White Paper

Compact Servo Lenses

CN-E18-80mm T-4.4

CN-E70-200mm T-4.4

December 5th, 2017

Canon Super 35mm 4K Compact Servo Lenses

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Abstract

The explosion in digital cinematography cameras and camcorders over the past fifteen years has seen an extraordinary evolution in their diversity. Super 35mm emerged as the central image format size for this new world of digital motion imaging although that is beginning to broaden as new Full Frame (FF) offerings loom. While FF imaging systems will likely penetrate high-end theatrical motion picture production it is certain that Super 35mm [S35mm] will continue to originate many other major movies and many genres of television and documentary production in addition to a significant segment of lower budget and independent filmmaking. The Canon Cinema EOS system – a family of Super 35mm camcorders and zoom lenses – was developed to service this broad diversity of productions. These zoom lenses come in three distinct categories. All are available in either PL or EF mount.

Top End Zooms	*CN-E14.5 – 60mm T-2.6*
	CN-E30 – 300mm T-2.95-3.7
Compact Zooms	*CN-E15.5 – 47mm T-2.8*
	CN-E30 – 105mm T-2.8
Cine Servo Zooms	*CN7x17 KAS*
	CN20x50 IAS

The widespread utilization of EF lenses on EF-mount digital cinema cameras (both Canon's Cinema EOS camera line and those of competitors) fostered a broad tiering in lower-cost digital cinema acquisition. The extensive range and diversity of EF primes and zooms significantly expanded creative choices. While these lenses continue to serve many diverse productions, their operational limitations in terms of long-established cinematography practices did frustrate many. That fact and the continuing emergence of ever-lower cost 4K cameras soon spurred global developments in a new generation of compact low-cost S35mm zoom lenses.

Canon's deep immersion in both low-cost EF lenses and Cinema EOS motion imaging lenses ignited consideration of a novel new category of low-cost compact cine lens that would flank the established Cine Servo Zoom lens family. A specific design goal was achievement of a Super 35mm zoom lens that embodied the following attributes:

- *1.1 Compact and lightweight to support highly mobile acquisition*
- *1.2 Meet established cinematography practices in lens operations*
- *1.3 High level Full 4K optical performance*
- *1.4 Include an integrated digital serve drive unit for zoom, iris, and focus specifically intended to empower those shooting under a diverse shooting conditions*
- *1.5 Low -cost*

This design quest gave birth to the new lens category we term the Compact Servo lens. It was the central emphasis on criteria 1.1 and 1.4 above that ultimately determined the innovative nature of these lenses. This White Paper will outline the multiple design attributes of this new lens category.

1.0 Introduction

Canon announced the embryonic Cinema EOS system in 2011 – based on the coordinated design of a series of Super 35mm digital cinema cameras and a new generation of S35mm cinematography zoom and prime lenses. The rollout of the Cinema EOS line of lenses started in 2011with the two Top End S35mm zoom lenses. These lenses were designed for the highest possible 4K optical quality and are intended for theatrical motion picture and episodic television production. The second phase was the introduction of two S35mm 4K Compact zooms intended for mobile acquisition, Steadicam, and shoulder-mount shooting. The third phase was the arrival of the two Cine Servo S35mm 4K zoom lenses. All of these zoom lens are available with either the Canon EF mount or the defacto cinematography PL mount.

