6] that replaces the more modest MPEG-2 codec of the C300.

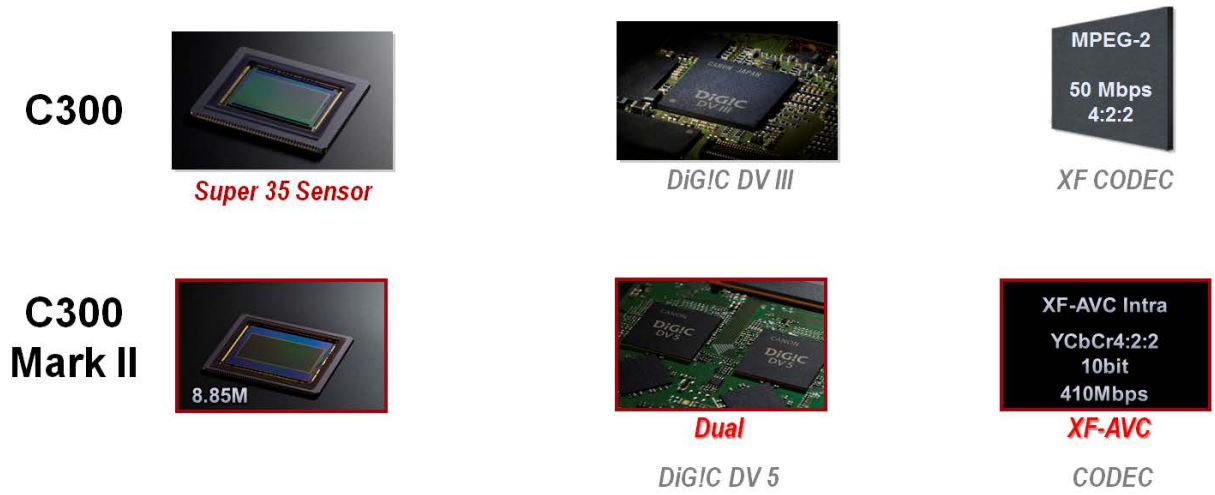

Figure 1 *Showing the core integrated circuits that constitute the core of the original C300 and the new C300 Mark II*

4.0 Formulation of 2K or HD RGB 444 Video Components

The image sensor parallel readout architecture breaks down the Bayer sampled 4K / UHD data into four parallel 2K / HD components as shown in Figure 2.

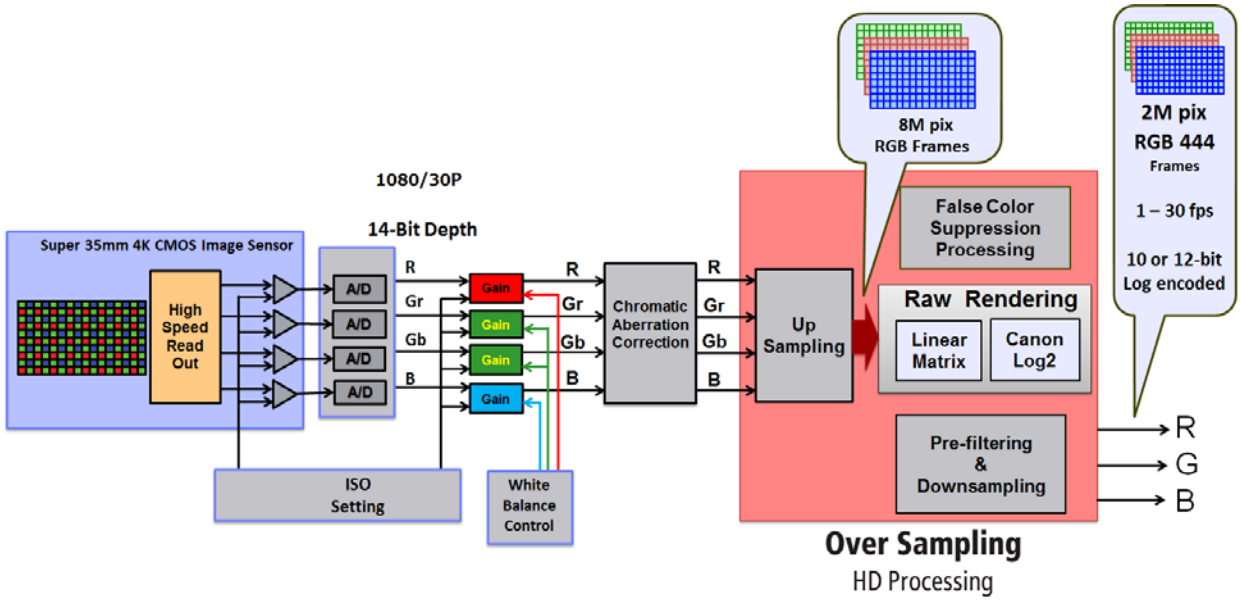

Figure 2 *Showing the unique component video signal processing in the C300 Mark II that formulates the 2K / HD RGB 4:4:4 video component set that is sent to the XF-AVC codec for recording*

