White Paper

New

Dual Gain Output (DGO)

4K Super 35mm

Image Sensor

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New Super 35mm 4K Image Sensor for HDR Imaging

Abstract

Full frame digital cinematography made its first appearance in 2017 and has since gained growing attention from many in the production community and also the manufacturers of associated lenses and cameras. It has extended creative options in both moviemaking and episodic television production. At the same time, the hugely established Super 35mm format remains solidly in place in digital motion imaging across the globe. Recognition of this important duality underlay Canon's approach to a new generation of digital cinematography lens-camera systems for the 2020s.

A worldwide experience gained over the past decade with the Cinema EOS system of lenses and cameras significantly refined the design approach to this new system. Modularity, convertibility, and connectivity – collectively constitute the mainstays of the remarkable full-frame EOS C500 Mark II camera that entered the marketplace in early 2020. But, a Super 35mm sibling camera system closely followed – in the second quarter of 2020 – the EOS C300 Mark III camera. And, here is a camera that takes motion imaging forward yet another important step.

The EOS C300 Mark III camera is physically identical to the EOS C500 Mark II camera in terms of the system components – but it deploys its own unique front end imaging system. Central to that is a totally new Super 35mm CMOS image sensor developed by Canon – the Dual Gain Output (DGO) sensor. The sensor leverages some novel characteristics of the CMOS readout system to overcome longstanding challenges in noise floor management in CMOS sensors. The 15-stop dynamic range of the recent Cinema EOS cameras is extended beyond 16-stops in the EOS C300 Mark III camera. The implementation of this innovation is described in this White Paper.

Introduction

The first Cinema EOS camera made its debut in September 2011 – and it was based upon a Canon-developed 4K single CMOS image sensor with a Bayer color filter array – the EOS C300 camera. That image sensor reflected a unique design strategy at the outset that recognized the industry's early preoccupation with High Dynamic Range (HDR) imaging. Each of the 8 megapixel photosites utilized two separate photodiodes – an innovation that speeds up the removal of the electrons from each (less distance to travel) and facilitates total capture of all electrons at each reset – thus elevating the effective dynamic range of the photosite. This basic photosite design has been maintained throughout the entire evolution of the Cinema EOS camera family – both the 4K Super 35mm and the 5.9K full frame systems. Progressive sensor improvement with each generation camera saw dynamic range reach 15-stops in the current Cinema EOS camera family.

In the new 4K CMOS image sensor developed for the EOS C300 Mark III camera, an additional strategy has been added to further extend dynamic range. This nature of the contemporary CMOS image sensor entails a novel vertical column readout strategy. Inherent within each of the multiple column readout circuitries is the strategic placement of an analog amplifier that lies centered within some four separate noise sources that collectively constitute the overall sensor noise. Because that is, by definition, a very narrow bandwidth amplifier it has negligible inherent noise and when its gain is increased it elevates the electronic signal above the succeeding noise sources – thus gaining an effective signal to noise advantage.

The Dual Gain Output process leverages this unique behavior of the column amplification by applying two distinct gain level settings to each of the two photodiode signal outputs followed by exposure adjustments – and then a blending of the two signals that produces a final signal output with fully protected highlights and a noise enhanced lower region.

New Technologies underlying a 4K Super 35mm Image Sensor Dual

Gain Output (DGO) Image Sensor

In this new 4K cinematography camera the two photodiodes are being additionally deployed in a new and innovative way. While each photodiode has a structure that inherently expands dynamic range, that is now being augmented with additional processing to add a further extension of their respective dynamic ranges. This is termed the Dual Gain Output (DGO) system – allowing the image sensor to further extend into the deep shadowed areas of a given scene while simultaneously preserving all of the highlight information

