

UNDERSTANDING ULTRA HIGH DEFINITION TELEVISION

TECHNOLOGIES FOR ENHANCED VIEWING EXPERIENCES

Consumer demand for ultra high definition television (UHDTV) is already showing huge potential – although the vast majority of television viewers have not yet experienced it.

By combining high dynamic range, wide color gamut and high frame rate, UHDTV can provide an even more compelling viewing experience than today. However, translating this potential into profitable business will require service providers to balance costs with perceived benefits to consumers.

WHAT IS ULTRA HIGH DEFINITION TELEVISION?

Ultra high definition television (UHDTV) combines 4K resolution, high dynamic range (HDR), high frame rate (HFR) and wide color gamut (WCG). At the same time, it poses some of the biggest questions about the future of the broadcast industry. Should we use 4K resolution, or do we need to wait for 8K resolution? Is some form of enhanced HD with HDR and WCG more likely to be commercially viable than 4K? What will have consumer appeal? Ultimately, will UHDTV be successful?

The Digital Video Broadcasting Project (DVB) has taken the technical standards of the Society of Motion Picture & Television Engineers (SMPTE) (ST 2036-1) and a number of International Telecommunication Union Radiocommunication Sector (ITU-R) Recommendations and produced a tiered practical commercial approach to enhancing television services beyond HD, known as UHD-1 Phase 1, UHD-1 Phase 2, and UHD-2.

Confusingly, UHDTV is also known as UHD-1, Quad HD, 4K TV or simply 4K. To keep things simple, this paper will use the term UHD-1 when referring to the standards and 4K TV when referring to the actual services and televisions.

The DVB has defined UHD-1 Phase 1 as:

- > 3840x2160 resolution (four times more spatial resolution than 1080i HD)
- > up to 60 frames per second (fps) (two times more temporal resolution than 1080i HD)
- > 8-bit or 10-bit sampling to the home
- > Rec. ITU-R BT.709 color space, or optionally a subset of Rec. ITU-R BT.2020 color space
- > standard dynamic range (SDR) (Rec. ITU-R BT.1886).

Together, these constitute what most people understand as 4K TV, and can offer consumers a far more compelling viewing experience than HD when very large screen sizes are used.

	1080i HDTV	UHD-1 Phase 1
Resolution	1920 x 1080	3840 x 2160
Scan type	Interlaced	Progressive
Max frame rate	25/30fps (50/60 fields/s)	50/60fps
Typical consumer TV size range at introduction	Up to 50"+	Up to 100"+

Table 1: A comparison between 1080i HD and UHD-1 Phase 1.

WHY IS 4K TV IMPORTANT?

Data from Ericsson ConsumerLab studies shows increased consumer interest in 4K TV [1]. This is perhaps unsurprising, considering the big push that consumer electronics equipment manufacturers are making to get 4K TVs into shops as a premium offering over and above HD.

However, content owners and broadcasters, together with IPTV, cable, satellite direct-to-home, and digital terrestrial television service providers, may not necessarily want, or be able, to keep pace with the growth of consumer devices.

There is a small but growing amount of 4K film content, drama and documentaries; however, it will take time to build up these repositories. In addition, the costs of fully 4K end-to-end content creation are still very high.

This is especially the case for live sports and events. Technically, live 4KTV event transmissions are now possible, and there have been an increasing number of live trials driven by major sporting events worldwide. However, it is still too early for a viable business model for widespread deployment.

4K TV DELIVERY

Screen size, viewing distance, viewing angle, frame rate and sample bit depth are all important factors for the delivery and consumption of 4K TV. However, an understanding of the human visual system (HVS) is important to shed more light on how these factors affect TV delivery and consumption.

HOW WE SEE IMAGES

Humans “build” resolution in a scene by very rapid and involuntary eye movement known as saccadic motion, of which they are typically not conscious when looking at an object.



Figure 1: Saccadic motion.

Both eyes move around objects of interest such as the human face, and together with depth information, the brain compares this data with stored reference models of what objects should look like. Some are learned, while others are possibly stored genetically, such as “this is a smile.” Various parts of the brain then work together to produce the image.

The biology of the eye also has a role. The structure of the human retina differs across its areas, which leads to varying capabilities of color vision, night vision and acuity (the ability to resolve detail). The part of the retina used when humans look directly at an object is known as the fovea centralis. This is only a few degrees of the overall vision, but the saccadic motion described above allows high acuity to be applied over a wider area – at least for reasonably static images¹.

