

Canon

WHITE PAPER

XF705

XF705

NEW 4K UHD/HD
PROFESSIONAL CAMCORDER



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Contents

	Page
ABSTRACT	
1.0 INTRODUCTION	1
2.0 IMAGING SYSTEM	2
2.1 1.0-inch 4K CMOS Image Sensor	2
2.2 The 1.0-inch 4K Lens	4
2.3 ND Filter system	6
2.4 Dual Pixel Auto Focus	6
2.5 Focus Guide	8
2.6 Image Stabilization	8
3.0 VIDEO PROCESSING	9
3.1 Choice of OETF and Color Gamut	10
4.0 OVERSAMPLING HD PROCESSING	11
4.1 Formulation of the FHD YCbCr 4:2:2 @ 10-bit Component Video Set	12
4.2 Formulation of the FHD YCbCr 4:2:0 @ 8-bit Component Video Set	13
5.0 INTERNAL RECORDING OF TWO HDR FORMATS	13
5.1 Hybrid Log Gamma (HLG) HDR Format	13
5.2 Perceptual Quantization (PQ) HDR Format	14
6.0 RECORDING CODECS	15
6.1 Recording Options in XF705	15
6.2 HEVC – High Efficiency Video Coding	15
6.3 Specific Video Formats Recorded Internally in the XF705	18
6.4 File Structure for Recording	20
6.5 Audio Recording 21	
7.0 CONNECTIVITY AND EXTERNAL RECORDING	23
8.0 SIMULTANEOUS INTERNAL AND EXTERNAL RECORDING	25
9.0 NETWORK FUNCTIONS	26
10.0 IP STREAMING	26
11.0 REMOTE VIDEO CONTROL	28
12.0 SUMMARY	29
13.0 REFERENCES	30

Abstract

Eight years ago Canon introduced a file-based HDTV camcorder – the XF305 shown below – that was intended to originate full broadcast quality HDTV in a compact and lightweight body. An integrated 18:1 zoom lens, three 1/3-inch CCDs (each having 1920 x 1080 sampling), and 50 Mbps 4:2:2 MPEG-2 recording was central to the high performance. This camcorder continues in popularity today (although it has switched to three 1/3-inch Canon CMOS sensors).



The new XF705 4K UHD camcorder shown to scale versus the established XF305 HDTV camcorder

The new XF705 camcorder is intended to originate both high-quality 4K UHD and HD and it deploys a single 1.0-inch CMOS image sensor. The XF305 uses an 18:1 zoom whereas the XF705 uses a 15:1 zoom – both having three ring operational control of zoom, focus, and iris. In addition, their respective recording codecs are very different – the XF705 is one of the first professional camcorders to deploy the powerful new HEVC codec (with four times the encoding efficiency of MPEG-2) which supports on-board recording of 4K UHD 4:2:2 @ 10-bit @ 60P/50P to low-cost SD memory cards. The central design priority of the XF705 is to achieve a compact and lightweight 4K UHD / HD acquisition system that will support highprofile television productions, sports and events, news gathering and documentary, and independent filmmaking. High image quality and HDR recording are central to the design goals of this camcorder. Both IP streaming and FTP file transfers are supported.

This White Paper will detail the multiple design choices underlying this new camcorder.

1.0 INTRODUCTION

HDTV has been with us in the USA for almost 20 years. But, the pace of technological advances in digital motion imaging has accelerated over those years and aspirations of content creators have also grown. Early in the life of HDTV continuing rapid developments in disparate technologies spawned interest in an unceasing quest to further elevate television system resolution. International standardization bodies ultimately produced a long term blueprint for broadcast television – in the form of detailed production standards for 4K UHD and for 8K UHD [1].

Added to these dynamics are the current global developments in 4K UHD television sets with vigorous competition now driving the marketplace to consider acquiring these TVs as a better alternative to HDTV sets. This, on the basis that the innovative internal upscaling in these TVs offers an excellent way of viewing current HDTV program material while new 4K UHD services slowly build-up in the years ahead. That same competition has rapidly driven down the costs of 4K UHD television sets.

4K UHD has acquired a visible global presence over the past few years. While U.S. over the air broadcasting is not yet offering 4K UHD services many broadcasters are quietly experimenting with the production format. Cable operations are also moving cautiously in terms of adoption. But Satellite operations in Europe and the USA are now offering early 4K UHD delivery services. Meanwhile 4K UHD streaming services are rapidly growing. The march to 4K UHD is underway.

It is in this context that Canon has introduced the XF705 camcorder. In these still early days of 4K UHD it is intended to support high quality YCbCr 4:2:2@10-bit acquisition in 4K UHD (3840 x 2160) up to 60 fps progressive, while also facilitating high performance 1080P YCbCr 4:2:2 @10-bit acquisition up to 120 fps progressive.

The XF705 camcorder represents a sharp departure from the Trisensor imaging system of the XF305. Capitalizing on significant technical developments in large image format single sensor imaging within our now extensive Cinema EOS portfolio this new camcorder utilizes a single one-inch 4K CMOS image sensor developed by Canon. This offers higher sensitivity than the three 1/3-inch CMOS camcorders of the XF305 while supporting a more cinematic control of depth of field. The performance and operational advantages of the tight integration of this sensor to a newly developed one-inch 4K zoom lens will be outlined in this White Paper.

Equally important was the core decision to base 4K UHD and HD recording squarely upon the newly established HEVC MPEG-4 AVC/H.264 (HVEC) compression algorithm – the Canon XF-HEVC codec. This helps produce high performance YCbCr 4:2:2@10-bit recording of both 4K and HD with a digital bit rate efficiency that allows the use of two standard and universally available and relatively low-cost SD cards.

The separate choice of an MPEG-4 AVC compression codec – Canon's XF-AVC – is outlined in the paper.

Genlock and Timecode interfaces are provided.

IP streaming of both XF-HEVC and XF-AVC is supported in the XF705 camcorder. A 12GB SDI interface and an HDMI interface both allow single cable transport of 4K UHD. The SDI interface can be mapped for 3G SDI transport of the HDTV signal.

2.0 IMAGING SYSTEM

2.1 1.0-Inch CMOS 4K Image Sensor

The size and number of image sensors is a pivotal design decision for all digital motion imaging cameras. Canon gave high consideration to this choice when planning the successor to the XF305. The final decision to employ a single one-inch CMOS image sensor was predicated on the following characteristics deemed important for a 4K UHD camcorder in 2018:

- 1.1 **High sensitivity** – facilitated by the larger photosite size (3.2 x 3.2 micron) of the 1.0-inch image format size
- 1.2 **High dynamic range and low noise** – based upon the larger photosite size that can be accommodated within the 1.0-inch image format size
- 1.3 **Shallower depth of field** – than the established 2/3-inch image format size (and also that of the even smaller 1/2-inch and 1/3-inch formats) – offering a more cinematic look to imagery that has recently proven popular in many broadcast program genres including broadcast News
- 1.4 **4K UHD resolution** – according to the ITU-R BT.2020 production standard of 3840 (H) x 2160 (V)

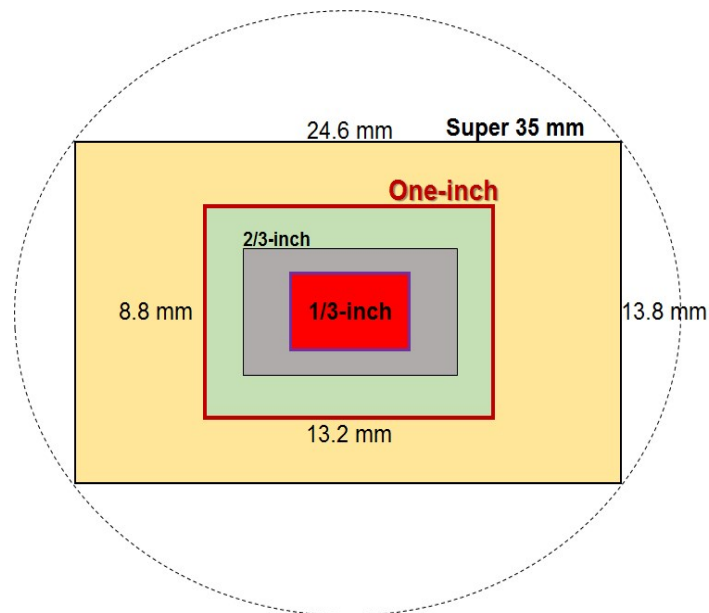


Figure 1 An overview perspective – a scaled graphic of the active image area of the 1.0-inch image sensor compared to established video image format sizes

A closer look at the active image area of the 1.0-inch image format is shown in Figure 2 where it is compared to the 1/3-inch image format size of the predecessor XF305 and also to the well-established 2/3-inch image format size.

