



SONY HDCAM:  
EXPOSURE LATITUDE -  
Issues of Dynamic Range

**24P TECHNICAL SEMINAR #3**

*by Laurence J. Thorpe*

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## ABSTRACT

For decades, motion picture film had enjoyed one indisputable advantage over video imaging – namely, a marvelous ability to capture very high contrast scenes. The medium has always inherently boasted an extensive dynamic range, or, as is commonly quoted in film parlance – a wide Exposure Latitude. Until recently, that is.

During the past decade, the contemporary digital camera has forged ahead of the best of the traditional video cameras that served the broadcast and production industries from the 1940s to the early 1990s. Propelled by stunning advances in solid state CCD imager technologies, flanked by digital signal processing circuits having impressive video processing prowess, the digital 24P high definition acquisition system will be shown to have an Exposure Latitude that rivals that of the 35mm motion picture film negative.

## DYNAMIC RANGE

Dynamic Range is a topic that has attracted increasing interest within the world of digital cinematography. With the advent of the new generation of 24P acquisition systems, it has emerged as a central topic -- and has also caused considerable confusion.

In the July 2001 edition of "In Camera," published by Kodak Entertainment Imaging, Mr. Tom Wallis, their Chief Technical Officer, made the following statement: "The best HD and other digital cameras offer a capacity for recording a dynamic range of about 100:1." If a high-level technical expert believes this about contemporary digital acquisition, it is little wonder that so many in the production community also retain some misunderstandings.

Certainly, there was a time when video acquisition fared poorly when its dynamic range was compared to that of motion picture film. That day is long gone. The stunning advances in CCD image sensor capabilities -- their abilities to capture scenes containing unusually wide contrast ranges -- have spurred a closer examination of how best to process the acquired video in order to optimize its ultimate tonal reproduction on an electronic display. Different considerations arise when the same digital 24P HD video is to be processed preparatory to a transfer to motion picture film for theatrical release.

## DYNAMIC RANGE IN VIDEO CAMERAS

For decades, video acquisition suffered from serious limitations in dynamic range capabilities. A variety of the imaging artifacts of photoconductive pickup tubes conspired to cloud tonal reproduction at the lower end of the video-output/light-input transfer characteristic. These artifacts included electronic noise of various forms, optical and imager flare, black shading aberrations, and highly problematic motion-related problems such as image lag. Any attempt to extract picture detail from deeply shadowed areas of a scene were severely impaired by the cumulative "masking" of these low-light picture impairments.

The upper end of the transfer characteristic -- the highlight handling region -- was also hampered by separate difficulties largely associated with the imager itself. Pickup tubes had severe electron beam limitations, which served to abruptly "clip" any overexposed content. Prior to the onset of such clipping, however, other image artifacts such as blooming, black halos, and comet-tailing combined to badly mar the reproduction quality of overexposed sections of the picture. Indeed, it became an established norm to resort to all sorts of expedients

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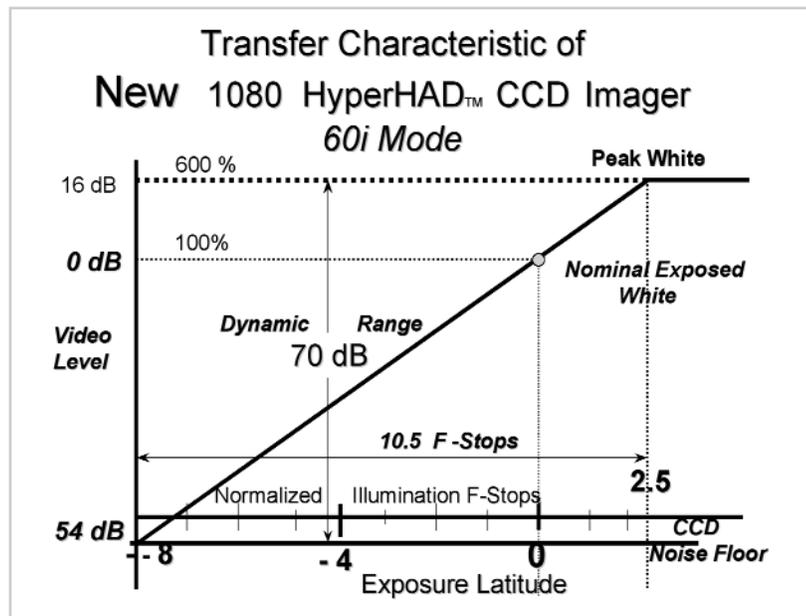
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to avoid the imaging of overexposed scenes. More than anything else, this problem definitively separated earlier video imaging from motion picture film imaging.