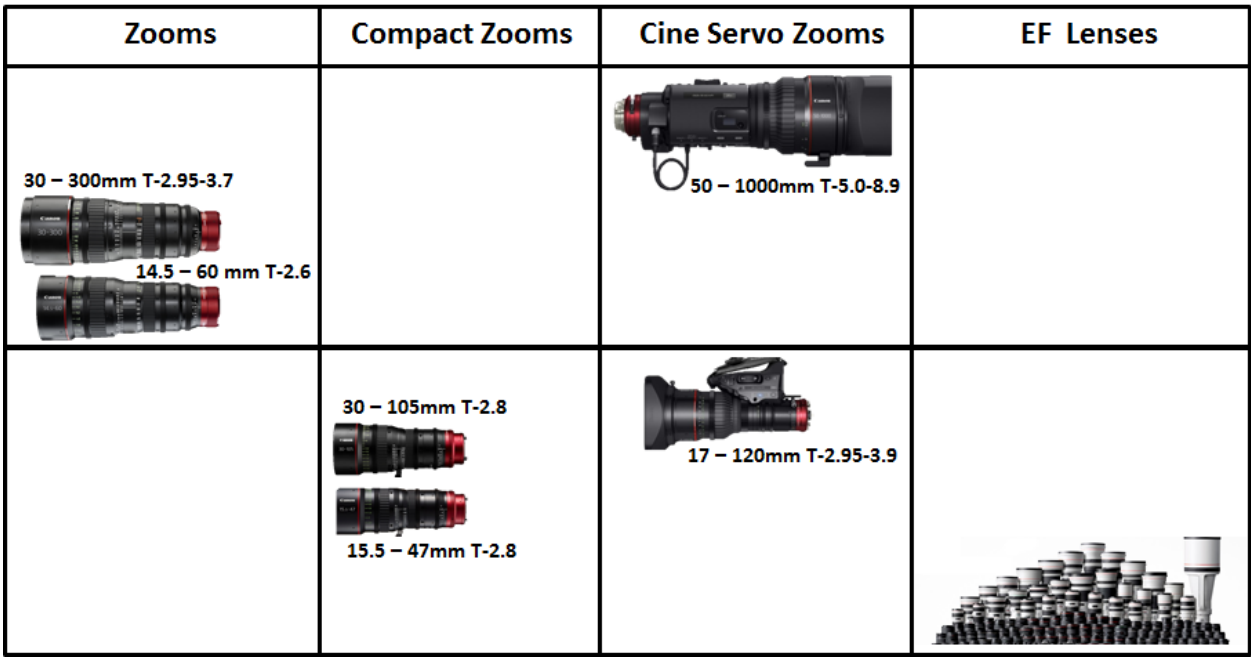

Figure 1 *The Cinema EOS lineup of high performance S35mm 4K zoom lenses are allied with the lower cost EF lens series to encompass a broad range of productions*

It was inevitable that the many owners of EF lenses would deploy them on the lower-cost Cinema EOS cameras as well as on the prolific range of other low-cost digital cinema cameras that have emerged over the past five years. Availability and affordability are the driving forces here. But, the inherent limitations of still photography lenses for motion imaging did result in frustration among those aspiring to established cinematography practices.

Canon's immersion in these two worlds of still and motion imaging soon exposed an opportunity to consider the development of a unique new category of cinema lenses. This would include low-cost zoom lenses that are imbued those operational characteristics sacred to cinematographers while drawing upon the highly refined design and manufacturing techniques of existing EF lenses, and embodying sophisticated BCTV capabilities such as servo control

2.0 Totally New Type of Cinematography Lens – Compact Servo Lens

Canon accepted the challenge of developing a true 4K S35mm cine zoom lens that met the operational needs of the cinematographer while reaching close to the cost level of the EF lenses. These lenses would distinguish themselves from the Cine Servo lens family by their specific priority on:

1. Small size
2. Low weight
3. Low cost

The low cost of these lenses would expedite an affordable upgrade from the use of EF lenses to a true cinematography motion imaging lens. The small size and low weight (which includes an advanced digital servo drive for zoom, iris, and focus) is intended to support mobile cinematography shooting. As a first perspective on the size of the new lens it is shown in Figure 1 in comparison to our two Cine Servo lenses.

Figure 2 *A comparative size perspective on the Compact Servo lens versus the Cine Servo lenses*

A central design decision for all of the cine lens family is the size of the input optical focusing group – which are typically the largest lens elements within a given lens optical system. The diameter of the input lens port (termed the Front Diameter) is a central determinant of the optical sensitivity of a lens. But, it is also the central determinant of the overall size and weight of the lens. For a given thickness of a single lens element, its mass is proportional to the diameter cubed. Accordingly, in deciding that the Compact Servo would be small and lightweight its Front Diameter was significantly reduced to achieve this goal – as shown in Figure 3.

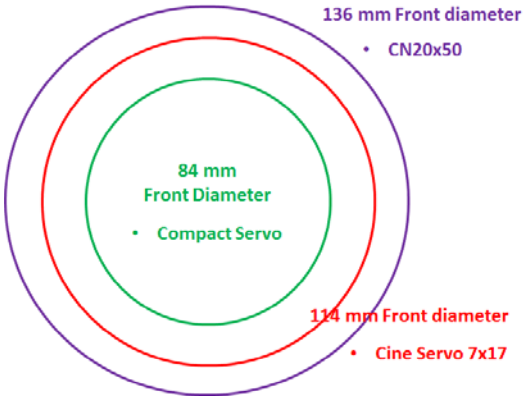

Figure 3 *Showing the Front Diameter of the Compact Servo lens (in green) compared to those of the two Cine Servo lenses*

The design goal was to realize a 4K S35mm cinematography lens – including an integrated digital servo drive – that would be as close as possible to 2.5 lbs. total. Canon launched its Super 35mm 4K Compact Servo cine zoom lens category in 2016. Two such lenses are currently available:

1. Wide-angle CN-E18 – 80mm T-4.4
2. Telephoto CN-E70 – 200mm T-4.4

Figure 4 *CN-E 18 – 80mm T-4.4 and CN-E70 – 200 mm T-4.4 S35mm 4K Compact Servo Lenses*

3.0 Broad-ranging Family of 4K Super 35mm Cine Lenses

The positioning of this new category of Compact Servo cine zoom lens relative to the entire cine zoom lens family is shown in Figure 5 below – on a relative pricing scale.

