Canon

WHITE PAPER

CINEMA EOS C500

HOW A 4K IMAGE SENSOR ORIGINATES A SUPERIOR REAL-TIME 2K OR HD

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CINEMA EOS

How a 4K Image Sensor Originates a Superior Real-time 2K or HD

As explained in a separate White Paper (CinemaEOS website: *"New 35mm CMOS Image Sensor for Digital Cine Motion Imaging"*) the Cinema EOS cameras (C500, C300, and C100) all utilize the same single Super 35mm CMOS 4K image sensor. Like most contemporary digital cine cameras, the image sensor is covered by a Color Filter Array arranged according to the established Bayer pattern shown in Figure 1 whose individual RGB colored pixels precisely align with the sensor photosites. However, unlike the traditional approach to reading out from such a single image sensor via singular RAW date stream that contains the encoded RGB information, the Canon image sensor uses four parallel readouts to deliver that RAW data as four separate 2K (or HD) data streams as shown in Figure 2. These four real-time video components carry all of the color information originated by the 4K Bayer CFA – and they are then delivered from the image sensor to the camera digital processor – for both 4K and 2K origination.

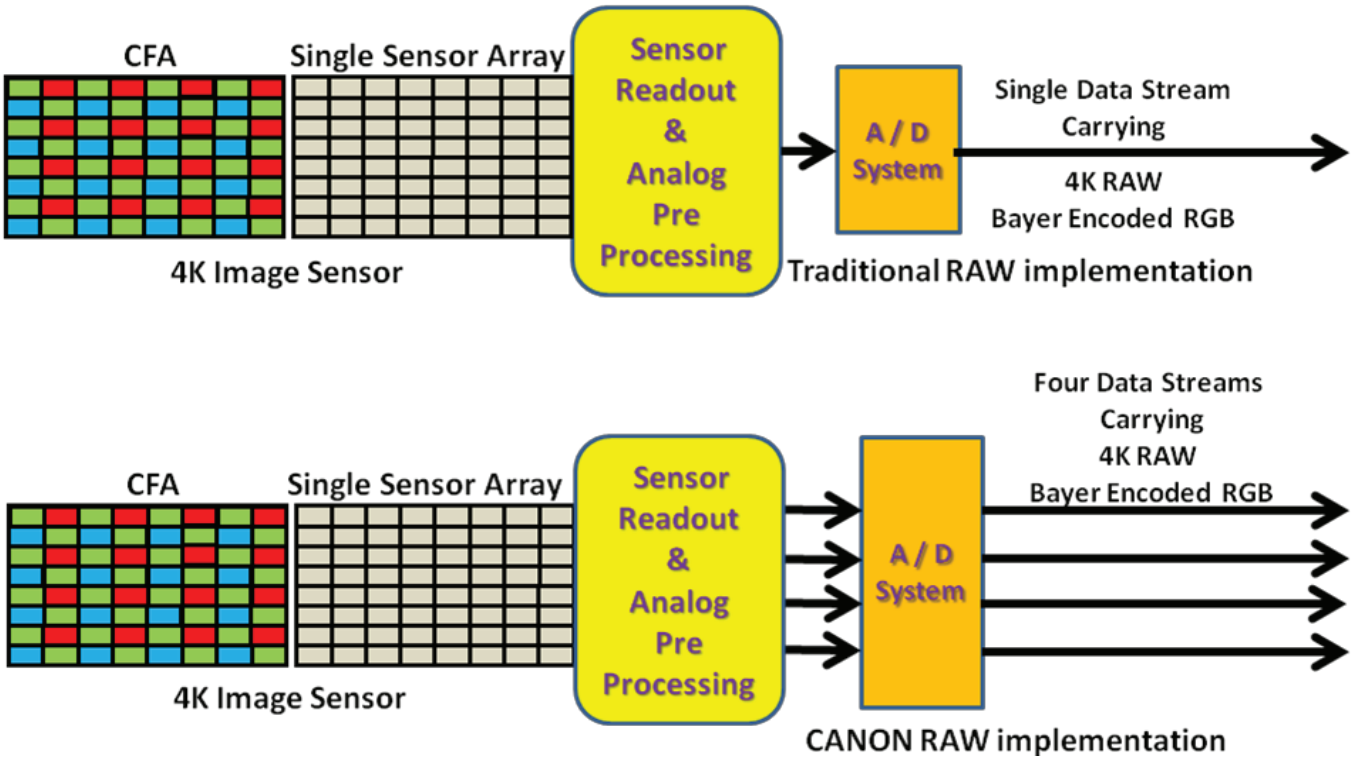

Figure 1 *Showing the Canon readout mechanism from the single 4Kimage sensor using four parallel 2K data streams in contrast to the more traditional approach of a single data stream readout*

