

POYNTON'S VECTOR 4 Legal, valid, and sensible colors

Studio HD technicians and home theater calibrators are familiar with 10-bit HD coding: Reference black is placed at interface code 64 and reference white is placed at 10-bit interface code 940. (The comparable 8-bit codes are 16 and 235.) These communities are less familiar with the origins of footroom and headroom, and are generally unfamiliar with proper treatment of codewords that lie in these regions. I will address these topics in this column.

$$V = 64 + 876 \cdot \frac{\text{units}}{100}$$

Eq 1 Mapping from units to 10-bit digital video code

$$\left(\frac{1019 - 64}{940 - 64} \right)^{2.4} \approx 1.23$$

Eq 2 Peak luminance fraction of reference white luminance

Codes 64 and 940 are meaningful across a digital video interface; however, for signal processing it is much more convenient to declare reference black and white to be zero and unity respectively. Call those levels 0 units and 100 units if you like. In standard HD, headroom extends to about 109 units; the corresponding luminance is about 1.23 times reference white. *Reference* and *peak* are different! Many ITU-R, EBU, and SMPTE standards get this wrong, mistakenly using *peak white* when *reference white* is meant. Codes 0–3 and 1020–1023 are prohibited across an HD-SDI interface.

The original digital studio video standard was CCIR Rec. 601, established in 1984. Analog studio video signals drifted somewhat; to introduce digital video required accommodation of analog signals having imperfect reference levels. Footroom and headroom were necessary. That reason has now vanished. However, several good reasons for footroom and headroom remain.

When presented with an input signal containing high frequency content, any practical filter – whether analog or digital, or lowpass, bandpass, or highpass – necessarily involves some degree of undershoot and/or overshoot. Premature clipping of undershoots and overshoots is detrimental to image quality: Clipping should be deferred to the last possible point in the signal chain. Footroom and headroom accommodate undershoots and overshoots. Historically, it has been generally agreed – if not properly documented – that signals shouldn't dwell in the footroom or headroom region for longer than half a dozen samples. I'll bring this assumption into question below.

A relatively recent reason for footroom is to convey the negative excursions of camera noise. All sensors generate noise, even around black. When a camera is sensing true optical black (e.g., capped), it is sensible to set the average signal value to reference black. However, noise has excursions above and below that level. If the negative-going excursions are clipped, then the noise is said to be "rectified": the average value of the noise then rises above reference black. It is

important to defer the rectification to the latest possible point in the signal chain.

A final reason for footroom is that it allows coding of the blacker-than-black (-2%) PLUGE signal element commonly used to set black level in studio displays.

A camera engineer typically aligns an HD camera to produce 100 units for a near-perfect white reflector in the scene. However, when the camera is turned over to the cinematographer, he or she may wish to convey specular reflections or light sources in the scene, and he or she may therefore reset exposure to place the white card well below 100 units. Light sources and speculars may lie anywhere above the cinematographer's white reference, and the speculars and sources won't let up until they clip! The headroom region ends up carrying these elements. Typically these elements have momentary excursions, but they may well be sustained across more than half a dozen samples.

All of the reasons that I have mentioned are arguments against clipping anything in the footroom and headroom regions! Indeed, to clip is bound to introduce some degree of visual artifacts. Movie studios use commercial "QC" outfits to review commercial content prior to mastering. Many QC outfits are motivated to report "violations." Most post houses take the easy way out and clip to "legal" before shipping content out to the QC houses. The potential visual quality of such material is compromised, and in the long term, the QC houses should be educated. Once the QC houses are well informed, the post houses will stop clipping.

Apart from footroom and headroom in the component digital environment, in the NTSC days it was important to prevent the transmitter from exceeding 120% power. That was generally accomplished through "NTSC legalization," a process too complicated to be detailed here. Suffice to say that over-the-air NTSC analog transmission no longer occurs in the USA. No studio or consumer equipment operates under the 120% carrier constraint of the now-absent broadcast transmitters. No NTSC legalization is required – indeed, none is appropriate – for any signals today, even those in NTSC form!

Unfortunately, in the consumer domain, manufacturers are motivated to compromise the headroom region for two reasons. First, consider a display with maximum luminance of 250 nt. By properly following the gamma curve all the way up to 109 units (historically, "IRE"), peak luminance is 250 nt, but reference white luminance is 200 nt. If the display follows the gamma curve up to 100 units then clips, the manufacturer can claim reference white at 250 nt! Consumers tend to think bigger numbers are better – but the clipped picture will suffer. A home theatre calibrator, on assessing the grey-scale response, will be savvy to this trick, and will adjust the display to follow the gamma curve all the way up to peak. Second, a manufacturer may be motivated to push the curve up in the midscale, then roll-off the higher regions in an effort to deliver higher average luminance. The well-equipped calibrator will similarly reverse the trick.

A well-known "standard" for wide-gamut, xvYCC, uses $Y' C_B C_R$ codewords outside the $R' G' B'$ unit cube to convey wide-gamut colors. To use such a system, gamut legalizers must be disabled. The wide-gamut arena will be the subject of a future column. ■