The advent of the solid-state CCD imager greatly reduced artifacts in the light transform of an electronic signal. With the advent of the CCD, tonal reproduction within the video medium acquired a whole new meaning. The capture "window" was dramatically opened. Today, even contemporary consumer camcorders exhibit remarkable exposure latitudes. The days of video cameras with "100:1 dynamic range" are ancient history.

**FIGURE 1** shows the dynamic range performance of the CCD imager employed in the new Sony HDW-F900 high definition camcorder -- when it is operated in the 50 or 60 Hz interlace mode. This chart shows the input light range to the camera expressed in F-stops, as well as the resulting video signal levels from the CCD imager.



**FIGURE 1.** Showing the dynamic range of the 1080 CCD in the interlace mode



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The CCD has an unprecedented dynamic range of 70 dB -- or 2500:1. The challenge to the camera designer lies in digitally processing that extraordinary dynamic range to formulate a signal ready for subsequent digital recording.

Switching the same CCD to operate in 24, 25 or 30 Hz progressive capture loses the double pixel row summation inherent in the interlace mode of operation; as a consequence, the dynamic range is lowered by 6dB [SEE FIGURE 2].

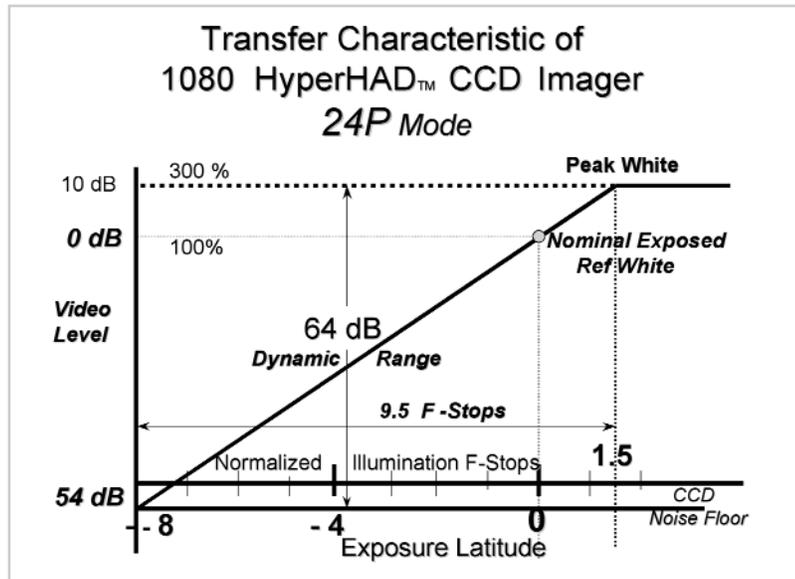


FIGURE 2. Showing the 6dB reduction in dynamic range when the same CCD is operated in the progressive scan mode

## CAPITALIZING UPON IMPROVEMENTS IN DYNAMIC RANGE PERFORMANCE

As the picture capture "window" of contemporary CCD imagers has progressively opened at both extremes, the camera design task has become one of optimally shaping the overall video transfer characteristic. Technically, this is necessary to ensure that the wide exposure latitude of the video signal initially created by the CCD imager can be properly accommodated within a variety of digital processes. It is also an artistic necessity, in order to achieve on the final display(s) the specific tonal reproduction sought by a specific production team.



