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2160p & UHD-TV Update

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Details conserving the Ultimate UHD-TV system keep immerging. In addition I'm also receiving requests for more comprehensive explanations of what we've talked about in the past so we have another installment of updates. What you'll read here reflects input from several conferences we've attended since the last edition. Not to fear by the time we finish writing this there are several more conferences coming up.

Some of the ideas here are just catching on in the industry. The idea that the color space specified in ITU-R BT.2020 probably shouldn't be implemented in displays is one of them. Not that we didn't take that position some time ago, but now more people are catching on and we're finding ways of making it easier to explain our position.

In review, this time with more details, here we go again, and certainly not for the last time.

What is UHDTV?

The term Ultra-high definition (UHD) is called out by the International Telecommunication Union (ITU) in the title of document ITU-R BT.2020 published in August 2012. The document's scope says *"Ultra-high definition television (UHDTV) will provide viewers with an enhanced visual experience by having a wide field of view both horizontally and vertically with appropriate screen sizes relevant to usage at home and in public places. UHDTV applications require system parameters that go beyond the level of HDTV."*

The body of the ITU 2020 document specifies UHDTV image system parameters for production and international program exchange. The implication of the document is the enhancements in it, over our current HDTV system, are higher resolution(s) and a larger color space. The increase in resolution allows you to be closer to the set, therefore providing a wider field of view. The picture size itself is not discussed beyond calling for an appropriate screen size.

The Consumer Electronics Association (CEA) followed the ITU in October 2012 by announcing the official term *Ultra-High-Definition* or *Ultra HD* would be used to describe any display with at least an aspect ratio of 16 by 9 (1.78:1) or wider, a resolution of at least 3,840 by 2,160 square pixels, and at least one digital input capable of conveying such a source signal.

The UHD video format as a consumer deliverable is credited to the Japanese Public Broadcasting Network NHK which worked closely with the ITU in coming up with the ITU-R BT.2020 specification document. You may recall from prior articles there are two sets of higher resolution listed in the document, one which four times the resolution

of 1080p, which I'm calling 2160p, and one 16 times 1080p, which I'm calling 4320p. In NHK's own terminology they've been calling the 2160p format UHD and the 4320p format 'Super Hi-Vision'.

There are multiple terms used to describe this new approach to television. There are similar distinctions such as *Ultra High Definition, UHD, UHD TV, UHDTV* and *Ultra HDTV*. Some TV set manufacturers initially called it *Quad Full HD*. There are erroneous names that do not accurately describe the format such as *4K* and *8K*. It was these last two names that prompted the CEA to call it *Ultra-High-Definition* or *Ultra HD*.

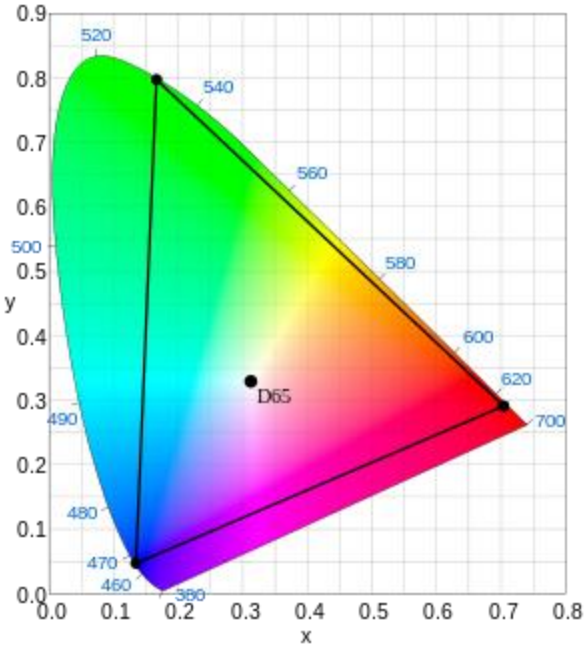
You'll often see me referring to the steps in increased resolution as 2160p and 4320p, numbers that should have been used to describe each if we had followed the naming convention of our other video systems; namely 480, 576, 720p, and 1080.

As much as we have not settled on the potential of 2160p to bring us new and wonderful things there are already hearing discussions of moving directly to 4320p, skipping 2160p beyond what is already on the market in product. In April 2014 the NHK will demonstrate the transmission of a 4320p signal over a standard 6 MHz broadcast TV channel during the National Association of Broadcaster convention in Las Vegas. (Once again, because of NAB, Las Vegas TV stations get to lead the way.) Did I forget to mention how fast this is moving and why so many updates are necessary?

Multiple things have become clear as a result of the consumer electronics industry's initial attempts to implement UHD displays.

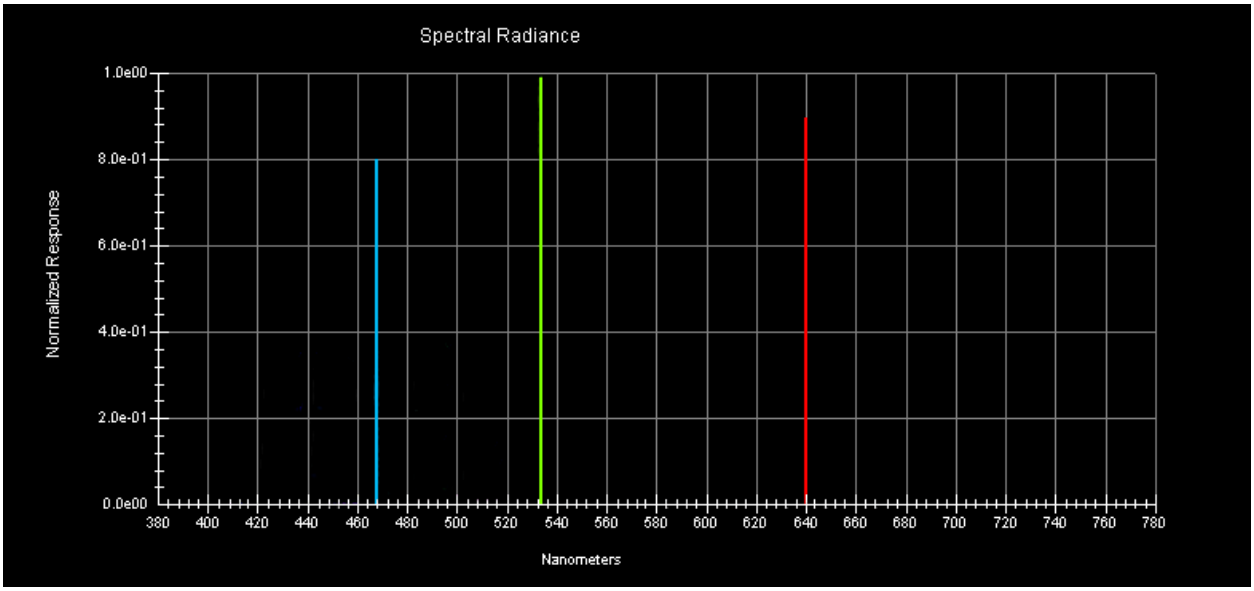
A. The color space specified in the ITU 2020 document isn't going to be real any time soon, if ever. There are strong arguments being put forth by organizations such as Munsell that even if it were implemented it wouldn't work from a human factors point of view.

This is a big one when it comes to a new understanding of UHD. The color space specified in ITU 2020 is/was the largest color space specified for a consumer display. It was said to have so much potential for a highly recognized feature of the new format.

