INNOVATION IN LIGHT

COMPRESSION IS COMPROMISING YOUR 4K VIDEO

Why compromise? Or more to the point, why needlessly use compression with your 4K HDMI video delivery system? Real 4K ultra high definition (UHD) video requires a lot of data to be transmitted from the source to the display when viewing real 4K video, especially with the increase in available high dynamic range (HDR) content. How much you ask?? A 4K, 60 Hz, 4:4:4 with 8-bit color video requires 18 Gbps, and for the great-looking HDR, with HDR10 or Dolby Vision, a 4K, 60 Hz, 4:2:0 with 10-bit color still needs 11.14 Gbps. That's a large amount of bandwidth, and unfortunately for consumers, many solutions degrade the data by using compression so they can send the data over a 10G link (such as HDBaseT, SDVoE, Video over IP) or even a 1G Ethernet network. What happens to the video when the signal is compressed by 50% or more? This whitepaper presents an overview of compression for HDR video and the tradeoffs that are made with these compression algorithms. For those who don't want to compromise, we'll show the comparison of these compression schemes to fiber solutions with uncompressed video, where the fiber can be pulled just like standard category cable and still have enough bandwidth for 8K and beyond.

COMPRESSION COMPROMISES ARE WORSE FOR HDR THAN SDR

The differences between standard dynamic range (SDR) and high dynamic range (HDR) are most noticeable with newer, more modern UHD TVs that unleash the power of HDR. With the great picture quality comes a big increase in the bandwidth, and some links can no longer keep up without using compression. The table below shows the difference in bandwidth between 8-bit SDR and 10-bit HDR video.

TABLE 1
Bandwidth Requirements for 4K HDMI Video

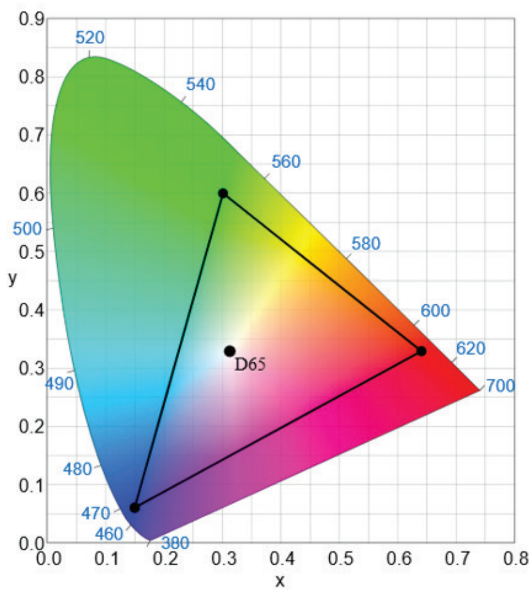
4K HDMI Bandwidth Requirements		
Resolution		**Date Rate**
SDR 8-bit	60Hz, 4:4:4	18 Gbps
	60Hz, 4:2:2	11.9 Gbps
	60Hz, 4:2:0	8.9 Gbps
	30Hz, 4:4:4	8.9 Gbps
	30Hz, 4:2:2	5.9 Gbps
	30Hz, 4:2:0	4.5 Gbps
HDR 10-bit	60Hz, 4:4:4	> 18 Gbps, Not Supported
	60Hz, 4:2:2	14.9 Gbps
	60Hz, 4:2:0	11.1 Gbps
	30Hz, 4:4:4	11.1 Gbps
	30Hz, 4:2:2	7.4 Gbps
	30Hz, 4:2:0	5.6 Gbps

The encoding of the video between HDR and SDR is also an issue due to development of displays that actually display a wider range of colors and brightness. Previously, using the ITU-R BT.709 color scale and electro-optic transfer function (EOTF) was sufficient because a display could only show luminance between about 0.1 Cd/m^2 and 100 Cd/m^2, which is a dynamic contrast ratio of 1000:1. This can be compared to the human eye which can adapt to a contrast ratio of 10,000,000,000:1 and, at a single time, can typically sense a range of 100,000:1[1] so even the best displays couldn't replicate real-life images. This started to change with the development of new display technologies, where TVs could achieve contrast ratios of 100,000:1, with luminance intensities of around 0.01 Cd/m^2 on dark images and up to >1000 Cd/m^2 for brightness[2] High dynamic range became an important feature because displays were now capable of