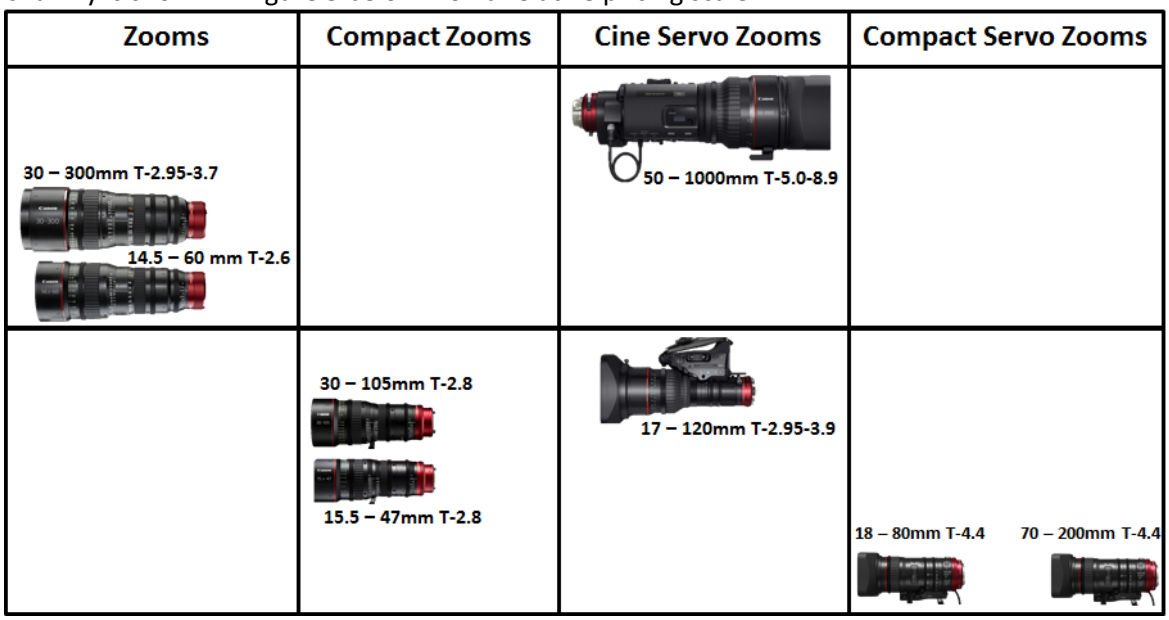

Figure 5 *The arrival of a totally new category of S35mm 4K cine zoom lenses*

Figure 6 emphasizes the total Cinema EOS lens family now offers outstanding flexibility in terms of supporting a very extensive range of both theatrical motion picture productions and television program genres.

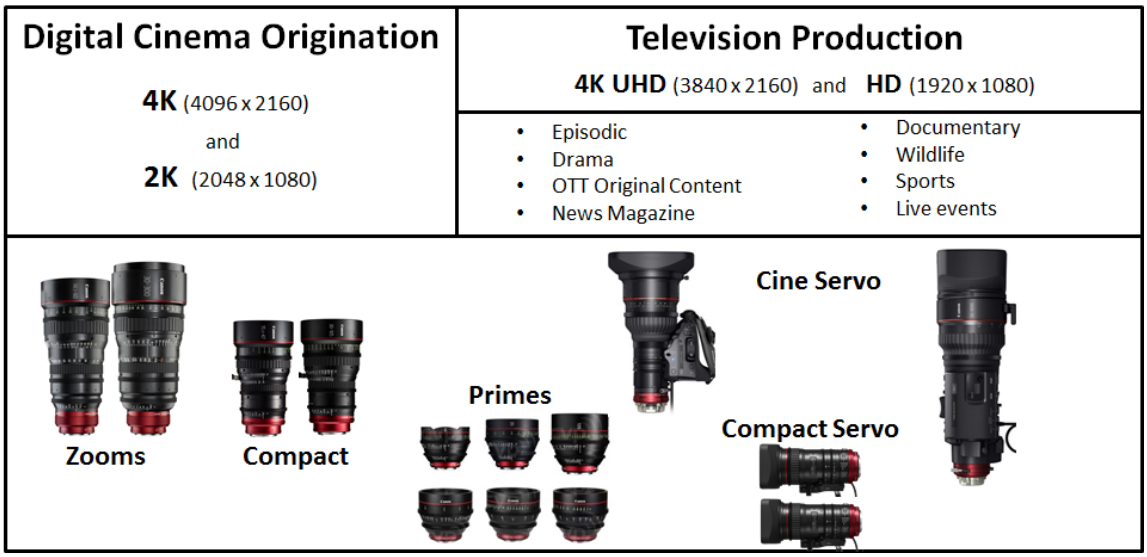

Figure 6 *Canon's portfolio of 4K Super 35mm lenses can now address a broad range of program genres and production budgets*