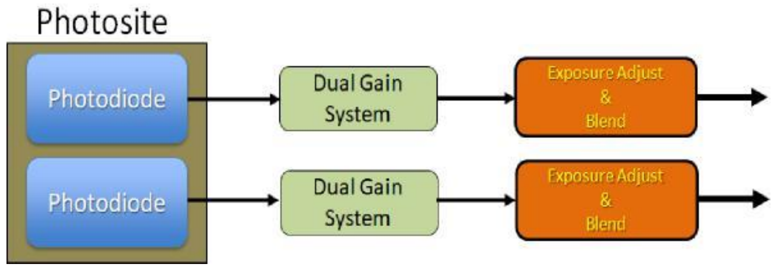

Figure 1 *Principle of the Dual Gain Output (DGO) system that protects highlights and extends low light range*

An additional processing strategy is implemented on each of the two photodiode outputs – in the form of application of two separate gain settings of the narrow bandwidth analog column amplifier. Prior to discussing how these two gain settings are actually implemented, the separate implications of each gain setting is explained.

Saturation Prioritizing Gain Setting

In Figure 2 the separate noise sources encountered in the readout process are listed. Of special significance is the disposition of these noise sources on either side of the column amplifier. The very narrow bandwidth of the column amplifier itself ensures that its thermal noise contribution is minimized even when its gain is elevated. Figure 2 summarizes the total noise at the output for the normal x1 gain setting – this is termed the ***Saturation prioritizing gain*** setting. The priority here is to recover the digital representation of the full dynamic range signal output from the image sensor – paying particular attention to protecting the scene highlight detail.

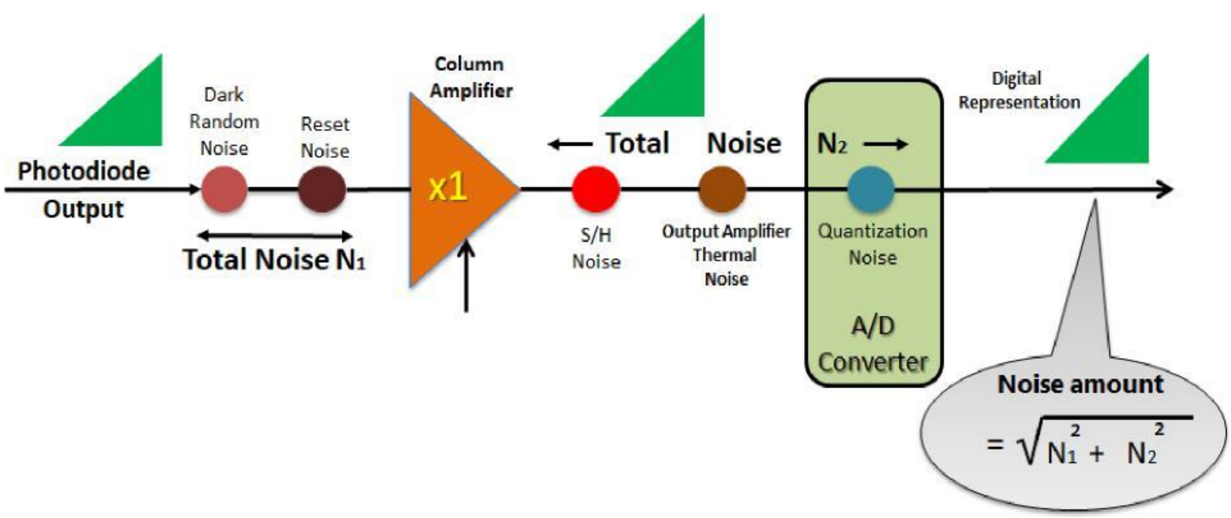

Figure 2 *Showing the final noise output for a gain setting of 1x in the column amplifier*

Noise Prioritizing Gain Setting

Figure 3 shows the final noise output when two sequential signal level adjustments are made – one, being an elevation of the column amplifier to a high gain setting xG — followed by an attenuation of both signal and noise by a factor of xG in the digital domain. The noise sources following the column amplifier are not amplified. In a sense, the high gain elevation allows the signal to effectively "step over" the N2 noise sources. This is termed the *Noise prioritizing gain* setting. The high signal levels may be clipped in the A/D converter (or even in the column amplifier) – but this is of no consequence as those highlights are protected in the separate Saturation Prioritization mode. It will be noted that the final lower output noise level speaks to the priority to recover the shadowed lower levels of the signal with enhanced signal to noise performance.

