Extron

Hitting the Moving Target of 4K

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Abstract

Display technology has progressed to the point where 4K video is now common within the consumer market and a requirement for many professional AV systems. Bandwidth, content protection, and image quality are key considerations for 4K AV system design. But 4K is a developing technology that will eventually evolve beyond what is available today. This paper will help you understand what you need to know about 4K signals for today's systems and will provide you with a glimpse of the 4K features that you will see in the future.

white paper

The 4K Video Signal – What You Need to Know Now

4K signals are on an evolving path. While the format's current capabilities provide advantages over 1080p HD, AV industry organizations such as SMPTE and the ITU have, or are developing, new technical standards that will supplement or enhance the 4K viewing experience. These changes propose to further increase the realism of 4K video presentations.

When designing 4K AV systems, the primary consideration is bandwidth, i.e. the maximum data rate that needs to be supported by every system component that transports, switches, and processes the 4K video signal. Compared to 2K and 1080p signals, 4K signals require considerably higher data rates to transmit signals from the source to the display. For optimal system design and equipment selection, it is important to understand 4K video data rate requirements and the potential trade-offs against performance.

Four key factors impact bandwidth requirements for today as well as tomorrow's 4K:

- Resolution
- Color bit depth
- Frame rate
- Chroma sampling

We'll examine each of these components and the impact they have on the presentation and the data rate of a 4K signal.

Resolutions – 4K DCI and 4K UHD

The term 4K refers to resolutions that can reach up to 4096x2160 pixels. 4K DCI was established by Digital Cinema Initiatives in 2005 as the standard for the next generation of high-resolution digital cinema projectors. This resolution was determined by doubling the horizontal and vertical resolutions of the 2K DCI resolution of 2048x1080.

Ultra High Definition – 4K UHD refers to the 3840x2160 resolution that is detailed in ITU-R Recommendation BT.2020 UHD-1 and adopted by the broadcast industry. It is twice the horizontal and vertical resolution of the current 1080p HD video broadcast standard, so it provides four times the resolution of 1080p HD.

4K DCI is prevalent in digital cinema applications. 4K UHD is primarily encountered in broadcast and consumer applications, but has become common in commercial applications as well. Throughout this document, we use the term 4K to refer to both 4K DCI and 4K UHD.

When Does it Matter?

4K resolutions represent a quadrupling or more of 1080p HD video, but depending upon the size of the display and the viewing distance, there may be no perceptible difference between an HD image and a 4K image. The benefits of 4K are most evident when viewed on large screen projection systems or large displays of 55 inches or more. 4K also can be beneficial in applications with close viewing distances, such as medical imaging, interactive display signage, and multi-window presentations such as videoconferencing sessions.

Color Bit Depth

The number of colors a digital system can reproduce depends upon the number of bits allocated for color information. The most common color bit depth is currently 24 bits per pixel, which allocates 8 bits for each red, green, and blue channel. An 8-bit word can store values from 0 to 255 or 256 total values for each channel. This results in a maximum number of 256^3 colors or 16,777,216 colors.

Note that digital component video often uses a smaller range of values for each channel. Instead of 0-255, values 16 to 235 are typically used in accordance with ITU-R Recommendation BT.601 and Rec. BT.709. Although the quantization range is reduced, total signal bandwidth remains unchanged compared to RGB as values 0-15 and 236-255 remain intact, but reserved for special use.

Table 1: Total Colors From 24, 30, 36, and 48-Bit Color Depths

Total Colors Based on Color Bit Depth			
Bit Depth	Bits per Color	Max Values per Color	Max Total Colors
24	8	256	16,777,216
30	10	1024	1.1 Billion
36	12	4096	68.7 Billion
48	16	65,536	281.5 Trillion

HDMI 1.3 introduced Deep Color which supports bit depths of 30, 36, and 48 bits per pixel or 10, 12, and 16 bits per color, respectively. These bit depths can produce billions and even trillions of colors, far more than human vision can discern. A major benefit is that these bit depths provide more values for each color channel, reducing the likelihood of color banding when displaying gradients between similar shades.

When Does it Matter?

The 16 million colors produced by 8-bit color depth may seem sufficient, but since only 256 values are available for each primary color, some content will reveal the limitations of 8-bit color. Transitions between similar shades, such as dark blue to medium blue or dark grey to mid grey, can reveal banding or stepped transitions in the gradients. Because of this, some critical viewing applications, such as medical imaging, often require greater color accuracy than 8-bit color can provide. The banding effect also can be visible in less critical video content, such as in the blue sky of an outdoor scene or shadow detail of a dark scene.