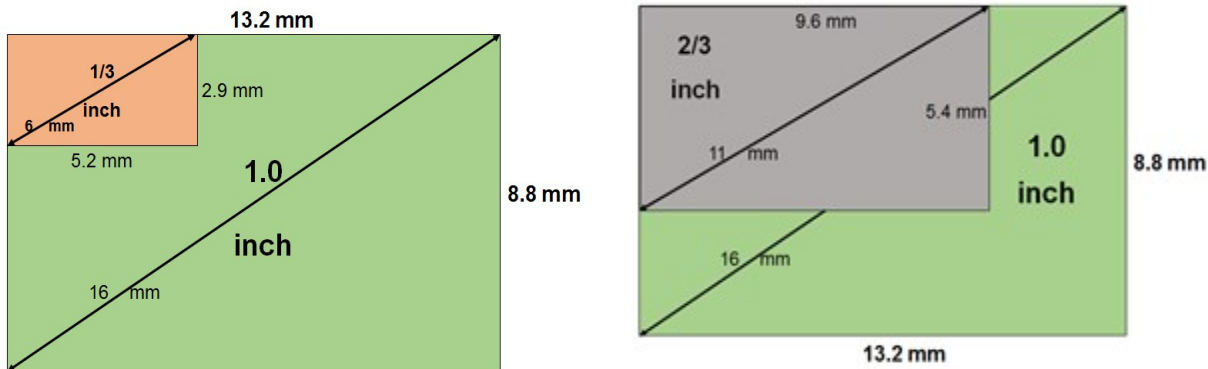


Figure 2 Scaled graphic showing the active image area and diagonal dimension of the 1.0-inch image sensor compared to those of both the 1/3-inch and 2/3-inch sensors

The 1.0-inch image sensor has more than 7.5 times the area of the 1/3-inch image sensor. It has 2.25 times the area of the 2/3-inch image sensor. At 4K UHD it has a photosite size of 3.2 micron squared versus the 2.7 micron squared of the 1080-line HDTV 1/3-inch image sensor.

Comparative Sensitivity

The distinct advantage of the single large 1.0-inch image sensor can be seen in a comparison of the Minimum Illumination specification of the XF705 compared to that of the 1/3-inch trisensor XF305:

XF705	3840 x 2160 @ 60P	1.7 Lux	Auto Slow Shutter ON, Shutter 1/30 sec
XF305	1920 x 1080 @ 60i	4.7 Lux	Shutter 1/60 sec

Note that the minimum illumination specification for the XF705 is for the 4K UHD video format at 60 progressive frames per second. Yet, it can deliver full Luma signal level at a mere 1.7 Lux of illumination.

In the case of the XF305 – which is constrained to HDTV origination – it requires 4.7 Lux of scene illumination to deliver full Luma level.

The XF705 includes infrared imaging when shooting is very dark situations.

2.0 The 1.0-inch 4K Lens

The 15:1 integral zoom lens offers full 4K optical performance and both a wide angle and a generous focal range that will service many program genres. Lens diffraction effects as aperture is stopped down are lessened in the larger image format compared to the smaller 1/3-inch image format of the XF305. The optical system comprises 14 groups of 18 elements (using 2-sided aspherical lenses and super-UD lens elements)

Focal Range: 8.3mm ----- 124.5 mm
(25.5 mm -----382.5 mm in 35mm equivalent)

Optical sensitivity: F-2.8 – F-4.5

Number Iris Blades: 9

Image Stabilization: Built-in Shift-IS

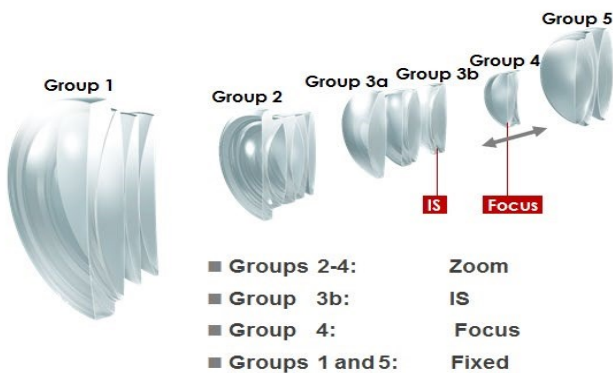


Figure 3 The 18-element lens that comprises 14 groups – and the three control rings for separate zoom, focus, and iris control

Multiple aspheric elements are included within the lens groups to achieve 4K image quality while correcting various aberrations over the entire zoom range. A three group zooming system helps minimize the size of the lens while also reducing chromatic aberrations over that focal range. Three independent control rings are provided – for zoom, iris, and focus. A carefully controlled torque in these rings provide satisfying operational adjustments. A zoom rocker for broadcast-type shooting has also been added to facilitate both a stable grip and reliable operability. The number of iris blades has been increased to 9 (from the 6 in the previous XF305 model) for a beautiful and natural bokeh that appears more circular. In addition, the odd number of blades has the quality of doubling the number of light rays – enabling the lens to softly diffuse light when shooting night scenes.

The focal range of the lens can be extended at both extremities by utilizing optional optical accessory adaptors offered by Canon – as shown in Figure 4.

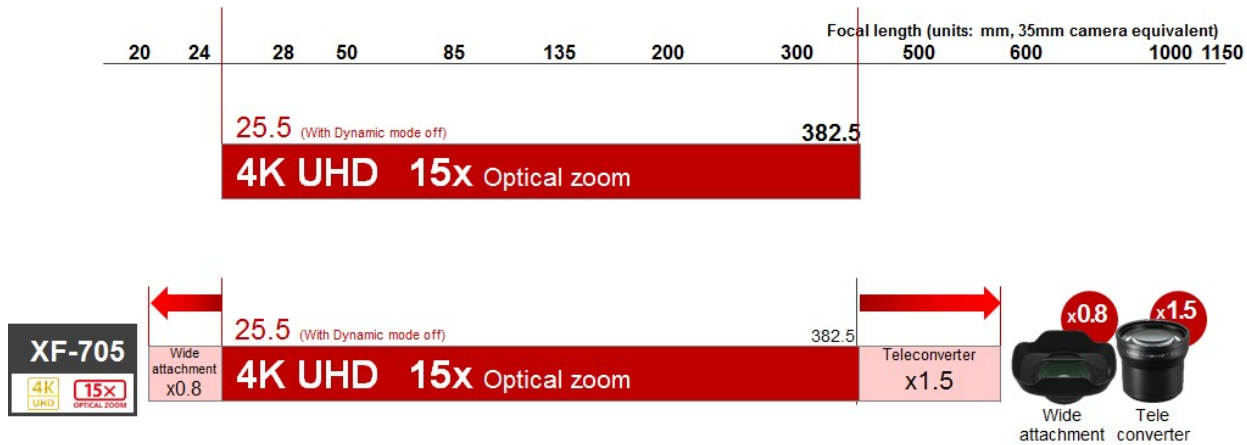


Figure 4 Showing the focal range of the XF705 lens (35mm equivalent) – and how it can be further extended at both extremes with optional optical attachments

When the XF-705 is set to operate in 1080P HDTV mode the effective focal length can be extended by invoking a 2:1 digital zoom – which is an HD image structure derived from the 4K pixel structure – providing an effective 765 mm focal range and helping facilitate high performance.

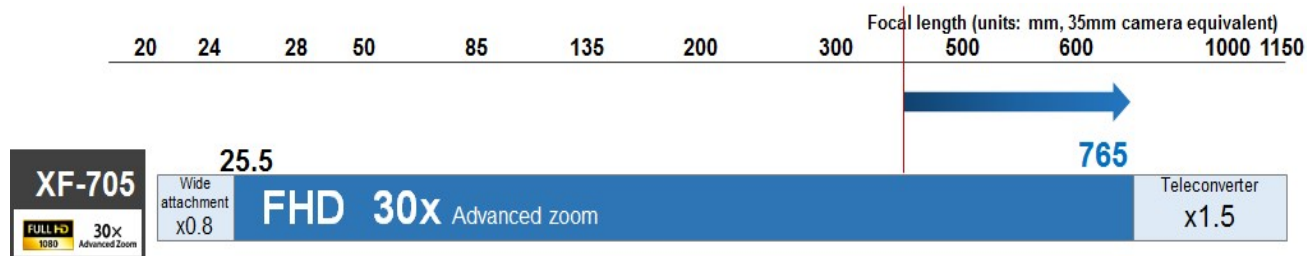
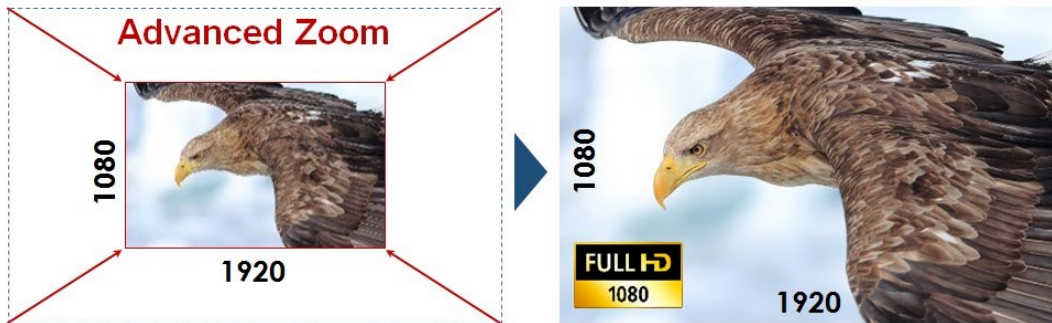


Figure 5 The effective zoom range can be digitally extended to 30:1 when the XF705 is directly originating 1080P HDTV

2.1 ND Filter System

Traditionally, the lower cost professional camcorders do not embody an ND filter. The XF705, however, offers a selection of three ND filters as well as the ND Filter OFF.

