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May 2014

Monitor Calibration & Colour - Introduction

- Nature of colour and light

- Colour systems – Video, 601 & 709 colour space

- Studio cameras and legalisers

- Calibrating monitors

- LCDs – special considerations

- Myths, the future and some resources for further reading

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The nature of colour and light

Our eyes are sensitive to wavelengths from below 400nm (blue) through to over 700nm (red). Other creatures see different ranges of wavelengths, but as people our eyes start working just after (what we call) ultra-violet (where EM radiation has enough energy to start being called 'ionising radiation') through to just short of 'infra-red'. The light from the sun is broad-spectrum (i.e. at every wavelength we can see, and in fact extending far above and below where our eyes work). This mix of all frequencies from the sun illuminates our world and different objects absorb some frequencies and reflect others - the reflected light enters our eyes and depending on the mixture of reflected frequencies we perceive a certain colour - plants absorb all frequencies bar those around 550nm which is reflected and we call the sensation that we get from that set of frequencies 'green'. The same is true of objects that emit light (like TV and computer monitors).

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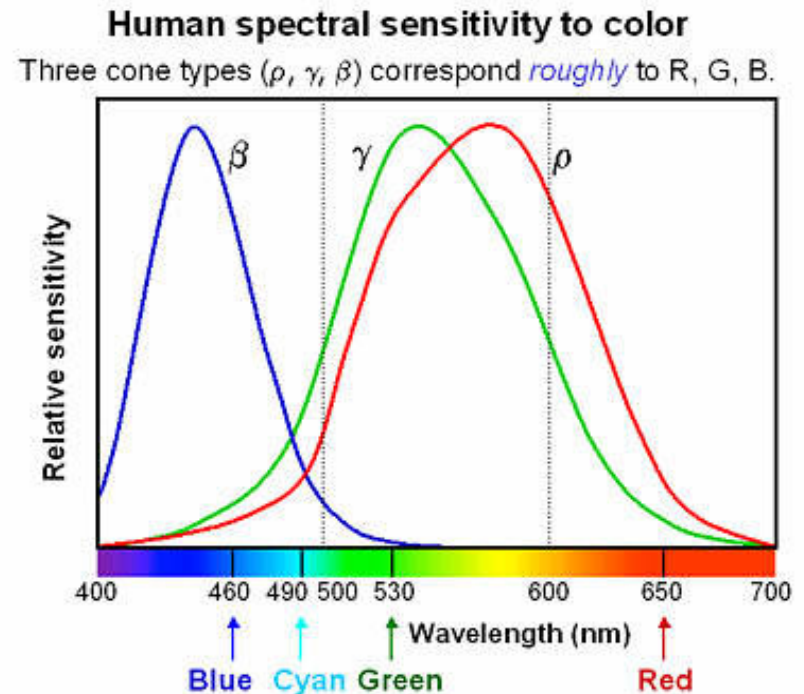
## Colour Systems

Perception

- Human vision is a 'tri-stimulus' system
- We perceive red, green and blue colour via our eye's 'cones'
- We perceive overall light level via our eye's 'rods'

The range of visible wavelengths (380 – 700nm) runs from ultra-violet through to infra-red. The much-smaller range of colours that a TV camera can capture are shown.

The range of display'able colours is referred to as the 'gamut' of the system.

D65 is the 'colour of white' that we use for TV.

Russians, Mondrian & Tetrachromats!