A video source with 10-bit color depth produces 1,024 steps per color channel or four times the number of colors per channel as 8-bit color. Video that supports high dynamic range, described later, requires a minimum of 10-bit color to produce the finer details that can eliminate the gradients and color banding that are sometimes visible with 8-bit color.

Given the color range of most currently available displays, further extending color depth to 12 bits or 16 bits will produce limited benefits. A subsequent section titled "Expanded Color Gamut" details Rec. BT.2020, a color specification for an expanded color palette that takes better advantage of the higher bit depths of 12 and 16 bits.

Frame Rate

The terms "frame rate," "frames per second," and "refresh rate" denote the number of images per second that are displayed by a film or video format. The film industry has employed a worldwide standard of 24 frames per second – fps since the 1920s, while the broadcast industry incorporated frame rates of 25 and 30 complete frames per second for standard definition video, and up to 50 and 60 frames per second for high definition video. The video industry has generally adopted the broadcast industry's frame rates, although 24 frames per second is sometimes used by DVD and Blu-ray formats for movie content. For computer video, 60 frames per second is generally the norm.

For many 4K applications, frame rates are restricted to 24 Hz or 30 Hz, due to limitations in carrying 4K signals over a single video link, while frame rates up to 60 Hz are possible using parallel paths of two or four video cables. With the introduction of HDMI 2.0 and DisplayPort 1.3, many interfaces on video peripherals and displays now support frame rates up to 60 Hz over a single cable. See the "4K Interfaces" section for details.

When Does it Matter?

Frame rates of 24 Hz to 30 Hz for 4K may yield satisfactory results in many applications with full-motion video, including streaming and videoconferencing. For more demanding applications, such as content with fast-moving images like sporting events or computer rendered content, 30 frames per second may result in motion artifacts, especially when viewed on large screens. On a computer screen, 4K at 30 Hz may be objectionable to some when tracking mouse movements and animation events with windows and graphics. Commercial AV implementations with 4K at 60 Hz will eventually become more prevalent, bypassing the need for 30 Hz applications.

Chroma Sampling

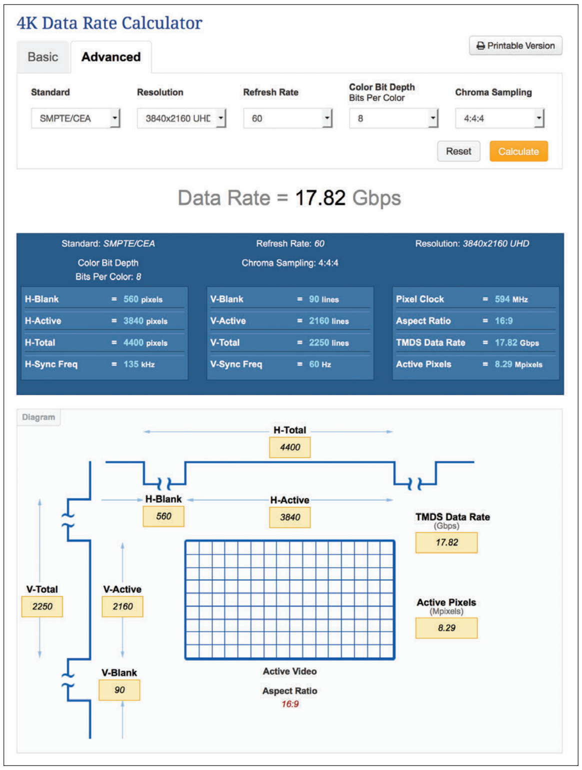
Video signals may be digitized and processed in RGB or component color space. Digital RGB signals are represented by equal amounts of data per red, green, and blue channel, and digital component signals are represented by luma (Y) and two chroma channels (Cb, Cr). If all the graphical information is preserved when converting from RGB to component color space, this is generally represented as a numerical ratio of 4:4:4 or full chroma sampling. This results in the sharpest, most accurate representation of an image since no data compression is being applied to the signal.

To reduce the amount of bandwidth required for a digital component video signal, chroma subsampling is sometimes applied. Since the human visual system is more sensitive to variations in brightness than color, the number of samples utilized for the chroma signals can be reduced, compared to the number of samples taken for the luma channel. A common chroma subsampling ratio is 4:2:0, which reduces the bandwidth of an HDMI or DisplayPort signal by 50% compared to 4:4:4 chroma sampling.