VIEWING ANGLE AND VIEWING DISTANCE

UHD-1 enables the use of larger TVs without softening or blurring, whereas 1080i HDTVs would have a visible pixel structure at these large sizes. The relationship between the viewing distance at which the image matches the capabilities of the HVS, and the combination of screen size and resolution is defined by the acuity of the fovea centralis.

Although humans have almost 180 degree total horizontal field of vision, the center 90 degrees (known as the central field of vision) accounts for the majority of what is perceived and remembered. Larger TV sizes enabled by UHD-1 mean that at the appropriate viewing distances, the TV image fills approximately 60 degrees of the horizontal field of vision.

At 60 degrees, a large 4K TV at the correct viewing distance dominates this central field of vision, and as a result provides a more natural and immersive viewing experience. By contrast, at the appropriate viewing distance, conventional HD only occupies around 30 degrees, meaning that the perception is largely of the

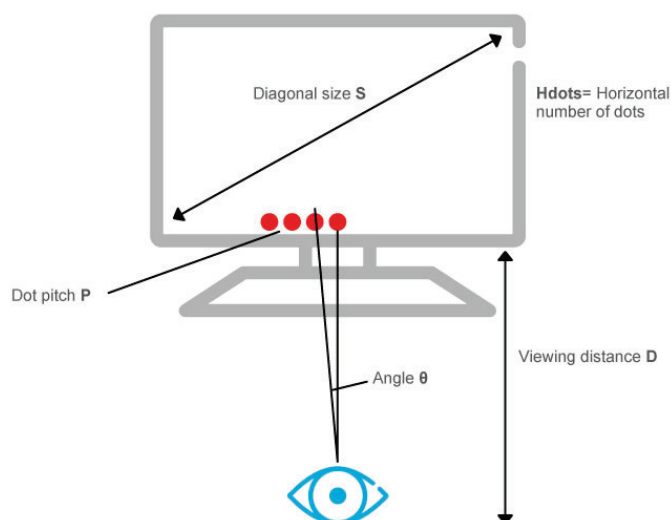


Figure 2: Example of the relationship between visual acuity and screen size.

¹ Within the fovea centralis, the acuity is typically 0.3 to 0.5 arc minutes, although the ability of the HVS to resolve detail such as sharpness also depends on contrast and other factors.

surroundings of the TV screen with the TV picture within that area.

That does not, however, mean that there is no benefit when sitting further away. If we perform the same calculation for HD resolution with the same screen size, we end up with the corresponding viewing distance being 3.2 meters. The additional visual benefits of UHD-1 change gradually between these two points, so that at, say, 2.4 meters, there is still some benefit for 4KTV, although it is not the full benefit.

However, the way that humans see detail is extremely complex and content dependent. Therefore, there is no single viewing distance that is “right” for all content. In practice, this means that smaller 4KTVs do not really give much consumer benefit at typical home viewing distances. The average lounge or bedroom viewing distance is typically around 2 meters, but can be much more. At these distances, 4KTVs need to be 80 inches or more for 4K resolution to have its full effect.

The question of viewing distance is therefore an important one to 4KTV as a business.

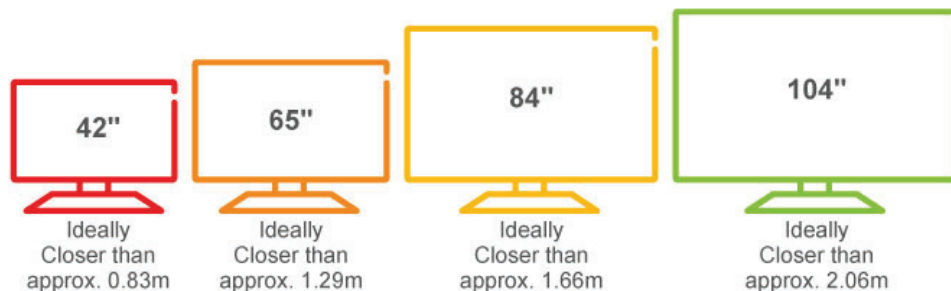


Figure 3: Some consumers may see little benefit in simply increasing resolution.

BIT DEPTH

Most viewers will have experienced unpleasant “banding” (or “contouring”) effects on screen images, particularly on gently graduated areas. This is a consequence of the sampling granularity: increasing the bit rate will not remove the contouring effect.