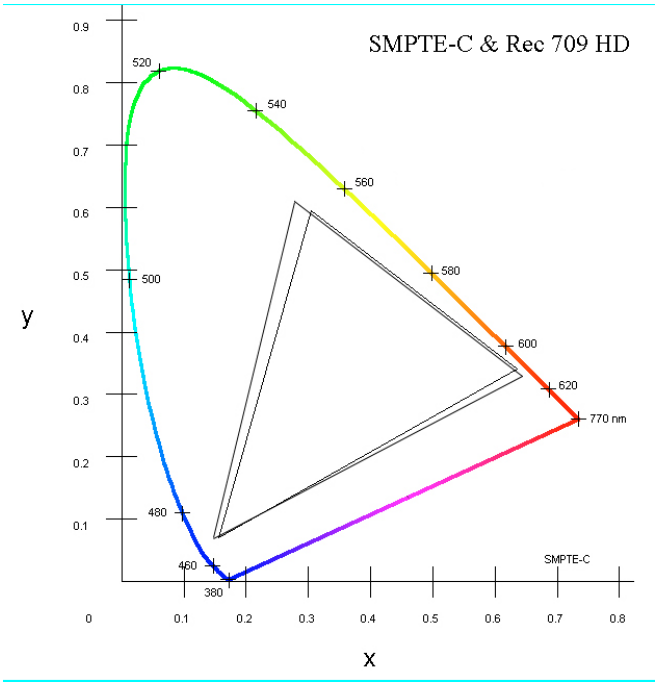


Color space spelled out in ITU-R BT.2020

The colors specified in ITU 2020 are at the outside edge of the CIE diagram. Any point along the outside edge of the CIE diagram is a single wavelength. (It would be a single frequency if we were working in the frequency domain.) It effectively means in order to get out there the bandwidth of each color is going to be extremely narrow.

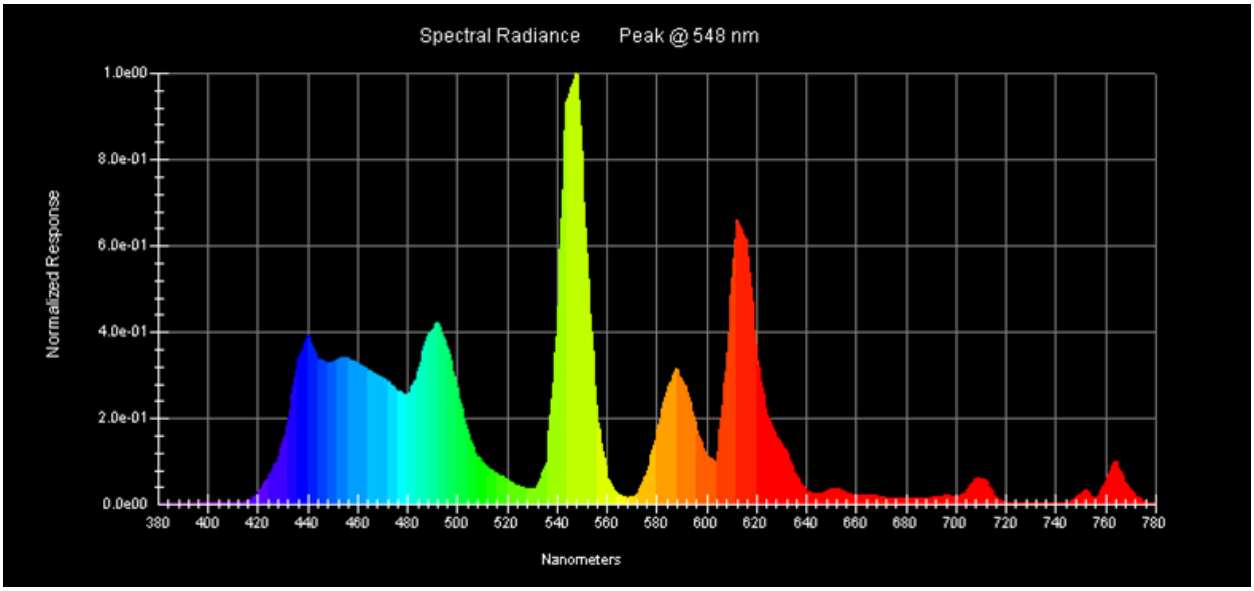


Emulation of what the 2020 visible spectrum might look like for white

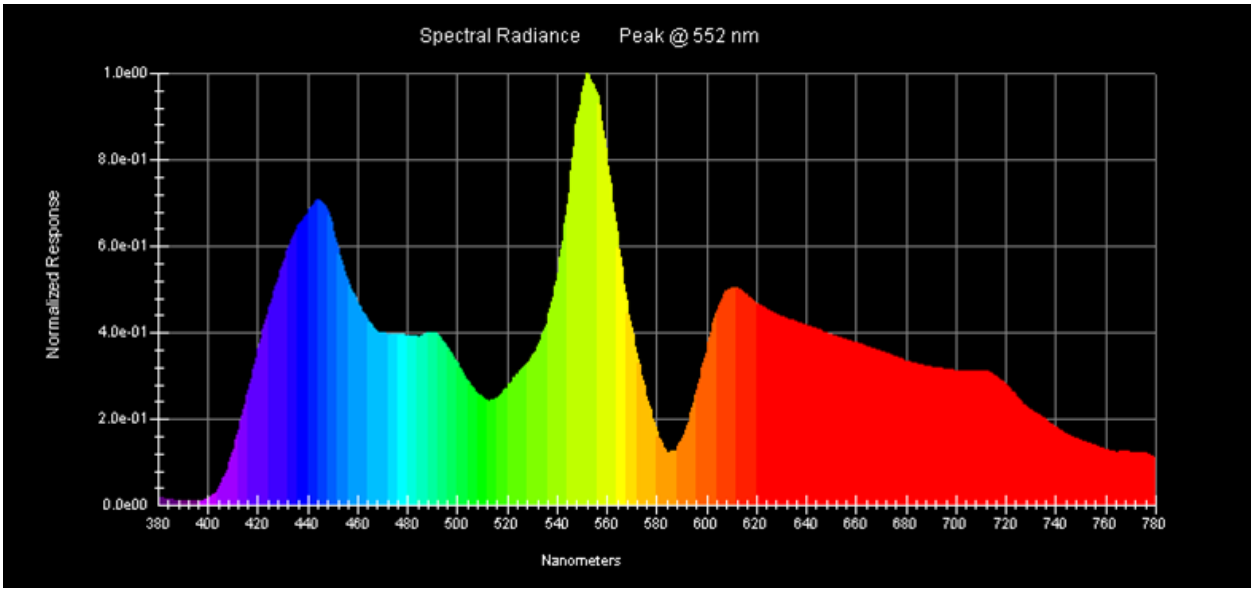


Color options such as SMPTE-C & Rec. 709 are inside the diagram

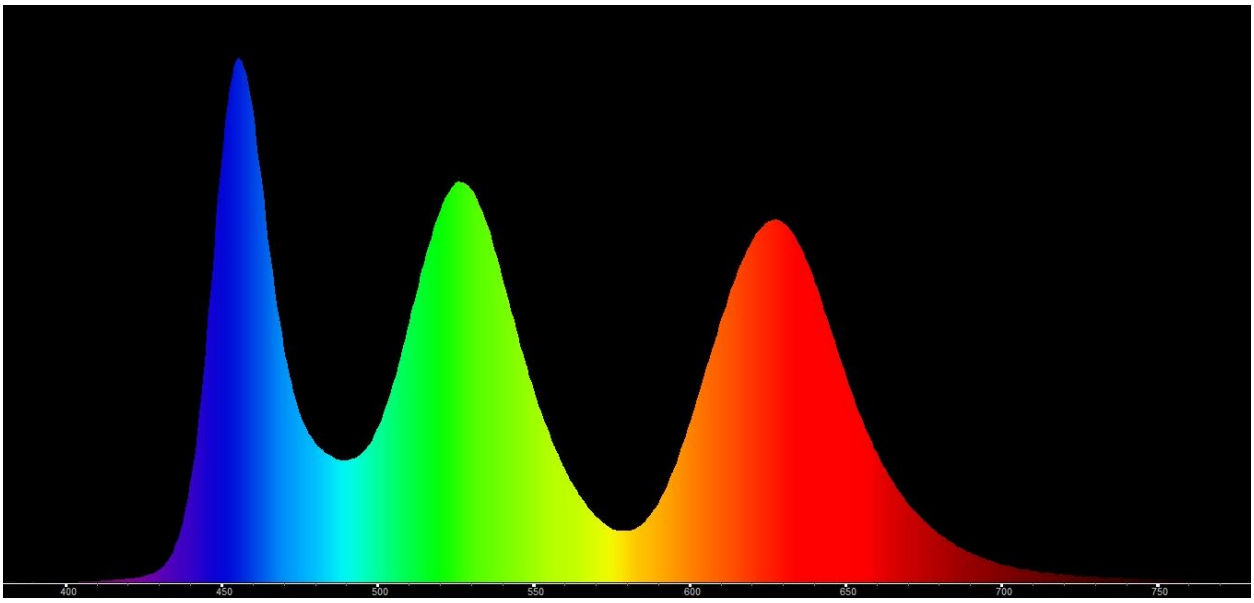
In our current consumer display systems colors are well inside the CIE diagram and have significant bandwidth, but they aren't all the same.



