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Video Standards

Signals, Formats and Interfaces

Part 4

From Light to Signal

VideoQ

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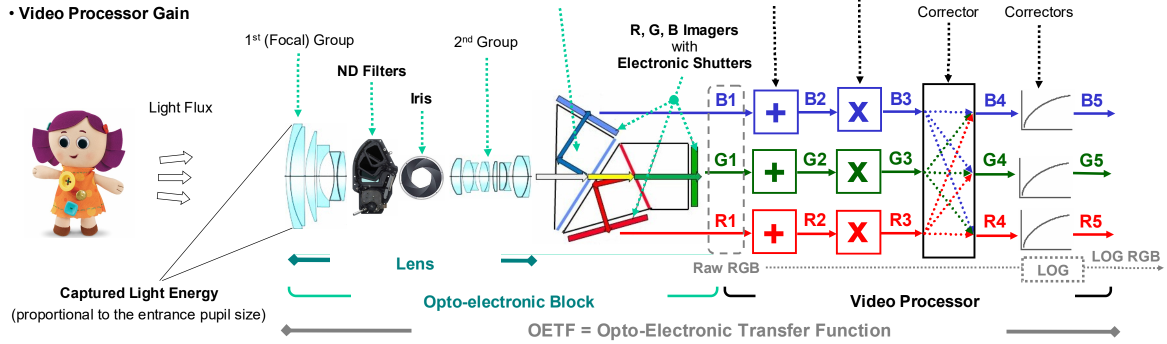
Video Camera Converts Light to RGB Signals

Overall camera **sensitivity**, i.e. light to video **conversion gain**, depends on:
- **Lens Speed** (Lens Effective Aperture)
- **Imager Gain** (which depends on Electronic Shutter settings)
- **Video Processor Gain**



RGB imagers **illumination** & RGB imagers **sensitivity** controls:
- **Neutral Density (ND) Filters** – preserving the depth of field & motion blur
- **Iris** (aka Aperture) – affecting the depth of field, but preserving motion blur
- **Electronic Shutter** – preserving depth of field, but affecting motion blur

Video processor controls:
- **R, G, B Offsets**, often labeled as **Master Black & Black Balance**
- **R, G, B Gains**, often labeled as **Video Gain & White Balance**

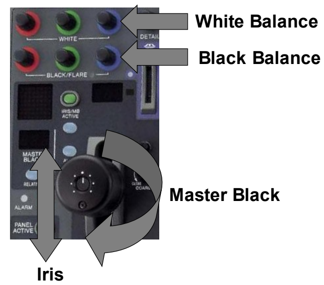
Note that any errors in these setting (prior to the gamma-corrector non-linear processing) ***can not be easily compensated downstream*** (after gamma-correction) !

Camera Controls

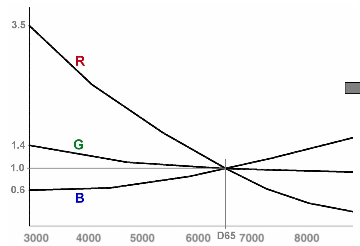
The **Black Balance** control purpose is to get **R = G = B = 0%** for zero light level condition, e.g. when the lens cap is on.
The R,G,B offsets are usually generated as a sum of **Master Black** (R, G, and B common offset) and three separate R, G, and B offsets labeled “Black”, “Black Balance” or “Black/Flare”.
*Black Balance controls can also compensate the unwanted shifts caused by **lens flare** (aka glare); such shifts are usually proportional to the light intensity in the corresponding channel (R, G or B).*

The **White Balance** control purpose is to achieve **R = G = B** output when camera is pointed to the **Reference White** object, e.g. to the **VideoQ VQMA-C** reflectance Test Chart (preferred way to do it), or to a sheet of white paper (not so accurate, but OK).