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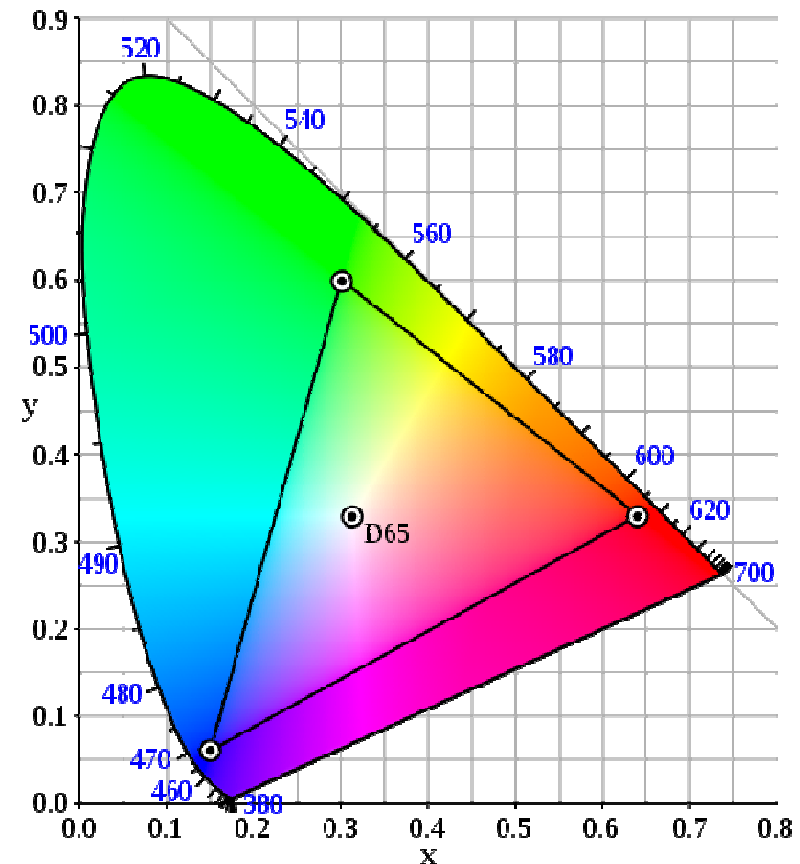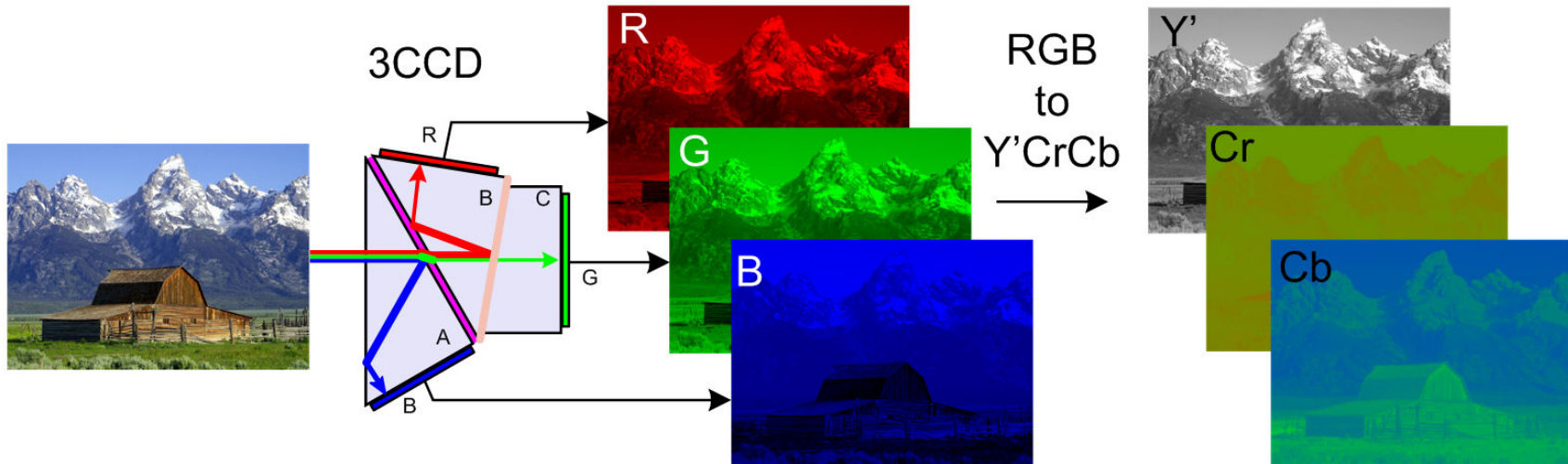
In Television we rarely deal with RGB pictures; pretty much all video we deal with on tape or disk is Y, Cr, Cb (often erroneously called Y U V) encoded – and since the two colour difference channels are only stored at half-data rate we sometime describe this as 4:2:2.