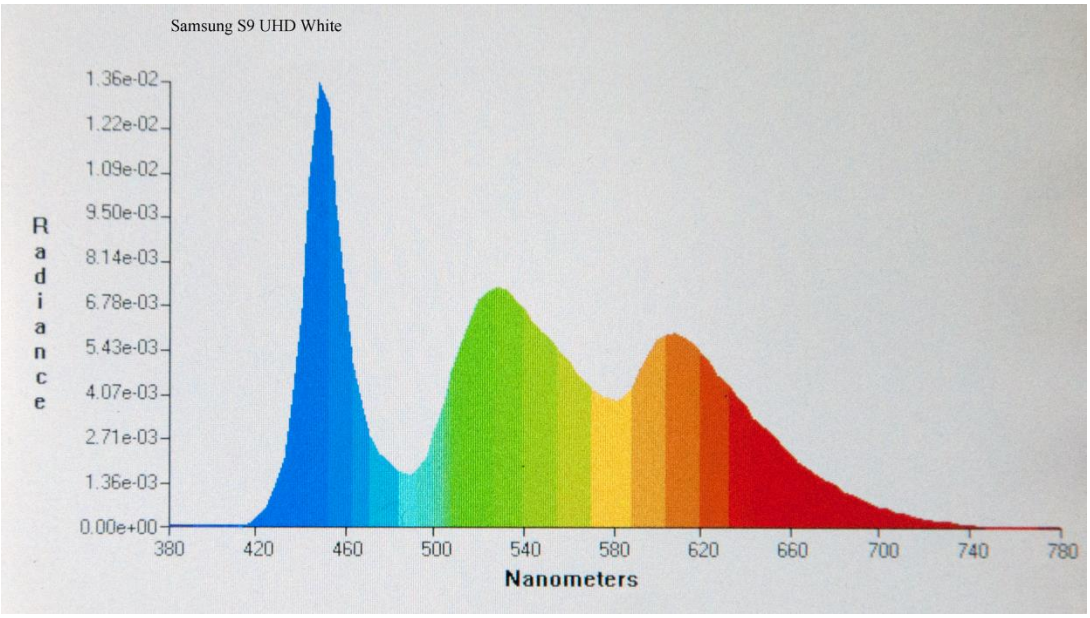
Spectrum of white from a CRT display



Spectrum of colors making up white in a UHP lamp driven DLP projector



Spectrum of colors making up white in an OLED display



Spectrum of colors making up white in a LED backlit LCD display of 709 colors

The wider, more inclusive spectrum of DLP projector produced a better color fidelity than CRT even though there was an exact match in the x and y coordinates of the colors. I remember when I was first started showing off my projector in the post production community many recognized it had to have broader bandwidth colors than the CRT. You'll notice the bandwidth of colors in newer display technologies has gotten wider than the red and green in the CRT.

You may have heard that individuals don't always see color the same way. Certainly the extreme is found in color blind people but our color perception also changes with age. If we cover a color with a fairly wide bandwidth we'll each sort of agree on what we are seeing. If we cover a color with a narrow bandwidth we'll not have nearly as much agreement on what color we are seeing. The narrow bandwidth for each displayed color will aggravate the differences in the way we each see color. If we use the narrow bandwidth primary colors associated with 2020 it is highly likely people in charge of color quality won't agree on what they are seeing, let alone the consumer.

The problem is not getting to the color space specified in 2020, we can do that with laser light and maybe even with Quantum Dots, but there will be many more disagreements about what we are seeing than if the primary colors are a bit further inside the CIE diagram.

One other thing, did you notice the area under each of the three curves? If the peak amplitudes were the same, which display do you think would be brighter?

There are technical papers that go into detail. One of them is **Mean Observer Metamerism and the Selection of Display Primaries** by ***Mark D. Fairchild and David R. Wyble, Rochester Institute of Technology, Munsell Color Science Laboratory, Rochester, NY/USA***

I'm kind of hoping you can look at the differences in the spectra graphs and get the idea.

B. An increase in resolution over 1080p HD isn't enough by itself to sell the idea of UHD TV to consumers.

It has been suggested by some in the industry since four times 1080p resolution is not making a serious impact on audiences we need to skip that step and jump directly to 4320p. Among the problems with this approach is one of diminishing returns from the extra resolution. It's takes at least a twelve foot wide screen before you'll be able to see most of what 2160p can deliver and oh by the way it will look far better on a fifty foot wide screen.

C. The first generation of TV sets consists primarily of an increase in resolution to 2160p, otherwise keeping most of the ITU-R BT.709 specifications intact, including 1080p limitations on frame rate.

This is what a large number of people associated with bringing UHD to consumers are seeing, resolution alone won't sell the format. As the first generation of UHD sets are coming out resolution is the only addition.

D. The frame rate capability of UHD is currently limited by the methods of compression; H.264 or H.265, being advocated for the format and the connector of 'choice' into the set; HDMI. At least one manufacturer is providing a DisplayPort connection on their set and others are hinting at compressed signals over a USB 3 port.

E. Picture size is important in delivering all of the capability of the two resolutions set out in the document, 2160p and 4320p. Recommendations for picture size need to be a consideration in the choice of UHD TV displays for either of these resolutions.

Doing some quick calculations, based on it taking at least a 6 foot wide screen to see most of what is in a 1080p signals, 2160p is four times the resolution so the area of the screen would have to be four times that of the 1080p screen. At a 1.78 aspect ratio four times the screen area comes out to a 12 foot wide screen. The 4320 format is sixteen times the resolution of 1080. It would take a 24 foot wide screen to begin to do it justice.

When I was asked about the practicality of a significant visual effect of 4320 I suggested the cost of getting the return wouldn't be in the display itself but in building a house big enough to show it. Yes there is no question in smaller images sizes, those that would fit in average American homes, you would be able to see a difference between 2160 and 4320, but little of what 4320 can deliver would be seen.

While I agree 4320 could be better than 2160, little of what 4320 has to offer would be seen in a screen size most consumers would want to purchase.

Moving from HD to UHD

You've read this part before. It is my opinion UHD TV, as it is currently being implemented, will have a shorter life in the consumer market than 3D to come before it if we don't make UHD much more than is suggested in the ITU 2020 document. Resolution alone will not sell the system, especially in screen sizes less than 50 inches in diagonal. It is highly unlikely the ITU 2020 proposed change in primary colors will ever be practical in displays because of the narrow spectral bandwidth of each of the three colors.

That said the ITU 2020 document has opening the door to the possibility of future implementations of television. The document hints of more to come and the potential value to the average consumer if significant changes are made in the new system over what we have today.

In creating a new system I believe it is important to look at where we are today with HD. We need to look at its promise in specifications versus its implementation. I'm of course suggesting the potential of our current HD system has yet to be fully implemented in the homes of consumers. We might start with the number of HD sets connected to HD sources. I recall the last set of numbers I read it was well below 50%. If you are connected to an HD source how much of it is real 1080p? We could go further and ask how many of you are watching 1080p above 24 Hz in the source material? If you seeing frame rates higher than 24 it is most likely 720p or 1080i being up converted.

What do we have now and how far could it go without UHD TV? Are there lessons to be learned from the potential of HDTV versus what we've got? Let's review HDTV as a starting point.

A. The current HDTV system display parameters are based on CRT technology, a technology that is essentially no longer being manufactured. HDTV display standards could be updated to take advantage of current technology.

B. In order to produce an accurate picture according to specifications for HDTV; ITU documents 709 and 1886, existing display technologies; DLP, LCD, plasma, LCOS, have to be altered from their natural capability to display a picture to something that emulates a CRT.

Unfortunately this often comes at a cost of noise and banding artifacts in the picture.

C. Capabilities in current displays, such as resolution and frame rate, often easily exceed anything imagined for the CRT or specified for HD.

It seems to be a well-known we missed out on an HD capability by not including 1080p/60 in the original ATSC system. Most every set can do 1080p/60 yet there is no specification for providing it from broadcast sources. Even support for transmitting 1080p/24 or 30, part of the original ATSC Table 3 of acceptable rates, was never supported in broadcast transmission. You may get a chance to see among the first 1080p/30 material in the Blu-ray disc format if or when the Todd-AO version of *Oklahoma* comes out. Hopefully *Around the World in 80 Days* won't be far behind.