4.0 Established Imperatives of the Compact Servo Zoom Lens

There is an inherent long-standing conflict in cinema zoom lens design that centers about meeting the desire for certain critical optical operational behaviors while at the same time trying to control the overall size and weight of the zoom lens. This becomes especially challenging for high mobility lens-camera systems. Zoom lenses designed for cinematography place high emphasis on the following four operational behaviors:

1. **Parfocal operation** – *maintaining precise focus over the entire focal range*
2. **Elimination of aperture ramping** – *lowering of optical sensitivity at the longer focal lengths*
3. **Precise zoom tracking** – *maintaining precise image positioning over the focal range (no axial shift of the image)*
4. **Minimization of focus breathing** – *avoiding alteration to the optical angle of view with focus adjustments*
5. **Color Science** – *producing cine-like warm color consistent with Canon's EF Cinema Lens series*

The optical strategies to achieve these important operational goals conspire to increase the number of lens elements and hence the weight of the optical system. To add to the challenge, the optical speed of the lens is largely determined by the size of the input optical group. It is especially important to note that Canon gave a first priority to achieving a physically small lens that was lightweight – with highest optical speed being a lesser design priority for this new lens category. This is discussed later in this paper.

5.0 What Distinguishes the Compact Servo Zoom Lenses?

The primary intent underlying the Compact Servo lenses is to make easy the acquisition of high performance 4K while unlocking creative freedoms using the following integrated operational features:

A) Support high mobility shooting – *tailored for active movie and TV episodic production*

B) Highly configurable – *to address diverse shooting environments in both movie and TV*

There are four key attributes in the design of these two lenses that significantly empower agility and mobility – most especially in situations entailing "run 'n gun" shooting:

5.1 Miniature digital servo

5.2 Zoom servo grip

5.3 Focus Support for 4K shooting

5.3.1 Dual Pixel CMOS Auto Focus

5.3.2 Focus Guide

5.4 Built-in image stabilization

Compact Servo lens is a uniquely new category of highly cost-effective 4K Super 35mm cine zoom lens.

5.1 Miniature Digital Servo

The label “Compact Servo” makes the first major statement on what differentiates these two lenses from other compact cine lenses. The integral servo system precisely controls Zoom, Iris, and Focus. Auto Iris and Remote Iris control are supported. Related innovative technologies within the drive and lens are outlined in the Appendix.

Figure 7 *Integral zoom servo unit separates the Canon Compact Servo lens from other Compact Lenses*

The attached digital servo system is unusually compact and is pivotal to the innovation that seeks to offer the production world a compact lightweight Super 35mm lens like no other.

5.2 Detachable Zoom Servo Grip – Supports Multiple Configurations

When attached, the zoom servo grip ZSG-C10 (an optional accessory) adds a second significant distinguishing operational feature of the Compact Servo lenses. Using a Rosetta mounting this can be coupled directly to the lens and rotated to suit the shooting angle. The grip offers touch-sensitive zoom control. With the big zoom rocker on the grip, extremely smooth accelerated zooms are possible. When fully pressed the zoom speeds through the entire zoom range from 18mm to 80mm (or 70 – 200mm) in about one second. At the slowest speed the zoom motor takes about 60 second to cover the entire zoom range when the zoom rocker is gently pressed. No other low-cost compact cine lens offers such creative operational capabilities.

Figure 8 *The zoom servo grip can be rotated to support high and low elevation shooting and can be detached for remote control of the lens*

The detachable zoom servo grip allows a variety of configurations as illustrated below. It can be directly attached to the lens, detached and mounted on an arm for shoulder mount shooting, or mounted on another form of arm for tripod shooting.

Figure 9 *Indicating the versatility offered by the optional servo zoom grip – shown in the right hand*

5.3 Focus Support for 4K Shooting

5.3.1 Dual Pixel CMOS Auto Focus

Cinema EOS cameras embody a powerful auto focus system that mobilizes the dual photodiodes within each photosite to create two separate images that facilitates a phase detection system indicating the degree of defocusing. Figure 10 illustrates the manner in which the two sets of dual pixel outputs from the CMOS image sensor are sent to the digital processing microcircuit developed by Canon. Within this processor, all of the decision-making and data processing associated with the selected Auto Focus modes are made and the correcting drive signal created that is fed to the focus motor within the lens. The accuracy and dependability of this system is now globally recognized. There are diverse modes of operation of the Auto Focus system – such as effortless rack focusing between several subjects in a single shot.