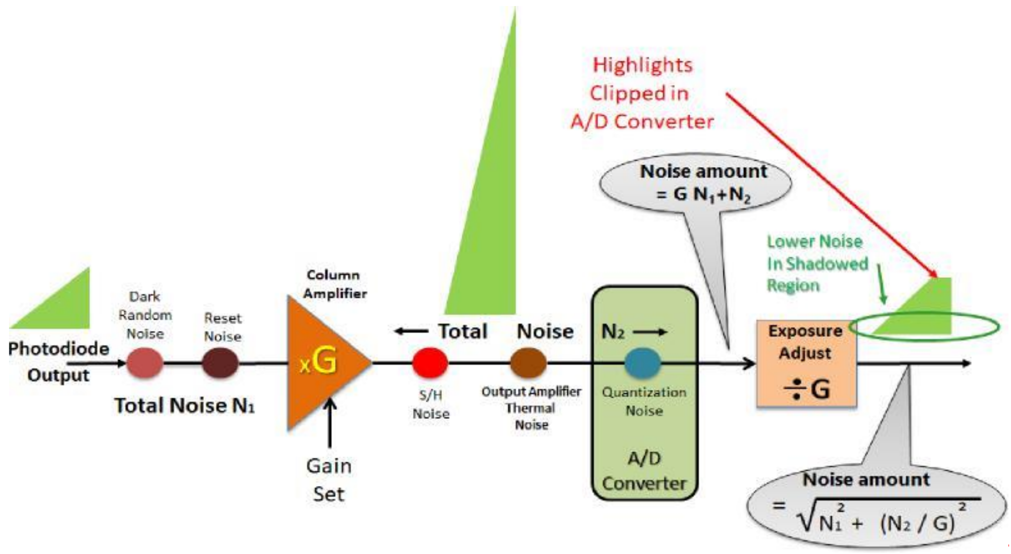

Figure 3 *Final noise level when the amplifier gain set is Gx and is followed by a gain reduction of G times*

Implementation of the Dual Gain Settings on Each Photodiode Output

During image sensor readout the signals from the two photodiodes are sampled row by row in parallel column readout architectures. That structure includes analog column amplifiers that are followed by a sample and hold stage which is then followed by a high-speed analog to digital converter.

The actual implementation of the two gains settings is a sequential process that is outlined in Figure 4. The process starts with the vertical column readout of the image sensor photodiodes operating at high speed – at 1/120 sec – and their outputs sent into a memory. From there two sequential readouts are clocked out – each at 1/120 sec – and are sent to the respective analog column amplifiers. The amplifier is synchronously switched to a high gain setting (xG) for a 1/120 sec and outputs the first signal. It is then switched back to unity gain for another 1/120 sec for the second input signal. The dual gain process has been implemented as a time-multiplexed sequence.