D. In HD alone, far better picture quality could be had if we were able to take advantage of current technologies.

Wider primary colors are the first thing to come to mind. The color space we are currently using in Digital Cinema has a better color capability than our current Rec 709 television specification. Even with implementation of the larger Digital Cinema color space called P3 there is an ability to efficiently light up the display at lower colors of gray, even below the D65 point, providing better color fidelity. The D65 color of gray is decidedly blue. Pulling it back to D6000 would get it much closer to the equal energy point in the CIE color diagram.

Obviously there is a lot we could do in our existing system to make HD more desirable to consumers. Some in the industry are asking should we not just do that. Part of the answer comes in the availability of 2160p sets. It's too late to look at just HD.

Reading articles and specifications you might think UHD is a separate issue. When you look at the future of UHD and the many additional changes being proposed for it you'll recognize most of the changes could also be applied to improving HD. In the quest for the Ultimate UHD system we might also include HD, making it better as well. We'd come up with a totally new system that would replace HD.

That's the thrust of what you'll read here as a proposal for an inclusive Ultimate UHD TV system.

We need to get over or get beyond some of the things we've done in the past

I'd long argued we need to stay with HDTV parameters based on the CRT as the variations in what is better in newer technologies is not shared by all of the technologies. I had supposed if we picked any single new technology as a reference for a new system we'd still be making every other technology conform to it. Equally important I've long known no matter where we go in the future we would always be stuck supporting the TV system based on CRT technology because of existing content. I had also supposed with so many options in new display technologies it would be nearly impossible to reach an agreement on a single new standard.

So what's changed?

Multiple factors have come into play causing me to reevaluate the possibility of creating a new video system.

A. Industry wide agreement has been reached in a desire to move beyond at least some of the capabilities of the CRT. While not stated in ITU 2020, the possibility of updating our video system is implied by specifying parameters for which the CRT wouldn't have done well. Included in this would be higher frame rates and a wider color gamut.

B. Most of the newer display technologies won't reach their display quality capability without a change in the rules for creating content.

C. Ultimately content creators have to be on board to feed the system.

D. In the ongoing quest to move forward in program content production we are already far exceeding what was imagined for the CRT. We actually had to shut the CRT off in post-production to move forward to HDTV color specifications, let alone go beyond it in areas like higher progressive frame rates and in implement the Digital Cinema system.

It is time to move beyond our current HD system. Do we create a super HD system, bringing it up to speed with existing display capability and or do we go for a more comprehensive system, one with a future?

What if we created a new system that added on to the old, updating it in the process? If we were to do such a thing could we impose those changes on what is now being called UHD TV, making UHD far more than is being proposed today.

As a reminder the ITU 2020 document spells out an increase of resolution and a change in color gamut. We don't agree that the color space specified in 2020 will ever be practical in consumer displays.

If a new system, something well beyond what is being suggested in ITU 2020 were to be developed it could have added value to most existing HD sets and provide us with steps towards any future we could see.

If we accept this idea of improving HD and providing for future capability, what would the new system look like?

How do we make UHD work … and potentially replace HD?

In order to sell the concept of 'Ultra' to the consumer it should be ultra, something recognizable as better than HD. Up front … any new system needs to accommodate and or incorporate the existing HD system. This provides the potential of a seamless transition to the new system. If done right the majority of existing HD sets would be capable of displaying an improved picture quality conveyed in the new system. As an example, our current HD content could be distributed at the level of its production, 10 bit 4:2:2 as opposed to 8 bit 4:2:0.

The definition of what 'ultra' is to the consumer should include their ability to see something good; better than what is available in currently distributed content. Existing sets could do more with a better source signal. The UHD distribution path would provide a better quality source signal than is currently available. A good example of this happening for the consumer comes from the transition from analog SD to DTV. Set top converter boxes provided better pictures on conventional TV sets than the older analog delivery system.

Making the Ultimate UHD system work well will require a change in focus. The UHD plan all started with resolution, but we quickly recognized it wasn't enough. Many other parameters needed to be considered. In looking at other changes being proposed it became clear it would take some time to get to a final system. Realizing things would be phased in some people at least theorized it might be good to create a system that would deal with change.

A forward looking UHD TV system should first create a foundation on which additions will be easy to implement at a pace technology and marketing determines. Conversely we need to avoid creating a system that will be outdated as innovations in technology come along. Examples abound in the past of our being short sided with new specifications. Leaving 1080p/60 out of the original ATSC system would be one of them. The large number of incremental changes in HDMI and Blu-ray are other examples of our not planning for the future. How many times do consumers have to repurchase their A/V processor to keep up with the ability of passing larger amounts of data to the display?

If we agree UHD should be the next step forward, as opposed to updating the HD system, the first step needs to be creating a 'future proof' pipeline, the signal delivery system. We aren't going to get 'better pixels'; a term now commonly used to describe all of the potential changes to our current system, without an ability to convey these pixels to the display.

Over our resent experience in the transition to digital video we've seen many elements in the pipeline change fairly often. It has been many generations of HDMI connections, including DVI to have come before it, and in some cases a totally different connection such as DisplayPort or Thunderbolt.

There are multiple issues to be considering in defining the pipeline, as it is today and what it should be in the near future.

A. The 'pipeline' should be defined as all of the elements from the point of departure of the content for distribution to a decoded full bandwidth signal inside the display.

B. It would include the compression scheme and any metadata needed at the decode end to describe how to recover the original signal.

C. Do we build a pipeline that gets bigger by increments, sometimes so small they are out of date before being released, let alone implemented? The latest example is HDMI 2.0. Its ability to convey a 2160p 60 Hz signal is far less than its ability to convey a 24 or 30 Hz signal. Really, we should take a hit in picture quality because we want to present more frames per second?

D. The codec used to compress the signal for delivery to the consumer has never been up to the capability of the source content. Initially it was behind our program production capability by design. Distributors never really wanted to provide the master quality. Most people today at least understand parts of the newly proposed UHD system are or can be far better than their masters and they need to create and release far better content to feed the system.

E. As design of the pipeline currently appears to be going, it is hardly keeping up with current signal source parameters and or display capability. Small steps in increasing the capability of the pipeline will be costly to consumers and manufacturers.

F. Is it possible we could take a giant leap in the size of the pipeline? Initially it would cost more to implement. We need to run an analysis, but I suspect what we'd find is it would be worth it in the stability of a single system being good for many more years.

Let's look at the speed of the components to run at 120 or 240 Hz at 4:4:4 rates up to 2160p. Certainly 10 bit versions of the technology exist today in sets being called UHD. The technology is there and is being used. Just maybe the cost of the technology would come down if it were being used in many other places. Distribution systems with a larger capability are being used in program production. While costly when compared to consumer products, a wider use of these better systems might bring the cost down for both parties.

Are there options beyond HDMI? The answer is of course yes. For some time now I've been pushing DisplayPort as an alternative to HDMI. Even there it is recognized we need a bigger pipeline than can be supported by version 1.2 of DisplayPort. While version 1.3 of DisplayPort is on its way, is it the right solution for the consumer industry? Politics aside, it is possible the work being done for DisplayPort will show a way to a far better interface. Faster silicon will be developed and used. Will this or any of the other factors in the future of UHD cause the HDMI organization to rethink incremental versus a giant leap?

It's been suggested by several HDMI connector makers the limitations in speed of data imposed on HDMI 2.0 could be the HDMI connector itself. In the past I'd been pinning it on short sidedness in planning 2.0 specifications, typical of their small incremental changes in the past. If we are in fact near the limitation of the HDMI connector the HDMI organization may need a more aggressive form of compression than the 4:2:0 added to HDMI 2.0 to keep it in the running as an A/V connection.

At the same time others are recognizing we will be doing 2160p/60, 10 bit or 12 bit at 4:2:2 or 4:4:4 using a decoder built into the set. At the moment the connection(s) of choice would be USB-2 or 3 and or wired LAN or WiFi. If a

display is to keep pace with the evolution of phases in the implementation of UHD, the delivery form to the set will most likely need to be compressed. The set will have to do the decoding.