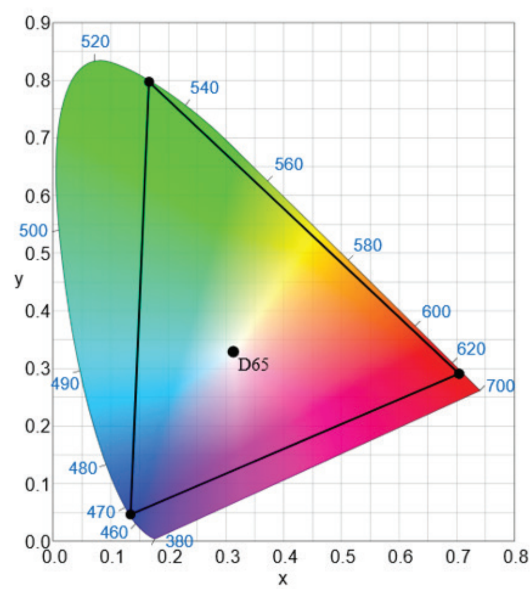
nearly replicating real life images. This then required a wider color gamut to support the expanded dynamic range, which is the corresponding wide color gamut (WCG) format that supports the ITU-R BT.2020 color scale and EOTF instead of the older BT.709. The difference in the range of colors that can be displayed is significant, with BT.709 covering ~33% and BT.2020

FIGURE 1
ITU-R BT.709 and ITU-R BT.2020 standard color space comparison, with BT.2020 covering nearly 64% of visible colors.
(Image courtesy of Microsoft)

BT.709



BT.2020



WHAT IS COMPRESSION AND HOW DOES IT WORK?

Compression is image or video processing to reduce the file size, often resulting in a tradeoff between picture quality and data integrity. It has become a key component for 4K video with the transition of HDR and higher frame rate content because many popular links between the source and the display just cannot support the full bandwidth. According to Thomas Wiegand of the Berlin Institute of Technology, "The basic communication problem may be posed as conveying source data with the highest fidelity possible without exceeding an available bit rate, or it may be posed as conveying the source data using the lowest bit rate possible while maintaining a specified reproduction fidelity" [3]

Either way, compression requires a trade-off right from the beginning, referred to as the compression ratio, which can be calculated according to the following equation[4]

$$Y = \left(1 - \frac{\text{COMPRESSION SIZE}}{\text{RAW SIZE}}\right) * 100\%$$

There are four primary methods that are used to compress video; spatial encoding, temporal encoding, quantization and entropy coding. These methods result in both lossless and lossy compression, combined to get a compression ratio that is large enough that the bit rate can be supported by the link. There are some fancy trademarked names for compression algorithms in the AV industry, but they are still using these types of compression methods.

Entropy coding is a lossless compression that can provide a reduction in data size compared to the original data but only for certain types of discrete amplitude and discrete time signals. The lossless coding relies on various mathematic concepts where the data is mapped to a codewords that can then be decoded accurately. Entropy coding alone can achieve about a 50% compression ratio[4] Most video codecs, including the common high efficiency video coding (HEVC) H.264 and H.265 use a component of entropy coding.[3] Entropy coding is important for streaming applications because they have sufficient time and processing power available to perform the decoding after downloading, which could require significant computational resources and time if a robust Huffman, arithmetic or probability interval portioning entropy coding method is used. However, for the real-time delivery of content, lossless compression becomes more difficult and very computationally expensive so most applications also rely on simpler, lossy compression methods.

Temporal encoding, or inter-frame encoding, is implemented in video compression as an inter-frame prediction, where algorithms consider how a scene varies from frame to frame and sends data related to the changes between the frames rather than all of the data within each frame. Inter-frame encoding is especially efficient when the scene changes slowly but becomes inefficient for scenes with high motion content, such as chase scenes, fight scenes or explosions. In these types of situations, the high-frequency changes can be lost in the compression processing.