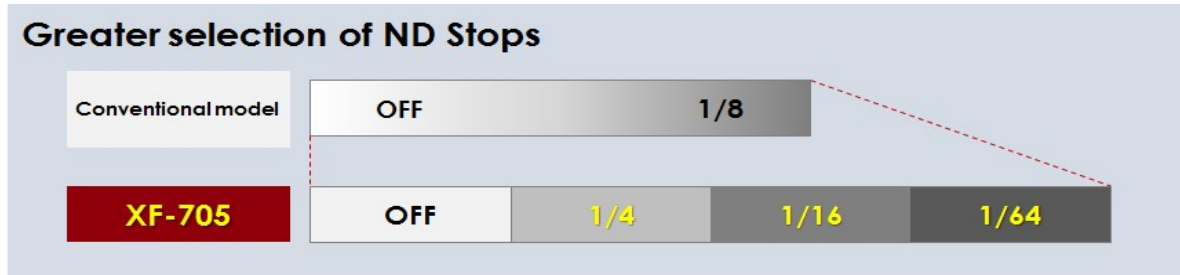


Figure 6 Outlining the choice of ND filters built into the XF705



Figure 7 Showing the internal turret mechanism used to select one of three ND filters in XF705

2.4 Dual Pixel CMOS Auto Focus

At this juncture the global reputation of Canon's breakthrough technology of Dual Pixel CMOS Auto Focus is well established. This system works – reliably and with high accuracy. It does so because the focus sensing takes place within the image sensor itself – using an innovative phase detection that is inherent within each and every photosite. Each photosite deploys two separate photodiodes which offers two distinct advantages – one, being the phase detection for AF, and the second, enhancement to the effective dynamic range of each photosite [2]. The data from the image sensor is processed using some powerful algorithms to produce a control signal that closes the servo loop around lens focus.

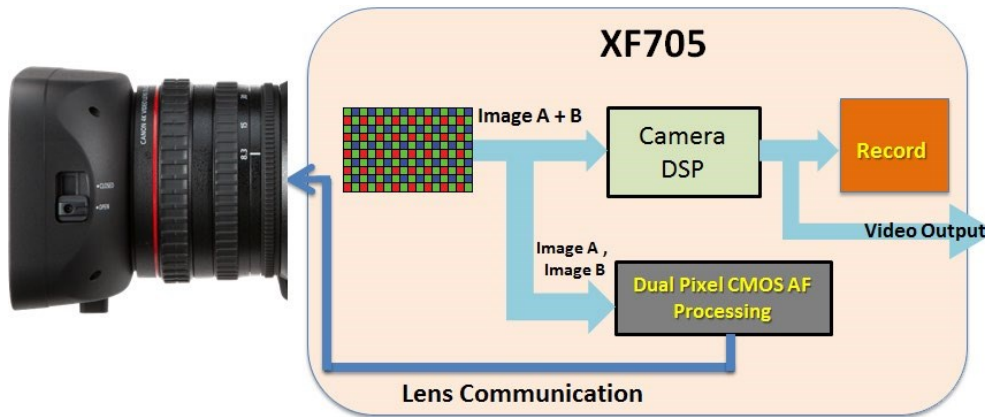


Figure 8 Showing the basics of the Dual Pixel CMOS Auto Focus control loop

The operational capabilities of the Dual Pixel CMOS Auto Focus system have been empowered by the 4.0inch LCD panel that incorporates a capacitive touch capability that supports intuitive operational controls. Among a range of focusing options a smooth rack focus between two subjects within a scene can be implemented by sequentially touching those subjects in the LCD screen.



Figure 9 The LCD monitor is a capacitive touch screen that supports movement of the focus frame (including magnification)

The new Dual Pixel CMOS AF system in the XF705 camera embodies a menu that allows two degrees of freedom in “tuning” the response time – they are “Speed” and “Response”. Each has a setting choice of Fast / Normal / Slow. Separately, what is termed the RESPONSE setting is a separate setting of the system that offers a choice in how quickly a focusing action is initiated – thus adding a creative dimension to a rack focus that has been decided between two subjects within the scene.

2.5 Focus Guide

For the cinematographer who prefers traditional creative manual focus operation the dual pixel system can alternatively be switched from the Auto Focus control loop encompassing the lens focus control to an open loop system that utilizes the Dual Pixel CMOS AF data processing to instead transfer precision signaling – shown in Figure 10 – in the camera viewfinder.

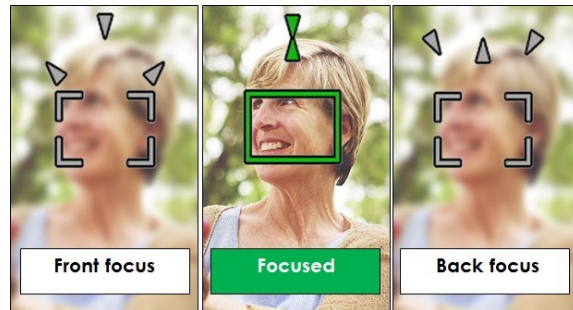


Figure 10 The viewfinder will signal the desired direction of manual focus and the appearance of the green cursor indicates achievement of an unambiguous precision focus on the chosen subject.

2.6 Image Stabilization

The Shift-IS technology lends itself well to correcting modest amplitude disturbances and vibrations in longer focal range lenses. In this technology, a lens group is placed near the rear of the 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 is implemented by a combination of optical lens-shift and electronic stabilization. Image rotation and camera movements in the yaw and pitch directions are corrected by a combination of angular velocity detection (using a piezoelectric vibration sensor) and sensor-based movement vector detection.

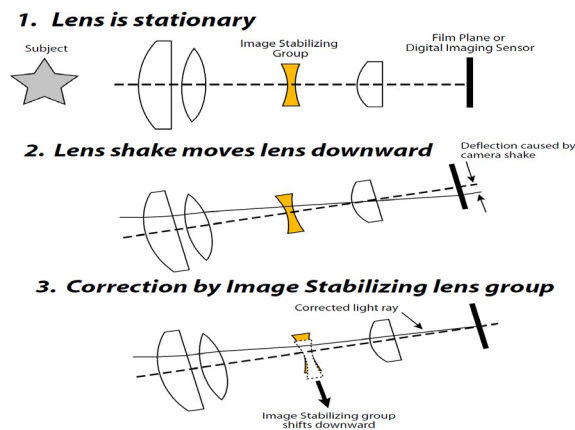


Figure 11 Showing the principle of the Shift-IS optical correction system

The correction principle is explained in Figure 11 above, outlining the correcting action of the Shift-Lens when the lens camera system is subjected to a sudden physical disturbance. The system has been designed to implement 5-Axis image stabilization as outlined in Figure 12.



Figure 12 *Showing the five separate axes of image stabilization in the XF705*

Image stabilization is effective with movement from 0.5Hz to 20Hz (1Hz is one movement cycle per second). This will cope not only with situations from simple camera shake (0.5Hz to 3Hz), but also the engine vibrations encountered when shooting from a moving vehicle or helicopter (10Hz to 20Hz).

3.0 VIDEO IMAGE PROCESSING

Two of the latest generation digital video processors – the DIGIC DV6 – are used to implement advanced video processing of both the 4K UHD video and the Full HD video.

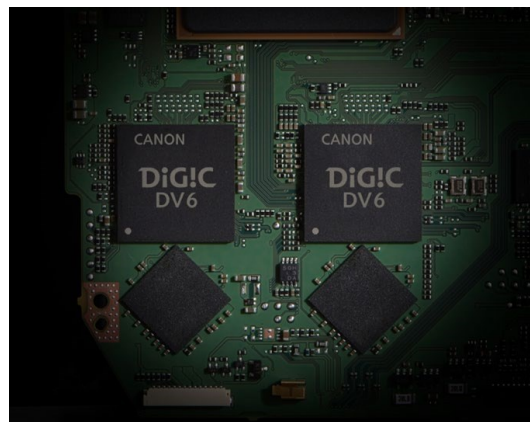


Figure 13 *Two DIGIC DV6 processors to implement all video processing prior to encoding for recording*

In terms of video processing and operational adjustments these two processors implement all of the following:

- 3.1 Debayering of the data from the 4K image sensor
- 3.2 Upsampling to 8 megapixel RGB
- 3.3 Oversampling HD processing
- 3.4 Linear matrix
- 3.5 OETF – a range of selectable options
- 3.6 Various “Custom Picture” settings
- 3.7 Formulation of both 4K UHD and FHD component sets of YCrCb 4:2:2 @ 10-bit
- 3.8 Conversion from high bit depth components to 4K UHD and FHD YCbCr @ 8-bit
- 3.8 HEVC H.265 encoding and formation of MXF wrapper preparatory to recording
- 3.9 XF-AVC encoding and formation of MXF File wrapper preparatory to recording

- 3.10 Dual Pixel CMOS AF
- 3.11 Focus Guide
- 3.12 Focus Enabled on-touch panel
- 3.13 Processing associated with the digital zoom extension of the 1080P HDTV
- 3.14 Preparation of 12G SDI serial video outputs
- 3.15 Preparation of HDMI video outputs

3.1 Choices of Camera OETF and Color Gamut

The XF705 is designed to support both High Dynamic Range (HDR) and Wide Color Gamut (WCG) – in both 4K UHD and 1080P HD. The camcorder conforms to ITU international standards – BT.2020 for WCG and to BT.2100 for HDR. The camcorder allows a selection of the following

- 3.1.1 OETF**
 - BT2100 PQ Perceptual Quantization HDR system
 - BT2100 HLG Hybrid Log Gamma HDR system

- Canon Log 3
- Wide DR
- Normal 1-4 (close to BT. 709 Gamma)

- 3.1.2 Color Space** BT.2020 WCG or BT. 709

The XF705 offers a choice in OETF. Canon Log 3 allows compatibility with Cinema EOS cameras. It also offers the standardized BT 709 transfer function for normal HDTV shooting in SDR. When postproduction

is not entailed, an excellent dynamic range can be achieved with the Canon “Wide DR” OETF curve shown in Figure 14.