Following this logic, if HDMI is to remain a part of connectivity, the new version of HDMI, beyond 2.0, may need to include carrying a highly compressed signal.

We have a way around the bottleneck of HDMI, which could be incorporate by the HDMI to keep it alive. We know that decoding inside the set gives us lots of options in delivering higher quality content.

One thing about the category of interface connections on devices I believe is clear; small incremental changes will cost consumers in new capability, let alone holding back sales, waiting for the next generation. Do we specify a new connector or pass a compressed signal over the existing connector. Is it possible we might do both?

Changes in the codec that are needed are covered further on into this discussion. What we should say here is we see similar small increments in the capability of encode and decode; often not enough to keep up with the content being created, let alone work in a pipeline that would be future proof for at least ten to 20 years. Industry discussions about what H.265 has to offer are certainly about small increments of improvement relative to what we are doing in content creation.

Ideally, we should be able to build a pipeline today big enough to take on 4320p. Specifications for the pipeline would have to include the codec, metadata and the connection. If not part of the UHD specification itself, the pipeline should come before UHD. No matter what it should be the first consideration in designing the Ultimate UHD TV system.

There are proposals for a 32 bit floating point codec that would have expansion capability to include 4320p, a 4:4:4 color sampling rate, higher dynamic range, and higher frame rates. It is a layered system, possibly containing 720p, 1080p and 2160p all in one data stream. Such a system exists and it works.

Once we've built the pipeline of the future we should then consider what we put in it.

Any new system should start with backwards compatibility. UHD TV has to include 720p and 1080p and current ITU 709 color and YUV matrix equations. It could deliver what are being called 'better pixels' in that more picture information would be contained in each pixel. Pixels can get better in steps or stages as we'll see in the following descriptions.

The Ultimate Ultra High Definition System

A. The new system has to include an ability to convey the current archive of HD content in a way it might look better to the consumer than they are seeing now.

Existing *Full HD* content is usually produced at a higher quality level (10 bit 4:2:2) than is being conveyed to the consumer in MPEG-2 or versions of MPEG-4 (8 bit 4:2:0). It could be conveyed at a higher quality in a UHD system and still be compatible with any existing TV set with an HDMI connection.

The first enhancement to HD and or UHD would be the capability of delivering 10 bit 4:2:2 to the consumer. What would be delivered to the consumer is part of the ongoing discussion in the studio community. There is a recognition the studios could sell their content yet again if it could be delivered at a far better quality.

As much as we've been creating HD content at 10 bit 4:2:2 for maybe 16 years we still are only able to deliver 8 bit 4:2:0. One proposal for an MPEG system suggests there might be a 10 bit base layer and an augmentation layer that could take the base layer up to 12 bits. This is actually fine for now but does not get us to 16 bits. It's odd in that

the professional community is confident with a larger color space and higher dynamic range 12 bits going to be critical. So how can 10 bits even be a consideration by anyone specifying a codec?

In most all of the technical conferences I've attended the feeling in the professional community is 12 bits is the starting point of a delivery system and 4:2:0 should not be allowed. Anything less than a 16 bit capability is asking for expensive increments getting to where we know we should land for the UHD pipeline.

B. The new UHD system has to include 720p as well as 1080p, with all with the better pixel options being available at these rates. The UHD system itself would include 2160p and 4320p, but the new system could be brought out ahead of either of the newer resolutions being generally available.

Every consumer currently owning a 720p or 1080p set with an HDMI input connection should be able to benefit from the new Ultra HD system. The pipeline delivery system would interface with existing sets through a set top box. The Ultra-capable source device or set top box would be able to determine what the display can do and adjust the signal to match the capability of the display. The EDID of the display should provide enough information to identify the transform needed to get from the condition of the source signal to the capability of the display. We certainly saw this work in DTV set top boxes in the transition from SD to HD. Picture quality improved for those with older SD, CRT based TV sets.

C. We fully anticipate the new system will have mandatory minimum requirements and options. We'd like to see the ability to transfer a 16 bit 4:4:4: signal included in the pipeline even if displays won't be able to take advantage of it at the moment.

A large pipeline now will provide a path to the future. Organizations such as the EBU are calling for UHD to be phased in. At least some targets have to be established now, with provisions to deliver less than those targets as the new system is phased in. The pipeline for UHD compatible equipment should be able to deal with 16 bit 4:4:4 on day one even if the majority of new UHD content is delivered in 10 bit 4:2:2 at the initial rollout of UHD.

I suppose one could ask do we phase in the size of the pipeline. We would again offer the though even though a good pipeline would initially be expensive, the need for the speed required for the interface connection is already in other parts of the display. At the moment the majority of proposals for a delivery system will be a chokehold on our ability to move forward with better pixels.

In support of building a far better pipeline we've been telling consumer buying a UHD TV set to look for a DisplayPort connection. If it isn't there don't buy the set. Even that turns out not to be the best advice now that we know we can build the decoder in the set and use USB or LAN to get the signal into the set.

The processing power needed for this pipeline we are proposing can already be found in products such as the Sony PS4 so there should be little doubt we can move to the ultimate pipeline path in the near future, not wasting time with incremental implementations.

D. A goal should be established for the new UHD system to take over for HD in a short fixed period of time, just as HD took over for SD.

It's interesting at the November EBU conference a period of 30 years was suggested for the transition from HD to UHD. The problem with increments is they can add to the implementation time as manufactures try to hang on to each bit long enough to break even on it. It well could take 30 years if we go about it a small fraction at a time. The SD to HD transition took more than 10 years and HD has a long way to go to live up to its potential.

In theory we should be able to move much faster today. Once we've established that UHD should offer something good for existing HD we should then look at UHD for what future capabilities it might deliver. With a big pipeline

in place it might even be logical to phase in significant changes to UHD like primary colors, higher resolution, and higher dynamic range.

E. The new UHD system should have a number of defined options that can be used by the program provider to establish what is best for conveying their content. Those options should have metadata in the signal clearly defining what capabilities of the new system are required and or need to be used in the receiver. If the display doesn't have those capabilities the metadata will help adapt to what the display can do. The receiver should be able to either convert to an existing capability or set itself up to the actual parameters being requested by the metadata.

We recognize the limitations of cross conversion among the potential display options you'll find in UHD TV. As an example it is not easy to get from the color space of P3, used in Digital Cinema, to the 709 color space. There will probably be a need for conveying metadata direction on how to do the conversion.

Among the latest proposals for taking content from one color space to another is to apply a fixed conversion between the two color spaces augmented by metadata describing scene by scene correction to the fixed conversion. As an example if everything were color corrected for the P3 color space there are certain colors that might not map well to 709 color space. The majority of color would map without changes as they are inside the 709 space. Manual decisions would be made for where to put colors outside the 709 space found in the P3 space. The metadata would tell the converter what the program producer wanted done with those colors.

Later on in the discussion of color space in the UHD system we'll introduce the idea of UHD eventually accommodating a much larger color space than is being defined for ITU 2020, not as a displayed color space, but as a carrier of information. The defined color space might be well served to match XYZ or ACES, now being used in Digital Cinema program production.

Official studio organizations such as MovieLabs has already proposed we have a color carrier space in the UHD pipeline of XYZ. http://www.movielabs.com/

F. Phased implementation. We should start phase two, the one beyond where we are now, with a minimum delivery capability of 16 bits with a sampling lattice of up to 4:4:4. It of course would allow all current 8 and 10 bit rates to be a part of the system.

This is partially about the pipeline again. Much smaller increments are being proposed. Not everyone will get to delivering 16 bit 4:4:4 on day one but it would be a shame to build an infrastructure that would short change our ability to get to that future at a pace it could be delivered by content providers.

On the other side of the color sampling issue there is no way we are going to get a system passed that doesn't include a capability of conveying 4:2:0 at 8 bits. This capability would need to be there to convey existing progressive HD content. The sampling lattice of 4:2:0 and or 8 bits has nothing to offer in picture quality that isn't already available in HD content, yet we won't gain acceptance of a new system without it being backwards compatible with the existing HD system.

G. Interlaced video would not be allowed in the UHD system.

While there are discussions of including interlaced, for legacy content, new codecs for the UHD system shouldn't have to contend with an interlaced signal. Any interlaced source content should be converted to progressive before being encoded. Progressive frame rates matching current interlaced video rates would be mandatory. In other words 60i would become 60p unless there was a 2:3 count in it. It could then be delivered at 24p.