4K Origination

When the C500 is originating 4K these four high bit-depth R, Gr, Gb, B components are logarithmically encoded to 10-bit and then formulated into a RAW Clip Structure (termed ***.rmf files*** – that combines the RAW video files with the digital audio files, metadata, and clip management files) as shown in **Figure 2**. The clips are then multiplexed to form a single serial RAW Component Data Transport Interface – in accordance with the SMPTE 3G SDI serial 3G SDI interface (ST 425-1:2011). Construction of the final 4K RGB components requires downstream debayering to build up the separate three 4K RGB frames.

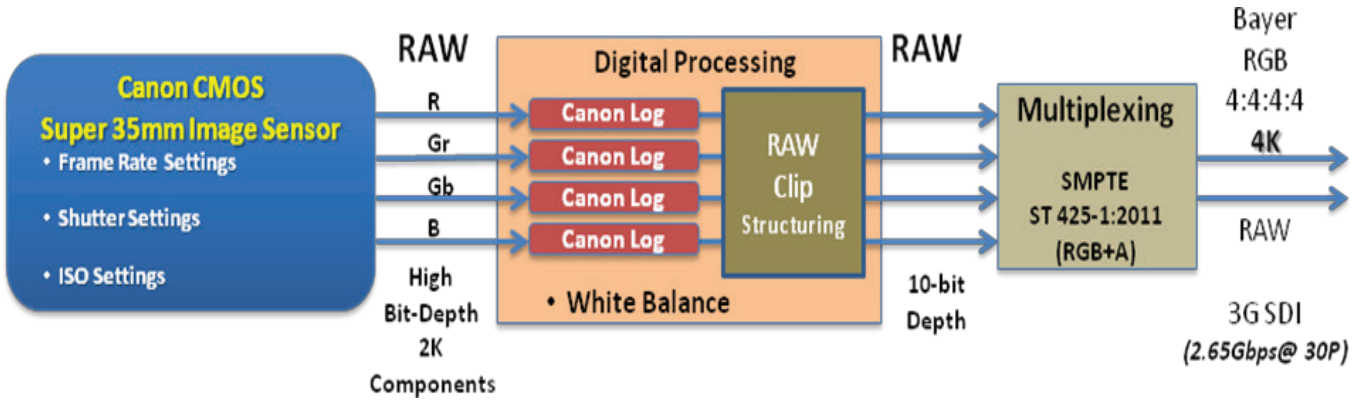

Figure 2 *Showing the formation of the single serial Canon Bayer RGB 4444 RAW data output for 4K origination – requiring a single 3G SDI interface for frame rates up to 30Pand two such interfaces for higher frame rates*

HD or 2K Origination

In the case of HD (or the alternative 2K) origination those same four component readouts are more simply processed in the manner shown in Figure 3. The two green components are digitally summed to form the final "super" green (the technical advantages of this are explained in detail in a White Paper on the Cinema EOS website: *"RGB Resolution Considerations in a New CMOS Sensor for Cine Motion Imaging"*). The real-time output RGB 444 HD video components can be selected as 12 or 10-bit and they are then directly transported from the camera via the same 3G SDI interface.