A low noise analog column amplifier implements the ISO gain control when the scene Illuminance is very low. This is followed by the A/D conversion process and digital gain controls that implement the camera White Balance adjustments at a high bit depth. At this juncture the video processing radically departs from that of the earlier C300 camera. First, a new processing feature is added – lateral chromatic aberration correction (of any EF lens that might be employed) – and this is then followed by Canon's unique Over Sampling HD Processing.

5.0 Oversampling HD Processing

This innovative video processing begins with the upsampling of the video components that had been directly readout from the 4K image sensor – to form three 8 Megapixel RGB frames as outlined in Figure 2. That upsampling moves the first order sideband (from original image sensor sampling) to a higher frequency which in turn opens spectral space to implement pre-filtering prior to a subsequent downsampling back to 2K / HD RGB444 or YUV422 frames. The net result of this sample rate conversion process – termed *"Oversampling HD Processing"* by Canon – is to produce three 2K / HD RGB components that have minimum aliasing and a more benign appearance to noise (in high ISO settings). At this stage these essentially linear light RAW representations of the image sensor outputs have a linear matrix applied to them to define the specific color gamut selected for the production (there is a choice of four such gamuts as will be discussed later). This is followed by application of the camera optoelectronic transfer function (OETF) which digitally maps the 14-bit depth linear components to a nonlinear set at either a 12 or a 10-bit coding. The OETF can be selected to be the new Canon Log 2 – optimized for the 15-stop dynamic range of the C300 Mark II – or the former Canon Log.

6.0 Formulation of the YUV 422 Video Component Set

The C300 Mark II can alternatively be switched to originate a Luma Y and two Chroma Cr and Cb 4:2:2 component set at a 10-bit depth and which can be selected to operate at all international picture capture rates up to 60 fps.

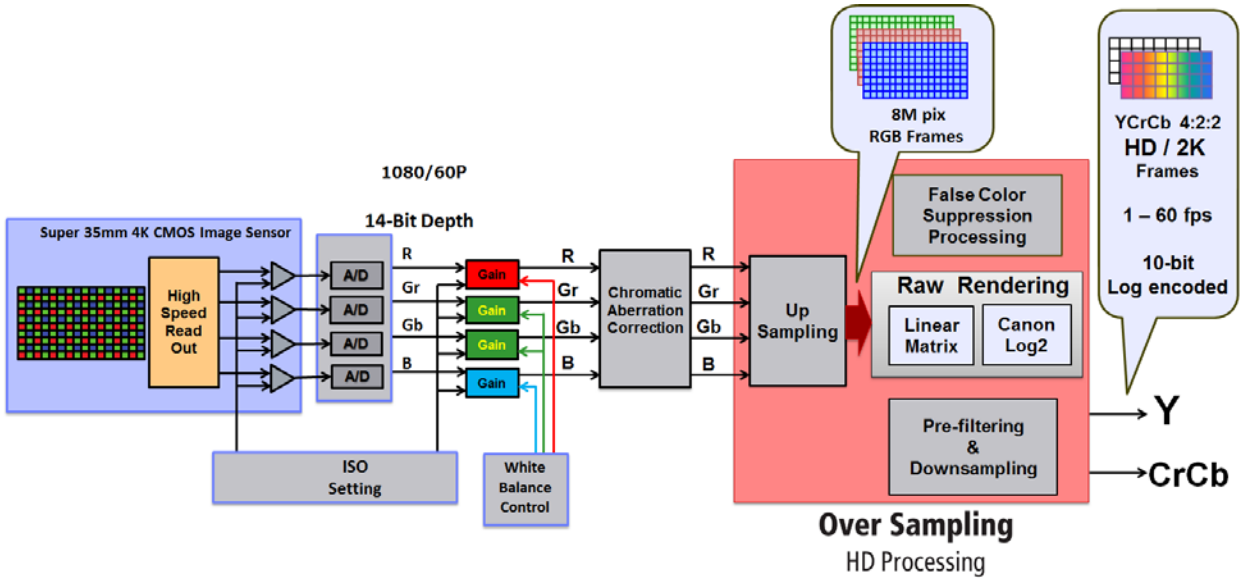

Figure 3 *Showing the formulation of the YCrCb 4:2:2 component video set which can operate up to 60 fps progressive*