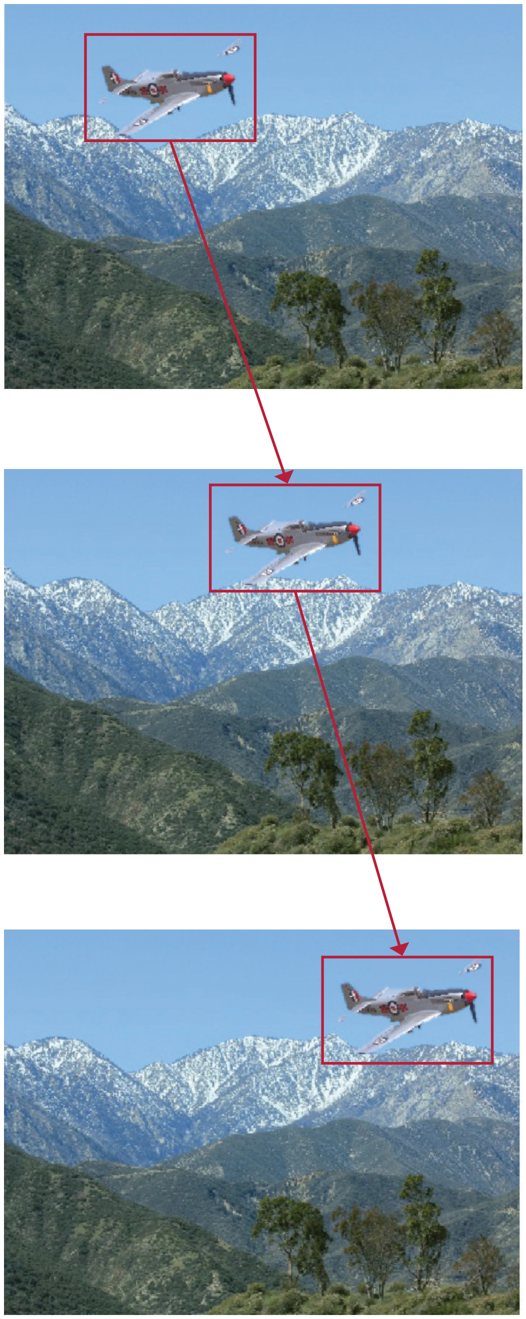


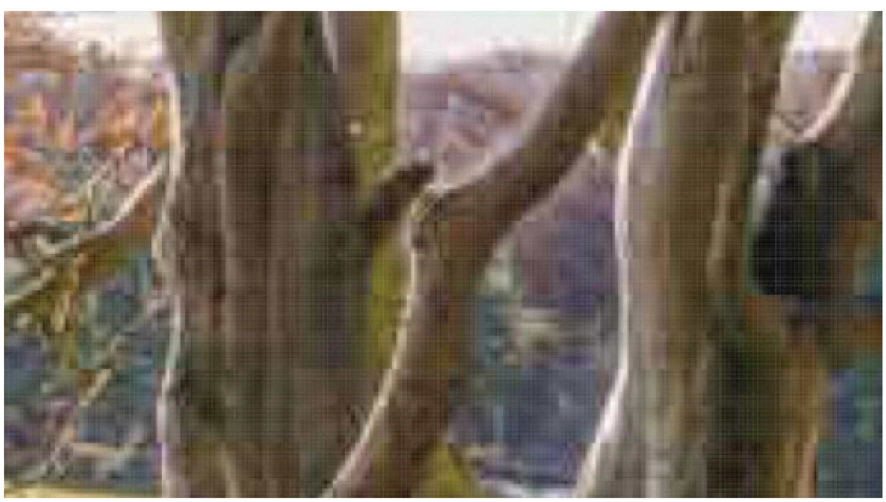
FIGURE 2
Temporal or inter-frame encoding sends information about how a scene changes from frame-to-frame rather than all of the information within a frame.