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Video – colour bars

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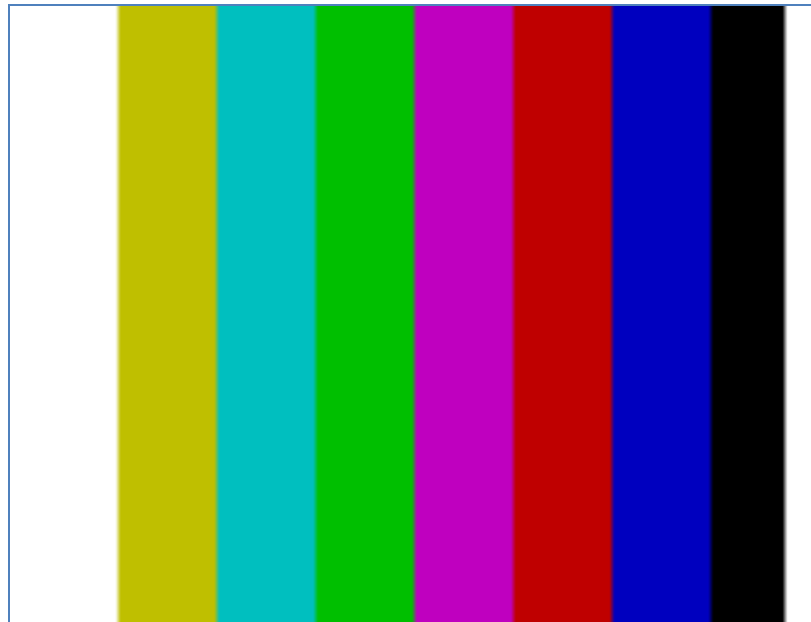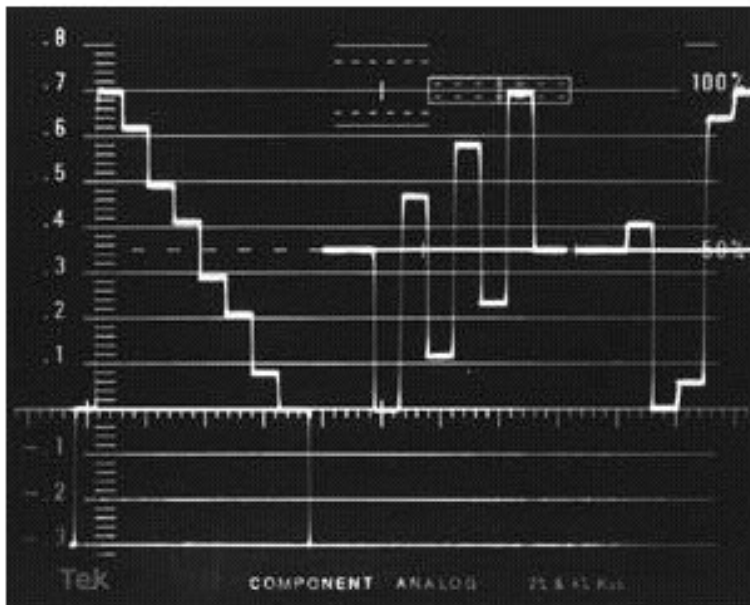
Again – count the number of bars (white through black) and match them to the colour bars on the monitor.

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Colour Systems – 601 colour space

Generation of colour component signals

Y = 0.299R +0.587G +0.114B
Cb = 0.564(B-Y) + 350mV   *(sometimes the U-signal)*
Cr = 0.713(R-Y) + 350mV   *(sometimes the V-signal)*

These equations define how we go from RGB to Y, Cr, Cb (and the reverse would be true).