The technical advantages of the ***Oversampling HD Processing*** for the RGB 4:4:4 and YCrCb 4:2:2 component sets are significant and can be summarized as follows:

- Luma & Chroma Resolution is improved
  - Improved control of H & V sampling sidebands and extension of optical low pass filter
- Luma aliasing is reduced
  - Sampling sideband control and pre-filtering
- Luma noise is reduced
  - The upsampling process spreads the total noise power over a wider frequency range. The subsequent filtering and downsampling reduce the noise power and imparts a finer grained appearance to the output noise
- False Color Moire is reduced
  - By special False Color Suppression following structuring of RGB HD frames

7.0 120 FPS Operation of 2K / HD

When the C300 Mark II is originating in 2K or HD it can record picture capture rates from 1 fps up to a maximum of 120 fps progressive. To do this, however, the data rate of the video components emanating from the image sensor system must be constrained so that the processing and recording can retain a high integrity. The expedient to accomplish this curtailment of maximum data rate is to center crop the image sensor readout. Thus, instead of the usual four frames of 2048 x 1080 digital samples – this now becomes four frames of 1024 x 540 (approximately one megapixel frames each). These frames are then subject to the upsampling process – shown in Figure 4 – where they are converted to three RGB frames of 2018 x 1080 digital samples. They are then processed in the same manner as the 2K / HD frames for the normal operation of the camera and delivered to the recording codec as YCrCb 4:2:2 at 120 fps.

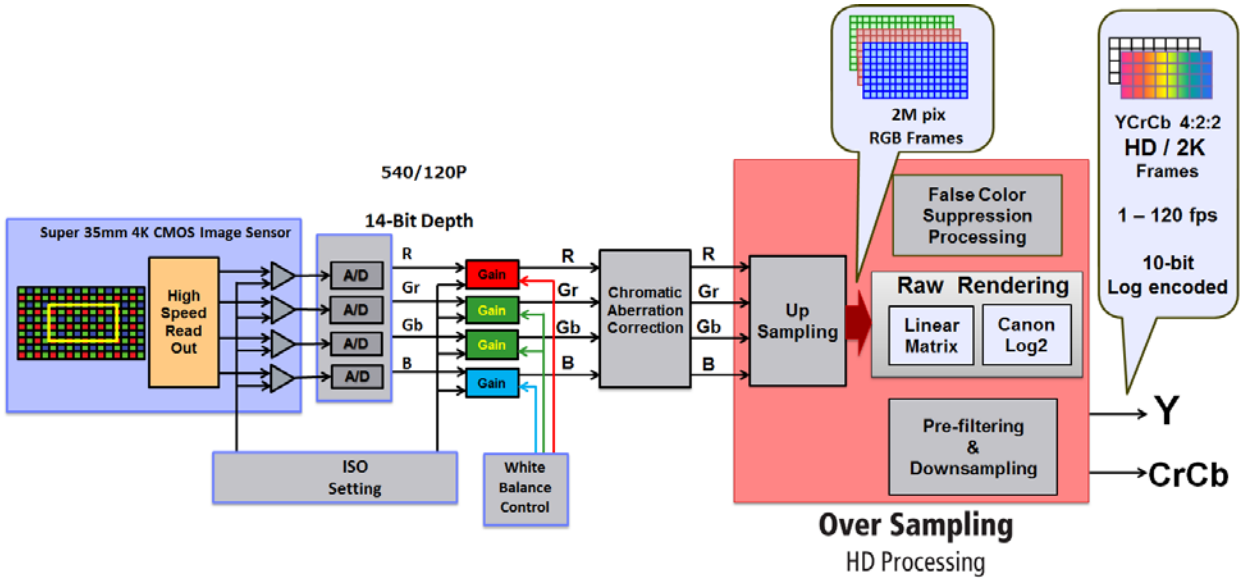

Figure 4 *To originate 2K / HD at frame rates as high as 120 fps progressive a center crop is readout of the image sensor as 1024 x 540 frames that are upsampled to produce three RGB 2048 x 1080 frames*

8.0 The 4K UHD Capability of the C300 Mark II

As listed above, the range of enhancements to the overall 2K / HD image performance are unprecedented. It was recognized that 2K / HD is still the center of worldwide digital productions and that technological advances had still much to offer in terms of facilitating further improvements to their picture quality – both for television and television commercial production, and also for a great deal of moviemaking. Today, both HDR and WCG are considered core elements of these picture enhancements.

At the same time, it is now clear that 4K / UHD is steadily advancing, and while such services to the home will still be limited for some time, there is growing adoption of these formats in digital production to support the shelf life of higher end programming assets.

For this reason, the C300 Mark II also incorporates the ability to originate very high performance video in the standardized 4K / UHD formats – at frame rates of 23.98 / 24.00 / 25.0 / 29.97 fps progressive.