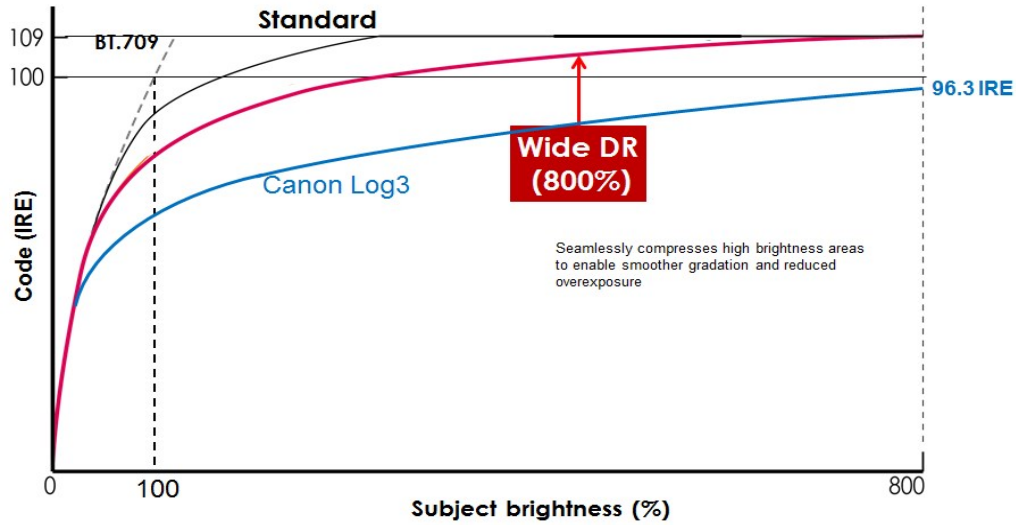


Figure 14 Showing the various OETF transfer characteristics that can be selected in the XF705

4.0 OVERSAMPLING HD PROCESSING

4.1 Formulation of the FHD YCbCr 4:2:2 @ 10-bit Video Component Set

The *Oversampling HD Processing* [3] is central to the formulation of the FHD 1080P YCbCr 4:2:2 @ 10-bit component set. It begins with deBayer processing to form three 8 Megapixel RGB frames from the 4K / UHD Bayer frame. That deBayer processing moves the first order sideband (from original image sensor sampling) to a higher frequency which in turn opens up spectral space that allows critical pre-filtering prior to a subsequent downsampling back to 2K / HD YCbCr 4:2:2 frames.

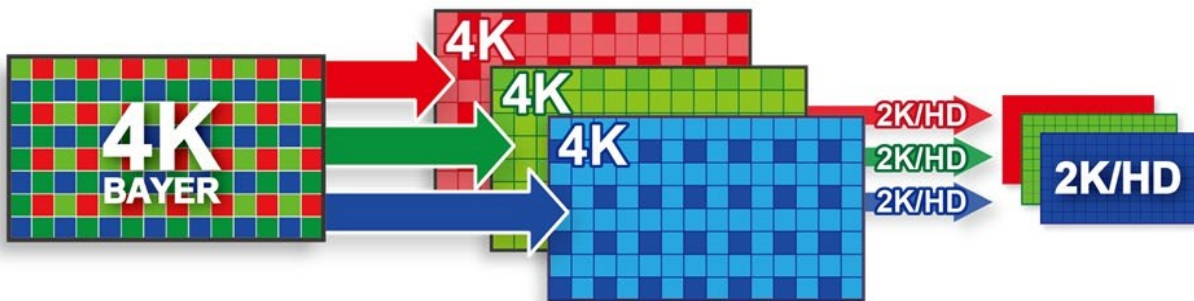


Figure 15 Showing the principle of the Oversampling HD Processing

The net result of this sample rate conversion process is to produce three 2K / HD RGB components that have minimum aliasing and a more benign subjective appearance to noise in high ISO settings.

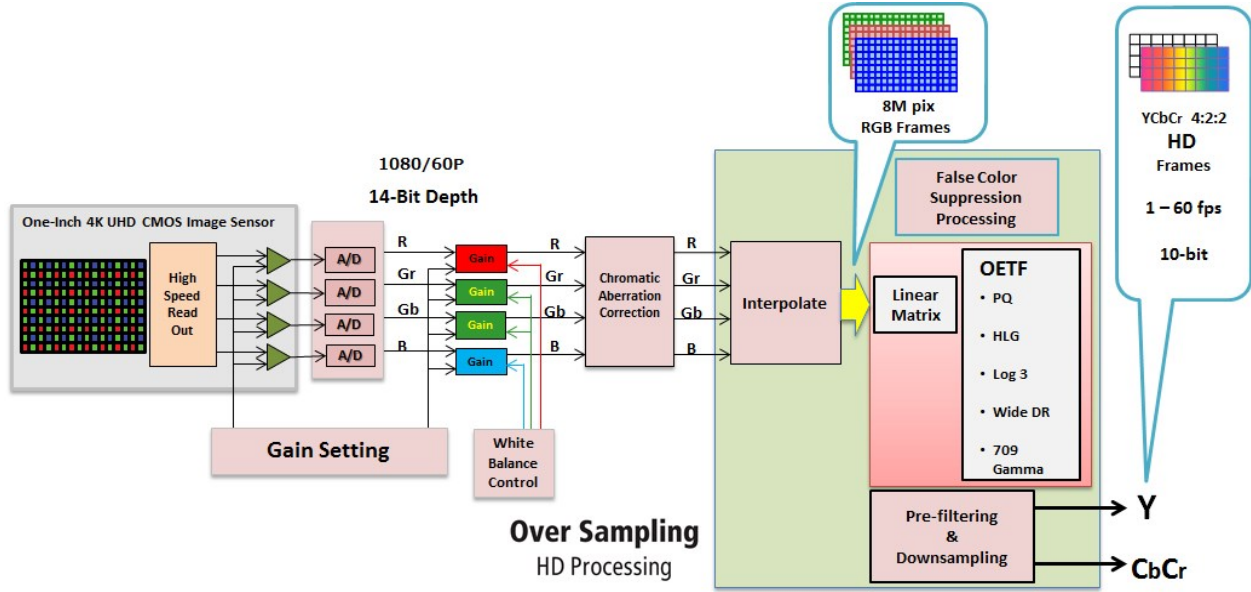


Figure 16 Formulation of the HD YCbCr 4:2:2@10-bit component video set that is sent to the HD codec

The three RGB HD components then have a linear matrix applied to them to define the specific color gamut selected for the production. This is followed by application of the camera optoelectronic transfer function (OETF) which digitally maps the high bit rate linear components to a nonlinear set at 10-bit coding. They are then matrixed to formulate a set of 10-bit YCbCr 422 components which are sent to the HEVC recording codec.

4.2 Formulation of the Full HD Component Set YCbCr 4:2:0 @ 8-Bit

For the XF-AVC recording a YCbCr 4:2:0 component set at 8-bit is structured. The intent is to flank the high performance 4:2:2@10-bit HEVC recording capability with an alternative codec that offers significantly extended recording durations on the SD cards with a performance level that will service many web applications as well as broadcast newsgathering.

Within the DIGIC DV6 video processor the four separate video components from the sensor are converted into an RGB 4:4:4 component video set that are passed through the HD oversampling process as described above – and then fully processed at a high bit depth – according to the functions listed in Figure 17. High attention is paid to the conversion down to the final 4:2:0 @ 8-bit component video set that is sent to the XF-AVC recording codec. Despite the 8-bit depth the recorded image quality has a high subjective performance.

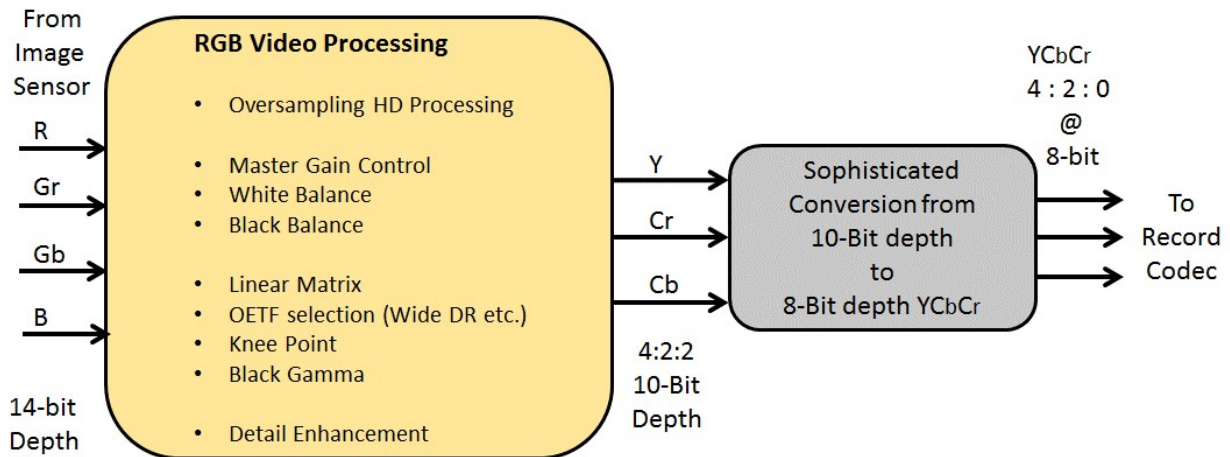


Figure 17 *Within the DIGIC DV6 processors the RGB video components are fully processed and then converted to YCbCr 4:2:0 @ 8-bit component set for the XF-AVC recording codec*

It should be noted that the direct readout from the CMOS image sensor of the four components R, Gr, Gb, and B is the method used to debayer this one-inch image sensor. This method avoids any algorithmic debayering processes and the associated reconstruction errors that can impair image quality. The final result of the subsequent *Oversampling HD Processing* and the bit depth conversion is a clean video component set having a remarkably high subjective image quality.