Rec 709 - New colour primaries defined

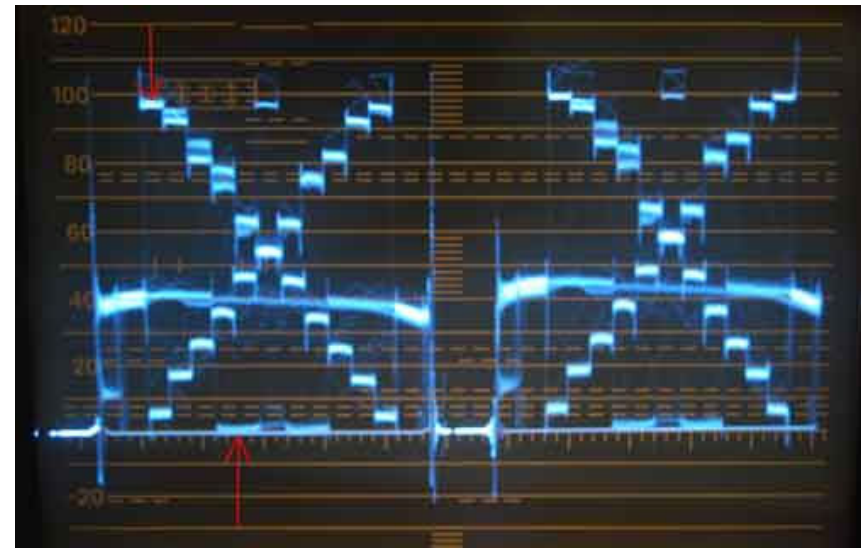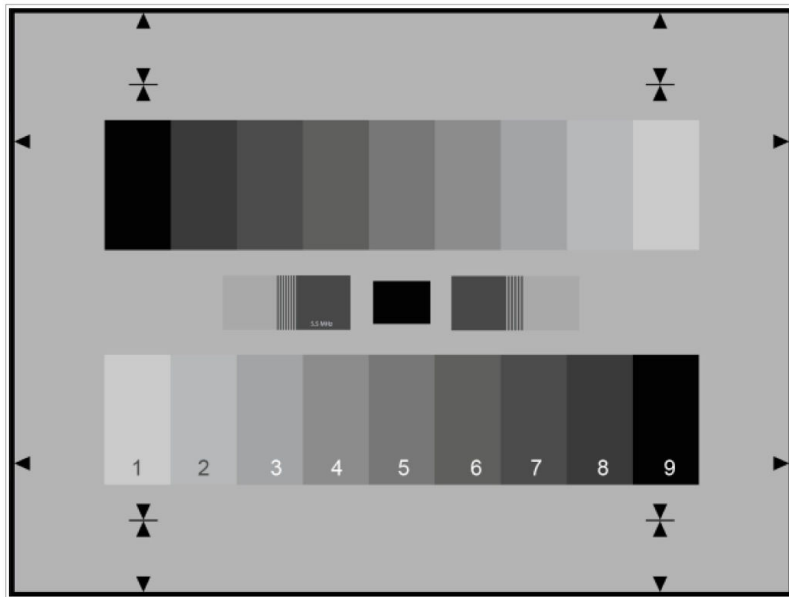Newer display technologies can display a greater range ('gamut').

The upshot of all this is that the RGB -> YUV transform has now changed;

Y   =   0.213R +0.715G +0.072B
Cb =   0.539(B-Y) + 350mV
Cr =   0.635(R-Y) + 350mV

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Studio camera chip chart

Notice the high frequency gratings either side of the 'Gregory Hole'

The studio engineer calibrates the camera for the luminance by neutralising the colour.

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Difference between shading/racking camera/TK and subsequent grading images

CTV's OB1 – up to ten camera control positions.

The racks engineer controls the output of the camera head, adjusting the R, G & B signals before they are digitised/transcoded to Y, Cr, Cb.

The colourist works with the R,G,B or Y,Cr,Cb signals as recorded.

It is better to get cameras matched/production look applied in the studio/OB than try and recover it later.

Colourists can only compromise the dynamic of the pictures.

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Overview and introduction to colour space and gamut

An important aspect of the production/post-production chain is maintaining correct colourimetry. If the director of photography or the lighting-cameraman want that certain shade of red to be correctly delivered to the viewer then attention needs to be paid to the correct representation from the camera (be it standard or high definition or even film) through all transfer operations (potentially going between resolutions, YUV/RGB colour spaces and bit depths) to the final display surface (be it a CRT, LCD or even cinema screen).