The root cause of this is the use of 8-bit sampling in current standard definition (SD) and HD television delivery systems. UHD-1 offers an opportunity to solve this unpleasant artifact (visual error) by introducing 10-bit sampled video. However, the definition of UHD-1 Phase 1 still allows the use of 8-bit sampling.

8-bit sampling means that adjacent digital levels have too large a step between them, which in gently changing areas leads to visible contour lines. When the content is also changing slowly (as can happen with graphics), the contour lines move across the images as the levels change, leaving an unpleasant effect.

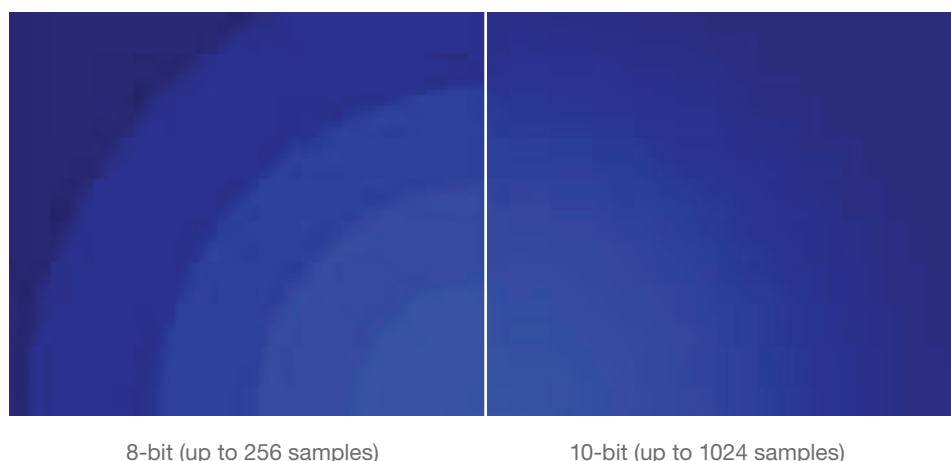


Figure 4: 8-bit sampling shows banding (left) to a much greater extent than 10-bit (right).

SD video has been acquired and edited in 10-bit samples for more than 20 years in order to avoid banding, and there is a growing consensus that 8-bit sampling is both aesthetically inappropriate and technically unnecessary for UHD-1 Phase 1. Since 8-bit has only up to 256 steps to represent a scene, it is difficult to manipulate a scene without either introducing artifacts or restricting choices.

The film industry, which also deals in large screen sizes, started to adopt digital technology in the early 1990s and quickly dropped 8-bit sampling for adopted 10-bit (or higher) sampling, offering up to 1024 steps².

It is often assumed that moving from 8-bit to 10-bit sampling will increase the required bit rate. However, this is not the case. In a video encoder, new pictures using prediction are encoded based on differences from reconstructed pictures (the reconstructed pictures in the video encoder are exactly identical to the pictures that will appear from the decoder's output). 10-bit sampling means that these reconstructed pictures do not have the 8-bit banding artifacts, so when these pictures are used as references for prediction of other pictures, they are a better representation of the source and the differences are smaller. It is the differences that eventually get coded into the bit stream, so a smaller difference means less data to encode predicted pictures. This offsets the additional data needed to provide the 10-bit intra coded pictures (i.e. pictures that are not predicted from any other picture) in the first place, so the overall effect is no net increase in bit rate of any significance.

The difference in the reconstructed picture accuracy can be seen in Figure 5 below: note the higher level of smoothness of the surface on the right (this surface shows the differences from the prediction).

UHD-1 Phase 2 may mandate that 8-bit is no longer an acceptable delivery method.

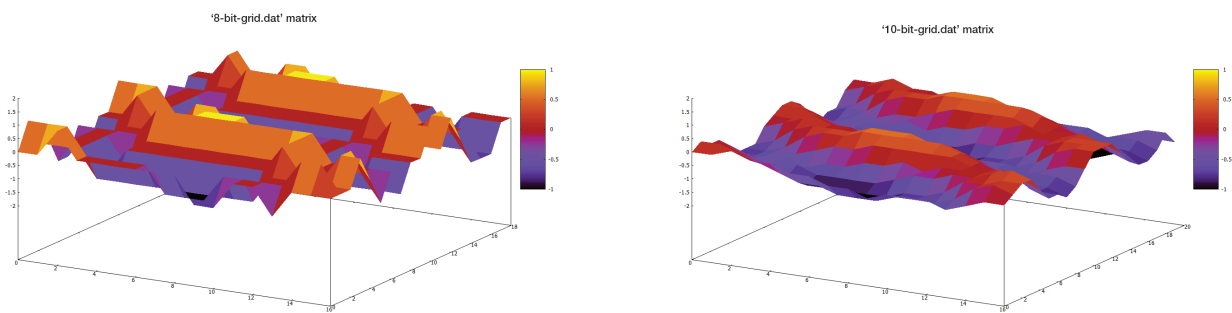


Figure 5: Residual errors are caused by 8-bit quantization (left) but 10-bit quantization (right) makes a better predictor, leaving less residual to be coded.