5.0 INTERNAL RECORDING OF TWO HDR FORMATS

Two internationally standardized HDR formats can be originated and internally recorded in the XF-705:

5.1 Hybrid Log Gamma (HLG)

This HDR format is optimized for live broadcasts and live streams maintaining compatibility with non-HDR TVs. As has always been traditional with broadcast television systems, the HLG system is defined on the camera side by the specification of the OETF curve – this being called a scene referred system. While effective in capturing and portraying an HDR production on an HDR display it also ensures a reasonable degree of compatibility in the image portrayed on an SDR display.

5.2 Perceptual Quantization (PQ)

PQ is an HDR format that has been optimized for pre-recorded productions (for theatrical motion pictures or high-end television episodics). Unlike the HLG system, the PQ system is defined on the display side by the specification of the display EOTF curve – this being called a display referred system. This will ensure that there is no ambiguity as to how the HDR signal should be displayed – it describes the absolute light output from the mastering display. The underlying science of the PQ EOTF curve is based on perceptual characteristics of the human visual system which in turn helps ensure an optimized efficiency in the digital code usage.

Figure 18 is a simplistic representation of the significant differences between the OETF curves for the HLG and PQ (this curve being PQ display EOTF -1) systems compared to the SDR system of BT. 709. Note that in the XF705 the HLG is limited to 420% dynamic range and the PQ is limited to 456% dynamic range.

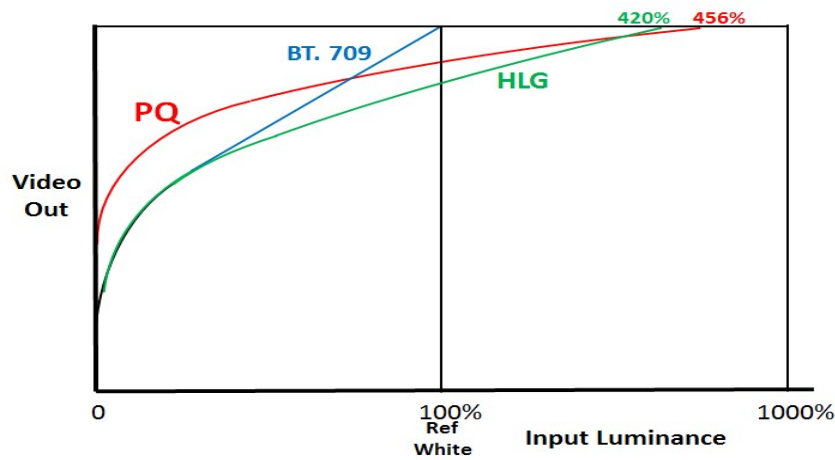


Figure 18 Illustration of the OETF differences between SDR (Rec 709) and the two HDR formats

BT. 709 curve clips at reference white. The HLG curve can be set to the specific requirements of a production (but is limited in the XF705 to a maximum of 420% above reference white). The PQ is a fixed curve and the 456% limit for the XF705 means only the lower portion of their specified curve is deployed.

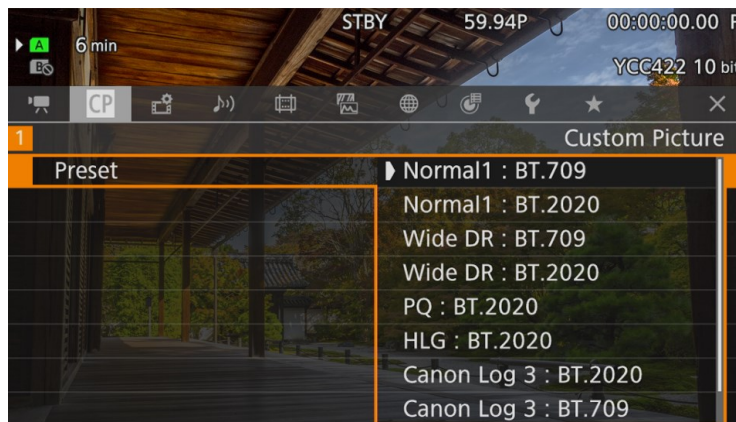


Figure 19 Showing the menu selection of HDR OETF in the viewfinder

6.0 RECORDING CODECS

6.1 Recording Options in XF705 Camcorder

The design team for the XF705 placed a high priority on making the capture of high performance 4K UHD program material very affordable:

- 6.1.1 **XF-HEVC Recording** – of 4K UHD YCbCr 4:2:2 @ 10-bit – up to 60 fps
- 6.1.2 **XF-HEVC Recording** – of 1080-line HD YCbCr 4:2:2 @ 10-bit – up to 120 fps
- 6.1.3 **XF-AVC Recording** – of FHD YCbCr 4:2:0 @ 8-bit – up to 60 fps
- 6.1.4 **External Recording** – of 4K UHD up to 60P – via the 12G SDI and HDMI connectors
- 6.1.5 **External recording** – of 1080-line HD up to 60P – via the 3G SDI or HDMI connectors

6.2 HEVC – High Efficiency Video Coding

The primary video compression codec used in the XF705 is Canon’s XF-HEVC. High Efficiency Video Coding (HEVC) is the latest video coding standard of the ITU-T Video Coding Experts Group and the ISO/IEC Moving Picture Experts Group (MPEG) organizations standards. It is sometimes referred to as MPEG-H Part 2 and ITU-T H.265. The primary goal of HEVC was to enable significantly improved compression performance relative to existing standards—in the range of 50% bit-rate reduction over H.264/MPEG-4 AVC for equivalent perceptual image quality. On December 22, 2016, HEVC/H.265 version 4 was approved as an ITU-T standard.

There were a large number of major international entities involved in the development of this important new compression standard – and among them was Canon Inc – see Figure 20.



Figure 20 Canon was formally involved in the development of the new HEVC compression standard HEVC was designed to address most existing applications of H.264/MPEG-4 AVC, while specifically directing attention to two important issues:

1. Greater video resolution images (4K and 8K are the standardized production formats)
2. Increased use of parallel processing architectures.

HEVC incorporates many improvements over AVC. It evolved from the many prior MPEG strategies but has added greater levels of contemporary sophistication. Figure 21 is intended to convey a sense of all of the “tools” that are embedded in the HVEC codec.