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## THE TECHNICAL CONSIDERATIONS INCLUDE:

- A/D Conversion: required to digitize the analog video output from the CCD imager prior to Digital Signal Processing within the cameras (this has today expanded to 12-Bit).
- Digital Video Recording: a challenge associated with the limited Bit-depth of contemporary HD video recorders (8-Bit being a current norm in HD camcorders).
- Digital Fiber Link: in the case of a 24P HD studio camera system, digital transmission from the camera head to the Camera Control Unit (CCU) must be considered.
- Postproduction Processes: such as color correction, transfer characteristic manipulation, etc. [to optimize the signal for presentation on electronic projection systems, where different projection technologies have their own unique transfer characteristics].

## IMPLEMENTING A DESIRED TRANSFER CHARACTERISTIC

In these early days of digital 24P HD cinematography, two distinctly different philosophies have emerged with respect to the desired final transfer characteristic:

- 1) Emulating the tonal reproduction of a specific film stock.
- 2) Achieving a tonal reproduction unique to the new digital medium (and distinctly different to that of film).  
These differences are a consequence of:
  - a) Some producers making the transition to digital acquisition from motion picture film (and seeking to preserve a familiar imagery).
  - b) Other producers recognizing the advantage of 24-frame operation for international distribution (its easy conversion to 50Hz and to 60Hz), and having no specific allegiance to film-based imagery.

In terms of how desired transfer characteristics are achieved, there are also two divergent philosophies:

- 1) Programing the camera's nonlinear DSP circuits to achieve the specifically desired overall tonal reproduction directly in-camera
- 2) Programing the camera to achieve the widest possible exposure latitude -- and later, manipulate the transfer characteristic in postproduction to achieve the desired tonal reproduction.

The in-camera approach relies on predetermining the desired transfer characteristic and carefully pre-programming this characteristic into the relevant DSP sections. The postproduction approach focuses on scrupulously capturing the most possible picture contrast information -- in the primary exposed "middle" regions as well as within the deep-shadowed areas and the over-exposed areas of the particular scene being imaged.

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## PRESENCE OF THE HD MONITOR ON THE CAMERA SET

Both the in-camera and the postproduction approach are compounded by divergent philosophies on using or not using an HD picture monitor on the set. Many directors and DPs have not only come to feel comfortable with the on-set monitor, but actually claim an empowerment in achieving the pictures they seek. Others completely shun such an on-set display.

Using an on-set monitor to determine the final image composition -- both in terms of the transfer characteristic and the color reproduction -- requires a disciplined technical setup of the monitor itself as well as a carefully controlled viewing environment. Work to date strongly reinforces the belief that pre-testing can facilitate a very successful implementation of this practice. Clearly, it is easier to implement in the studio than in the uncontrolled lighting conditions of the outdoor set.

With respect to location shooting, some producers have resorted to the use of a small truck that houses a digital control room to achieve the carefully adjusted viewing conditions required. When the postproduction suite is the planned venue for final adjustment of the transfer characteristic, the task on the camera set becomes one of adjusting the camera transfer characteristic to favor adequate capture of both highlight and lowlight scene content under all encountered shooting conditions. Having a known transfer characteristic (one that allows adequate capture) programmed in the camera DSP circuits will make it easier to predict the subsequent manipulation required to achieve a desired effect.

## TRANSFER CHARACTERISTIC – THE BROADCAST TELEVISION MODEL

Traditionally, the setting of video camera RGB processing circuits followed the decades-long "broadcast television" orientation. Broadcasters sought to maximize the signal-to-noise ratio of the normally exposed image and sharply curtail any signal levels above that -- in order to avoid downstream circuit overloading, especially overloading of the television transmitter. This approach, in turn, dictated setting the reference scene white (as defined by the 89.9% white chip on a standard television grey scale chart) at the maximum video level -- the well-known 100 IRE level on the measuring waveform monitor. All signals exposed above the 100 IRE level were of secondary importance, and typically were eliminated by a white clipping circuit set some few percent above that level. Cameras had their lens iris adjusted in real-time throughout the shoot to maintain scene white as close as possible to the 100 IRE level -- a continual intervention in order to sustain the optimum video S/N ratio.