H. Mandatory frame rates in the system should reach at least 60 Hz.

All of the current rates and their 1/1.001 variations need to be included for existing materials. Going above 60 Hz should be optional at the beginning for TV sets but included in the pipeline capability. Future phases of the system would include higher frame rates. It's clear that currently available sets won't accept anything above 60 Hz. In pushing content above this rate we'd be reaching a thin market. Some ceiling should be placed on optional frame rates in the system. It might be argued 240 Hz should be that limit.

There is a strong movement to get rid of 1/1.001 for all new UHD content. As long as we have a good pipeline this can go in whatever direction on any time table.

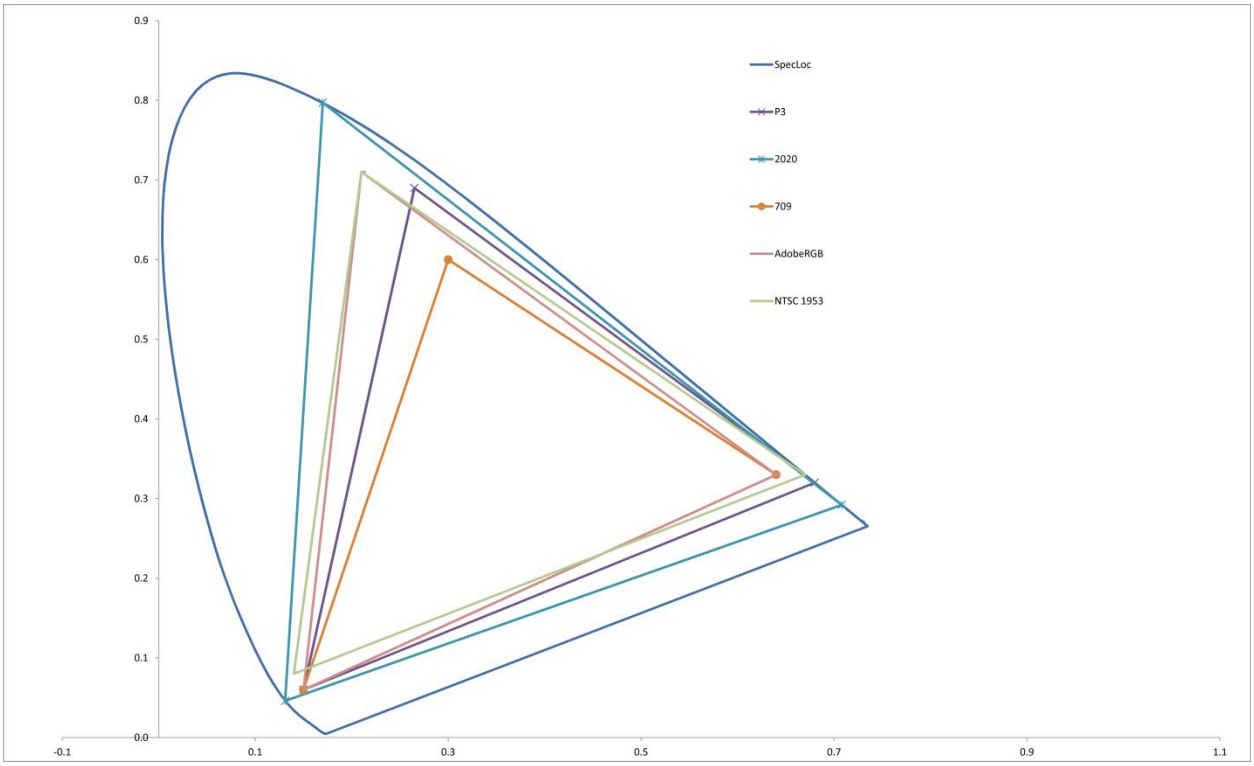
In talking about the upper limit on frame rate we've seen presentations claiming we might want to go as high as 700 Hz for 'real' motion at high brightness levels. We as human beings become more aware of flicker at higher brightness levels and or when the image occupies more of our periphery. Implementing higher frame rates, above 60 Hz, will be part of the phasing in of UHD. The question becomes what is practical in a delivery system. We might be forced to take into consideration we've long gotten away with flicker rates far below the 700 Hz number and accepted it as part of the presentation.

It is not likely 24 Hz will go away any time soon in current content production. It will take some adjustment on the part of viewers to accept the proposed 60 Hz rate for motion picture story telling even though we've been watching live action on television at 60 Hz for most of our lives.

There is also the issue of persistence of vision in human beings. That's us remembering the prior frame as the new frame comes along. We depended on persistence of vision for interlaced TV to work. You may recall the first half of the image was scanned on to a CRT before the second half came along. In reality the first half of the image was gone from the CRT when the second half came along. Our persistence of vision allowed us to see a complete image.

Persistence of vision can actually be an issue in displays that are always on, such as DLP technology. In some cases we currently need to do black frame insertion to erase the mind before the next image comes along. Depending on the technology, LCD as an example, the duty cycle required to erase our mind at high rightness levels may need to be in the order of ¼ on time; black 75% of the time. In many cases we may be stuck with flicker at any refresh rate. If the off time isn't long enough there will appear to be blur in the motion.

As we go higher in brightness, as we would with high dynamic range images, there will be a greater need to erase the mind of one image before the next comes along. While this will be a display issue it will put an upper limitation of frame rate and there will be flicker associated with blur free high brightness images. From what we know now it may be a long time before we consider anything above 240 Hz.



I. There should be multiple primary color options — with a mandatory capability of the 709 color space plus at least one other larger color space.

It is clear every set has to be capable of showing content in the 709 color space. Among the things not clear at the moment is any need or reason or viability of going out as far as is specified in ITU 2020. There are a number of us who believe the 2020 color space is neither practical to implement or even good for viewers. There are issues with how people will judge the color quality of a narrow spectral bandwidth, let alone where the light output energy is going to come from. There is speculation conveying the 2020 color space would require a 16 bit word per color/ per pixel. This is not currently practical for displays.

We've let you know we don't believe the color space proposed in ITU 2020 is practical. No matter what, I believe there is confusion between the 2020 color space and what is practical for a consumer display.

It is well established a 12-bit word is required to go out to the P3 color space used in Digital Cinema. We should at least consider the P3 color space to be an option in UHD. Some would argue we might even go out to the Adobe RGB color space used in electronic photography. Going out beyond either of these color spaces may not offer a useful return in the consumer market on so many levels.

Many of the current UHD displays on the market are attempting a larger color space. They are often called out in terms of the 1953 NTSC color space. Ironically 709 and P3 have a better blue and P3 has a better red. If we were to include P3 red and blue in the discussion the difference would be in the green between the original NTSC and P3. There may be room for both in the UHD system, but certainly not before phase two or three of the implementation of the system.

Once again, we could phase in capabilities as technology improves. We'd start with a pipeline big enough to deliver the content at any time.

In reality in ITU 2020 specifying such as large color space for productions purposes might not have gone far enough. We should probably fix the color space in the document to say the color space specifications describe

producing content for UHD. As in Digital Cinema it should include using XYZ or the ACES color space, both much larger than the 2020 triangle. What was alluded to but not spelled out in some of the UHD conferences I've attended is we should produce content in an all-inclusive color space, as is now being done in Digital Cinema. Again taking a cue from current Digital Cinema, there would be an output display transform (ODT) that would take the signal to the color space of the display. We have a working example of this system.

Again, in planning such a direction the size of the pipeline is critical, … and I'll stop reminding us of that when the pipeline is built and in place.

J. The bit depth dynamic range would include a capability to go below black. White, when conveyed in a 10-bit or larger sample would be at the top of the dynamic range.

A below black capability is required because of issues with luminance uniformity in displays. The ability to go below black is also useful in setting black level on a display. We don't necessarily need to go as far below black as we are going in the current HD video system. Something in the order of 2 percent below black should be good enough.

The space above white in our current system is often wasted for lack of understanding on the part of set manufacturers. Their lack of understanding often gets translated into whites being clipped in program production at level 235 in an 8 bit word in an effort to make sure the signal doesn't get clipped by the display. The space above white is wasted.

There are a number of reasons to not waste this space above white in a 10-bit or larger word. High dynamic range is one of them.