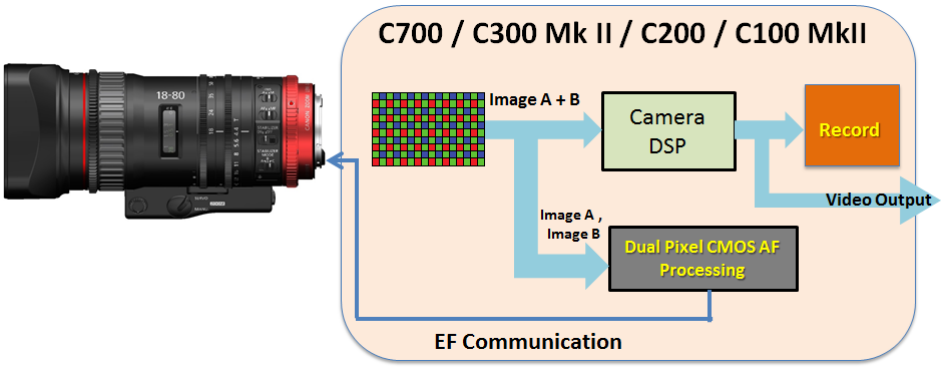

Figure 10 *Principle of the Dual Pixel CMOS AF system – data from dual photodiodes within each photosite constitutes a phase comparison which is processed to create a control signal for the lens focus*

5.3.2 Focus Guide

For the cinematographer who prefers traditional creative manual focus operation – the same dual pixel system can alternatively be switched from the Auto Focus control loop to an open loop system that utilizes the Dual Pixel CMOS AF data processing to instead transfer precision signaling in the camera viewfinder. This provides a totally unambiguous indication of precise focus – essential to 4K sharpness.

Technical details of the Dual Pixel CMOS Auto Focus and the Focus Guide systems can be found in reference [1].

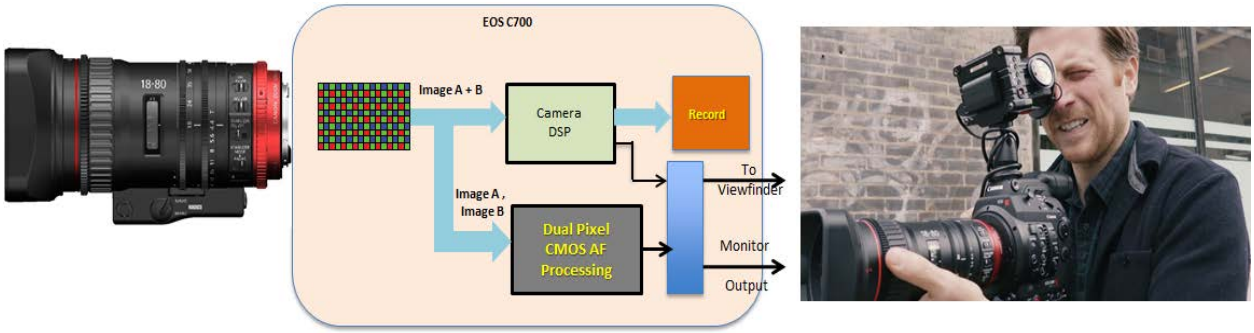

Figure 11 *Principle of the Focus Guide system – where manual actuation of the lens focus control is detected by the image sensor and the data processing signals the viewfinder*

5.4 Built-in Image Stabilization

Camera shake is one of the enemies opposing 4K sharpness. Camera movement during exposure can blur the image – the degree depending upon the shooting conditions, shutter speed, and lens focal length.

Shift-Image Stabilization technology can be ideal for correcting modest amplitude disturbances and vibrations in longer focal range lenses. This technology has been highly refined by Canon over generations of consumer and broadcast lenses. It introduces an opposing movement to the inadvertent camera movement within the lens that helps maintain the image position on the camera sensor. With this technology, a lens group is placed near the rear of the overall lens system and the correcting action entails a horizontal or vertical (or both) physical shifting of that lens group to implement the requisite change in the path of the light rays. The correction principle is simply explained in Figure 12.

There is direct On-Off switching of the stabilization system. When in the IS mode there are three distinct anti-vibration modes to select from: Standard mode for handheld; Maximum mode for higher frequencies (such as engine vibrations encountered when shooting from a moving vehicle, helicopter, or boat); and, a Smooth mode for small vibrating tripod mount shooting. Shift-IS is of particular benefit for the longer focal lengths encountered in the CN-E70 – 200 mm Compact Servo lens.