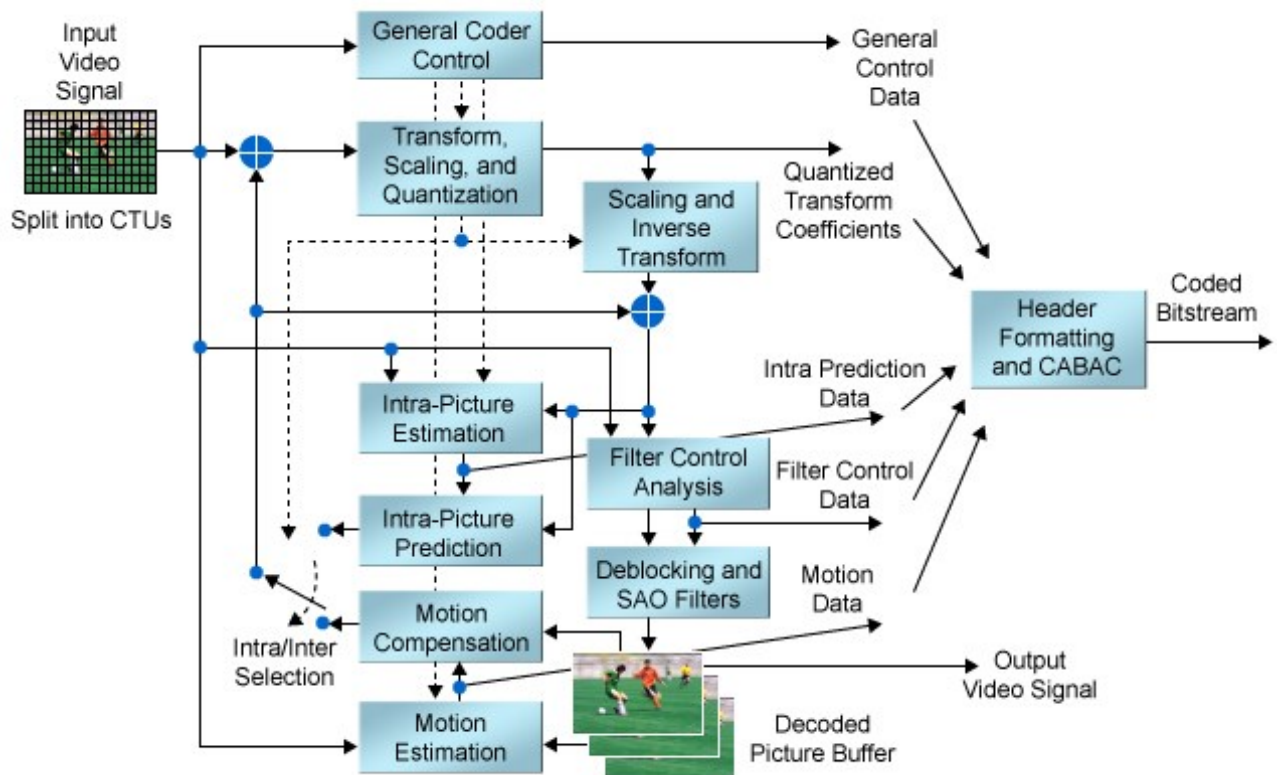


Figure 21 Block diagram of HEVC encoder outlining the multiple strategies within

Since 2013 the HEVC codec has been involved in worldwide tests and deployments across a wide range of applications that include OTT, VOD, and satellite DTH. They included 4K UHD broadcasts where management of bandwidth and preservation of high image quality are especially important. These tests stimulated the expansion of the Levels, Profiles, and Tiers of the HEVC standard to accommodate the multiple digital formats sought globally for both production and for distribution.

Feature	Version 1		Version 2						
	Main	Main 10	Main 12	Main 4:2:2 10	Main 4:2:2 12	Main 4:4:4	Main 4:4:4 10	Main 4:4:4 12	Main 4:4:4 16 Intra
Bit depth	8	8 to 10	8 to 12	8 to 10	8 to 12	8	8 to 10	8 to 12	8 to 16
Chroma sampling formats	4:2:0	4:2:0	4:2:0	4:2:0/4:2:2	4:2:0/4:2:2	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4
4:0:0 (Monochrome)	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
High precision weighted prediction	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cross-component prediction	No	No	No	No	No	Yes	Yes	Yes	Yes
Intra smoothing disabling	No	No	No	No	No	Yes	Yes	Yes	Yes
Persistent Rice adaptation	No	No	No	No	No	Yes	Yes	Yes	Yes
RPDCM implicit/explicit	No	No	No	No	No	Yes	Yes	Yes	Yes
Transform skip block sizes larger than 4x4	No	No	No	No	No	Yes	Yes	Yes	Yes
Transform skip context/rotation	No	No	No	No	No	Yes	Yes	Yes	Yes
Extended precision processing	No	No	No	No	No	No	No	No	Yes

Figure 22 Showing the Profiles of the HEVC compressions system

Profiles retain the same meaning as in prior standards – that is, specifying the diverse tools required for different applications. There are multiple Levels, each of which specifies a maximum digital sample count and frame rate. For each Level the output data bit rate is determined by the Tier.

The HEVC codec does entail increased complexity. For a given image format, it elevates processing complexity by a factor of 10 to 20 times. Given the extended resolutions that are supported, HEVC coding demands higher processing speed (implemented in either software or hardware). As a consequence, parallel processing is deployed, empowering separate processing engines to independently work on different regions of the image to expedite in the many processing tasks.

The HEVC codec embodies new innovations that include: new prediction block structure, intraprediction, inverse transforms, motion compensation, loop filtering and entropy coding. It employs Coding Units (CUs) – which sub-partition an image into arbitrary rectangular regions. The CU replaces the macroblock structure of the AVC/H.264 codec (which broke down images down into areas that could be coded using transform functions). While AVC/H.264 improved on MPEG-2 by allowing multiple block sizes for transform coding and motion compensation, the HEVC coding tree blocks can be either 64x64, 32x32, 16x16 or 8x8 pixel regions, and the coding units can now be hierarchically subdivided, down to 4x4 sized units.

The macroblocks are compressed as single units and in the decoding process a computation series of what are called “intra-prediction directions” are performed to rebuild these macroblocks into the same original image, only with slightly less detail in areas that aren’t subjectively critical. This new flexibility in macroblock size offers greater flexibilities in digital bit disposition between detailed areas of an image and areas where there is little detail.

The size of the image that can be shifted by a single motion vector is also variable – and the two are independent of each other. HEVC reduces blocking artifacts, while at the same time providing a more efficient coding of picture details.

CUs can contain one or more Transform Units (TUs, the basic unit for transform and quantization). It can also include Prediction Units (PU) the elementary unit for intra- and inter-prediction.

- H.264/AVC defines macroblocks up to 16x16 pixels – but HEVC can describe a much larger range of block sizes, up to 64 x 64 pixels
- HEVC allows predicted blocks to be coded in different block sizes than the residual error. For instance, this allows the residual error from a 32x32 inter coded coding unit (CU) to be represented by a mixture of 16x16, 8x8, and 4x4 transforms.
- HEVC can encode **motion vectors** with greater precision. There are 35 motion vector directions within a given video frame, compared with only 9 for H.264/AVC
- HEVC includes Adaptive Motion Vector Prediction, a new method that improves interprediction.
- Improved de-blocking filter
- Sample Adaptive Offset – an additional filter that reduces artifacts at block edges

An internal bit-depth increase allows encoding of video pictures by processing them with a color depth higher than 8 bits. Motion compensation is provided with two new methods, and Luma and Chroma motion vectors are calculated to quarter and eighth-pixel accuracy, respectively.

6.3 Specific Video Formats Recorded On-Board in the XF705

Table 1 HEVC Recording

CODEC	Resolution	Color Format	Bit Depth	Frame Rate fps	Bit Rate Mbps	File Format
HEVC Long GOP	3840 x 2160	YCrCb 4:2:2	10-bit	59.94P / 50P	160	MXF
				29.97 / 25P / 23.98P	110	
	1920 x 1080	YCrCb 4:2:2	10-bit	59.94P / 50P	60	
				29.97P / 25P / 23.98P 59.94i / 50i	45	
			120 / 100P	180		

The XF705 camcorder offers internal recording on a versatile SD card. Two card slots allow settings for backup, relay recording, or a variety of other recording methods. This flexibility is intended to streamline workflows and assist with archiving.



Figure 23 *The XF705 uses two SD memory cards – well-placed for ease of use*

When recording at 160 or 110 Mbps the Class U3 SD card should be used. For recording at 60 or 45 Mbps then Class 10 or Class U1 or Class 3 SD cards should be used.

Table 2 XF-AVC Recording

CODEC	Resolution	Color Format	Bit Depth	Frame Rate (fps)	Bit Rate (Mbps)	File Format
XF-AVC Long GOP	1920 x 1080	YCbCr 4:2:0	8-bit	59.94 / 50P	45	MXF
				29.97 / 25P / 23.98P	35	

TABLE 3 XF705 Recording Durations

SD Card Capacity	Recording Data Rate (Mbps)			
	45	60	110	160
32 GB	90 min	65 min	35 min	25 min
64 GB	185 min	140 min	75 min	50 min
128 GB	375 min	280 min	150 min	105 min
256 GB	755 min	565 min	305 min	210 min

6.4 File Structure for Recording in the XF705

The file structure used in XF705 for both the HVEC and XF-AVC codecs is MXF – the Material eXchange Format – which is a digital multimedia wrapper format designed for capture, editing, distribution, playout, and archiving of video and audio program material. This wrapper can also store metadata such as subtitles and still images. Stream files are formatted in compliance with the MXF format defined in the SMPTE 377-1-2009 standard. The File system is FAT32/exFAT.

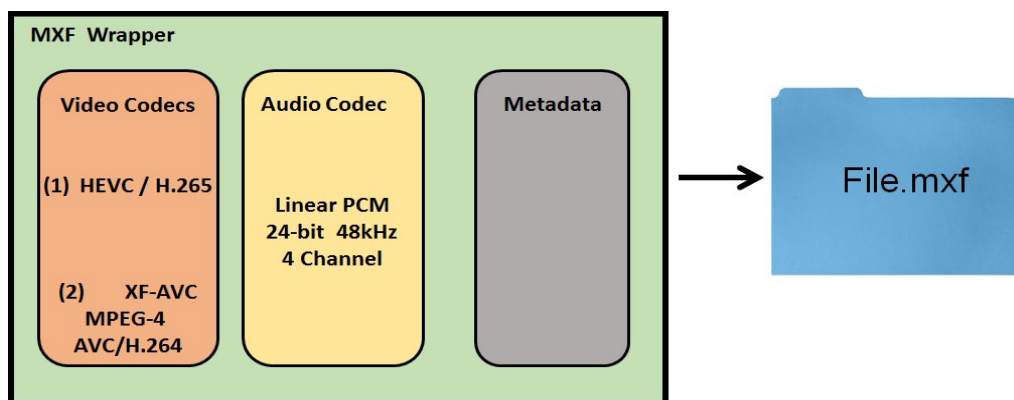


Figure 24 Illustrating the MXF wrapper used for XF705 recording – which includes separate compression for audio and video tracks

For HEVC / H.265 encoding, data is recorded in accordance with the MXF specifications for HEVC mapping as independently defined by Canon, with allowances for compatibility with the SMPTE ST 381-3:2013 standard.