HFR

In addition to requiring a higher bit depth, UHD-1 will also need higher frame rates than those used for current HD and SD services.

Today, all SD and 1080i HD TV is transmitted at 25i or 30i (meaning 25fps or 30fps interlaced, equivalent to 50 or 60 fields/s). Interlacing a picture helps reduce motion artifacts by increasing the temporal sampling of movement. Interlacing, however, brings its own artifacts. The exception to interlacing in HDTV is at the 720p format, where 50fps or 60fps are used. 720p HD has lower spatial but higher temporal resolution than 1080i. There are also versions of HD using the 1080p format, where 50fps or 60fps are used, but these are not in common use for direct-to-consumer transmission.

60fps is the maximum frame rate specified for UHD-1 Phase 1. 50fps or 60fps are needed on the large screens used in 4K TV to avoid a motion artifact known as motion judder.

²Traditional 35mm optical film negative has a very wide color gamut and can handle a very high dynamic range. 8-bit optical film scanning products were quickly driven out of the market by 10-bit. Later, when digital film cameras first came on the scene, 8-bit was not even considered for high-quality film acquisition.

Frame rates that are too low result in either motion blur (on the left of Figure 6) or motion judder (on the right of Figure 6). These occur for long or short shutter times respectively. Ideally, a shorter shutter time with a shorter interval until the next exposure will provide the best representation of moving content.

Film camera operators tend to shoot cinema releases differently from TV, and postproduction houses are often asked to take video drama and “make it look more like film.” 24fps content has a certain “look” that some prefer, and there is no push for frame rates above 60fps for drama, soap operas, news or most documentaries.



Figure 6: Motion blur (left) and motion judder (right).

However, at the other extreme, HFR cameras have been used for many years on certain kinds of shots in wildlife documentaries or sports to get sharp pictures of fast action³. Increasing UHD-1 frame rates above 60fps for sports such as soccer (which involves fast-moving action and camera work) can be shown to produce sharper images and is currently under study for long-term UHD-1 sports services. However, 100fps and 120fps will incur extra costs over and above current 4KTV estimated deployment at many stages of the production and postproduction process.

A TV channel that shows a mixture of sports, news, drama and movies would not need HFR all the time – for a lot of content, HFR simply generates additional costs with little consumer benefit. The majority of content does not involve very fast-moving camera work with very fast-moving objects. Even content like soccer includes sequences where the camera and subject are slow-moving or relatively static. Ideally, it would be possible to create extra frames in production and in distribution only when needed.

It should also be noted that HFR is about delivering the equivalent resolution of slow-moving images on fast-moving images. Like spatial resolution, it is dependent on viewing distance, and image enhancements may be lost if the viewer sits too far away.

³These can either be shown at normal transmitted frame rates by “integrating” or to create “super-slow-motion” sequences.

IS 4K RESOLUTION ENOUGH FOR CONSUMER APPEAL?

As described earlier, proper viewing distance considerations lead some to the conclusion that UHD-1 Phase 1 will have little consumer benefit over HD, since the main enhancement is a higher spatial resolution.

On the other hand, UHD-1 Phase 2 specifies additional enhancements – higher dynamic range, a wider color gamut and deeper bit sampling depths – which may provide tangible improvements to the viewing experience beyond a spatial resolution increase.

100/120fps is also included within the scope of UHD-1 Phase 2. However, cost considerations may restrict the cases where this is used in practice.

HDR

The current front-runner as the next enhancement is HDR. The HVS, as described, is equipped through evolution to see a very wide dynamic range – from starlight to the midday sun.

The dynamic range of the HVS is huge: from 10^5 cd/m² (candela per square meter or “nit”) bright sunlight to 10^{-4} cd/m² dim starlight – see Figure 7. It is highly complex, adaptive and not fully understood in terms of television viewing.