When Does it Matter?

Chroma subsampling can have a negative impact on image quality, the degree of which varies depending on the type of content. As fewer chroma samples are taken, color detail is lost and images can appear soft. Video content, such as a movie, is very forgiving of chroma subsampling, especially when the content contains motion or comprises “natural” imagery such as faces, landscapes, and other materials devoid of fine-line detail. For computer video however, the reduction in quality can be particularly evident. Computer imagery, such as computer-aided design drawings or maps, frequently has single-pixel line widths or transitions. Chroma subsampling causes this fine pixel and line detail to change color, distort, or disappear. Colored text against a colored or black background also is severely impacted. Because of this, your application’s content determines whether chroma subsampling will have a negative effect on the viewing experience.

Figure 1: Extron 4K Data Rate Calculator



Bandwidth – Data Rate

Resolution, frame rate, color bit depth, and chroma sampling all independently affect the bandwidth needed to transport and process video signals. When any of those values increases, so does the required data rate. Since 4K signals contain at least four times the pixels of 1080p HD, the bandwidth requirements are four times that of a 1080p signal with comparable frame rate, color bit depth, and chroma sampling. For example, a 1080p signal with a 60 Hz frame rate, 10-bit color processing, and 4:4:4 chroma sampling requires a 5.57 Gbps data rate. A 4K video signal with similar frame rate, color bit depth, and chroma sampling requires 22.28 Gbps.

Table 2 presents the data rate requirements for several variants of 4K, along with 1080p and 2K for comparison.

Bandwidth requirements for 4K signals can be lessened by reducing one or more of the following three variables: frame rate, color depth, or chroma sampling. Reducing the frame rate to 30 frames per second and trimming the color depth to 8 bits maintains 4K resolution, but yields a data rate of 8.91 Gbps, less than half of the 22.28 Gbps required for a 4K signal with 60 Hz frame rate, 10-bit color, and 4:4:4 chroma sampling. The extent to which these bandwidth-saving measures result in acceptable image quality depends upon factors such as content, viewing distance, and customer expectations. Extron's website provides a convenient online video data rate and timing calculator for you to determine 4K video data rates, given your input for 4K resolution, frame rate, color depth, and chroma sampling.

An important consideration concerning bandwidth requirements is the interface that transports the signal. The next section of this document examines popular 4K interfaces and the bandwidth that they can support.

Table 2: Data Rate Requirements for Various Video Signals

Data Rate Required for Video Signals					
Resolution	**Frame Rate**	**Chroma Sampling**	**Pixel Clock**	**8-Bit Color**	**10-Bit Color**
1080p / 2K	60 Hz	4:4:4	148.5 MHz	4.46 Gbps	5.57 Gbps
4K	30 Hz	4:4:4	297.00 MHz	8.91 Gbps	11.14 Gbps
4K	60 Hz	4:2:0	594.00 MHz	8.91 Gbps[1]	11.14 Gbps[1]
4K	60 Hz	4:4:4	594.00 MHz	17.82 Gbps	22.28 Gbps

1. Support for 4:2:0 chroma subsampling for 4K was added in the HDMI 2.0 specification. This effectively reduces 4K transmission bandwidth requirements by 50%.

4K Interfaces

Due to the high bandwidth requirements of 4K signals, the interfaces transmitting the signals must support very high data rates. HDMI and DisplayPort are currently the most popular interfaces capable of delivering 4K content over a single cable.

HDMI

The HDMI 1.4a specification, released in 2010, establishes a maximum data rate of 10.2 Gbps. It can support 4K resolutions with 8-bit color at 24 Hz, 25 Hz, or 30 Hz frame rates over a single HDMI cable.

The HDMI 2.0 specification, released in 2013, increases the data rate to 18.0 Gbps. This allows a maximum 4K frame rate of 60 Hz with 8-bit color over a single HDMI cable or up to 30 Hz with 16-bit color. HDMI 2.0 also supports 4:2:0 color subsampling for 4K at 50, 59.94, and 60 Hz. The luma (Y of a YCbCr signal) with 4:2:0 color subsampling is divided among two TMDS channels, and the chroma (Cb and Cr) signals are combined onto a single TMDS channel. This enables a 4K signal with a 60 Hz frame rate, 8-bit color depth, and 4:2:0 chroma subsampling to be sent at the same data rate as a 4K 30 Hz signal with 8-bit color and 4:4:4 color sampling. However, both the source and the display must support this mode of operation in order for the signal to pass successfully. This signal falls within the bandwidth specifications of HDMI 1.4a, although HDMI 1.4a does not support 4:2:0 chroma subsampling.