For XF-AVC / H.264 encoding, data is recorded in accordance with the MXF specifications for AVC mapping as defined by the SMPTE ST 381-3:2013 standard;

Audio essence data is recorded within the file in accordance with the MXF specifications for AES3 mapping as defined by the SMPTE 382M standard.

The operational pattern of the MXF files is “OP 1a,” and frame wrapping serves as the wrapper for essence data.

6.5 Audio Recording

When recording video – using either the HEVC or the XF-AVC codecs – the XF705 also supports 4-channels 24-bit 48 kHz (@ 4.5 Mbps) high-quality LPCM audio. There is a built-in stereo microphone, Ø 3.5mm stereo mini-jack, and an XLR 3-pin jack (two channel).



Figure 25 Identifying the audio interfaces in the XF705



Figure 26 Identifying the potential use of the four audio channels in XF705

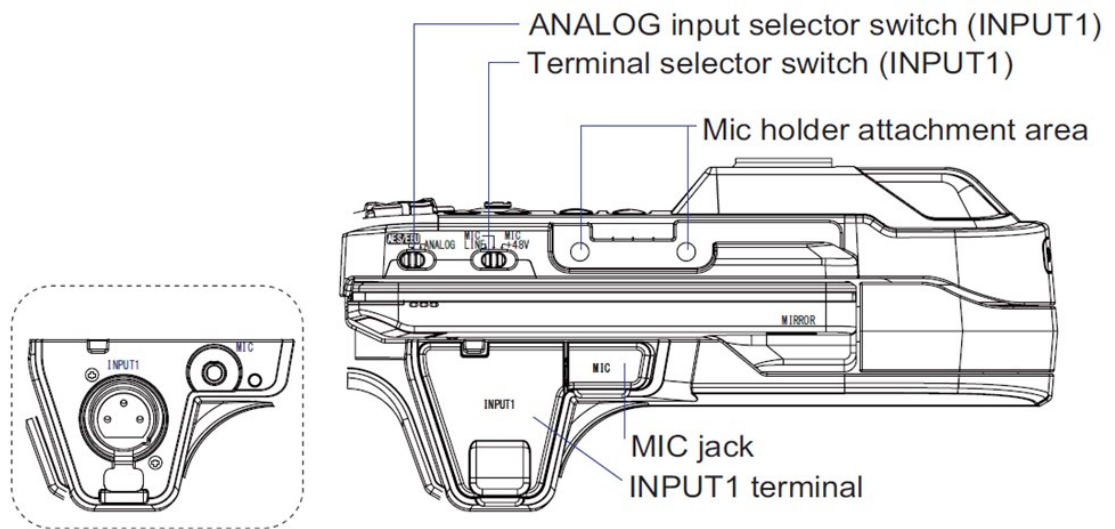


Figure 27 The XF705 camcorder has flexible audio options

The Audio Recording Level Selector switch/adjustment dial (CH1/CH2) will adjust the audio levels recorded to CH1 and CH2. Either Auto (A) or Manual (M) can be selected for the audio levels input to CH1 and CH2. The adjustment dial can adjust gain from $-\infty$ to +18 dB with 0 dB serving as the center position for volume control.

7.0 CONNECTIVITY AND EXTERNAL RECORDING

The XF705 is rich in connectivity as shown in Figure 28. It offers a further important recording option by facilitating external uncompressed recording via the 12G SDI and the HDMI output interfaces.

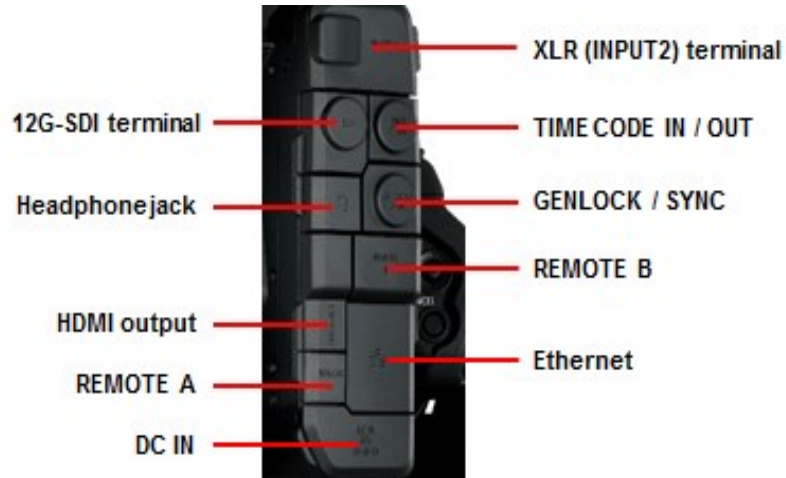


Figure 28 Showing the many interfaces provided on the XF705

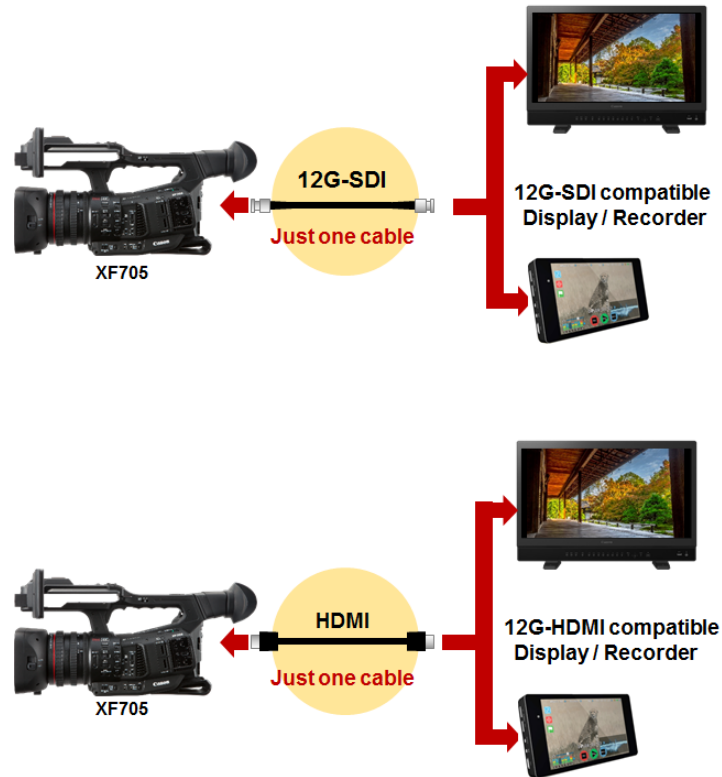








Figure 29 The XF705 features a 12G SDI and an HDMI interface that can deliver up to 4K@60P

Table 4 Signal Outputs available on the 12G SDI and the HDMI Interfaces

Format	 SD Card Record	 SDI Out 4:2:2 @ 10-bit	 HDMI Out 4:2:2 @ 10-bit	
XF-HEVC	4K UHD	60P / 50P	4K UHD 60P / 50P	4K UHD 60P / 50P
		24P	FHD 60P / 50P / 60i / 50i	FHD 60P / 50P / 60i / 50i
			4K UHD 24P	4K UHD 24P
		30P / 25P	FHD 24P	FHD 24P
			60i	60i
		FHD 30P / 25P	FHD 30P / 25P	FHD 30P / 25P
	FHD	FHD 60P / 50P	FHD 60P / 50P / 60i / 50i	FHD 60P / 50P / 60i / 50i
		FHD 60i / 50i	FHD 60i / 50i	FHD 60i / 50i
		24P	24P	24P
			60i / 50i	60i / 50i
		FHD 30P / 25P	FHD 30P / 25P / 60i / 50i	FHD 30P / 25P / 60i / 50i
		FHD 120P / 100P	FHD 60P / 50P / 60i / 50i	FHD 60P / 50P / 60i / 50i

Format	 SD Card Record	 SDI Out 4:2:2 @ 10-bit	 HDMI Out 4:2:2 @ 10-bit	
XF-AVC	FHD	60P / 50P	FHD 60P / 50P / 60i / 50i	FHD 60P / 50P / 60i / 50i
		24P	24P	24P
			60i / 50i	60i / 50i
30P / 25P	FHD 30P / 25P	FHD 30P / 25p		
		FHD 30P / 25P / 60i / 50i	FHD 30P / 25P / 60i / 50i	

When the SDI output terminal is selected for 4K UHD signal transfer the menu selects the correct 12G SDI mapping according to the SMPTE standard ST 2082. Alternatively, if this terminal is selected to transfer 1080 FHD then the menu will map as a 3G SDI interface according to the SMPTE standards of ST 424 or 425.

8.0 SIMULTANEOUS INTERNAL AND EXTERNAL RECORDING

The XF705 enables simultaneous recording of two versions of a signal – one, being a 4K and a 2K version – or simultaneous recording of an HDR and an SDR version as illustrated in Figures 30 and 31.