TVs, tablets, PCs and smartphones only display a small fraction of what the average person can see. Unlike increased resolution, which works best on a very large screen, increasing the dynamic range that a viewer can see is applicable to any screen size.

Human perception of a scene, especially the dynamic range between deep shadows and bright highlights, is very different from a camera lens/sensor combination – it has non-linear, color-adaptive, frequency-based and wavelength-based characteristics. Evolution has equipped humans over millions of years with a system designed to seek food and avoid danger.

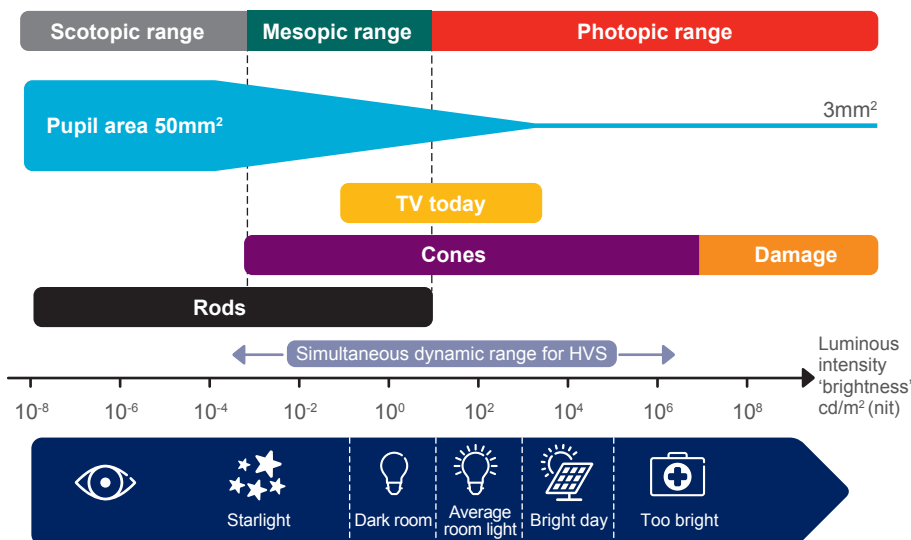


Figure 7: The dynamic range of the HVS is much wider than that displayed by current TV technology.

Practically speaking, if a viewer is watching a soccer game on TV on a bright winter afternoon, either the details in the deep shadows cannot be seen or the highlights, such as clouds in the sky, are lost.



Figure 8: Sport is a potential killer app for HDR, as today audiences cannot easily see specular highlights plus detail in shadows.

The human visual system has numerous mechanisms that are used to process information of varying light levels, the details of which are too complex to cover in this paper. What is important to UHDTV are three phenomena:

- > The ability to perceive detail is related to contrast. It is harder to see detail in low contrast images and easier to see in higher contrast images. This is one reason why high dynamic range can offer greater perceived sharpness [2].
- > The HVS is more sensitive to high frequency (fine detail) in brighter images. This is another reason why high dynamic range can offer greater perceived sharpness [3].
- > The HVS adapts to brighter images and recalculates what a scene should look like. This gives rise to the phenomena of color constancy [4].

Modern digital cameras – the first part of the optical chain – can capture a much wider dynamic range than is used in TV transmissions. If we can use this wider range and encode it, it is technically possible to build a new generation of televisions and other display devices with higher light output and reduced light leakage (the last part of the optical chain) which could offer a better viewing experience⁴.

A transfer function to get from camera lens to display is required, and there are several competing proposals.

HDR also potentially means that the gamma curve needs to be modified from Rec. ITU-R BT.709, which was defined for cathode ray tube (CRT) televisions. While CRT-based TVs were once common, these have now been replaced by various flat-screen technologies. The modification of the gamma curve will have an impact throughout the production chain.

The gamma curve (or more correctly curves), also referred to as electro-optical transfer function (EOTF), represents how different coded levels (whether analog voltage or digital numbers) are converted into luminance output levels by a TV. Originally, this came from a desire to simplify the electronics of a CRT, however, it also happened to be a reasonable match with the sensitivity to changes in luminance levels of the HVS – at least over the range available on CRT TVs at the point the levels were standardized.

A typical legacy CRT (for which the old NTSC and PAL TV systems were designed) can go from about 0.1 nit to 100 nits. The dynamic range is thus about 1000, so the intensity can double roughly 10 times, called “10 stops.” Viewers have never been offered HDR TV or cinema services, and are often watching “clipped” pictures, where highlights or details in shadows are lost.