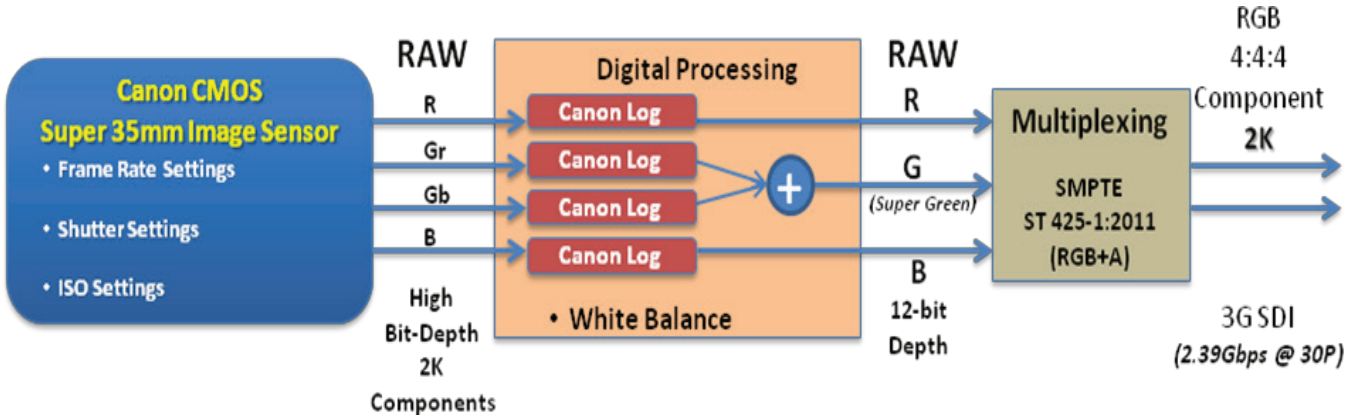

Figure 3 *For 2K/HD origination the four real-time video components are restructured to three RGB 444 components*

The essential difference between the 4K and 2K camera outputs is that the 4K is in the form of file clips that require downstream "development" to structure the desired 4K RGB video components, whereas the 2K/HD output is real-time standard RGB 444 video components. Also, in the case of the 4K the Canon Logarithmic conversion from the high bit depth sensor outputs is to 10-bit. On the other hand, for 2K or HD origination, that log conversion is to 12-bit, with 10-bit being an alternative user selected option. The significant innovation here is that the 2K or HD component set is a real-time process that requires no debayering algorithms – thus totally avoiding any attendant reconstruction errors.

Management of C500 Output Data Rate – Logarithmic Encoding

Considerations of RAW data rate outputs from the EOS C500 differ from that of most other single sensor cameras – and they are two-fold:

1. In close consultation with no less than five separate digital recording manufacturers we established a consensus on a maximum camera data rate output that could be managed by each (even though each had different recording strategies)

2. Very important – Canon specifically wanted to use the SMPTE ST 425-1:2011 serial 3G SDI interface as the transport mechanism for our RAW data – in order to facilitate:

    - A standardized (and universal) serial digital delivery to each of the disparate recorders

    - Passage of the camera output RAW data into broadcast 4K/2K/HD infrastructures that utilize standardized 3G SDI system elements (camera CCUs, routers, encoders etc)

Accordingly, the RAW data rate output is constrained to less than 3Gbps for both 4K and 2K having frame rates up to 30P – so only one 3G SDI interface would be required.

This data rate was achieved without resorting to compression by constraining the camera output to a bit depth of 10-bit for the 4K RAW and to 12-bit for the 2K RAW – as outlined in the following:

Canon **4K:** 4444 Bayer RAW Data rate @ 30 fps

2048 x 1080 x 4 x 10 x 30 = 2,654,208,000 bits/ second

Canon **2K**: RGB 4:4:4@12 -bit Data Rate at 30 fps

2048 x 1080 x 3 x 12 x 30 = 2,388,787,200 bits / second

Both of these data streams fit comfortably within the 3G SDI interface standard. For higher frame rates – up to 60P – the elevated data rates (still less than 6 Gbps) will require two 3G SDI interfaces.

To meet those two bit-depth constraints without compromising restoration of the higher bit-depth of the image sensor output in postproduction *resort was made to an alternative bit rate reduction strategy* – namely, logarithmic encoding of the image sensor linear representation (according to the mathematically prescribed Canon Log). Specifically, the high bit depth of the image sensor digital outputs are logarithmically transformed to a 10-bit depth for the 4K mode, and to a 12-bit (with 10-bit as a selectable option) for the 2K mode. This is a completely reversible process. While Canon does not disclose the bit depth of our A/D converter – we do affirm that the linearization process (de-Canon Log) can reproduce the linear representation at 12-bit, 14-bit, or 16-bit (DPX or Open EXR).

What Do Production Teams Seek in 2K and HD?

There is now a broad collective experience in what production teams seek in a contemporary 2K / HD digital acquisition system intended for theatrical feature production and very high quality television episodic production:

1. **High Sensitivity –** the higher the sensitivity of the image sensor the greater are the flexibilities offered in setting lens aperture and shuttering (controlling depth of field)

2. **High Picture Sharpness** – as high as the 2K or HD system can support *without resorting to digital image enhancement in the camera* (which raises visibility of noise and artifacts) to ensure excellent sharpness reproduction – especially for portrayal on a large cinema screen

3. **Wide Dynamic Range** – to allow simultaneous capture of details in deep shadowed portions of a scene and in overexposed portions of that same scene