Part of the problem is that all of our machines acquire images in the RGB space (TV cameras, Telecines, graphics workstations etc.) but for the most part we post-produce in a YUV space (with the exception of Sony's new HDCam SR format, an RGB high-definition VTR) which represents an immediate lowering of the colour space. This has been the case for a long time and is well understood.

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Calibrating monitors

Small side-note concerning units of luminance

- Lots of folks quote it in Foot Lamberts - terrible measurement!

- It assumes monitors are a point-source of light (they aren't)

- It is a mix of SI (Lambert) and Imperial (foot) measurements

- Far better to use the SI unit of the Candela per square metre.

Practical demo with Klein and DK-LCD probes

- Why 80Cd/m2?

- Why 6504K?

- procedure - remember to use the appropriate probe!

- What requires a test set and what can be done by eye?

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LCD monitors

Since LCD displays have largely displaced CRTs it's worth giving them special attention

- CF backlight or LED backlight?
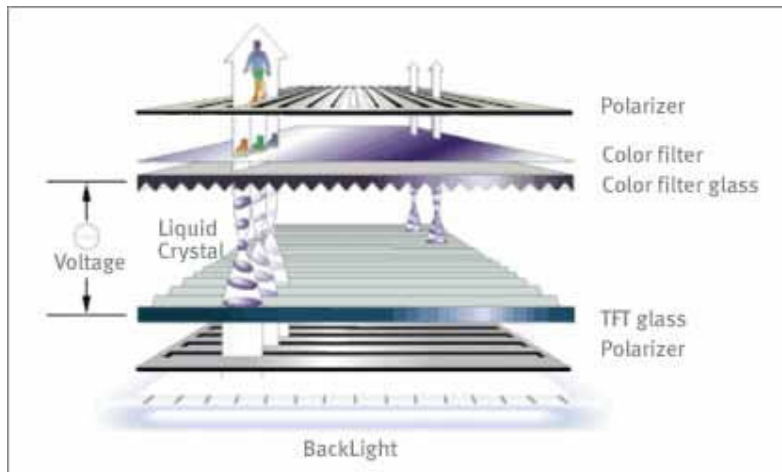
But, for most LCD displays the colour white is made by the backlight and the two orthogonal display elements shut down red/green/blue sub-pixels.

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Myths & Gotchas

- Test signals for monitor calibration aren't hard - 10% gray, 50% grey, 100% peak white, various saturated colour fields, 100% bars and PLUGE allow you to do anything to a monitor that doesn't need the covers taking off and you getting down to component level.

- Cheap USB photometers that claim to cover different display technologies are plain wrong; LCDs, CRTs, Plasma and OLED all have different **metamerisms** - a spectralradiometer is the only gadget that is display-technology agnostic.

- Computer monitors and TVs are not grading displays - the MacBook Pro that I'm typing this on is calibrated using Apple's colour tool to D65 but when I point the PM5639 at it the colour temperature is 7340k at 220Cd/m2 (how wrong can it be for grading work?!)

- LUTs can only decrease the dynamic range of a display device - never improve it. The best thing is to get the display calibrated before you start applying LUTs (and then only to simulate the look of a film stock etc).