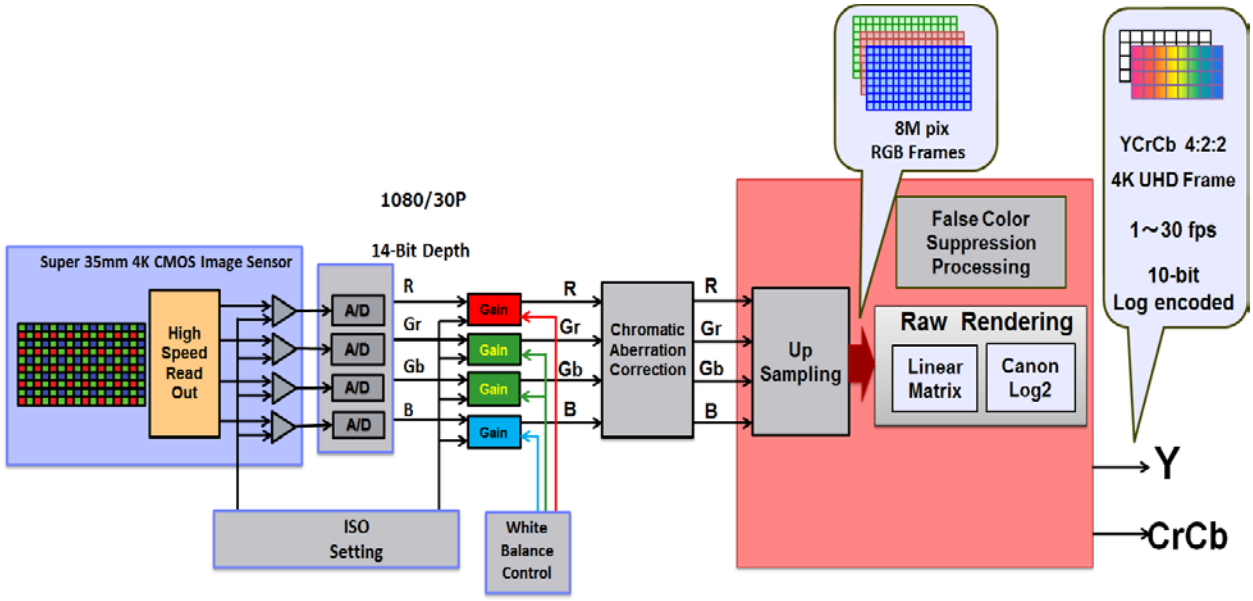

Figure 5 *Showing the video processing system to create the 4K / UHD YCbCr 4:2:2 video that is sent to the XF-AVC codec for recording*

9.0 High Dynamic Range (HDR) and Canon Log2

The original Canon Log in the EOS C300 camera was tailored to manage a 12-stop dynamic range within the constraint of an 8-bit MPEG-2 codec. While in general it worked remarkably well there were identified limitations in terms of reproducing tonal ranges within deep shadowed scene segments. The C300 Mark II has a significant extension of dynamic range to 15-Stops – offering impressive HDR imaging capabilities – and the linear light digital representation for each of the 2K / HD video components is at a high 14-bit depth. This, in turn, allows for a far more favorable disposition of digital codes when mapping the nonlinear Opto Electronic Transfer Function (OETF) – a logarithmic curve termed Canon Log2. It is reproduced in Figure 5. This curve has been carefully designed to ensure an optimum allocation of the output digital codes to express all of the tonal gradations within dark areas of a scene while simultaneously faithfully representing the details contained within the highlight areas of that same scene.

The on board recoding in the C300 Mark II has the powerful capability of recording 2K / HD RGB 444 at a 12-bit or 10-bit depth. Accordingly, the digital coding for various video levels at both of those bit depths (and the 8-bit level is also included) is listed in Figure 5. The peak level of 1600% (corresponding to saturation of the image sensor photodiodes) has an IRE level of 92.7 and the 18% gray reference is at 39.2 IRE. An important extension was made to the Canon Log2 curve above the peak white level (the maximum level that can be delivered by the image sensor) – this being a 2-Stop continuation of the transfer function that is intended to support possible “push-pull” image manipulation in the color grading process.