HDMI 2.1 will be released in Q2 2017; it adds 48 Gbps maximum data rate, video resolutions up to 8K/60 and 4K/120, metadata exchange for dynamic HDR, and variable refresh rate for computer gaming. New cables will be required to support its 48 Gbps data rate, but they will be backward compatible with earlier versions of HDMI.

Table 3: Video Formats and Data Rates

Standard	Max Data Rate	Max Uncompressed Resolution		
		8-Bit Color	10-Bit Color	12-Bit Color
HDMI 1.4	10.2 Gbps	4K/30 4:4:4	1080p/60	1080p/60
HDMI 2.0	18 Gbps	4K/60 4:4:4	4K/60 4:2:0	4K/60 4:2:0
HDMI 2.1	48 Gbps	8K	TBA	TBA
DisplayPort 1.1	10.8 Gbps	4K/30 4:4:4	1080p/60	1080p/60
DisplayPort 1.2	21.6 Gbps	4K/60 4:4:4	4K/60 4:4:4 VESA CVT-RB Timing	4K/60 4:2:0
DisplayPort 1.3/1.4	32.4 Gbps	8K/30 4:4:4 VESA CVT-RB Timing	8K/30 4:4:4 VESA CVT-RB Timing	4K/60 4:4:4

The Extron Digital Design Guide is an essential resource for digital video in professional AV systems, with information on the latest technologies, as well as principles for formulating effective approaches to system design.

DisplayPort

DisplayPort data rates also have increased to improve support for 4K video at a 60 Hz frame rate. With a 10.8 Gbps data rate, DisplayPort 1.1a supports a 4K signal with a 30 Hz frame rate and 8-bit color over a single cable. In 2009, DisplayPort 1.2 doubled its data rate to 21.6 Gbps, enabling transmission of a 4K 60 Hz signal with 10-bit 4:4:4 color sampling over a single cable. A further update to the DisplayPort specification in 2014, version 1.3, provides even higher data rates up to 32.4 Gbps, with the ability to support resolutions up to 5120x2880 at 60 Hz. DisplayPort 1.4 was released in 2016; while its maximum data rate remained the same as version 1.3, the new version adds features such as Display Stream Compression, Forward Error Correction, and metadata exchange for static and dynamic HDR. DisplayPort is well-suited for 4K applications that require high frame rates, accurate color rendition, and the ability to show a very high level of image detail.

Content Protection

HDMI, DisplayPort, and DVI interfaces incorporated High-bandwidth Digital Content Protection – HDCP versions 1.0 through 1.4 to prevent unauthorized access of protected content up to 1080p and to enforce restrictions on authorized playback.

Content protection schemes continue to play an important role in the delivery and presentation of native 4K media. In 2008, HDCP version 2.0 was introduced which presents major changes to the protection scheme, including more secure encryption techniques and support for wireless transmission. To protect high-value 4K content, major consumer electronics manufacturers have embraced HDCP 2.2 as the first version of HDCP to be incorporated into their products. These products include displays, cable and satellite set-top boxes, AV receivers, and 4K Blu-ray players. HDCP 2.2 compliance is essential for accessing commercial 4K content through streaming, downloads, or physical media.

Any AV system intended to present encrypted 4K content must include components that support HDCP 2.2. Currently, this includes DisplayPort 1.4 and HDMI 2.0 connections.

For more information about HDCP, please refer to the Extron Digital Design Guide.

The 4K Video Signal – Improving Image Quality

Beyond simply adding more pixels to a displayed image, 4K yields the potential to deliver video signals that provide a more vivid, lifelike viewing experience. Features such as expanded color palettes, brighter, more detailed images, and increased frame rates have been introduced as enhancements to 4K signals and peripherals. The following sections explore the effects that these improvements have on the visual impact and the bandwidth requirements of the 4K video signal.

High Dynamic Range

The dynamic range of a video signal is the difference between the darkest black and brightest white that can be produced. Current broadcast and Blu-ray standards limit peak white to a maximum value of 100 nits[1]. Though some display devices are capable of producing a peak white beyond 100 nits, in some cases 2,000 nits or more, this value still falls far below what the human eye can perceive. It is not uncommon to see luminance levels of 15,000 nits or higher when viewing natural objects outdoors with the naked eye.

