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Towards 4K, HDR First: Post-Print

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Abstract

This study primarily investigates the priority development focus in contemporary television program production and broadcasting. Based on the technical characteristic that resolution and HDR are not bound together in the 4K Ultra High Definition national standard, combined with the current status of the broadcasting industry, and grounded in human visual characteristics, it proposes a technical approach wherein the broadcasting industry should prioritize the promotion of HDR technology in the production and broadcasting chain, rapidly establish high-quality image production capabilities, and facilitate a smooth transition of the broadcasting industry toward 4K.

Full Text

Towards 4K: HDR as the Priority

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Abstract: This paper explores the priority development focus for television program production and broadcasting in the current stage. Based on the technical characteristic that resolution and HDR are not bound together in 4K ultra-high-definition national standards, combined with the current state of the broadcasting industry and grounded in human visual characteristics, this paper proposes a technical approach where the broadcasting industry should prioritize the promotion of HDR technology in the production and broadcasting chain. This strategy would rapidly establish high-quality image production capabilities and facilitate a smooth industry-wide transition to 4K.

Keywords: 4K; resolution; HDR; color gamut; Rayleigh criterion; HVS

1. Industry Status

In the new era, characterized by an explosion of entertainment, information proliferation, and rapid economic growth, people's pursuit of film and television entertainment has shown distinct hierarchical features. On one hand, there is a substantial increase in mobile viewers using phones and tablets seeking convenient, portable enjoyment. On the other hand, a significant number of audiences pursue higher-level audio-visual experiences through large-screen televisions and high-end projectors. As living standards improve and cultural aspirations grow, an increasing number of people are willing to pay for premium experiences [?]. With the formulation of 4K technical specifications and standards by the Ministry of Industry and Information Technology and the National Radio and Television Administration, television equipment has rapidly entered the 4K era. Across the consumer market, the television receiver industry has comprehensively transitioned to the 4K ultra-high-definition stage. However, 4K ultra-high-definition content production has not kept pace and will be difficult to achieve a breakthrough in the short term.

Radio and television broadcasting is currently in a transitional phase from high-definition to 4K ultra-high-definition. Many broadcast stations have just completed the full high-definition transformation of their technical systems. If the broadcasting industry were to immediately undertake comprehensive 4K ultra-high-definition technical system construction, it would face enormous implementation difficulties, risk excessive investment, and fail to rapidly establish content production capacity. Compared with high-definition, the challenges are twofold: first, the investment required for 4K technical systems is massive, with construction difficulty increasing exponentially; second, the production process for 4K programs is significantly more complex [?].

Therefore, the broadcasting industry must first address how to improve picture quality from the production and broadcasting technical chain, substantially enhancing image quality to meet actual demand for high-quality content, and ultimately achieving a smooth transition. It is necessary to establish a gradual technical roadmap from high-definition to 4K under the premise of protecting investments, identifying priority areas for technical system development towards 4K, and then progressively realizing a comprehensive 4K transition across the entire "acquisition, editing, broadcasting, management, storage, and distribution" technical chain.

3. Analysis of 4K Standards and Specifications

The "Ultra-High-Definition Video Standard System Construction Guide (2020 Edition)" jointly formulated by the Ministry of Industry and Information Technology and the National Radio and Television Administration clearly states that high dynamic range (HDR) television production and exchange image parameter values follow the international standard ITU-R BT.2100-1 (hereinafter referred to as BT.2100). According to BT.2100 specifications, resolution (container pixel

count) includes: 7680×4320 , 3840×2160 , and 1920×1080 . Per these standards, HDR program production supports all three resolutions. Moreover, BT.2100 explicitly defines that 4K resolution and HDR are not bound together. Therefore, apart from increasing resolution, improving picture quality through HDR is also an effective method [?].

4. Using HDR Technology to Enhance Viewing Experience

4.1 Limited Impact of Ultra-High Resolution

4.1.1 The Finite Resolution of Human Vision Television technology has evolved from black-and-white to color, and from standard-definition to high-definition. The transition from black-and-white to color transformed monotonous images into vivid ones. The shift from standard-definition to high-definition changed the aspect ratio from 4:3 to 16:9, increased resolution by more than four times, allowing more elements to be displayed with greater detail and providing a visual experience closer to human vision. 4K ultra-high-definition further quadruples resolution, making picture details unprecedentedly delicate and realistic.

Although video technology continues to advance and equipment resolution keeps increasing, human visual capability is fixed. According to established research, optical imaging is subject to diffraction effects, and the human eye, as an optical device, is similarly affected [?]. Consequently, there is a difference between actual imaging and what the human eye perceives; ideal geometric imaging does not occur. Display pixels thus appear as light spots—similar to Airy discs—making it difficult for the human eye to distinguish pixel gaps on screens.

When two pixels are too close together, their light spots overlap, making it difficult to discern whether it is one pixel or two. Optical systems have a resolution limit, and this resolving capability can be calculated using the Rayleigh criterion. Human eye resolution must also satisfy the Rayleigh criterion:

$$\Delta Q = 1.22\lambda D$$

The human eye's pupil diameter D ranges from 2mm to 9mm. Taking the median value of $D = 5\text{mm}$, with the central wavelength of visible light (the wavelength most sensitive to human vision) being 5500 \AA , the human eye's resolution limit angle is 1 arcminute. When an object's viewing angle is less than 1 arcminute, the human eye cannot resolve its details; it appears as a single point, with the image on the retina matching the size of a single photoreceptor cell.