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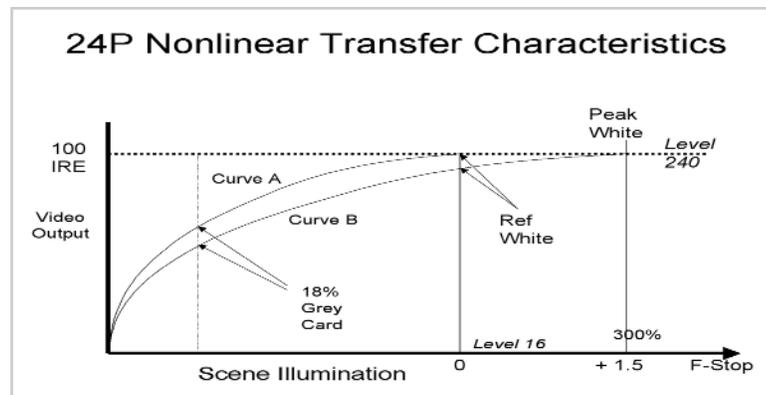
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**FIGURE 3** illustrates the principle of choosing different transfer characteristics for widely varying conditions of scene illumination. In a studio situation, where lighting is carefully controlled to eliminate, or minimize, specular highlights, the traditional "broadcast video" transfer characteristic can be employed (see Curve A). The ITU 709 HD standard precisely prescribes such a curve. This allows the camera to be exposed in a manner that places reference white at 100 IRE (on a standard television waveform monitor). This exposure would maximize the signal-to-noise ratio. Note: curves are generic and are intended to be illustrative.



**FIGURE 3.** Curve A is the specified ITU 709 Gamma Curve for a nominally exposed camera; Curve B is an alternative extended range characteristic for handling scenes with 1 1/2 F-stop overexposure. Note the attendant drop in level of reference white level.

If, however, the camera is on location, where uncontrolled scene illumination can contain highlights in excess of reference white, the transfer characteristic can be programmed to produce a light-input/video-output relationship as represented by a generic Curve B.

The 24P camera exposure can be further altered (by using ND filters or closing down the lens) to ensure that even higher scene highlight information is captured, further lowering the level of the reference white. Figure 4 shows a hypothetical scenario where the scene peak white is 2 1/2 F-stops above reference white in the example shown.

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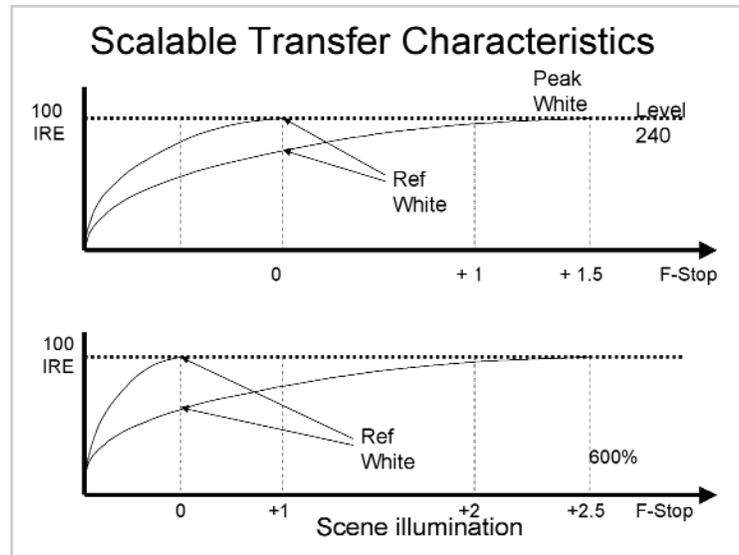
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**FIGURE 4** shows a hypothetical scenario where the scene peak white at 2 1/2 F-stop above reference white in the example shown. Note: curves are generic and intended to be illustrative. The first set of curves depict the principle of a transfer characteristic intended to capture signals exposed to 1 1/2 F-stops above reference white; the second set of curves show how this might be altered to capture up to 2 1/2 F-stops above reference white.