4. **High Bit Depth** – to reduce digital quantization artifacts and noise, while also ensuring as faithful a reproduction of the wide dynamic range as possible to support extensive color grading in postproduction, and to also facilitate complex digital image manipulation

5. **4 : 4 : 4 Coded RGB** video components – to provide as wide a color space as possible, and support Bluescreen and Greenscreen compositing for special effects

6. **Wide Color Gamut** – that can be set for Rec 709 for television programming or to wider color gamuts that better emulate the look of motion picture film

7. **Very Clean Images** – low in noise, aliasing, and demosaicking artifacts (especially important on movies that are shown on very large screens)

8. **High Progressive Scan Frame Rates** – to accurately reproduce fast action scenes, and also to support special effects such as Slow Motion and Fast Motion

Enter the EOS C500

The EOS C500 fulfills ALL of the above. Let's take a look at why this is so:

FIRST:

It starts with the huge advantage that we have in the manner in which we extract our 2K and our HD video by direct parallel readout of the RGB components from the 4K image sensor. ***No debayering process is entailed*** – which avoids reconstruction errors that can sometimes by noted on scene edges – especially if those output video images end up on a large cinema screen. The C300 has firmly established this advantage and the EOS C500 operates in precisely the same manner.

SECOND

The direct readout of the four separate video components: R Gr Gb B as a 4 : 4 : 4 : 4 set of 1920 x 1080 is followed by the digital summation of the two green components Gr and Gb – to ***produce the "Super Green"*** that has been one of the striking differentiators of the C300, C100, and C500 cameras. That special Green video has enhanced dynamic range, higher resolution, and virtually zero aliasing.

THIRD

The sensitivity of the EOS C500 extends from ISO 320 up to ISO 80,000. The noise that manifest itself at the higher ISO settings is devoid of any fixed pattern structure and exhibits a random organic appearance that is evocative of motion picture film grain

FOURTH

There is a choice of four color gamuts available in the C500: The standardized Rec 709 for television or the wider DCI-P3 as standardized by SMPTE. Canon also offers a wider variant we term DCI-P3+ that can favor a closer emulation of motion picture film color gamut. A fourth variant – the Canon Cinema Gamut will fully encompass the color gamut of all known motion picture film stocks.

FIFTH

Unlike the C300 – which is constrained to an 8-bit depth by virtue of the MPEG-2 codec – the EOS C500 can ***deliver each of the three RGB components at 12-bit depth***. This is an enormous distinction from the C300 in that it provides far greater digital latitude to the color grading process in postproduction.

SIXTH

The external recorders from AJA, Codex, and Convergent Design – all have the capability to record this uncompressed 12-bit RGB 4 : 4 : 4 camera output component set. Codex and Convergent Design recorders record these signals uncompressed. Only the AJA resorts to compression within its recorder – but that is done with the industry-recognized high performance ProRes 444 compression algorithm.

SEVENTH

Another significant 2K / HD leap over the C300 is the ability to originate the ***RGB 12-bit set at frame rates as high as 60 progressive fps*** (recall that the C300 is constrained to 8-bits and 30 fps). This allows superb capture of fast motion – as encountered in sports or fast-moving scenes in movies and television dramas. For special effects – if a video is captured at 60 fps and played back at 24 fps that provides a 2.5 : 1 slow motion.

EIGHTH

If even higher frame rates are sought – the EOS C500 can be switched from RGB 4:4:4 to ***YUV 4:2:2 and this component set can be originated as high as 120 progressive fps.*** Note that a video capture at 120 fps can provide a 5:1 slow down if played back to 24 fps – a truly wonderful slow motion effect.

Unprecedented Color Latitude

In the 2K / HD origination mode the C500 offers superb color latitude. Two separate design criteria contribute to an extraordinary capability in color grading:

1. Choices in wider color gamuts extend color flexibilities to meet a broader range of creative aspirations in theatrical feature production and in high-end television episodic production

2. The 12-bit RGB color space offers more than 68 billion color gradations

1. ***Color Gamut:***

In addition to the extended color bit depth the C500 now offers a selection of color gamuts. The standardized Rec 709 color gamut is likely to remain central to a great deal of HDTV program genres. But, digital cinematography – for feature theatrical production and many genres of television episodic production – continues to seek emulation of the long-established cinematic look associated with motion picture film. Those film stocks still popular today come in a variety of color gamuts that afford flexibility to directors and cinematographers in choosing a particular look for a particular production. To offer a similar choice in the digital domain, the C500 can be switched between a range of widening color gamuts that, with appropriate testing, can help the production team reach a "look" that should come close to what they aspire to achieve.