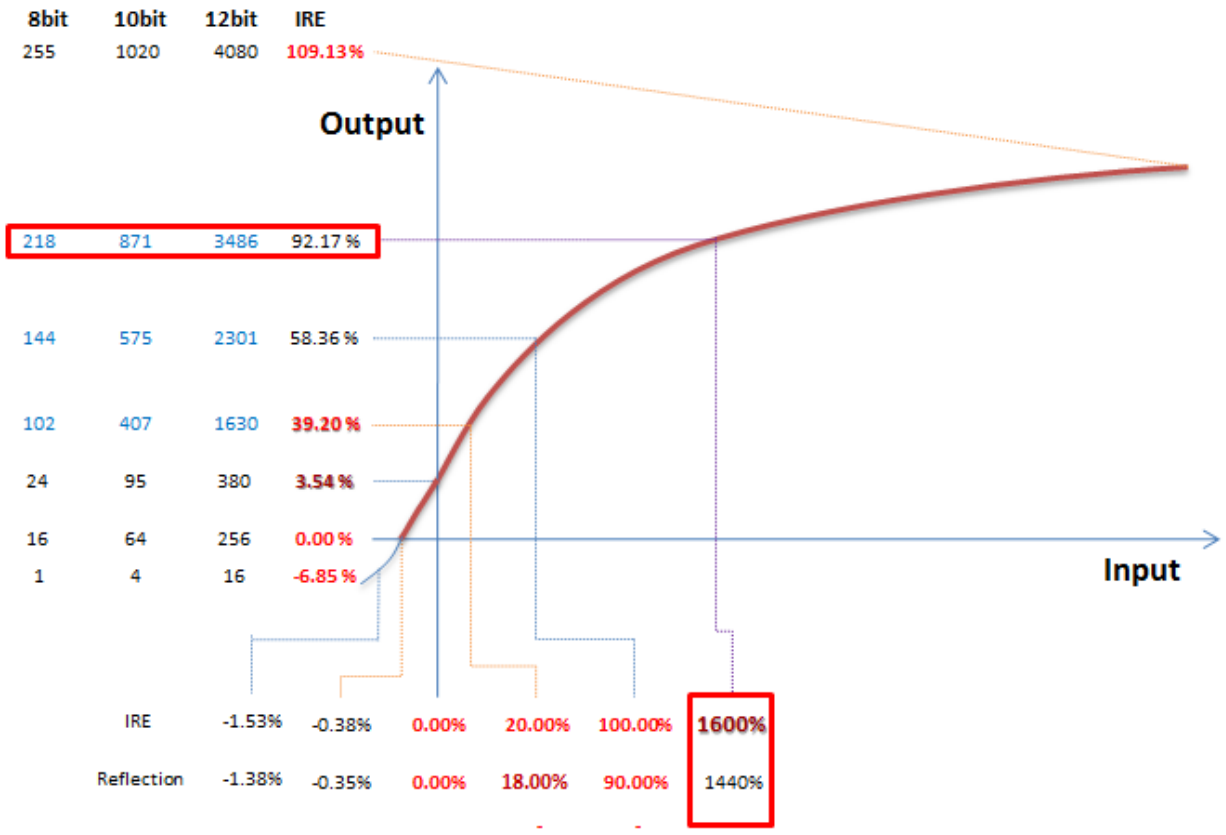

Figure 6 *New Canon Log2 Opto Electronic Transfer Function (OETF) for the C300 Mark II*

The Canon Log2 curve was radically redesigned over Canon Log at the lower end (below 5 IRE) to do far greater justice to reproduction of the all-important lower tonal ranges that can now be achieved by the exceptional 15-Stop exposure latitude of the C300 Mark II.