K. High Dynamic Range (HDR) – see a separate section for details

I'm pulling this discussion out into a separate category, allowing space to cover a number of concerns. For the purposes of this point, HDR is said to be one of the things that will sell UHD. While I understand the idea I'm not confident we've given it enough thought.

One might suggest I'm proposing a delay in its implementation. In fact I am. My concerns center around how do we get to such bright displays and still stay within reasonable power consumption. I would also like to revisit experiments where audience members were said to like levels as high as 20,000 nits. I certainly know I'd need sunglasses at those levels and don't understand why such levels wouldn't do the same to others.

L. A new codec would have to be developed that would have a mandatory 16-bit 4:4:4 capability.

One of the papers presented at the SMPTE Fall conference suggested would should go all out and aim at a 32-bit floating point codec that already exists and has been in limited use for at least six months. Another suggested a 12-bit 4:4:4 Pro version of H.265 was no more than a year away. As much as 4:2:0 version of H.265 is currently being favored for the pipeline a new version of it could come along in a year.

I don't see any system stability in a proposal that doesn't include at least 4:4:4 at 16 bits. We need to go to something that offers us a long term future.

M. Options in color of gray should be included in the system.

We've long known D65 is biased towards the blue. Better color fidelity could be had with a color of gray a bit below D65, say 6000 K, something easily reached with control over backlighting. We should also include a 5500 K color option for black and white content and make it an official part of the UHD system.

N. A change in Gamma is on the table.

Certainly the current specification of 2.4 isn't the best choice for the majority of display technologies. Something lower would be better for current display technology. More important the fixed gamma curve isn't ideal for HDR. We might even explore a variable gamma. A variable gamma may be necessary to take full advantage of technologies such as OLED.

O. System options and Metadata

Shortly into the implementation of UHD, metadata would be calling out all sorts of options in the display. Included would be dynamic range in both bit depth and light output, higher frame rates, a limited numbers of options for primary colors, color of gray, changes in gamma, where black level is in the source signal, and of course pixel count. All of these metadata options would suggest better sets would have all of these display options.

I'm in favor of a lot of options in this system if for no other reason that it forcing the display manufacturer to allow the source signal to dictate what the display is doing. This would be a producers dream, the source signal setting up the display for viewing. Yes there would be options for the consumer to bypass this capability, but it would go a long way towards a producer, director, content provider, having control over the way their content is viewed. We can even see them figuring out what parameters give them the best control of the set and focusing on that capability in creating their content.

P. Image Size

In my opinion, based on observation of 1080p images it takes at least a six foot wide screen, driven by a good DLP projector, before you can begin to see what's in the picture. Yes smaller sets will look 'good' but you'll start noticing more in the image when the display is at least six feet wide. The resolution of 2160p is four time that of 1080p so an image area of a least four times that is required. It comes out to be a little over twelve feet wide.

We need to recognize this in program production as well as what we suggest to consumers for their home viewing. It is one more reason UHD should include our current progressive HD resolutions of 720p and 1080p. Otherwise a large portion of the population will be left out of it.

Q. Viewing Distance

There are so many aspects of viewing distance to discuss. How close to the set do you want to sit? How close do you have to sit in order to begin to see the value of the higher resolution? How many people can fit in this closer space?

Seeing the capability of 2160p to convey information over 1080p will require the viewer to sit closer to a given size screen in 2160p than in 1080p. This was certainly recognized in the ITU-R BT.1769 specification.

Appendix 2

Viewing angles for the hierarchy of LSDI image formats

TABLE 2

Horizontal viewing angle for the hierarchy of LSDI image formats

LSDI system	1 920 × 1 080	3 840 × 2 160	7 680 × 4 320
Viewing distance (relative to picture height)	3	1.5	0.75
Viewing angle (degrees)	31	58	96

These values are calculated, assuming the distance at which scanning lines just cannot be perceived by people with visual acuity of 1.0.

I believe these numbers are misleading for a good display. If the majority of each pixel is lit, no visible boarders around the pixel and the MTF of the display is good at single pixel transitions, you will want to sit closer. The viewing distance for me watching my 1080p display is 2.5 picture heights, not the 3 specified in the document. I know from experience with the LCD 2160p display you lose much of the effect of 2160p at anything beyond the 1.5 specification. It is a maximum distance, yet I'm not yet comfortable being closer to the set. The viewing angle is too wide and I tend to lose track of what is happening at the outside of the image.

The viewing angle on the 85 inch LCD display is such that only one person can see all that it has to offer. Sit to the left or right, above or below or further back and you lose the quality.

It reminds me that to get much out of a higher resolution some significant viewing restrictions are going to be imposed. Much large images are the solution, if you can find room for them.

Note the close viewing distance

In a fixed room size where the viewer would be sitting a fixed distance away from the set the viewer will be more engaged by a larger set than a smaller set.

High Dynamic Range (HDR) in greater detail

We can approach HDR from several points of view.

A. We often capture far more dynamic range in the picture taking process than can be displayed on a conventional 8 bit consumer display. Would it be of interest to increase the dynamic range of the display to take advantage of what is being captured?

Here we see there is detail in the bright part of the picture

In the current system a lot of the real dynamic range in images, which are often captured at 14 or 16 bits, either gets clipped at the top end or buried at the bottom end. If the picture to be presented on an 8 bit display the higher bit rate source images is adjusted so the average parts of the image look correct. Specular highlights may be blown out and or detail lost in the black. If the specular highlights are preserved the rest of the image may look too dark.

As we open up the middle of a limited dynamic range we lose the top part of the picture

We can feed an image of a higher bit depth into a display that can handle it and get a smoother image, but the image won't take on the characteristics and or feel of being bright without increasing the light output of the display.

As we open it up further in a limited dynamic range we lose the top all together

B. We can make an image appear to have more dynamic range just by increasing the light output of the set.

This is actually part of what the 'dynamic' mode in most TV sets do. It jacks up the contrast to make the set much brighter. If you look at the absolute image quality it gets far worse in the dynamic mode versus the best picture quality mode. Some of the picture degradations come from other changes beyond significantly increasing the light output. They would include changing the color of gray, turning sharpness up and possibly turning the color level up. Other degradations come from simply over driving the set. A clipped white may appear to be a super white.

This isn't the goal of an ultra HD system.

This image will look more ‘real’ on a display with a higher light output

C. Getting a good picture in a true high dynamic range requires more bits in each pixel and an ability to display them.

If an 8 bit image is displayed in a limited dynamic range you probably won’t see the steps from one level to the next. Spread that image over a larger dynamic range and the steps will become more visible. If you increase the number of steps from black to white, covering this large light output capacity the steps will be less visible.

D. How bright do we need to make the display for HDR?

Absolute numbers for light output depend on the environment of the display. In a bright room the display can appear to be dim. In a dark room that same display light output may appear to be bright. If a comparison between ‘normal’ light out and HDR light out; in the process of trying to establish how bright HDR needs to be, you’ll find something on the order of 3 times the normal light output will give one the impression of HDR. The problem with this is if you go back to the normal mode the image will appear to be dim.

One could argue the light level of the HDR mode has to be so bright as to never be confused with the normal mode of the set. On the other side of that, depending on the environment of the display it is easy to reach a point where the image is too bright.

Of course once consumers get used to being able to have a brighter picture and still have good image quality there will be demand of the set to make all program content bright. I fully expect HDR to raise the light output of all of our viewing. The only way we’ll recognize real HDR may be in the lack of contouring in the image.

Resent Observations

My industry focus has been on UHD-TV for more than a year. In that time I've been attending conferences, industry engineering meetings and exhibitions, working with display manufacturers, producing test and demonstration content in 2160p and looking into what others are doing in program production. There are so many issues to discuss.

It's fairly obvious so called UHD displays arrived in retail stores prior to content being available. What's less obvious is they arrived prior to content providers knowing what UHD really is, let alone what they would like to see in it or what roll they want to play in providing content. This has resulted in display manufacturers scrambling to find content to support their new sets. Looking back at other transitions, high definition as an example, there was a long gestation period, marked at the beginning by a mandated from congress for the next progressive step forward from standard definition TV. (Unfortunately someone allowed interlaced video to be included and didn't include 1080p/60.) Engineering for the HD system took years, all while the studios were well aware and participating in its creation. By contrast UHD seems to have appeared on the market before anyone knew it was coming or what it was. I would argue it will be a while before we know what UHD-TV is. We're running as fast as we can in the content world to make something of what is already here.