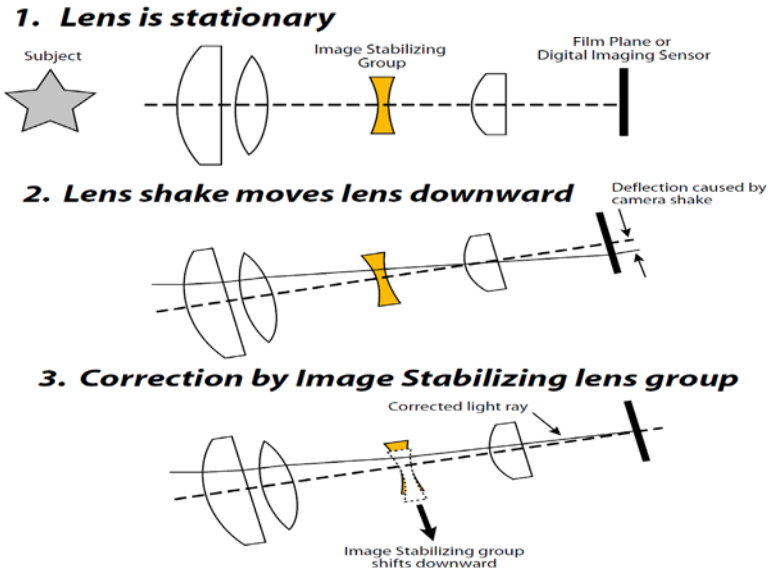

Figure 12 *Outlines the correcting action of the Shift-Lens when the lens-camera system is subject to a sudden physical disturbance*

6.0 Perspective on T-4.4 Optical Speed

Achieving high optical speed quickly escalates both volume and weight of requisite glass elements in any given lens – most especially the front end input optical system. The higher priority in achieving a low total weight of approximately 2.7 lbs. (including servo unit) and short length of 7.2-inches in the two Compact Servo lenses helped determine the choice of an 84mm Front Diameter. This, in turn, predetermined the T-4.4 maximum relative aperture specification for each. That optical speed specification, however, does remain constant over the total focal range of both lenses.

An important perspective on that optical sensitivity specification recognizes the excellent advances in the operational sensitivities of contemporary Super 35mm digital cinema cameras. An example of this is our own EOS C300 Mark II cinema camera. The chart below shows (in red) the sensitivity specification for this camera (2000 lux illumination, a T-11 aperture setting will produce 100 % reference Luma level). Canon specifies this sensitivity at 1920 x 1080 @29.97P.

Thus, the maximum relative aperture setting of T-4.4 will maintain full Luma level in a scene illumination of only 350 Lux. A camera ISO 12,800 setting will maintain that same Luma level at only 31.25 Lux with a very acceptable noise level. The ND filters handle the higher illumination levels. Overall, the lens-camera system handles a particularly wide illumination range – covering most real world shooting environments from extremely bright sunlight to late dusk.