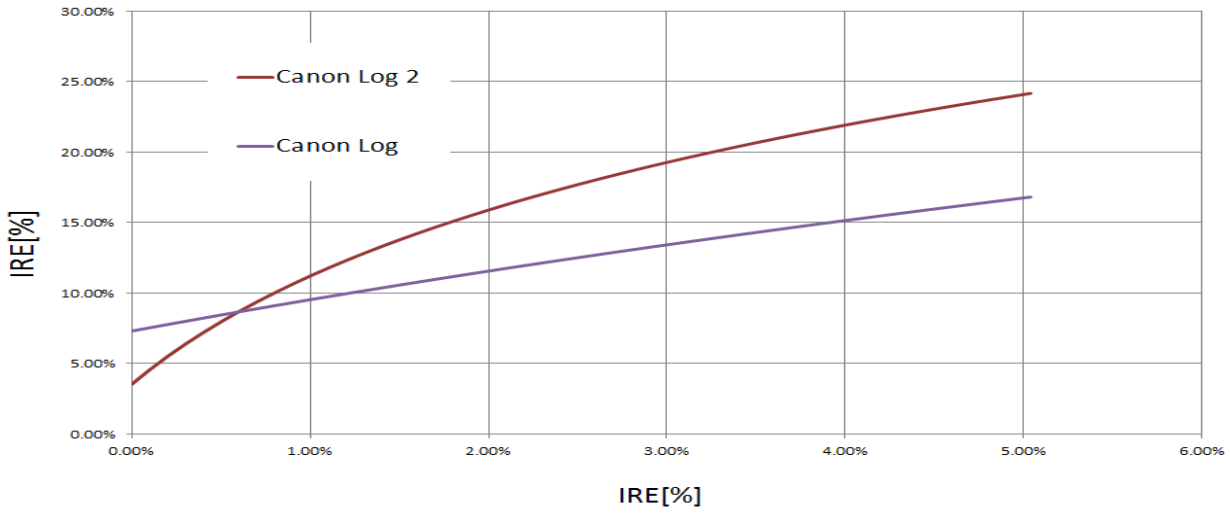

Figure 7 *Comparing the lower region of the new Canon Log2 with that of the original Canon Log*

10.0 HDR combined with a Unique Sensitometric Characteristic

The proprietary signal extraction strategies within the CMOS image sensor facilitate a remarkable control over the disposition of exposure latitude above and below the 18% reference gray exposure. At low ISO levels the master gain control is implemented by the digital gain control in the external image processing system (shown in Figure 2). As this gain is lowered below the 0 dB reference the exposure latitude is greatly favored below the 18% gray level. This allows for extraordinary capture of tonal levels in deeply shadowed scenes and will prove a boon when doing precision compositing where light levels can generally be controlled to curtail highlights. These low ISO settings also support opening the lens aperture in high scene illuminace conditions – with attendant deployment of the appropriate ND filters – to achieve very shallow depth of field and artistic "bokeh" effects.

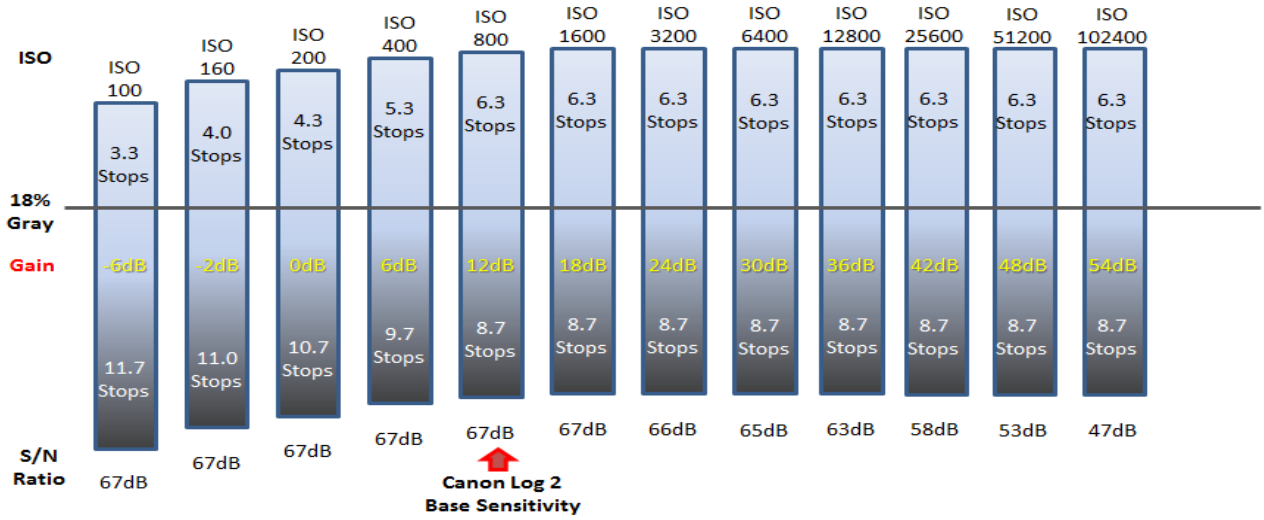

Figure 8 *Showing the overall Sensitometric behavior of the C300 Mark II*

At ISO 800 the exposure latitude is 6.3-Stops over gray and 8.7-Stops below gray – and this is termed the Base ISO. Increasing ISO levels above this Base level is implemented by an analog gain control within the image sensor itself and this helps maintain a consistent disposition of exposure about the gray reference all the way up to maximum ISO 102,400. This characteristic is particularly beneficial to extending the scope of the color grading processes that seek to separately adjust details within both shadowed and highlight regions of a given scene.