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**Spectrum of different display technologies - CRT**
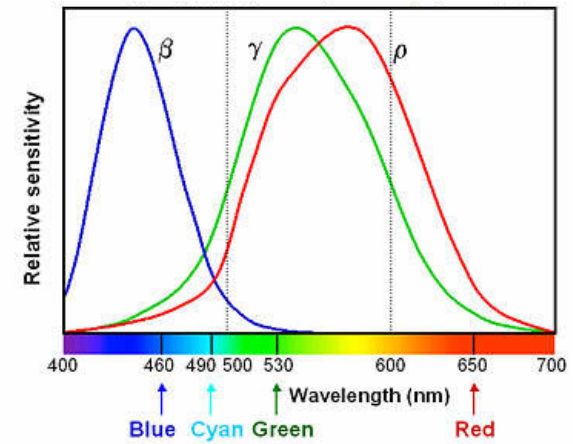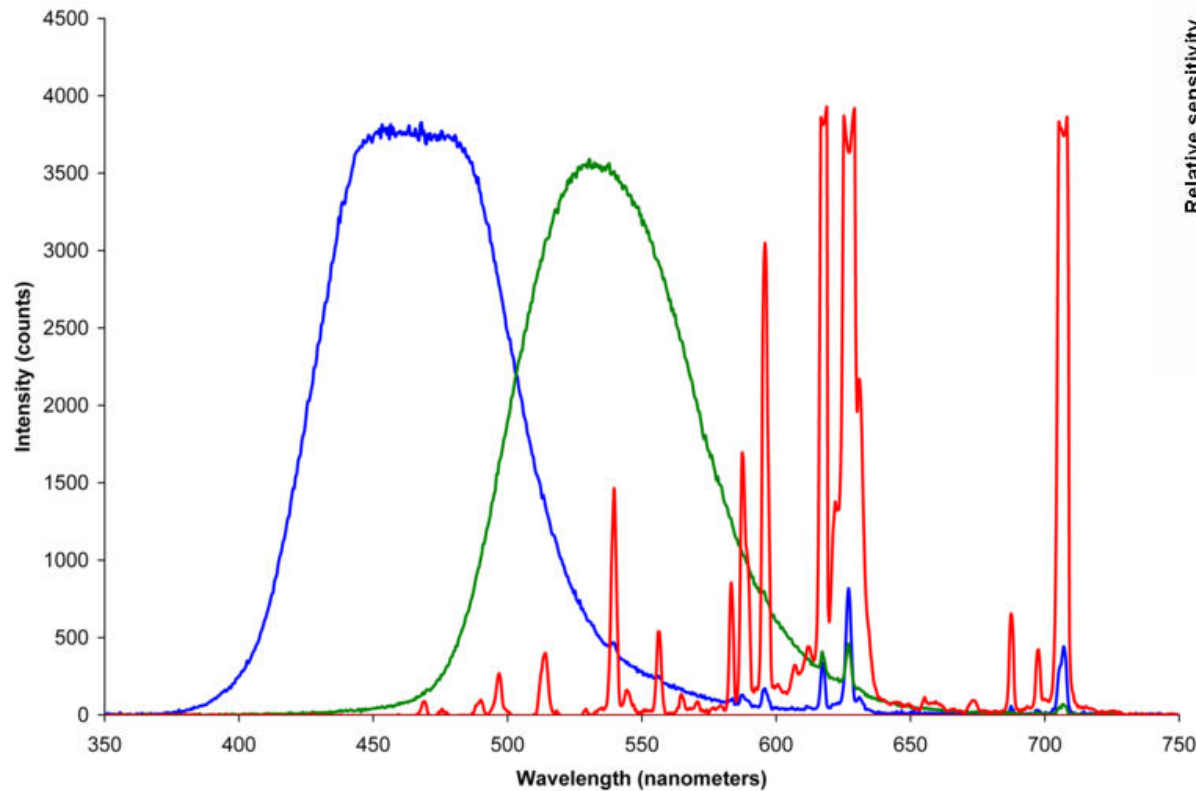
The manufacturer has to *weight* each colour to get an approximate match between the spectrum of their display and human colour perception. This used to be called a *matrix* and is now a 1D LUT.

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How can a photometer be useful for different display types?

The eye's sensitivity curves for its three sensors X, Y and Z:

Klein Filters v.s. CIE

Legend:
- CIE (X2)
- Klein (X2)
- CIE (Y)
- Klein (Y)
- CIE (Z)
- Klein (Z)