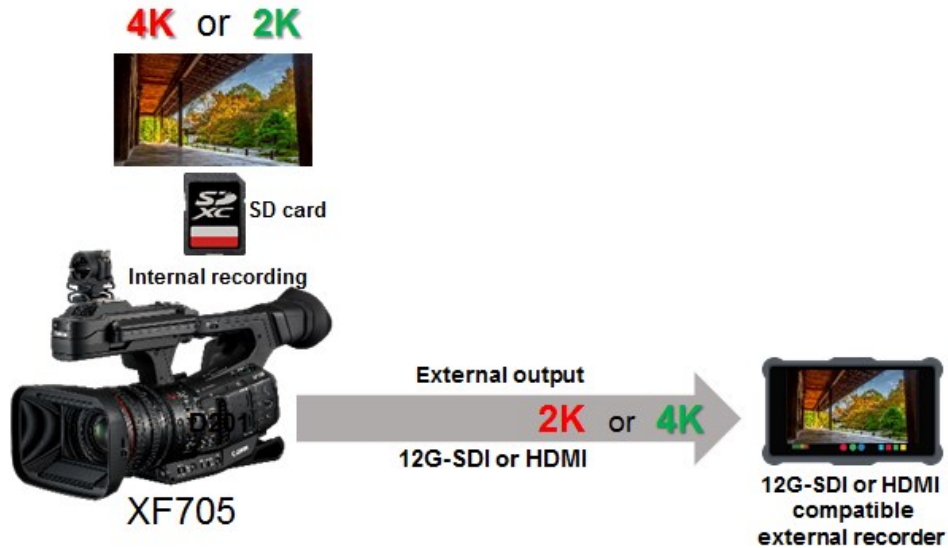


Figure 30 When 4K is being internally recorded a separate 4K or 2K uncompressed version can be simultaneously recorded externally. During internal 2K recording only a 2K output is available for external recording.

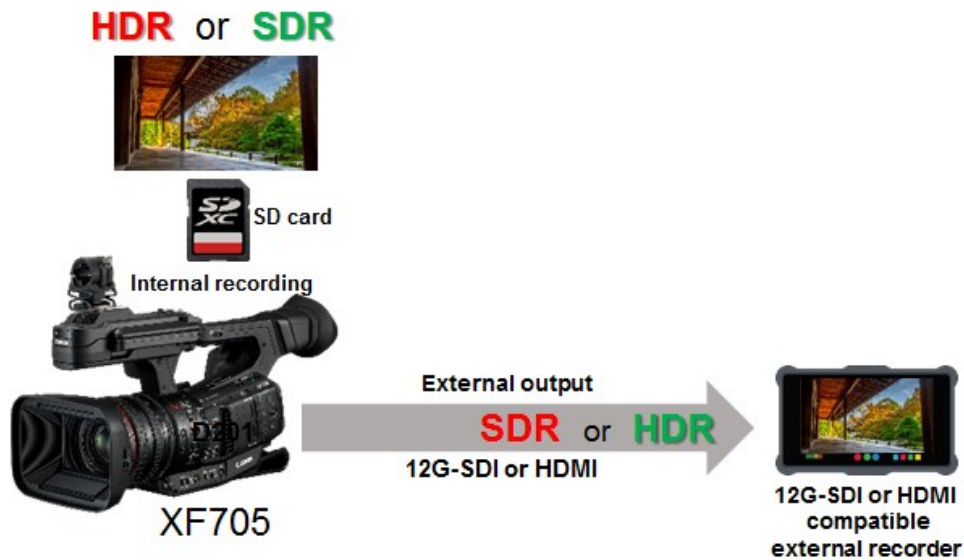


Figure 31 When HDR is being internally recorded a separate HDR or SDR version can be simultaneously recorded externally. When SDR is internally recorded a separate SDR can also be externally recorded

9.0 NETWORK FUNCTIONS

The XF705 can be connected to a wireless network or a compatible network device using either: a)

Wi-Fi™

b) Wired network using an Ethernet cable

Table 5 Summarizing the Supported Network Function in XF705

Network Function	Description	Wi-Fi™		Wired Network
		Camera Access Point Direct connection to one Wi-Fi enabled device (wireless router etc.) IEEE802.11b/g/n/a (2.4 GHz/5 GHz)	Infrastructure Connection via an external access point	
Browser Remote	Remote control of XF705 from web browser of connected device	●		
IP Streaming	Stream live and audio over IP to a compatible IP video decoder connected to the network			●
FTP File Transfer	Transfer clips recorded in XF705 to another device connected to the network using FTP protocol		●	●

Using Browser Remote the XF705 live view video can be checked and various recording settings can be controlled. On the Browser Remote screen, the remaining recording time on the card, remaining battery charge, and the camcorder's time code can all be checked. A future firmware update will facilitate IP streaming from the XF705 as described in the following section.

10.0 IP STREAMING

A future firmware update will allow the XF705 to be connected to a network via the Ethernet connector RJ45 that supports 1000 BASE-T. The camcorder will then stream live video and audio over IP to a compatible IP decoder that is connected to the network. This decoder can be a dedicated video transfer device or decoder software in a computer. This IP streaming can be used for live broadcasts or to send a new flash from a location with poor network connectivity. When recording four channels of audio two of those four can be selected for IP streaming.

Table 6 Showing details of the video and audio that can be streamed from XF705 (Future Firmware Update)

Video Format	Streaming Configuration			Audio
	Video			
	Resolution	Bit Rate	Frame Rate	
XF-HEVC (H.265/HEVC Compression)	3840 x 2160	16 Mbps, 9 Mbps	59.94P/29.97P/50P/25P	MPEG-2 AAC 256 Kbps 2-Channel
	1920 x 1080	9 Mbps, 4 Mbps		
XF-AVC (MPEG-4H AVC/H.264 Compression)	1920 x 1080	9 Mbps, 4 Mbps	59.94i/ 50i	

Before IP streaming – settings related to the transfer (such as protocol, port number, and configuration of the streamed video) must be set.

The protocol options that can be selected are:

UDP This prioritizes transfer speeds but does not guarantee the reliability/integrity of the data. Lost or delayed packets will be ignored

RTP Standard for video/audio broadcasts over the network. Lost or delayed packets will be ignored.

RTP + FEC This uses the RTP protocol and adds a layer of FEC error correction so that a compatible FEC decoder on the receiving side can recover lost or delayed packets

11.0 REMOTE VIDEO CONTROL

Remote control of multiple video functions is enabled using the optional accessory RC-V100 remote control panel. It is important to note that this includes remote control of the lens iris, zoom, and focus. This is especially effective when used for crane shots and other remote operations.



Figure 32 Canon remote controller RC-V100 connects directly to the XF705 camcorder

In addition to the traditional video controls the RC-V100 remote controller provides access to the three operational controls of zoom, focus, and iris as shown in Figure 34.



Figure 33 The lens zoom, focus, and iris can all be remotely controlled from the RC-V100

12.0 SUMMARY

In this current broadcast television era, where large format imaging has become popular within many program genres, the 1.0-inch image format single-sensor camcorder has made a rapid ascendancy – now being supported by a number of the major professional camera manufacturers. It offers a combination of a more cinematic depth of field and a higher sensitivity than 2/3-inch and 1/3-inch camcorders.

In the context of the 1.0-inch image sensor movement, in 2015 Canon introduced a 4K miniature camcorder – the XC-10 with a 1.0-inch CMOS image sensor – which utilized MPEG-4 H.264 compression and an MXF wrapper with both 205 and 305 Mbps recording data rates. This was followed a year later with the upgraded XC-15. In 2017 Canon introduced the XF-405 – a compact 4K UHD camcorder which also uses a 1.0-inch CMOS image sensor. It uses an MPEG-4 H.264 codec with an MP4 file wrapper.

The new XF705 camcorder discussed in this paper offers a compact lightweight video acquisition system for 4:2:2 @ 10-bit 4K UHD and 1080P HD that is specifically tailored for high-end television production – including episodic TV, drama, documentaries, news magazine shows, sports, concerts, major events, and television commercial production.

XF705 camera utilizes a new 1.0-inch 4K CMOS image sensor developed by Canon that is optimally coupled to an integrated new 15:1 zoom lens – the combination helping to ensure origination of an impressive 4K image quality. This 1.0-inch image sensor features Dual Pixel CMOS Auto Focus which significantly empowers high mobility shooting. Two of Canon's DIGIC DV6 digital video processors are used for a variety of innovative image processing functions which enhance the low-noise performance and help elevate the operational sensitivity. In the case of 1080P the recorded video image quality is very high – being YCbCr 4:2:2 @ 10-bit at frame rates up to 60P – created using the *Oversampling HD Processing* [4] that elevates Luma MTF and lowers aliasing.

The XF705 offers 25 minutes recording duration of 4K UHD YCbCr 4:2:2 @ 10-bit up to 60P on a single lowcost 32GB SD memory card. The powerful new HEVC codec makes this possible. It greatly improves the efficiency of 4K data handling. The 60 fps supports 4K slow motion effects. Provision for dual cards is provided. The on-board 1080P HD recording can be as high as 120 fps which offers even more impressive slow motion capabilities.

External uncompressed recording of both 4K UHD and 1080P HD is supported via the 12G SDI / 3G SDI interface and the HDMI interface.

BNC Timecode In/Out interface and BNC Genlock/Sync interfaces are supported.

An Ethernet connector supports IP streaming of the 4K UHD and HDTV formats – both compressed according to the HVEC system. The alternative XF-AVC can also be streamed.

In addition to the built-in two-channel stereo microphone, the camera has a stereo 3.5mm MIC jack plus twin XLR connections with phantom power on the detachable handle. Four channel recording is supported in LPCM mode, giving additional flexibility for recording ambient sound while carrying out an interview.

13.0 REFERENCES

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