11.0 Wide Color Gamut (WCG) Capabilities

The C300 Mark II is first and foremost intended to offer significant 2K / HD image performance enhancements over the original C300 system. This encompasses elevations in sensitivity and dynamic range, lowering of aliasing and color moire, utilization of greater bit depth – and finally, offering choices in color gamut to meet needs of HDTV, UHDTV, and theatrical digital motion picture production. The color gamut choices are extensive and include:

1. BT.709 Gamut — Supporting HDTV
2. DCI-P3 Gamut — Supporting the digital cinema standard
3. BT.2020 Gamut — Supporting the new wide color gamut standardized for 4K UHDTV
4. Cinema Gamut — Canon wide gamut supporting theatrical motion picture production

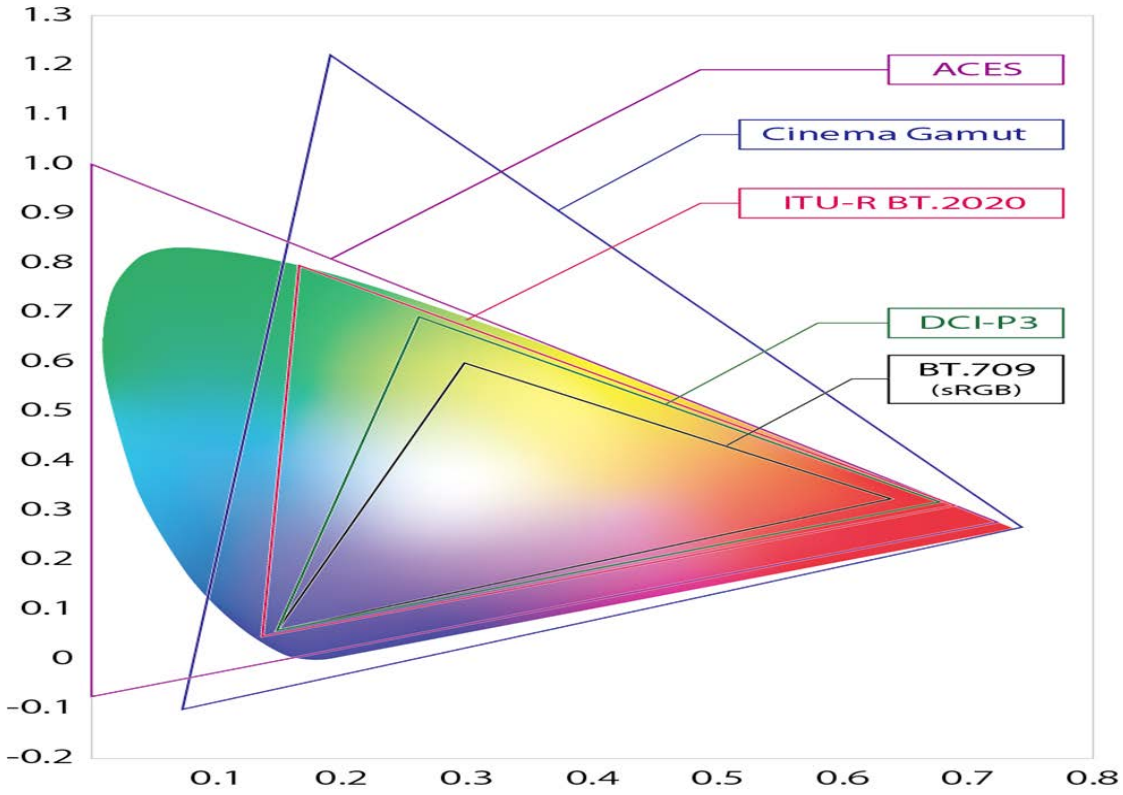

Figure 9 *Showing the four color gamut choices in the C300 Mark II*

The unusually wide Cinema Gamut is intended to support digital movie production where the production team might wish to emulate (in the color grading process) the look of a specific motion picture film stock. This unusually wide color gamut encompasses the color gamut of all known film stocks used in motion picture production today and in the past.

The significantly extended virtual primaries support the specification of positive code values within the Horseshoe representing the visible colors. Canon will supply 3x3 color matrices that will convert the code values of Cinema Gamut to each of the standardized color gamuts of BT.709, BT.2020, and DCI-P3.

12.0 Summary of 2K / HD Image Performance Enhancements of C300 Mark II

The original EOS C300 gained a worldwide reputation for producing high quality imagery. Of special note is the excellent facial skin tone reproduction of that camera – regardless of ethnicity. In planning the second generation C300 Mark II camera the Canon design team preserved these unique attributes while also setting a goal of a further significant elevation of the bar in overall image quality – paying close attention to all of the multidimensional aspects of contemporary digital motion imaging. Many recommendations by users of the original C300 were factored into the many design considerations of this new camcorder.