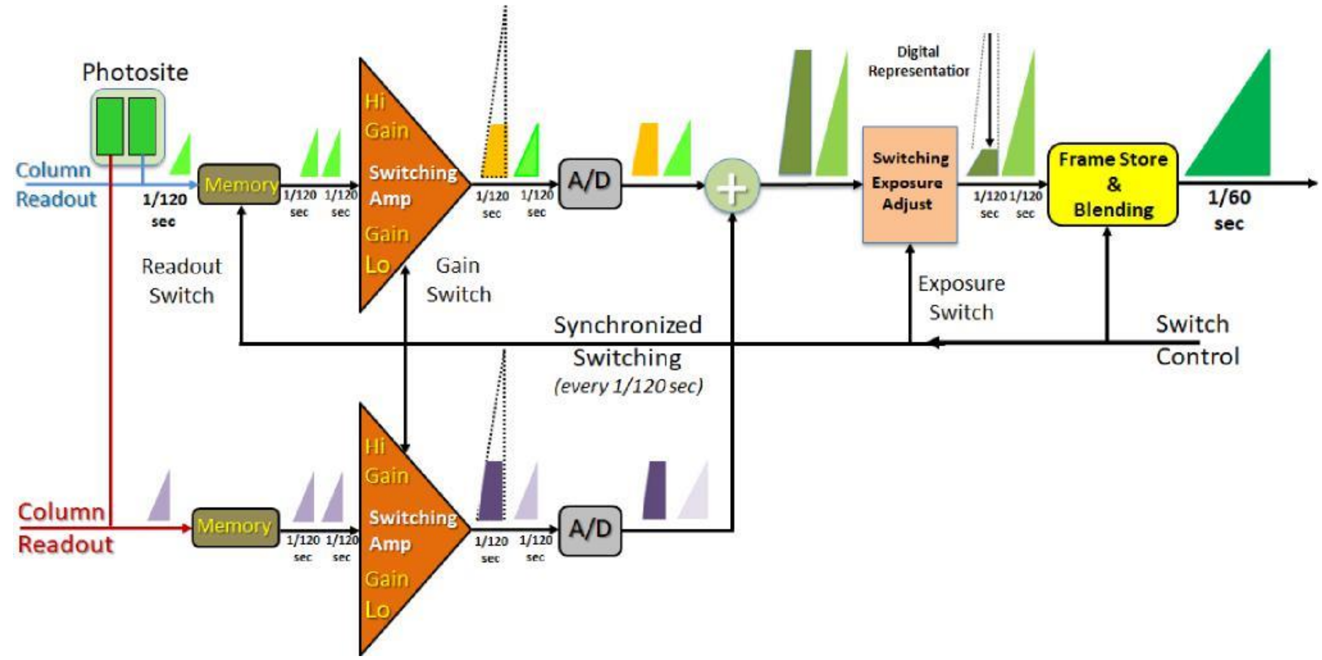

Figure 4 *Dual Gain Output (DGO) system – showing the synchronous clocking system that controls dual sequential clockout of the input signals, dual clocking of gain between High and Lo, and the exposure adjust*

The two signals pass through the analog to digital conversion and into an exposure adjustment process – which is synchronously switched to attenuate the High Gain (xG) signal component level by a factor of G – producing a version of the input signal having a higher signal to noise performance. At 1/120 sec later, the exposure adjustment is switched to allow the Low Gain signal component to pass with no level adjustment – producing a version of the input signal that has fully protected the highlight portions of the signal.

The two sequential 1/120 sec equal amplitude component signals are finally sent to a frame store that implements a blending of the two signals and then that singular composite signal is read out at the original picture capture rate to which the camera had been set (23.98 / 25 / 29.97 / 50 / 59.94 fps).

This is the final HDR product of the Dual Gain Output (DGO) process – which protected all of the highlight detail while also lowering the noise floor by more than 1-Stop – producing an extension of the dynamic range into the very dark areas of the scene. The process also minimizes the visibility of those low level readout artifacts which are buried within the noise floor but can be sometimes be visible depending upon the nature of the scene content.

Figure 5 is a simplistic pictorial representation of the DGO process.