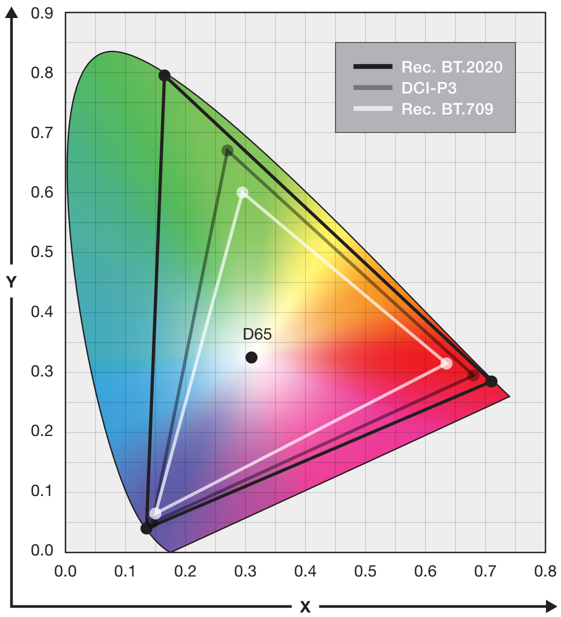
To make the video viewing experience more lifelike and engaging, research has been conducted to enable video signals to more closely reproduce the images we see in real life. This technology is called "high dynamic range" – HDR. Adding HDR to a 4K image is the differentiator that takes 4K far beyond what 1080p HD can offer.

The full HDR experience involves an end-to-end process that begins with the source content. Live action is shot with HDR-enabled cameras that can better capture the dynamics of the material being recorded. Then it is edited and mastered with peripherals that retain the expanded visual information. Finally, the content is transmitted and presented on display devices that can produce peak whites of several thousand nits and properly decode the HDR signals, which may include metadata containing information about how the content should be displayed. Computer generated content, such as video games, also can take advantage of this technology, which is already supported by game engines and other content creation software, graphics cards, and gaming consoles.

HDR has become an integral part of the maturing 4K format, with several industry-leading manufacturers and service providers supporting the technology. Several models of Blu-ray players supporting HDR are widely available, and major display manufacturers offer multiple product lines capable of displaying HDR content. In 2015, HDMI version 2.0a added support for HDR; it includes references to the CEA – Consumer Electronics Association's published standard that defines HDR metadata extensions to HDMI and EDID.

[1] A unit of measurement of luminance, or the intensity of visible light, where one nit is equal to one candela per square meter – cd/m^2.

Figure 2: Color Gamut Comparison



Expanded Color Gamut

The range of colors that a given visual medium can reproduce is called its color gamut. The color gamut defines the primary red, green, and blue colors, plus all of the colors that can be derived from these primary colors.

ITU-R Recommendation BT.601 and Rec. BT.709 define color gamuts for standard definition and high definition signals, respectively. Rec. BT.2020 is a new standard that introduces an extended color gamut. It dramatically increases the range of colors that can be produced compared to Rec. BT.601, Rec. BT.709, and DCI-P3 – the color standard adopted by Digital Cinema Initiatives.

Color gamuts are often visualized on a CIE 1931 color space diagram, with each primary color represented by a vertex on a triangle, and all colors in the gamut range falling within the boundaries of the resulting triangle. Figure 2 shows the color gamut for Rec. BT.2020 as the larger outer triangle, compared to the smaller triangles representing the Rec. BT.709 and DCI-P3 color gamuts.

The HDMI 2.0 standard supports Rec. BT.2020, as does H.264/MPEG-4 AVC and H.265 High Efficiency Video Coding – HEVC. Several major display manufacturers now produce TVs and displays that support the expanded color gamut. In 2015, the Blu-ray Disc Association completed the Ultra HD Blu-ray specification which supports Rec. BT.2020. Some Blu-ray discs that support Rec. BT.2020 have been released, with more on the way.

With industry support for Rec. BT.2020 spreading, 4K content and displays can present imagery with dramatically wider color representation than traditional high-definition video. This could have just as much impact on the viewing experience as 4K's increased resolution, and potentially even more so on smaller screens where the advantages of increased resolution are less pronounced.