*White Balance adjustment makes sense only when Iris and Master Gain controls provide approximately 100% output in the G channel. In such case it is enough to modify only R and B gains because the G channel output is controlled by **Iris** and **Master Gain**.*
In the simplified camera models the White Balance controls are also used as Master Gain control, then R, G and B gain controls are labeled “White” (not “White Balance”).

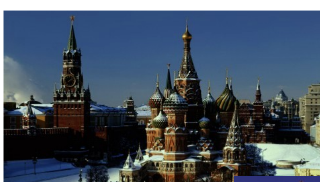


Iris and **Master Black** controls are often combined in one joystick for an operator convenience.
With AUTO mode enabled this joystick is still functional – modifying the auto systems target values .



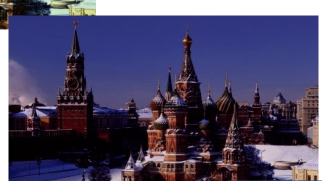
Depending on the **spectral responses** of trichroic prism R, G and B channels and the **light source color temperature** the levels of **raw RGB signals** may vary a lot.
For example if the White Balance was set at D65 illuminant, and then the light source was changed to 3000 K, the G channel level goes up to 140%, B level goes down to 60%, and R channel is jumping up to 350%.
So, we need a wide range of RGB gain controls. *Low light shooting may require an extra boost – up to 24 dB!*

Color Balance – Before and After



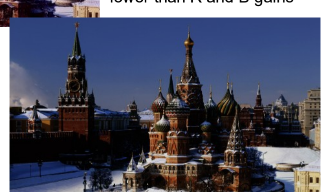
RGB1

Raw video exhibits **Black Balance** error:
Black Level in **G** channel is higher than in R and B channels, though the mid-range colors (**Gray Balance**) are about right, e.g. the color of snow in the bottom left corner



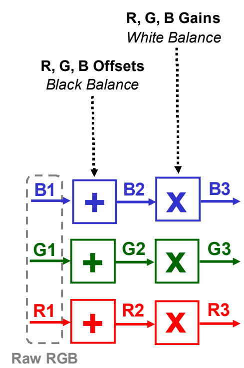
RGB2

White Balance error:
Positive black offset in G channel is now compensated, but **G** channel **gain** is lower than R and B gains



RGB3

All offsets and gains are now balanced; no Black Balance or White Balance problems, but image **saturation** is reduced and **mid-range levels** in all 3 channels (R, G and B) are too low wrt peak levels (gamma-correction required)



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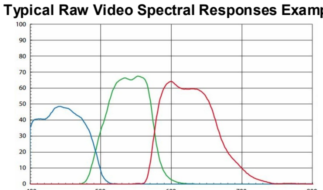
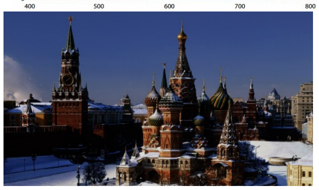
Color Correction Matrix

Optimal choice of the color correction **matrix coefficients** is very important.
CC Matrix converts R, G, and B "raw video" spectral responses to something closer to the **ideal (theoretical) color separation curves**.
For example, to get G4 curve with two negative lobes we subtract small fractions of R3 and B3 from G3: **G4 = - Krg x R3 + Kgg x G3 - Kbg x B3**
Because the SD, HD and UHD systems use different primaries the ideal curves (and the corresponding matrix coefficients) differ a lot.
Color Correction Matrix coefficients can be further tweaked when the light source **color temperature changes**, *and some professional cameras do it*.