⁴People will not want to wear sunglasses when there is sunlight on screen (even if such a screen were to exist). TV sets will exist in real homes, not movie theaters, so the ambient light level for “black” needs to be chosen sensibly to balance effectiveness with bit cost/granularity.

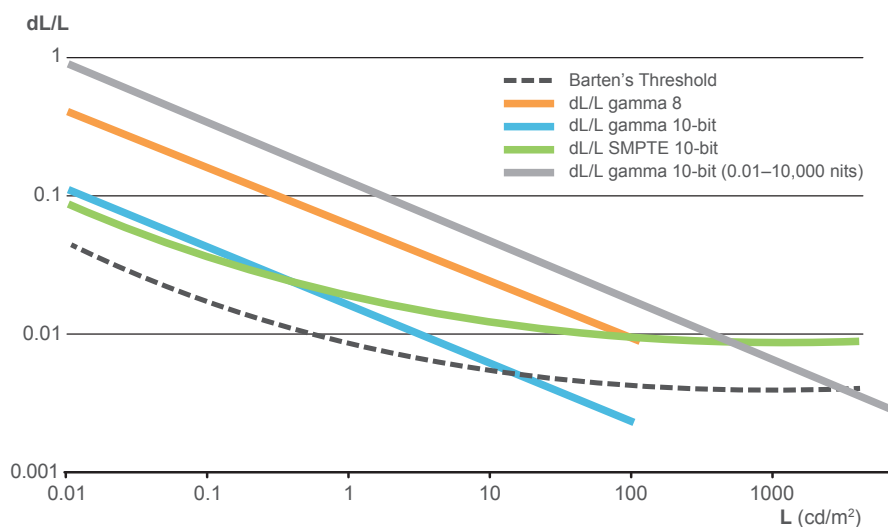


Figure 9: Gamma curve (EOTF): change to the use of gamma may be needed.

Figure 9 shows the sensitivity of the HVS to potential gamma levels. The vertical axis shows the ratio between luminance step size and absolute step size; it is a measure of proportion of luminance level in the step.

The dashed line shows a widely used representation of the limit of human ability to detect steps in luminance levels. As always with the HVS, the details are more complex and content-dependent; however, this is a reasonable starting point. Levels below this dashed line (known as Barten's Threshold) are invisibly small to humans. Steps greater than this (those above the line) are potentially visible, and more so the further above the line the level is.

The orange line (labeled "dL/L gamma 8") is the EOTF used by today's TV systems, with 8-bit quantization. The line is significantly above Barten's Threshold, and more so for darker colors. Moving to 10-bit representation moves the line (the blue line in the figure) much closer to Barten's Threshold. In fact, at 10-bit sampling, the step sizes are small enough that for all practical use, the steps are not visible. It is possible to synthesize a test signal that will show the levels, but for normal content, it is very unusual to be able to see the contours.

Finally, HDR needs an extended range of luminance to be represented (so further along the horizontal axis). If we were to simply "stretch" the existing gamma curve to represent a wider range of luminance levels, the result would be a reintroduction of banding artifacts.

The gray line in Figure 10 shows the result of extending a 10-bit gamma EOTF to 10,000 nits (without any change to the value of gamma), which is a possible maximum value that is currently being discussed for HDR. There are also other options being discussed to achieve this maximum value such as Lmax (maximizing luminance) and higher values for gamma.

Overall, the gamma curve is not very efficient for representing the wider range of luminance levels needed for HDR. A different curve is needed, and the green curve is one of the proposals for an EOTF that has a better match to the HVS over the larger range of luminance levels needed for HDR. There are a number of EOTFs that could also fulfill this criterion.

Current TV systems specify Rec. ITU-R BT.709 as the OETF (Opto-Electrical Transfer Function), and this acts as the overall reference point (as the EOTF is a combination of the inverse OETF and the desired system transfer function). Ideally, if an EOTF can represent an appropriate range of luminance levels without any noticeable banding, while using straightforward 10-bit levels, then it may well be very suitable for HDR TV systems and could potentially work with existing High Efficiency Video Coding (HEVC) Main 10 profiles, which offer better video-compression efficiencies than the MPEG-4 advanced video coding (AVC) widely adopted today.

WCG

Just as the HVS can see a wider dynamic range than current TV, it can also see a wider color gamut than the color space currently used in HD, Rec. ITU-R BT.709.