Hollywood is trying to catch up, and maybe get ahead of what comes next by forming MovieLabs. http://www.movielabs.com/ They seem to be focused on what UHD should be as opposed to what is showing up in retail stores now.

In several of the engineering meetings we've talked about a minimum of three phases of UHD being implemented. Phase one is already here, being dictated by the sets and interface connections currently on the market. In phase one we are essentially limited by HDMI 1.4, in spite of HDMI 2.0 becoming available. It will be into next year before you'll have choices in everything you need in an A/V system using HDMI 2.0. While ways are being discussed to make HDMI 2.0 a bit more than originally promoted, it may still not be enough for phase two or three of UHD.

Interestingly enough we are already seeing proposals to get around HDMI, some options that could have legs in the consumer industry and could possibly be integrated into the HDMI itself. What this would do is save the connector, but change everything on either side of it.

I suspect everyone recognizes the format isn't anything without content. So where do you suspect is the first source of original 2160p is coming from? Most of you know it will be the internet. Look for *Game of Cards* on Netflix among other sources. Once you have it, how will the compressed signal be decoded? How about by the media players inside your smart TV? What's the delivery connection for this 2160p content? We know it will be wired LAN or WiFi from Netflix, maybe directly into your set or via USB from an external server.

Here it comes, the forest for the trees. Did we just get around the HDMI connection? Yes we did.

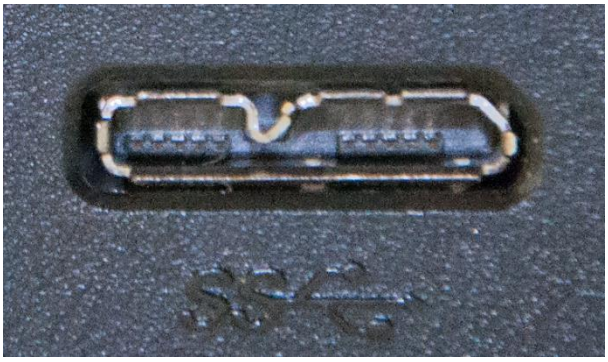
If 2160p content is HEVC encoded what device is going to be out there to decode it so the viewer can watch it? Your smart TV needs to be the answer. Ask about it before you buy.

How big is that market? The market is currently small, as in even if decoding weren't an issue, displaying the signal at 2160p is. The only people who might be concerned about any of this are those owning 2160p sets. Here's the secret. A smart TV has or should have an HEVC - High Efficiency Video Codec - H.265 decode capability of some sort built into the set.

I didn't even see that one coming, although I've read about some sets including an HEVC decoder. Here all of this time I was thinking of needing a Display Port connection to get that kind of information into the set. Here's where it gets interesting. I don't need the capability of either HDMI or DisplayPort if the set can decode the signal. A USB connection could be good enough if the set would do the decoding.

It's been suggested the limitation of HDMI 2.0 in speed of data crossing its connections may be the HDMI connector, not some short sidedness in planning 2.0 specifications as I originally thought. If HDMI is to move forward in the world of ever greater pixel quality it may need a more aggressive form of compression than 4:2:0 to keep in the running as an A/V connection. At the same time others are recognizing we will be doing 2160p/60, 10 bit or 12 bit at 4:2:2 or 4:4:4 using a decoder built into the set. At the moment the connection(s) of choice would be

USB-2 or 3 and or wired LAN or WiFi. If a display is to keep pace with the evolution of phases in the implementation of UHD, the delivery form to the set will most likely need to be compressed. The set will have to do the decoding.



USB3 connector – possible future of UHD delivery?

Following this logic, if HDMI is to remain a part of connectivity, the new version of HDMI, beyond 2.0, is going to need to include carrying a highly compressed signal.

So we have a way around the bottleneck of HDMI, which could be incorporate in HDMI to keep it alive. We know that decoding inside the set gives us lots of options in delivering higher quality content. We know the only people who care will be those owning 2160p sets.

When it comes to delivering content we're fairly confident Blu-ray will be an option. Thinking about it, it is not likely the first generation of UHD Blu-ray will incorporate a codec that will allow playback in a lot of different conditions of UHD. Remember UHD could eventually include high dynamic range and a completely different color space. What we see as a probability for the first generation of UHD Blu-ray is it will only deliver 2160p or higher. If this happens you'll see one more format of a disc going into a Blu-ray package. There will be the Ultimate UHD disc, the HD Blu-ray and the DVD and or the Digital Copy disc.

This gets us back to the pipe line delivering the content. It is the first item that should be defined in the Ultimate UHD-TV system. We should come up with a compression system (and define conditions of the signal being compressed) good enough to allow future expansion over the next 20 years. We've had hinted at a 32 bit floating point compression system which already exists. It could take on the 12 bits needed for high dynamic range as an example.

We see compression as an issue in choices being discussed for the next phase of UHD. Options being discussed are just enough to get us through the next phase. As with the Blu-ray format and HDMI implementation things seem to be incremental. Go just far enough to accommodate the next thing to come along. It's bad for the consumer in that their equipment for playing and transporting the signals always seems to be out of date. As an example, I still haven't gotten the HDMI 1.4a update to my primary AV processor, let alone HDMI 2.0 or the generation after it to come out when? I did buy a separate audio system to go with my UHD TV set but at the time, six months ago, it was still HDMI 1.4.

A lot more of what we suggested for an Ultimate UHD system is actively being discussed. In engineering meetings we've learned the cost of using a much large color space as a container for conveying content won't be of concern in building UHD compliant devices. There is the argument of needing 16 bits to convey 12 bits of useful image quality. The question becomes if there is only 12 bits of useful information why do we need at 16 or 32 bit compression system? Our answer is related to the discussion of taking baby steps in system implementation instead of making one giant leap for mankind.

Before moving on to more of the technical side of UHD I'd like to write about some of what I'm seeing in program production. It would be an understatement to say 2160p caught the studios by surprise. 'You want to do what?'

‘Did you know most of our current working masters are only 2K?’ Almost everything containing special effects has been mastered at 2K, 2048. Principal on set photography may have been done on film or in 4K, 4096 video, but it was all converted to 2K when the effects were integrated into the film. The finished product for distribution in Digital Cinema is 2K.

Where is the real 4K, 4096, content coming from? Scans of film, mostly older content where the entire feature was done on film. Interestingly enough, films that were shot in 65mm, are often being scanned at 8K and down converted to 4K. This, as it turns out, should be among the best demonstration material for 2160p.

Of interest to us is 4K scans of film date back to 1992. It was in 1993 that Disney’s *Snow White and the Seven Dwarfs* became the first feature length movie to be scanned at 4K, fixed for age and other issues and then recorded back to film. It was done at Eastman Kodak’s Cineon facility in Hollywood. Many years later, in 2008, *Baraka* became the first 65mm negative to be scanned at 8K. FotoKem, who I worked with in 2007 of *DVE HD-Basics*, did the transfer.

Summary

We are past due to improve HD to at least match current display capability.

In conferences about UHD there is a general recognition that a UHD standard will replace our HD standards – in about 30 years. What I don’t see currently happening is designing the UHD specifications to replace HD. At the moment higher resolution, being called UHD, seems to be a separate item. I believe if UHD were to be left to that single parameter as an improvement it will fall flatter than 3D to come before it. An argument could be made that the ITU 2020 document also included a change in color, but to something that shouldn’t ever be implemented.

We need to make the ‘Ultra’ in UHD TV mean something good to the average consumer if it is to become a long lasting reality.

The best way to make UHD work is to build a pipeline big enough to convey anything we can think of for the future. A set top box can be used to match what is coming down the pipeline to the set’s capability. Since almost ever set built today could benefit from a better source signal these sets would all see a benefit from UHD and could be called UHD sets. It would also allow every manufacturer to build up to future capabilities at their own pace. As content becomes available demand for sets of better capability would drive the market. There would be no fear on the part of the content provider in doing more with the system because set top boxes would make it good with existing sets and make it better for those stepping up to newer displays.

Fixing the pipeline to be future proof would allow us to phase in features of UHD at a pace more reasonable to display manufacturers.

It would also mean almost every set being built today could be a part of the UHD system.

Joe Kane