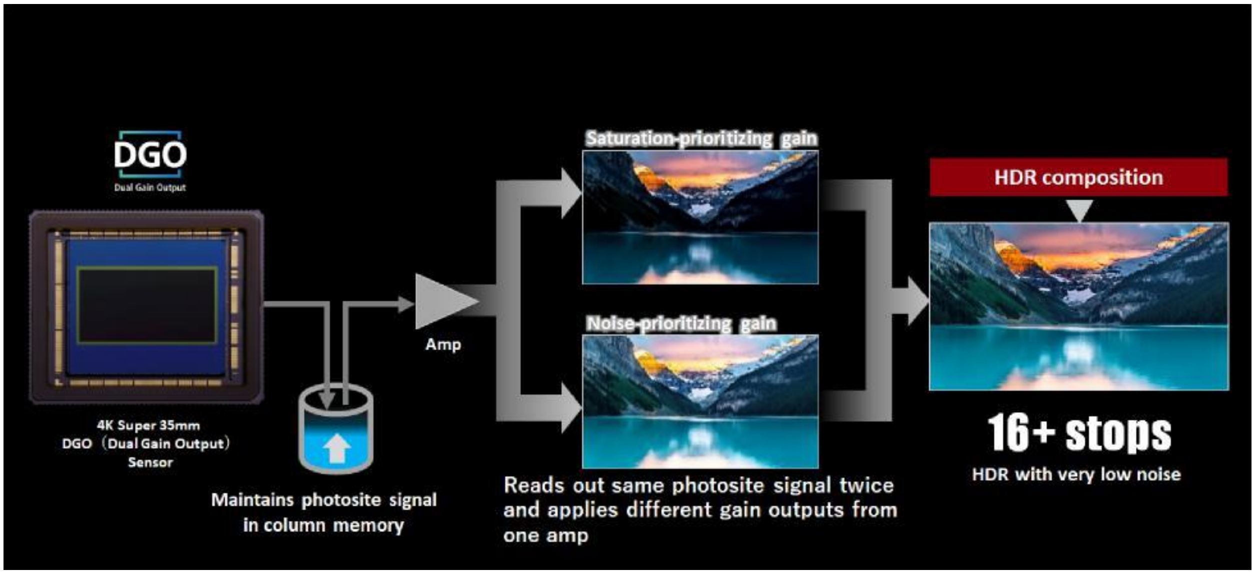

Figure 5 *Simple representation of the two images that are ultimately blended to achieve the desired extension in dynamic range*

Dynamic Range Performance of Camera with Dual Gain Output S35mm Image Sensor

The measured dynamic range of the Cinema EOS C300 Mark III camera deploying the Dual Gain Output (DGO) image sensor is shown in Figure 6

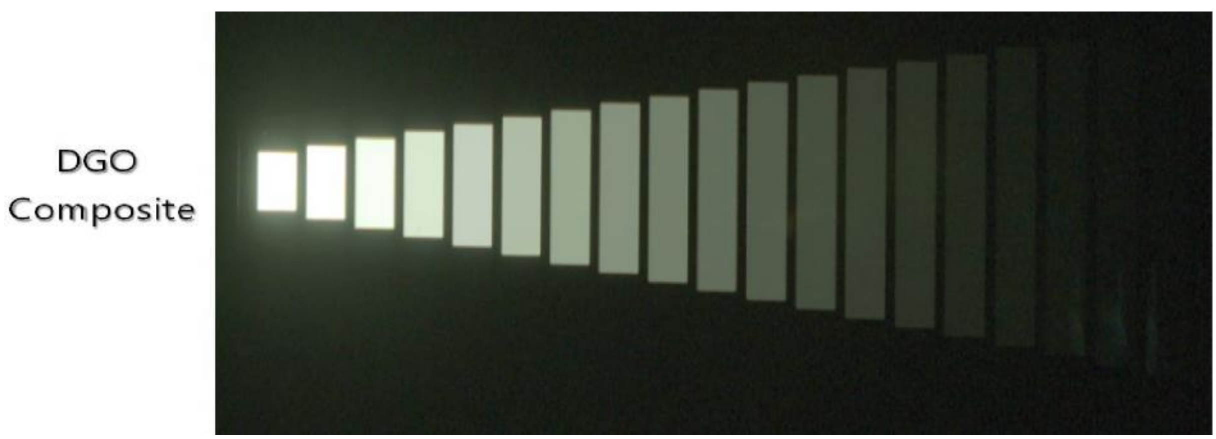

Figure 6 *Performance of EOS C300 Mark III camera using the S35mm Dual Gain Output(DGO) image sensor*

The enhanced sensitometric characteristic of the Dual Gain Output Cinema EOS camera is shown in Figure 7 – when Canon Log 2 OETF and Cinema Gamut are selected, and the camera's base sensitivity is set to ISO 800.