Current UHDTV specifications extend the color space from BT.709 to Rec. ITU-R BT.2020, which gives a closer rendition to human color perception. A very wide range of content could potentially benefit from this change, although there is no solid consumer data on how much of a positive impact this will have on the average viewer.

WCG and HDR are related, as each can be involved in producing bright saturated colors. 8-bit sample depth is unsuitable for delivering the benefits of these enhancements with sufficient consumer appeal.

Today there are many digital film cameras capable of capturing 4K, HDR and WCG (in some cases all three) for non-real-time film, drama and documentaries⁵. At the time of writing, the choice of cameras capable of running 4K resolution at 100fps or 120fps progressive is very limited.

Postproduction editing, compositing, color correction and graphics systems that support 4K, HDR and WCG (again, in some cases all three) are also available.

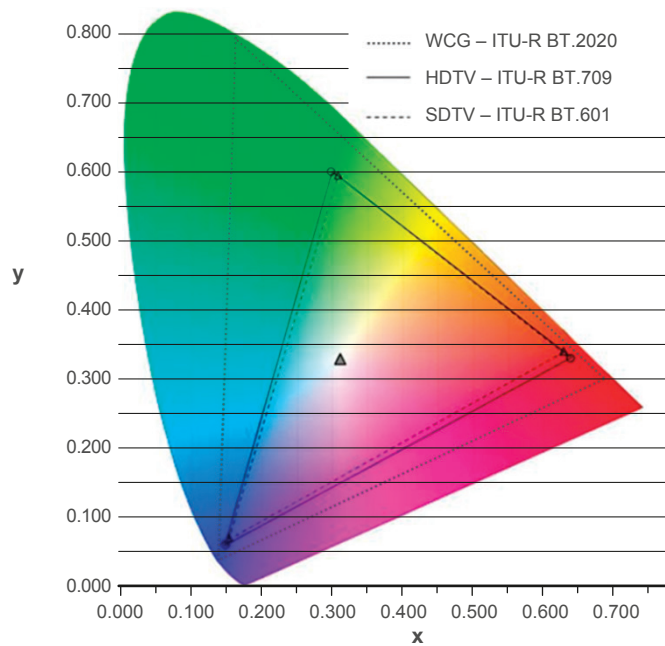


Figure 10: HVS-visible surface colors compared with SDTV, HDTV and WCG color gamuts. The UHDTV color space gives viewers a more realistic and rich color experience.

HEVC COMPRESSION

HEVC is the latest international standard for video compression. It is often quoted as offering 50 percent bitrate efficiency improvement compared with MPEG-4 AVC. In reality, as with all compression schemes, the efficiency is a function of operating point (target bitrate), algorithm sophistication and content complexity. A single figure can therefore be misleading.

Nevertheless, it is clear that HEVC will be the encoding standard of choice for delivery to the home for all formats beyond existing HD, since HDR and higher frame rates both impact the bitrate needed.

HEVC and HFR

HFR has two effects that increase the required bitrate for comparable quality:

- > more pictures to be encoded
- > more detail in moving scenes.

The first of these is obvious. Since there are more pictures to encode, it is intuitively obvious that the bitrate will also increase. Since these extra frames are temporally located between where frames would occur anyway, there is a better probability of temporal prediction producing a good match.

This temporal prediction is content-dependent. In slowly moving scenes (such as drama), the temporal prediction will typically be very good, and so very little additional bitrate will be required. As the content's temporal complexity increases, the differences between adjacent pictures will also increase, and content that has close to random motion (such as flowing water) will incur a proportionately higher bitrate.

Increase in detail is a side-effect of the shorter exposure times that are in turn a consequence of the higher frame rate. Motion blur, although undesirable in some sense, is also a temporal filter, the effect of which is to reduce detail in the background of a fast-panning shot. As a result, higher frame rates tend to require more bits per picture, even for the pictures that are co-timed with those that would have occurred at the conventional frame rates.

Unfortunately, both of the effects above have a proportionately larger impact on the required bitrate of content that is already the most challenging to encode, namely the higher temporally complex content that already needs higher bitrates.

HEVC and HDR

HDR content is, by definition, color-graded differently than existing SDR content and contains more information. As we have seen earlier in this paper, detail will be perceived more with HDR monitors, including the visibility of artifacts. As such, it is clear that the level of artifacts will need to be mathematically lower in order to be subjectively similar, which therefore implies an increase in bitrate.