4.1.2 Limited Impact of Ultra-High Resolution on Ordinary Viewers

Video image resolution refers to the set of pixel counts constituting the image in width and height. For example, standard high-definition (HD) resolution has 1920 pixels horizontally and 1080 pixels vertically. The current broadcasting

standard for 4K resolution has 3840 pixels horizontally and 2160 pixels vertically. Since widely used image pixels are square, calculations only need to address a single direction—specifically the horizontal direction to which human eyes are more sensitive.

Based on display terminal physical attributes, we calculate: - Distance between adjacent pixels on an HD screen: $D_{HD} = W/1920$ - Distance between adjacent pixels on a 4K screen: $D_{4K} = W/3840$ - Minimum resolvable distance between adjacent pixels by human eye: $D_{res} = X \cdot W \cdot \tan(1')$

Where $X = D/W$ is the ratio of viewer distance to screen width, W is screen width, and D is viewing distance.

If $D_{HD}/D_{res} \geq 1$, then $D_{HD} \geq D_{res}$. Similarly, if $D_{4K}/D_{res} \geq 1$, then $D_{4K} \geq D_{res}$, indicating the human eye can resolve pixel spacing and the picture appears coarse. If $D_{HD}/D_{res} < 1$ and $D_{4K}/D_{res} < 1$, the human eye cannot resolve pixel spacing, resulting in a smooth, delicate picture.

The resolution threshold coefficients are: - For HD: $D_{HD}/D_{res} = (1920 \cdot \tan(1'))$
- For 4K: $D_{4K}/D_{res} = (3840 \cdot \tan(1'))$

Where X is the ratio of viewer distance to screen width. Calculating X determines whether viewers can distinguish between HD and 4K.

Currently, the best-selling TV sizes are 55-inch and 65-inch. Using the larger size for calculation: a 65-inch TV has a screen width $W = 80.94$ cm. Typical viewing distances in living rooms or bedrooms range from 3m to 4m, with 4m rarely achieved; the average is 3.5m. Thus, $X = D/W = 3.5/0.8094 = 4.32$.

The resolution coefficients are: - HD image: $D_{HD}/D_{res} = 0.414 < 1$ - 4K ultra-high-definition image: $D_{4K}/D_{res} = 0.207 < 1$

According to the Rayleigh criterion, under these viewing conditions, both HD and 4K ultra-high-definition video achieve smooth, delicate display effects that exceed the human eye's actual discriminatory capability, satisfying daily viewing needs. Therefore, at present, most viewers find it difficult to distinguish between 4K and high-definition in terms of resolution.

4.2 Positive Impact of HDR on Viewing Experience

4.2.1 Brightness Impact Analysis Beyond resolution, the human visual system (HVS) describes how human eye characteristics respond to light. Different colored light produces varying brightness sensations, with brightness largely influenced by light intensity—stronger intensity yields higher brightness, and vice versa [?]. Human brightness perception relies on two types of photoreceptor cells on the retina: cone cells densely distributed in the central area directly opposite the pupil, and rod cells primarily in the peripheral area.

Human eyes exhibit remarkable brightness adaptation, with real-world brightness ranging from approximately 10^{-6} to 10^9 cd/m². The perceivable brightness

range is about 10^{-3} to 10^6 cd/m^2 , with instantaneous visual dynamic range contrast reaching $1:10^5$. Pupil size controls light intensity reaching the retina, varying from 2mm to 8mm in adults—equivalent to four f-stop levels with a 16-fold difference in light intensity.

However, human brightness response is not linear. For instance, candlelight appears bright in a dark room but becomes invisible in noon sunlight, indicating that human response to brightness changes diminishes as brightness increases. This characteristic approximates a logarithmic function.

In broadcasting, to align with human visual characteristics and enable viewers to correctly perceive transmitted content, the ITU-R BT.709 standard (used since 1993) defines an OETF (opto-electronic transfer function) known as the current SDR (Standard Dynamic Range) standard. Notably, this standard was constrained by technological limitations at the time of its creation, defining peak brightness at only $100 \text{ cd}/\text{m}^2$ with contrast ratios of 1000:1 to 2000:1—specifications that no longer meet actual requirements.

To better reproduce the real world and enhance viewing experiences, HDR technology has developed rapidly in recent years. Although multiple HDR standards exist, all currently provide peak brightness above $1000 \text{ cd}/\text{m}^2$ and support color spaces up to P3 or Rec.2020 [?]. The OETF/EOTF curve comparison between BT.709 and ST 2084 (the popular PQ standard in HDR) clearly shows HDR's vastly superior luminance signal description capability.

Leveraging HDR technology in content production and broadcasting yields immediate improvements in viewing effects—viewers can discern picture quality differences without needing to approach the screen. Given the current state of the broadcasting industry, a gradual technical roadmap from HD to 4K must be established. The potential of existing HD production and broadcasting systems should be fully exploited through HDR technology to rapidly form large-scale high-quality content production capabilities, meeting market demand for high-quality content, enhancing industry influence, and promoting comprehensive 4K upgrades while facilitating deep media integration.

This model has already been promoted internationally. Quality and technology-focused media platforms such as Netflix and YouTube support 1080P HDR viewing modes, lowering barriers while significantly enhancing audience experience and accommodating mobile device viewing. Since 2019, mainstream mid-to-high-end mobile devices including smartphones and tablets have achieved hardware and software support for 1080P HDR display modes.

4.2.2 Color Gamut Impact Analysis Compared with traditional SDR video images, HDR video images offer richer colors. Current mainstream HDR standards support the REC.2020 color gamut, significantly larger than the original REC.709 gamut and closer to human visual range. HDR video provides better highlight and shadow details, enhanced contrast, and delivers a superior viewing experience that brings television pictures closer to the real world, elimi-

nating SDR' s problem of highlights that “can' t get bright enough” and shadows that are “crushed to black.”

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Note: Figure translations are in progress. See original paper for figures.

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