Spatial encoding, or intra-frame encoding, considers a single frame and makes estimations of how the image of the single frame varies at different positions. Intra-frame encoding is always a lossy compression method as it only compares adjacent pixels within a single image. However, it can be a faster compression algorithm to apply for lower latency applications because there is no need to wait for subsequent frames for decoding and recreating the signal. JPEG2000, which is used for video over IP applications, can offer low latency because it only uses intra-frame compression, though it can only achieve compression ratios of 4-6:1 and creates visual artifacts, especially for high color contrast (which is common in HDR video) and computer graphics applications.[5] JPEG2000 implementations have a latency of 30-50ms.[6] This latency may be acceptable for some video viewing applications but will likely be undesirable for gaming applications, where reaction time matters.

FIGURE 3
Spatial encoding, or intra-frame encoding considers changes between adjacent pixels within a single scene.

Quantization is another lossy compression method that breaks a frame into discrete matrix blocks that can then undergo a discrete cosine transform to the frequency domain and rounding to discrete values so that the same data is presented with a smaller range since neighboring pixels in a frame tend to be highly correlated.[7] Using quantization compression, the frequency components that are more visually perceptible have a higher weight than frequency components that are less visually obvious. A common implementation of quantization in video compression is color space conversion, where intensity is weighted higher than actual color. A downside of the discrete matrix blocks is that these can become visible in an image through the compression process.

FIGURE 4
Blocking artifacts can be visible with quantization compression [6]



REAL-TIME COMPRESSION VS DELIVERY COMPRESSION

Much of today's content is delivered via streaming applications, which definitely do not send the full bit rate of video when delivering the content to the streaming device media player. One could argue that this entire discussion on compression doesn't matter since the content was already compressed and therefore compromised just by downloading it. Well, that's not an accurate comparison. This type of compression uses high efficiency codecs, such as HEVC/H.265 and VP9, and the compression of downloadable/streamable content is less problematic because the content only has to be compressed once by a system that has vast time and computational resources. The compression of real-time video, such as when sending that HDMI video from your player to your display, becomes much more challenging. This is because HEVC/H.265 uses significant inter-frame compression, which can be used to achieve a much higher compression ratio, at the expense of high latency. This tradeoff of added complexity and processing time, which may be 1-5 seconds [6], can provide a high fidelity video recreation after compression - so it is a very good solution for delivery of content, but a poor solution for real-time compression.

Lossy compression results in an irreversible loss of data from the original as the data is reconstructed using approximations and estimations of the original. This type of compression provides a significant reduction in the required data rate using various compression algorithms so that the video can fit within the allotted bandwidth of the link; this is how a 4K/60 4:4:4 or 4K/60 HDR signal can fit within a 10.2 Gbps (or even a 1 Gbps) link. The reconstruction of the high-bit rate signal at the TV assumes that the majority of the viewers will not notice the difference. A very fast compression scheme is Dynamic Range Compression, which converts from 10- or 12-bit to 8-bit color. This leads to a reduction in bandwidth from 11.1 Gbps to 8.9 Gbps for 4K, 60 Hz, 4:2:0 HDMI video and therefore allows the video signal to fit within the limitations of a 10 Gbps link. However, this has just reduced an HDR video to and SDR video… and in the process loses the expanded color range that is most sought after in HDR. Additionally, the 8-bit color is known for the creation of banding artifacts, such as the one shown in Figure 5 below that clearly degrade the viewing experience.

FIGURE 5
Compression of data through conversion from 10-bit HDR down to 8-bit SDR can result in undesirable visual artifacts, such as banding.
(Image courtesy of Aurich Lawson, https://arstechnica.com)

Another option for fast compression is to change the chroma sub-sampling from 4:4:4 to 4:2:0, this time leading to a 50% reduction in bandwidth. The premise here is that because humans are more susceptible to intensity than color, the resulting loss of fidelity in the image is acceptable. The change in chroma sub-sampling to 4:2:0 keeps the full intensity of the image, and then reduces the horizontal and vertical resolution, resulting in all pixels having the original intensity but the nearest neighbor pixels having to copy the neighboring pixel's color, as illustrated in Figure 6. What does this do to an actual image? Shown in Figure 7 is an original test pattern with a full chroma 4:4:4 signal and a 4:2:0 sub-sampled version of the same test pattern, clearly illustrating the loss of data through compression.