The following specifically summarizes the many areas of design attention in striving for that goal:

1. **High Sensitivity –** the exceptionally high sensitivity of the image sensor supports image capture in those infrequent situations where scene illuminace is unusually low (the camera supports sensitivity settings up to ISO 102,400). This level of sensitivity also offers creative flexibilities in setting ND filters, lens aperture, and electronic shuttering – for controlling depth of field – over a range of low light situations. At the other extreme, the ISO 100 setting can support control of the depth of field in very bright illuminace with the aid of the extended ND filters in the camera [7]. The excellent Luma signal to noise ratio of 67dB (up to ISO 1600) ensures superbly quiet imagery

2. **Very Clean Images** – Innovative internal signal extraction and readout strategies in the new image sensor combine with the novel *Oversampling HD Processing* earlier described to produce 2K / HD having very low noise, aliasing, and color moire artifacts (especially important on images intended to be shown on very large screens)

3. **High Picture Sharpness** – extension of the optical low pass filter cutoff was made possible because of novel anti-aliasing strategies thus elevating the 2K / HD Luma MTF

4. **High Dynamic Range (HDR)** – The 15-Stop range allow simultaneous capture of details in deep shadowed portions of a scene and in overexposed portions of that same scene. This capability empowers the C300 Mark II to be a significant HDR origination system.

5. **Constant Exposure Latitude Above and Below Reference 18% Gray –** protects the preservation of detail in both shadowed and highlight regions of a given scene over a very broad range of ISO settings. This also greatly supports “Push” and “Pull” manipulations in postproduction that seek to creatively alter the “look” of a given scene.

6. **2K / HD High Progressive Scan Frame Rates** – All standard international frame rates up to 60 fps progressive for 2K / HD are supported. Frame rates can also be selected anywhere from 1 to 120 fps to support special effects such as Slow and Fast Motion

7. **Lower Rolling Shutter Distortion** – the C300 used a high-speed readout mechanism from the image sensor to reduce the visibility of the vertical skew distortion associated with CMOS rolling shutter. This readout has been doubled to 120P in the C300 Mark II which further reduces the subjective visibility of this distortion

8. **Extension of White Balance Range** – on the blue side of the visible spectrum offers extended creative options as well as being able to accommodate more faithful image capture in underwater scenarios

9. **Wide Color Gamuts** – choice that can be set to ITU-R BT.709 specified colorimetry for HDTV programming, to wider color gamuts for digital cinema portrayal, or to support emulation of the look of specific motion picture film stocks. Finally, the newly standardized ITU-R BT.2020 wide color gamut can be selected

10. **4:4:4 Coded RGB** 2K / HD video components – provides the maximum color space to support sophisticated color grading as well as Bluescreen and Greenscreen compositing for special effects

11. **High Bit Depth** – up to 12-bit RGB for 2K / HD origination effectively eliminates digital quantization artifacts and noise, while ensuring faithful reproduction of the wide dynamic range and wide color gamut to support extensive color grading in postproduction. Bit depth, though not strictly related to color space, is a key determinant of the fidelity of reproduction of the image color palette

12. **No Compression** – the digital video processing entails no compression whatever. That comes later in the high-end XF-AVC codec used for on-board recording. Mapping from the original 14-bit depth to a 12 or 10-bit output using the mathematically prescribed Canon Log2 is the method used to achieve the necessary bit rate reduction that can deliver the various camera output formats via a standardized 3G SDI serial interface. The Canon supplied mathematics for Canon Log2 ensures the ability to faithfully restore a high bit-depth linear light representation of the image sensor output in the downstream postproduction processes.

13. **RAW 4K Output** – the uncompressed 4K / UHD RAW output can be delivered to an external recorder (or to a video village) via the SMPTE ST 425-1:2011 3G SDI interface

14. **2K / HD Component Video Output** – the various uncompressed 2K / HD digital video formats (at 12 or 10-bit) can also be delivered via the same 3G SDI interface.

13.0 Summary

All of the imaging attributes that collectively earned the unique reputation for picture quality of the EOS C300 digital motion imaging camera remain as the underpinnings for the design of the second generation EOS C300 Mark II. But a further three years of ongoing R&D were able to see development of a new Super 35mm image sensor with significant enhancements – most especially in achieving a 15-stop dynamic range that makes this camera a serious source of HDR imagery.

More powerful video processing – notably the deployment of sample rate conversion (termed *Oversampling HD Processing*) – contributes to the production of superb 2K / HD RGB 4:4:4 video component quality as well as the alternative 2K / HD YCrCb 4:2:2 component set. In addition, the C300 Mark II offers an important bridge into the emerging world of 4K / UHD production.

A companion paper [6] describes the powerful on-board recording system that faithfully captures all of that image quality. A third white paper [7] outlines the many ergonomic and operational enhancements to the C300 Mark II – most of which were based on suggestions and recommendations from many end-users of the first generation Cinema EOS camcorders.

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[3] Canon White Paper: Extended Recording Capabilities in the EOS C300 Mark II

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