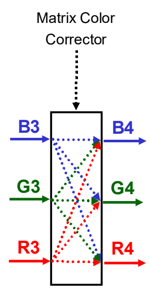
Typical Raw Video Spectral Responses Example



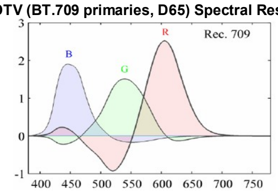


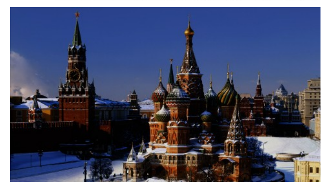
RGB3

Reduced Chroma Saturation, some colors may be shifted



Ideal HDTV (BT.709 primaries, D65) Spectral Responses





RGB4

Saturation boosted about 50%, visible on blue sky color

Gamma Correction

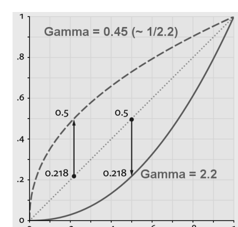
Historically, the purpose of camera gamma correction was to pre-compensate the nonlinearity of a typical display **Electro-Optical Transfer Function** (EOTF). Gamma is just a Greek letter γ commonly used to define a more or less accurate approximation of this EOTF by a simple power function.
CRT's EOTF is traditionally approximated by the function **L = V**$^{\gamma}$, where **V** = control voltage, **L** = light output.

To achieve full compensation of the EOTF non-linearity in the camera its OETF (the **inverse gamma** function aka **gamma-correction** function) should be: **V = L** $^{1/\gamma}$, where **L** = light input, **V** = camera output signal (Y,R,G, or B).

For the monochrome CRT display standards specify γ **= 2.2**, but for color CRT some documents specify γ **= 2.8**.

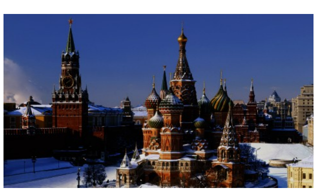
However, to preserve **backward compatibility** and for several other reasons, all broadcast systems, including the latest UHDTV systems (except High Dynamic Range systems), still use gamma correction value of **0.45 = 1/2.2**.

*For the modern displays the flat panel EOTF is in fact linear, i.e. γ could be 1.0, but the designers add special gamma-corrector to make it 2.2, because they **must** get the EOTF mimicking a 70 years old monochrome TV. Once again we see how important is to stay **backward compatible !***



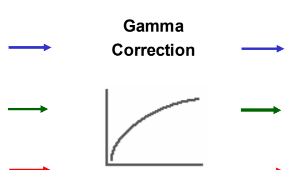
Display: **x** = signal, **y** = light, γ = 2.2
Camera: **x** = light, **y** = signal, γ = 0.45

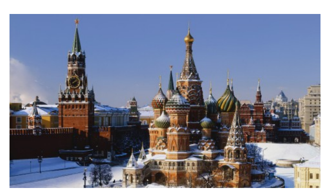
Real gamma correctors use **variable**, **adaptive**, and much more sophisticated functions.
So, we should remember that the OETF functions defined in the standards are just a guidance.



RGB4

Mid-range levels are too low, "hard" picture





RGB5

Mid-range levels are now much higher, good picture

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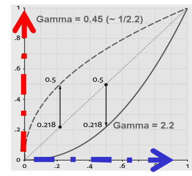
More About Standard OETF & Gamma Correction

The slope (gain) of the theoretical display EOTF at the Reference Black point, i.e. at V = L = 0 point, is $2.2 \times 0^{2.2 - 1} = 0$.

To compensate such gain the inverse OETF slope must be equal to 1/0, i.e. **infinity** !

In practice the maximal gain of gamma corrector is, of course, limited. What the standards tell us about the issue:

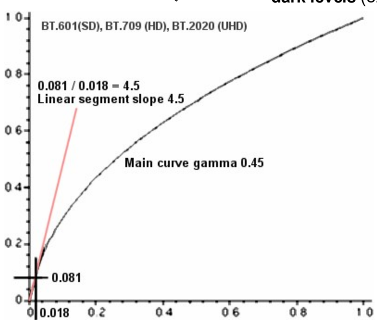


$$E' = \begin{cases} 4.5E & 0 \le E < \beta \\ \alpha E^{0.45} - (\alpha - 1) & \beta \le E \le 1 \end{cases}$$

$\alpha \approx 1.09929682680944$ $\beta \approx 0.018053968510807$

This hardly digestible formula has very simple graphical representation.
It means **gain 4.5** up to the **L** value **0.018** (1.8 % of the Reference White) translated as **V** value **0.081** (8.1 % of the Reference White); after this point the original 0.45 gamma curve is slightly scaled and shifted.