The current proposals for HDR EOTFs are more non-linear than the existing Rec. ITU-R BT.1886 EOTF used today. HEVC, in common with most compression standards, uses linear processing of the data. With SDR, the non-linearity is sufficiently small that artifacts introduced as a result of treating the data as linear are not significant. With HDR EOTFs, this may no longer hold true, and some content may be subject to visual artifacts as a result of the transforms and filtering being applied to more non-linear data.

CAPTURING 4K TV CONTENT

Today there are many digital film cameras capable of capturing 4K, HDR and WCG (in some cases all three) for non-real-time film, drama and documentaries⁵. At the time of writing, the choice of cameras capable of running 4K resolution at 100fps or 120fps progressive is very limited.

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Enhancement	Baseband network costs	Baseband storage costs	Post-production products	Live production products	Content dependency	Legacy content enhancement
WCG	▶ Cheap	▶ Cheap	▶ Some	▶ Few	▶ Most content benefits	▶ Yes
HFR (100/120fps)	▶ Expensive (HD) ▶ Very expensive (4K HD)	▶ Expensive (HD) ▶ Very expensive (4K HD)	▶ Few	▶ Few	▶ Mostly limited to sports	▶ No
HDR	▶ Cheap	▶ Cheap	▶ Some	▶ Few	▶ Most content benefits	▶ Yes
4K UHD resolution	▶ Expensive	▶ Expensive	▶ Some	▶ Some	▶ Most content benefits	▶ Some

Table 2: Some relative production cost benefits of enhancement schemes.

⁵The term “4K” can be misleading, as there are very good cameras whose sensor arrays are lower than 4K that can produce excellent results.

CONCLUSION

For all of the reasons outlined previously, ultra high definition is a more complex topic than it sometimes appears. The industry has reached similar tipping points in the past where alternative technology routes became available. The technology enhancements that succeeded were those that addressed consumer needs and gained consumer acceptance.

Trying to support too many standards may not make commercial sense for most organizations. Today, HD is commonly understood as 1080i25/30 or 720p50/60. Much the same may happen with 4K TV, and a few proposals or combinations of enhancements will get enough support to become commercially successful.

Service providers will require in-depth information and guidance on all the technology choices available, and a thorough understanding of the implications for each, at every step of the video delivery chain. Table 3 gives an overview of some of these implications.

Attribute	TV	STB silicon	Compression	Backward compatibility
Wide color gamut	▶ New generation TV	▶ May be possible in next generation chips	▶ Low cost	▶ Low: Requires format conversion
High frame rate (100/120fps)	▶ Low cost	▶ May not be possible in next gen. chips	▶ High cost	▶ Low: Requires frame rate conversion
High dynamic range	▶ High power consumption	▶ Requires 10bit support	▶ Depends on scheme	▶ Depends on scheme used
4K UHD resolution	▶ Requires ≥55" plus screens	▶ Requires HEVC 10bit support	▶ High cost	▶ Depends on scheme used

Table 3: Impact of different options.

Any successful business proposition, regardless of industry, is dependent on income exceeding costs. As this paper has explained, all of the proposed extensions to 4K TV, namely HDR, HFR, WCG and enhanced audio, have the potential to increase customer appeal, but all have technology and platform implications. The fact that content consumption over mobile networks and on mobile devices is increasing also needs to be part of the discussion.

In conclusion, 4KTV and all the aforementioned technologies present potential new opportunities for the TV industry. Translating that potential into profitable business will be a balance between costs and perceived benefits to consumers.

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- [4] Foster, D. H., 2011, Color constancy, Vision Research 51 pp.674–700, available at: <http://www.sciencedirect.com/science/article/pii/S0042698910004402>; see also the well-known trade-show effect that an HDR screen placed next to a conventional screen can seem to degrade the sharpness of the conventional screen.

FURTHER READING

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GLOSSARY

AVC	advanced video coding
CRT	cathode ray tube
dL	delta L
DVB	Digital Video Broadcasting Project
EOTF	electro-optical transfer function
fps	frames per second
HDR	high dynamic range
HEVC	High Efficiency Video Coding
HFR	high frame rate
HVS	human visual system
ITU-R	International Telecommunication Union Radiocommunication Sector
L	absolute luminous intensity
MPEG	Moving Picture Experts Group
NTSC	National Television System Committee
OETF	Opto-Electrical Transfer Function
PAL	Phase Alternating Line
SD	standard definition
SDR	standard dynamic range
SMPTE	Society of Motion Picture & Television Engineers
UHDTV	ultra high definition television
WCG	wide color gamut