Wavelength (Nm)
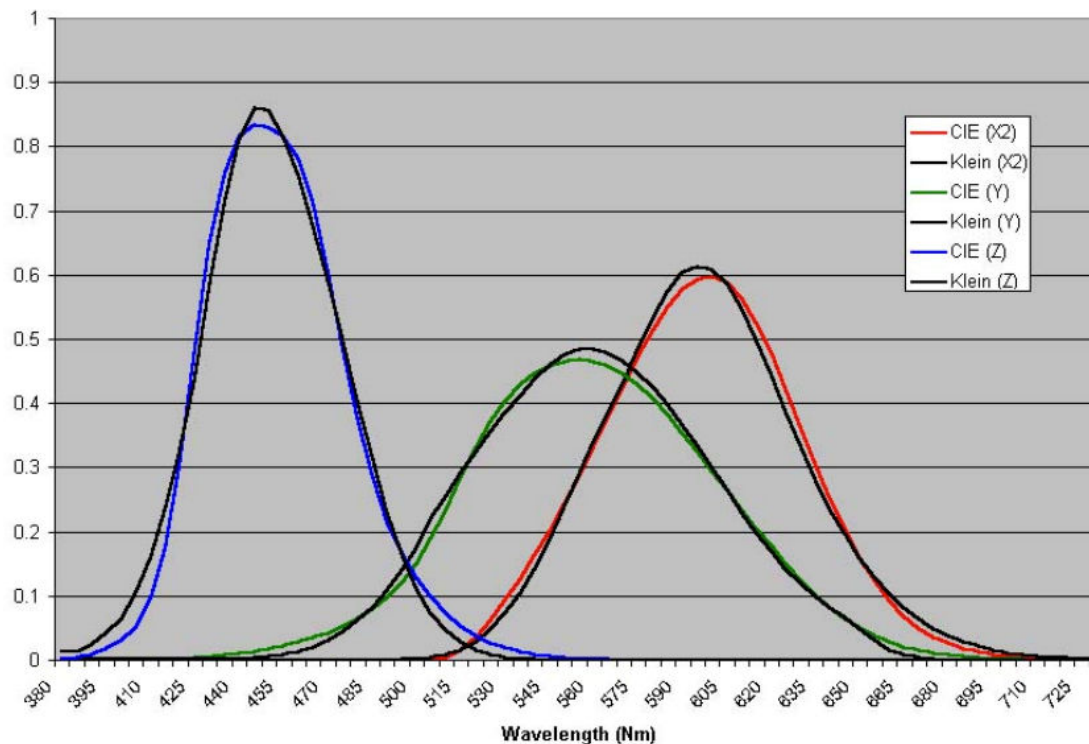
The Klein KT-10A is unusual amongst photometers (R,G,B tri-stimulus probes) in that it very closely mimics the response of the human eye. It therefore suffers the same metameristic failure as human vision and not a particular display technology.

It is the only photometer (i.e. sub £20k gadget!) that does this – all others are made to match the metamers of a particular display technology (CRT, LCD etc).

Within constraints we can use the Klein the measure all monitors without the expense of a spectralradiometer (typ. Photo Research PR655 etc)