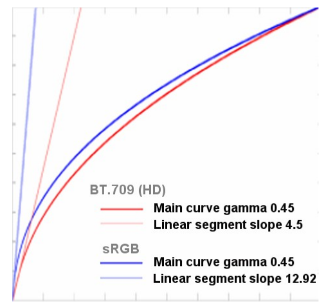
Partial replacement of the ideal power function by a **linear segment** has one unpleasant side-effect:
dark levels (e.g. deep shadows) are **not fully compensated**, so the display EOTF will compress them.



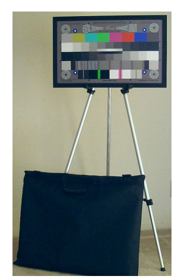
One possible solution is to increase the linear segment slope thus reducing the unwanted compression of dark gradations.
On the other side, higher gain means higher levels of noise and other artifacts.

This mode is often labeled "**Black Stretch**".

In **sRGB** (web video) standard the 4.5 slope increased to nearly 13; some broadcast cameras also use this trick, so to say "breaking the law".



Testing Light to Signal Conversion

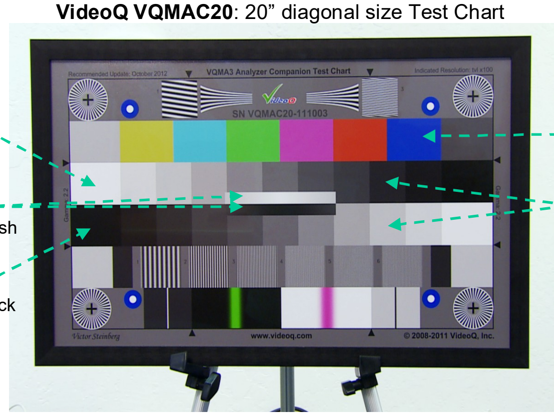


Real cameras seldom have parameters close to the nominal target values set by standards.
With few exceptions the standards do not specify **the tolerances** for light to signal conversion parameters.

Sometimes these tolerances are specified by broadcasters, *but quite often they are not specified at all.*

However, there are tools and methods suitable for video cameras performance **subjective estimation** and/or **objective measurement**:

VideoQ VQMAC20: 20" diagonal size Test Chart



Reference White

Shallow Ramps aimed to check Black Crush & White Crush

Reference Black

Color Bars aimed to check Color Rendition

Grayscales aimed to check Black, Gray & White Balances (Dynamic Balance) and Gamma

About This Presentation

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Based on the book
"Video Standards: Signals, Formats and Interfaces" by Victor Steinberg
Published by Snell & Wilcox

For further reading we recommend wikipedia.org

About VideoQ

Company History

- Founded in 2005
- Formed by an Engineering Awards winning team sharing between them decades of global video technology.
- VideoQ is a renowned player in calibration and benchmarking of video processors, transcoders and displays, providing tools and technologies instantly revealing artifacts, problems and deficiencies, thus raising the bar in productivity and video quality experience.
- VideoQ products and services cover all aspects of video processing and quality assurance - from visual picture quality estimation and quality control to fully automated processing, utilizing advanced VideoQ algorithms and robotic video quality analyzers, including latest UHD and HDR developments.

Operations

- Headquarters in Sunnyvale, CA, USA
- Software developers in Silicon Valley and worldwide
- Distributors and partners in several countries
- Sales & support offices in USA, UK