In this scenario, the low-light level information is somewhat disadvantaged; however, the high S/N of the 24P camera can readily accommodate this. The low-light information can still be satisfactorily restored in postproduction. When the camera is used to image scenes with even greater levels of overexposure, the limitations of the progressive scan imager must be taken into account.

### TRANSFER CHARACTERISTIC AS A MEANS TO OPTIMIZE DYNAMIC RANGE CAPTURE

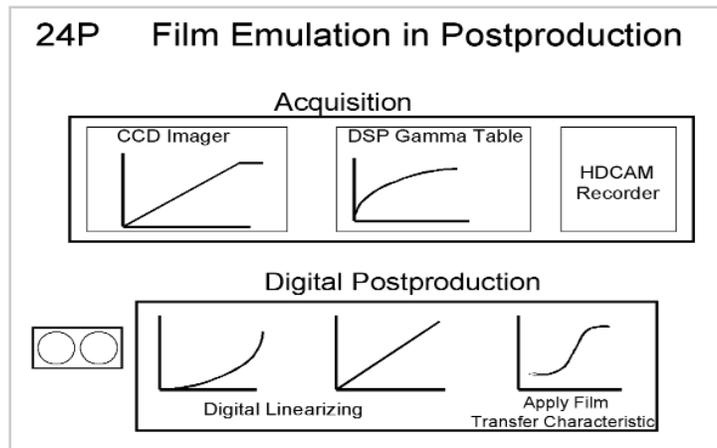
As shown in our earlier seminar on operating sensitivity, the contemporary 24P digital camera has a quite high Exposure Index (EI). This "overhead" in sensitivity can be exploited to allow the S/N of the nominally exposed portion of the signal to vary widely in order to capture the widest possible dynamic range. In this approach, the reference white level is allowed to drop lower than the prescribed 100 IRE level and the DSP nonlinear circuits are manipulated accordingly to favor assignment of the transfer characteristic to overexposed signals (those that lie above reference white). Scene lighting is adjusted where possible to set the peak white extremities of any given scene to just below the white clipping level in the three RGB circuits. If the transfer characteristic has been set to a nominal known curve, then all of the information recorded can be linearized in postproduction.

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When the original capture is subsequently linearized (perhaps in a computer or color corrector), it is a relatively simple process to superpositate any desired replacement characteristic (for example, the Cineon color space standard) in postproduction; see **FIGURE 5**. Note: curves are generic and intended to be illustrative.



**FIGURE 5.** Showing application of the desired transfer characteristic in postproduction

## TRANSFER CHARACTERISTIC AND DIGITAL BIT SAMPLING DEPTH

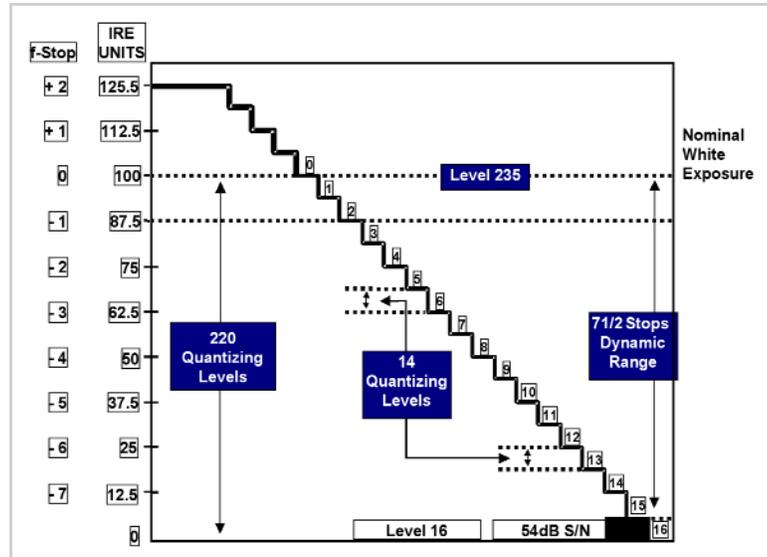
To faithfully capture a satisfactory tonal reproduction over the entire dynamic range of the imaged scene, it is important to consider the relationship between the prescribed transfer characteristic and the bit sampling in the associated digital recorder. Satisfactory transmission of the wide dynamic range signal through an 8-bit or 10-bit system (fiber or Triax etc) is equally important.