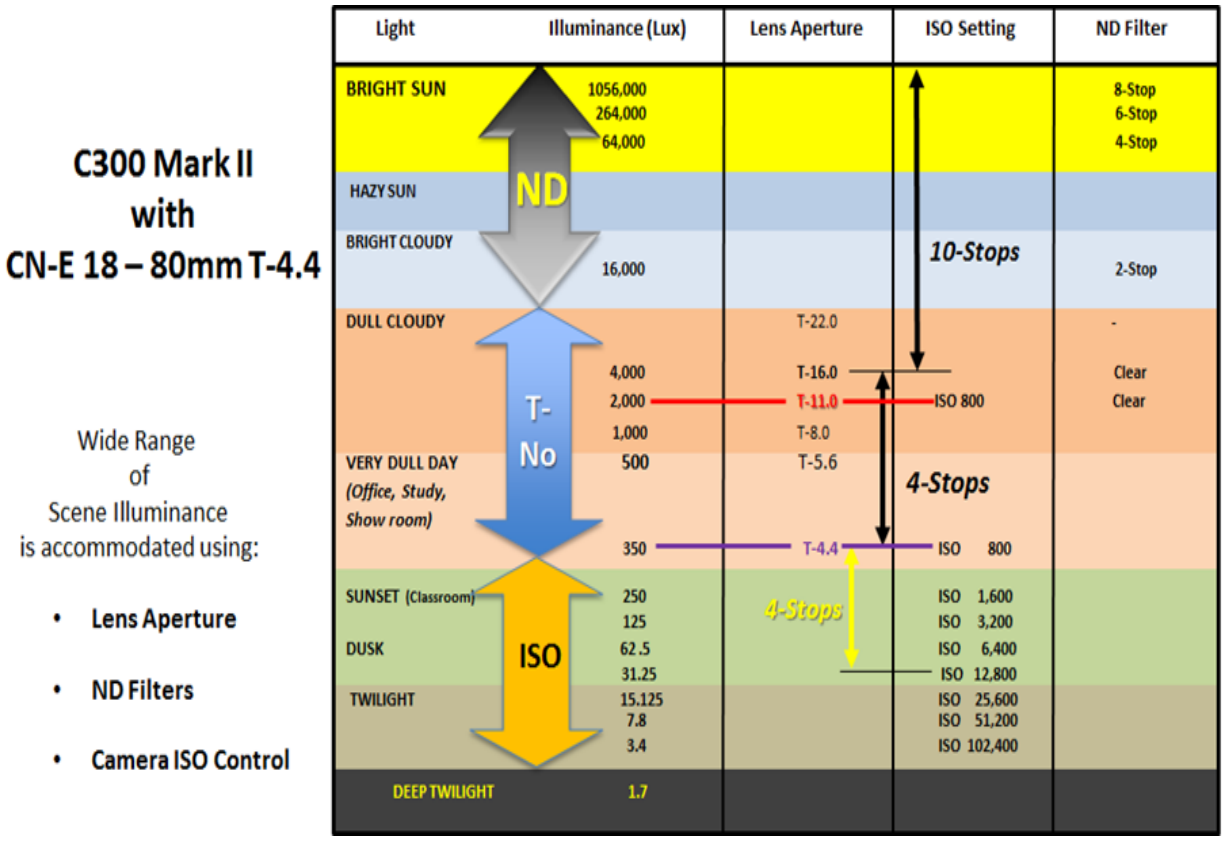

Figure 13 *Perspective on the T-4.4 optical speed of the Compact Servo lens with a sensitive camera*

7.0 Compact Servo Lenses as Variable Primes

The constant T-4.4 maximum relative aperture of both of these lenses allows consideration of their use as variable primes. Between the two a range of 18mm to 200 mm is covered. Figure 14 compares their composite focal range with two well-known sets of Super 35mm prime lenses – showing that together they completely encompass both prime sets.

Figure 14 *Two Compact Servo zoom lenses cover the total focal ranges of popular prime sets*

8.0 Compact Servo Lenses Configured for Low-Cost Studio System

The single 20-pin connector on the two lenses facilitates use of either a standard broadcast Zoom controller or Focus controller. Alternatively, Zacuto have engineered a Y-Cable that allows both controllers to be used with these lenses.

Figure 15 *Zacuto developed a Y-cable supporting standard Broadcast Zoom and Focus Controllers*

9.0 Summary

International published reports and reviews of our Compact Servo lenses [2], [3], [4], [5], [6], are largely favorable – but many are tinged with small criticisms, and expressions of puzzlement and misunderstandings. On one hand, it is to be expected that direct comparisons will be made between the features, performance, and costs of our two lenses and those of the recently arrived competitive low-cost compact Super 35mm cine zoom lenses. However, it has to be stressed that direct competition with those more traditional cinematography lenses was not the primary goal of these two Compact Servo lenses.

Canon's central goal was to go beyond the traditional cinematography norm by adding operational empowerment of the operators of these lenses – to help facilitate achievement of excellent 4K imagery under a wide range of dynamic and challenging shooting conditions. That core design goal led to specific design decisions unique to these two lenses:

Reduction in lens size and weight – preempting any quest for the highest optical speed

Precision servo control over Zoom Iris, and Focus – preempting wider rotation angles

Precision Dual Pixel CMOS Auto Focus – preempting manual focus control having hard stops

When one takes the time to study all of the remarkable capabilities that have been built into these lenses you have to marvel at the assemblage of technologies and design ingenuities that constitute a lens that really is like no other.

It needs to be emphasized that full achievement of 4K optical performance was of paramount importance in these lenses. The optical MTF meets this criteria and the fall-off toward the image extremities is modest. Special strategies were incorporated to minimize chromatic aberrations which can be the nemesis of high quality 4K. The published reports have generally been laudatory of our overall 4K performance

Being a very new generation design – High Dynamic Range (HDR) was an additional central design factor. The handling of specular highlights and the simultaneous reproduction of deep blacks are remarkably good for such a low-cost lens.

The arrival of the CN-E70 – 200mm T-4.4 Compact Servo lens greatly strengthened the Canon story. Their identical size, weight, and optical speed make them a superb working pair.