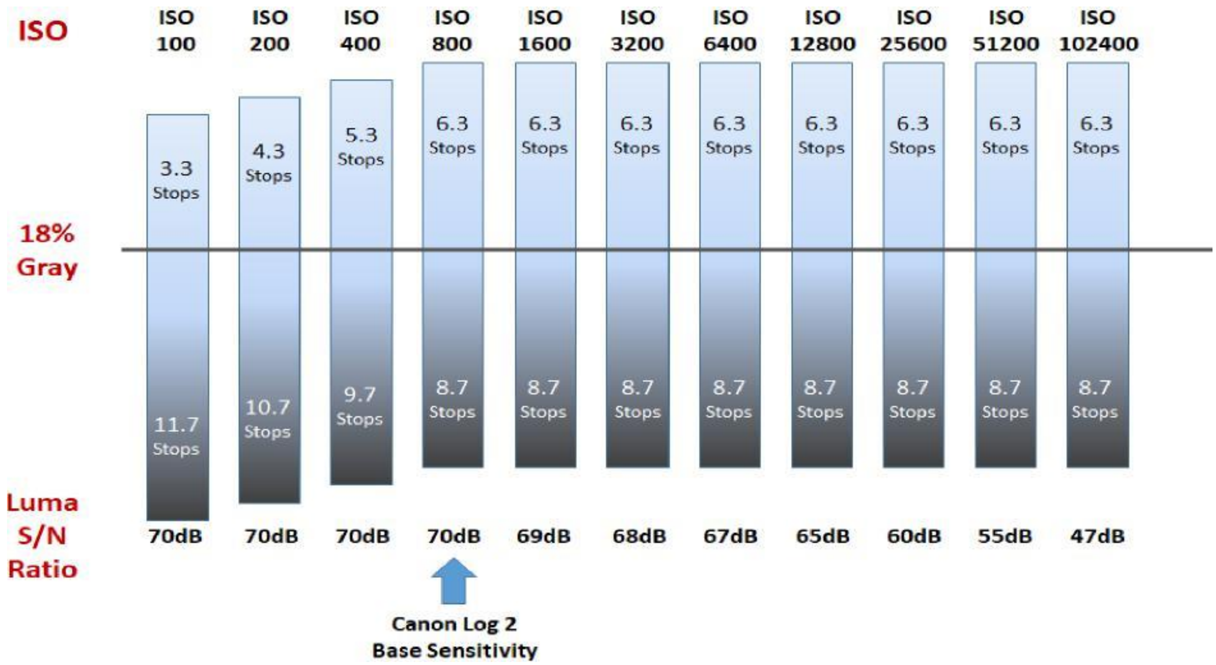

Figure 7 *The sensitometric characteristic of the EOS C300 Mark III camera using the DGO sensor*

As shown in Figure 7 the EOS C300 Mark III camera can extend approximately 8.7-stops below reference 18% gray over a wide exposure range while holding a very respectable signal to noise ratio up to ISO 12,800.

Summary

Following extensive worldwide experiences in HDR motion imaging an awareness that full exploitation of all that HDR offers includes the ability to extend the exposure latitude in both regions above and below the reference 18% gray exposure. In early days high attention was initially paid to faithful capture of highlight details. However, modern moviemaking and high-end episodic television productions appear to be increasingly seeking reproduction of scene details in deeply shadowed areas of many scenes. The Dual Gain Output (DGO) technology supports such imaging. In real world shooting, in twilight at an exposure setting of ISO 6400 the camera produces an impressive deep exposure latitude and very acceptable noise level.