There can be considerable confusion on this issue. That is why we need to look more closely at the sampling of a camera video signal that has been pre-corrected according to the nonlinear transfer characteristics discussed earlier. We will first consider the case of a scene with a 7 1/2 F-stop exposure latitude, then the more taxing case of a scene with exposure latitude of 9 1/2 F-stops.



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**FIGURE 6.** The waveform monitor depiction of a 7 1/2 F-stop dynamic range capture where reference white is set to 100 IRE units

The lower boundary of this reproduction is assumed to be that final grayscale step where the S/N ratio is unity -- in other words, where noise totally masks the step, defining the lower limit. This "black" level is assigned digital coding level 16. The camera has been exposed so that the reference 89.9% white chip is at the nominal 100% level -- or 100 IRE units on the standard waveform monitor -- and this is assigned digital coding level 235, to allow overhead. With a nonlinear Gamma precorrection prescribed by the ITU-709 standard, the camera output would be as shown in Figure 6. Note that under these conditions, each step of the grayscale chart is amplitude-sampled by no less than 14 coding levels -- more than enough to accurately reproduce the steps over the entire luminance scale.

Now consider the same camera exposing the grayscale chart and an additional 2 1/2 F-stops of highlights above reference white. When this peak white level is adjusted [by lens aperture or ND filter] to the 100 IRE video level, the resultant waveform applied to an 8-bit A/D converter would be as shown in Figure 7.



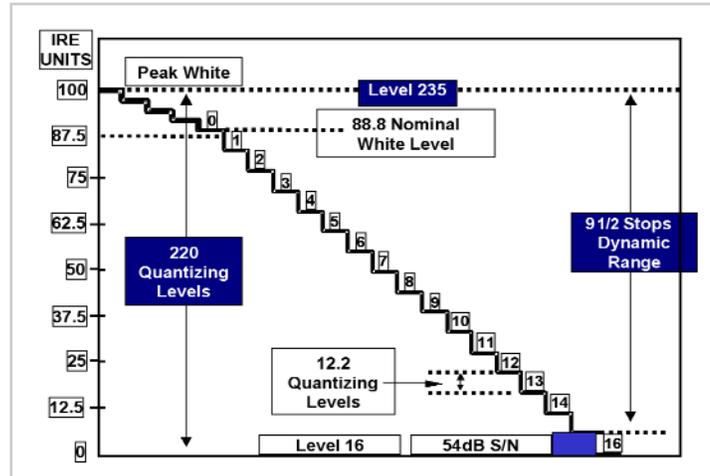
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**FIGURE 7.** Showing a 9 1/2 f-stop scene dynamic range applied to the 24P camera when this is carefully exposed to set the peak white level to 100 IRE

Note that in this case, reference white has been lowered to the 88.8 IRE level and that there are now just over 12 amplitude samples of each step of the grayscale -- again, more than adequate to accurately capture each level.

We conclude that 8-bit recording is more than adequate to faithfully capture a dynamic range of 9 1/2 f-stops when a signal with wide dynamic range is exposed in the manner prescribed (with overexposed peak white signals carefully set to the 100 IRE level), provided that this signal has been pre-compressed according to the principles outlined above.

### REFERENCES:

L.J. Thorpe, "HDTV and Film - Issues of Video Signal Dynamic Range."  
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