The unique Canon EF mount further empower these two lenses. Power is transferred from camera to lens through this mount. Very important – metadata is also transferred from lens back to camera. This lens reference information includes precise settings of Zoom, Iris, and Focus. On Cinema EOS cameras this data can be displayed in the viewfinder during shooting while being recorded for later use in postproduction. Lateral chromatic aberration and vignetting corrections can also be implemented in these cameras.

10.0 APPENDIX – Advanced Technologies within Digital Drive Unit

The Compact Servo lenses drew upon decades of technologies and expertise gained in the extensive worldwide EF lens developments. In particular, the drive system for zoom, iris, and focus capitalized on some of these technologies:

10.1 Zoom Drive – *using Miniature DC Motor Technology*

Canon utilizes a miniature DC motor within the Compact Servo lens for driving the zoom action. This form of motor is termed a DC Coreless motors – based upon the fact that it has no iron core within the rotor. Instead, a copper wire winding in a basket configuration (coil) rotates around the outside of a cylindrical magnet.

Three advantages of the coreless motor are as follows:

- The lighter, basket shaped rotor makes the moment of inertia smaller, allowing for rapid acceleration and deceleration
- Absence of an iron core in the rotor prevents cogging caused by magnetic induction; hence the rotation is smooth, with minimum noise and vibration
- Miniaturization of the motor itself becomes feasible.

10.2 Focus Drive – *using Ring-Type USM Technology*

The ring-type USM motor is the most widely used AF motor in the Canon EF lens range. Of the 49 Canon lenses that use USM motors, 42 of them feature a ring-type USM. To be effective, the ring-type USM motor needs to meet certain requirements. They must be powerful enough to drive the focusing lens group quickly and easily at low speed so as to avoid the need for a gear system to reduce the speed. They must exhibit high levels of holding power so that once the motor is switched off, the focusing lens group is held in place without any further input needed. They should be simple to manufacture and should start and stop quickly to ensure the best focus response. They should also be as quiet as possible in use.

The ring-type USM is actually very simple in operation. It is composed of a rotor and a stator – an elastic body with a piezo-electric ceramic voltage element attached to it. By applying an A/C current with a resonant frequency around 30,000Hz to the stator, vibrations are created causing the rotor to rotate continuously. The frequency 30,000Hz is in the ultrasonic range, and this is where the USM motors derive their name. Figure 17 shows the ring-type USM motors -- emphasizing the simple construction and arrangement of the rotor and stator. The stator is the toothed ring at the rear.

Figure 17 *Showing the basics of the ring-type USM motor used for focus drive*

10.3 Iris Drive – *using Electro-Magnetic Diaphragm Technology*

A Cinema lens requires an iris that can be smoothly adjusted between wide open and closed. Continuous adjustment allows not only for precise exposure control, but also smooth live adjustment while recording. This can be useful to help compensate for change in exposure due to spotty clouds or moving between indoor and outdoor light levels within a shot.

The auto exposure system in the two Compact Servo lenses capitalizes on Canon's Electromagnetic Diaphragm (EMD) technology that has been highly refined over many years in the EF lens series. This technology integrates the lens iris assembly and a miniature stepping motor in a single unit. Electronic pulses from the camera controls the motor to map numerous steps across the full range of the iris mechanism. This AE control loop is fast and silent. An AE Shift mode allows a small manual override for fine adjustments to exposure.

Compared to conventional camera systems that use a mechanical lever in the camera body to control the aperture blades, the EMD is highly accurate. Eliminating the shock caused by the mechanical lever, this system is also exceptionally smooth and quiet.

These two lenses can smoothly adjust between open and closed for precise exposure control and live in-shot changes. The 9-blade iris creates a rounded aperture so out-of-focus highlights appear circular. An odd number of iris blades also help create a less distracting flare. Their aperture can close completely, allowing no light to pass through. This is useful in black balancing a camera.

Figure 18 *Showing the EMD system for precision lens aperture control*

References

[1] Canon White Paper *"Significant Operational Features of C700"*

https://downloads.canon.com/nw/camera/products/cinema-eos/c700/white-papers/eosc700-whitepaper-significant-operational-features.pdf?cm_mmc=nw-_-c700-_-white-papers-_-operational-features

[2] https://www.cinema5d.com/canon-18-80mm-review-test-compact-servo-lens/

[3] http://gadgetflux.net/canon-cn-e-18-80-t4-4-cine-servo-zoom-review/

[4] https://www.videomaker.com/article/r02/19043-review-canon-compact-servo-18-80mm-t44-ef-is-a-surprisingly-affordable-cine-lens

[5] http://www.studiodaily.com/2017/03/review-canon-compact-servo-18-80mm-t4-4-ef-lens/

[6] https://www.cinema5d.com/hands-on-with-the-canon-compact-cine-servo-70-200-t4-4/