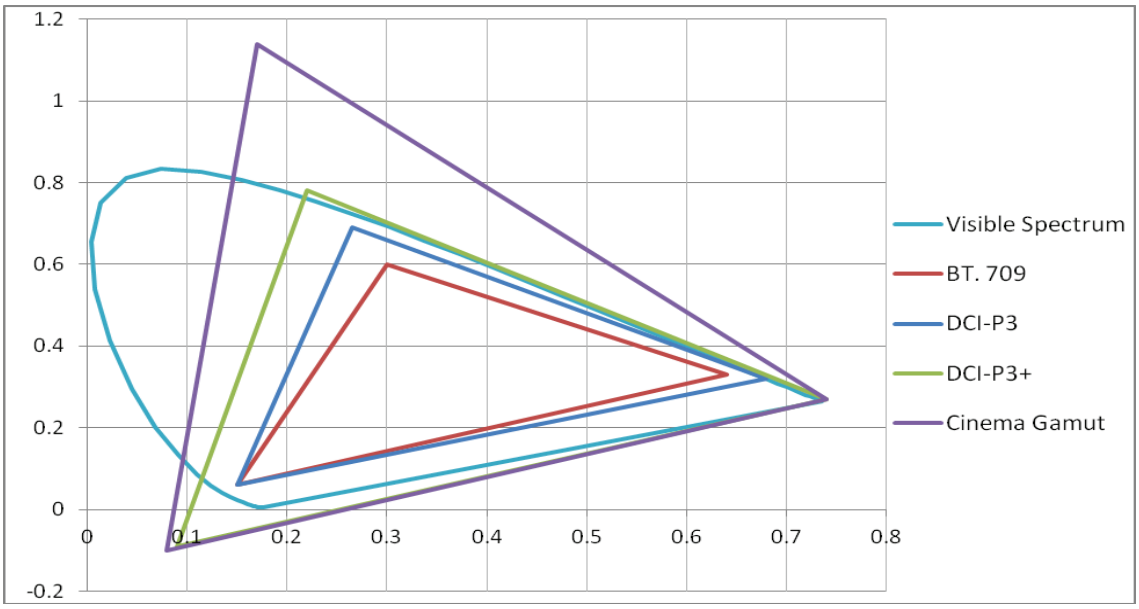

Figure 4 *Showing the range of color gamuts that can be selected in the C500 camera*

2. ***Color Space:***

If a camera has an 8-bit depth for each of the RGB video components, that will translate into 256 different intensity values for each of those primary colors. Because the camera combines the three primary colors to create a specific unique color any color space based on this RGB model is limited to 2^{8*3} or 16,777,216 different colors. For this 8-bit system, this combination is referred to as 24 bits per pixel. For a 12-bit RGB origination we have 36 bits per pixel which supports 2^{12*3} different colors – or 68.7B colors. While a chosen color gamut is not changed by this higher bit depth, a far greater range of intensities is supported to all colors within that gamut. This greatly extends the latitude of color grading in postproduction.

SUMMARY

The EOS C300 launched our Cinema EOS agenda and has been strikingly successful in the documentary arena and many broadcast HDTV productions where 422 MPEG-2 at 50 Mbps is an established platform.

On the other hand, the EOS C500 elevates 1920 x 1080 HDTV imaging performance to an entirely different level. In addition, the camera can be switched to originate 2K 2048 x 1080 for digital cinematography. The direct origination of real-time full-bandwidth HD / 2K RGB 444 at a choice of 12-bit or 10-bit offers the superlative level of performance expected for high end moviemaking – where heavy digital manipulation may be entailed in postproduction, and where blue-screen and green-screen compositing may be central to many scenes. This is the level of HD performance also expected for prime time television program production and high-end television commercial production.

The newly extended sensitivity of the C500 (up to ISO 80,000) offers the director of photography unprecedented flexibilities. When imaging details within deeply shadowed scenes the higher ISO settings can produce a bright image attendant with a noise level that is remarkably acceptable in both its appearance and level. Separately, the wide range of ISO settings offers the opportunity to simultaneously readjust both lens aperture and ISO setting to exercise wide control over depth of field. As one example, if the lens is set to T-2.8 and ISO set to 850 with a scene illumination of 150 Lux – full Luma signal level is achieved with a very shallow depth of field. Stopping the lens down to T-8.0 and readjusting the sensitivity to ISO 6,400 will significantly deepen the depth of field and retain the same Luma signal level with a surprisingly modest level of noise.