High Frame Rate

A section of Rec. BT.2020 details the frame rates for 3840x2160 and 7680x4320 – 8K signals. While including frame rates already common in consumer, broadcast, and digital cinema industries such as 24, 25, 30, 50, and 60 frames per second, the specification introduces increased frame rates including 100 and 120 fps. These frame rates can render content, such as fast-moving objects and camera pans, more fluidly than frame rates of 60 Hz and below. These higher frame rates deliver a more lifelike representation of the on-screen action, while potentially reducing eyestrain and fatigue. High frame rate – HFR is especially beneficial in digital cinema and other applications requiring the presentation of video signals on very large screens, by utilizing more frames to represent the motion of an object. At lower frame rates, a moving object could potentially jump several feet between frames as it moves across the screen, causing an artifact referred to as motion blur. Camera pans also may look unnaturally jerky at lower frame rates.

The Impact of Rec. BT.2020, HFR, and HDR on Bandwidth

Rec. BT.2020 color gamut, high frame rates, and high dynamic range all represent significant advancements in video signal quality. But these advancements come at a cost, since adopting any of these technologies places additional demands on the bandwidth required to store, process, and transport video signals.

Rec. BT.2020 utilizes the extended capabilities that greater color depths provide, but this requires more bandwidth than the 8-bit signals to which we have grown accustomed. Without the use of temporal video compression, a doubling of the frame rate doubles the required bandwidth of a signal. Additionally, HDR content requires a minimum of 10-bit color depth, which represents a 25% data rate increase compared to content with 8-bit color depth. If more than one of these technologies is applied to a 4K signal, the bandwidth demands are compounded.

To accommodate the high bandwidth that tomorrow's video signals will require, new video interfaces may emerge, and existing interfaces will need to offer higher throughput capabilities. One interface rising to the challenge was announced by the MHL Consortium. Mobile High-Definition Link – MHL is an interface already integrated into many types of consumer electronics to allow connection to high-definition televisions. The superMHL specification, released in 2015, defines support for 8K signals at 120 frames per second, Rec. BT.2020, HDR, and 48-bit color depth through a single 32-pin connector. Another contender is HDMI 2.1 because its 48 Gbps maximum data rate will support video resolutions up to 8K/60 and 4K/120.

Planning for the Future

4K video is an evolving technology. Today, 4K offers four times the resolution of 1080p, providing detailed images for large screen applications and visual clarity for the most critical viewing applications. However, not all 4K signals are created equal. Frame rate, color bit depth, and chroma sampling also contribute to the presentation of 4K images and should be considered when designing a system.

Extron offers over 100 products to support your 4K requirements, including the XTP II CrossPoint modular digital matrix switcher which provides high performance

Figure 3: Extron True4K Specification for XTP II CP HD 4K PLUS I/O Boards

TRUE 4K SPECIFICATION

Max 4K Capabilities		
Resolution and Refresh Rate	Chroma Sampling	Max Bit Depth per Color
4096 x 2160 at 60 Hz 3840 x 2160 at 60 Hz	4:4:4	8 bit
4096 x 2160 at 30 Hz 3840 x 2160 at 30 Hz	4:4:4	12 bit
4096 x 2160 at 60 Hz 3840 x 2160 at 60 Hz	4:2:0	12 bit

Frame Rate[1]	24, 25, 30, 50, or 60 fps
Chroma Sampling[1]	4:4:4, 4:2:2, or 4:2:0
Color Bit Depth[1]	8, 10, or 12 bits per color
Signal Type	HDMI 2.0b, HDCP 2.2
Max Video Data Rate	18 Gbps (6 Gbps per color)

NOTE: Use our calculator at www.extron.com/4Kdatarate to determine video parameters supported by this data rate.

switching of video and audio with a 50 Gbps digital backplane that exceeds the data rate requirements for 4K video formats for a future-ready, integrated solution. Other 4K solutions include videowall processors, signal extenders, streaming encoders and decoders, and twisted pair and fiber optic signal distribution products.

To ensure that you select the correct Extron 4K products, Extron identifies all of the parameters that are critical to meeting 4K video performance requirements. This detailed product specification for 4K video performance is called the Extron True4K™ Specification. A True4K Specification always includes resolution, frame rate, chroma sampling, and color bit depth, plus information about the 4K video signal types and the maximum 4K data rate supported by the product. See Figure 3 for an example of a True4K Specification.

For additional information about 4K, refer to “Distributing 4K and UHD Signals in Professional AV Environments.” For additional information about HDR, refer to “Elements of High Dynamic Range Video.” Both are available at www.extron.com/technology.