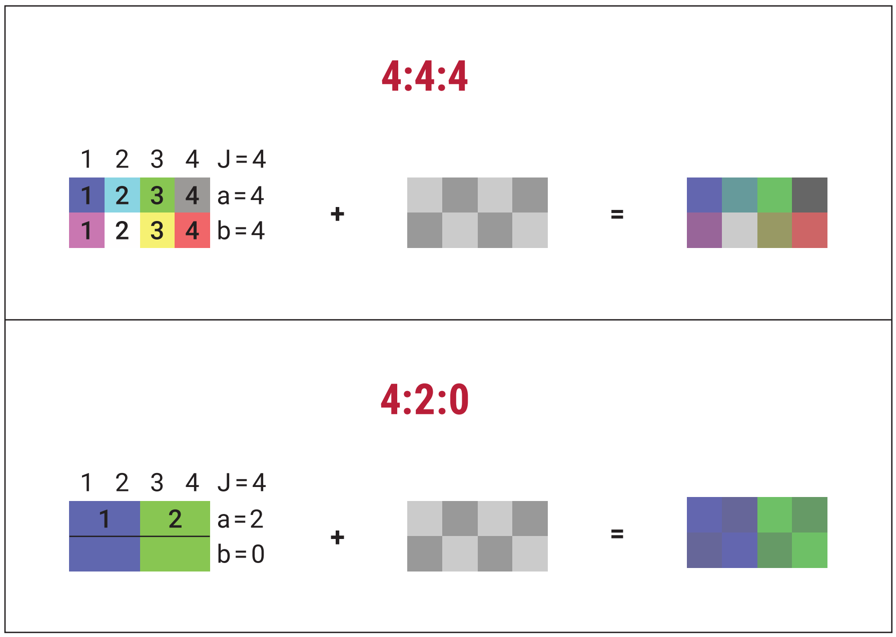


FIGURE 6
Chroma sub-sampling down-conversion is a fast form of compression for video transport but data is irreversibly lost

FIGURE 7
Chroma sub-sampling can reduce the band-width but there is data loss with the compression method

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WHAT HAPPENS AS WE MOVE TO 8K?

With bandwidths continuing to increase, the need for even greater compression ratios will arise. While this is feasible for long-latency video distribution like HEVC H.265 compression, it will likely move from a realm of the so-called "visually lossless" to "acceptable visual quality" because compression artifacts will be obvious with solutions that are trying to compress the video to a 10G or even 1G link.

TABLE 2
8K video bandwidths continue to increase beyond copper capabilities for meaningful distances.

Resolution	Frame Rate	Color	Bandwidth (Gbps)
4K, HDR (10-bit color)	30 Hz	4:4:4	11.14
	30 Hz	4:2:0	5.57
	60 Hz	4:4:4	22.28
	60 Hz	4:2:0	11.14
	120 Hz	4:2:0	22.28
8K, HDR (10-bit color)	30 Hz	4:4:4	44.55
	30 Hz	4:2:0	22.28
	60 Hz	4:4:4	89.10
	60 Hz	4:2:0	44.55
	120 Hz	4:2:0	89.10

FIBER ADAPTERS AND EXTENDERS SUPPORT UNCOMPRESSED 8K

Is the compression compromise and tradeoff inevitable? No, it doesn't have to be! Fiber solutions are available now that support the full 18 Gbps without any compression on a single, industry-standard fiber through optical adapters and optical extenders. As the industry moves beyond the current 4K to support higher frame rates and additional HDR content, bandwidth requirements will move to 22 Gbps and higher even before full 8K content becomes available, and that's not a problem for fiber. The bandwidth of fiber is >>100 Gbps, so video rates can increase significantly before the limits of fiber are reached. Additionally, when higher data rate video becomes available, the fiber infrastructure can be left installed, with the adapter and extender ends simply swapped out for the next generation 8K products and beyond. With simple field termination kits and matrix switches, fiber can be pulled just like category cable to provide a solution that doesn't require compression. No compromises required… just amazing video as it was meant to be seen.

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FRIENDS DON'T LET FRIENDS COMPRESSION COMPRESS VIDEO