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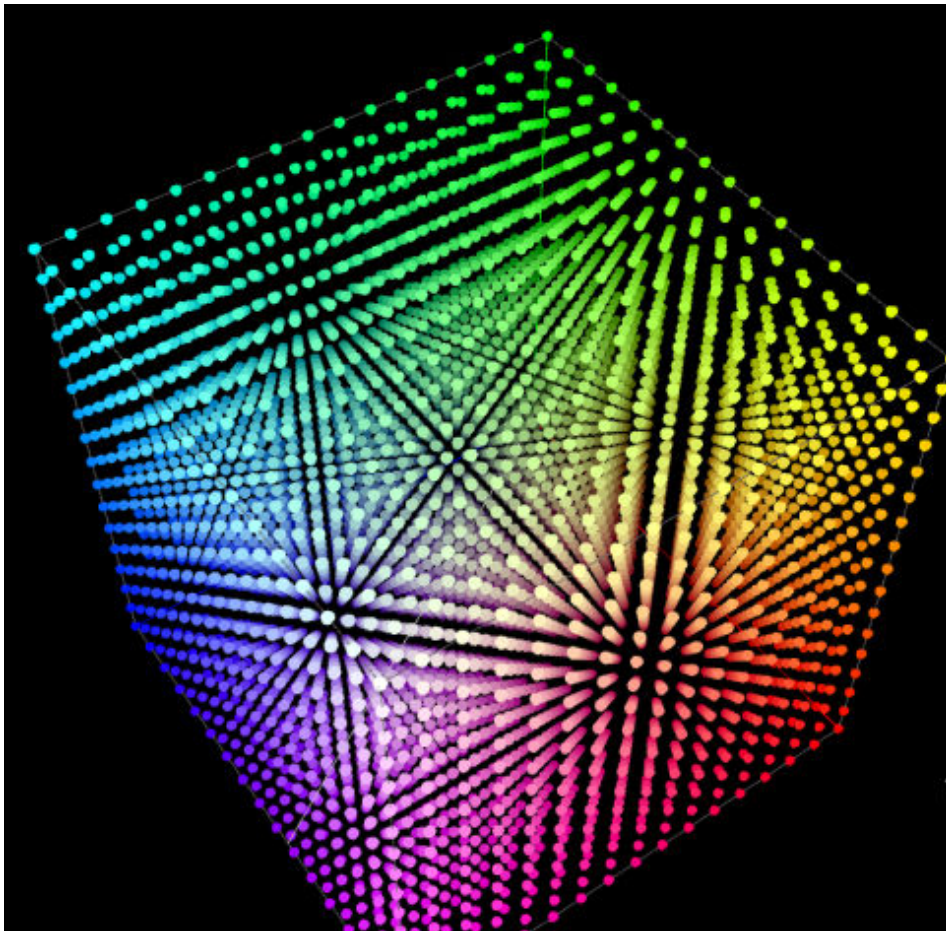
3D LUT

Essentially a set of 1D LUTs for every permutation of RGB values.

Assume 12-bit video

So, a full 3D LUT would be;

2^{12} x 2^{12} x 2^{12} = 6.8 x10^{10}

Or, nearly seventy giga 12-bit words or approx. 100Gbytes of data!

Most 3D LUTs don't map the colour space directly, they use every 20th value (or so) and "smooth" for the values between.

3D LUTs are useful for matching a monitor to a film stock for look, but you have to have a calibrated monitor to start with.

Remember – LUTs can only compromise the dynamic range of a display.

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![root6 technology for the creative]

The future!

ITU Rec.2020 is the document that covers 4k & 8K (AKA "UHD TV).
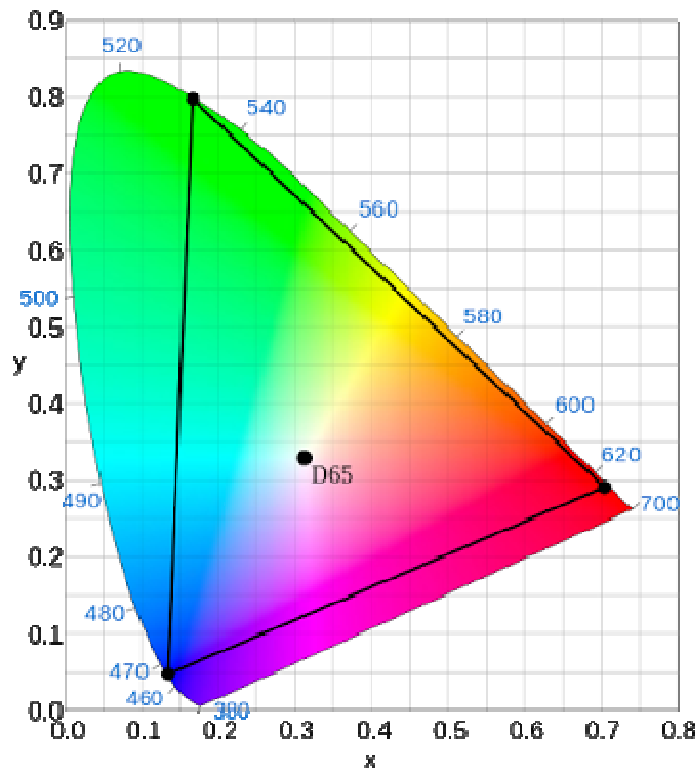
The colour space is monstrous! The 2020 triangle is even bigger than the P3 colour space (as defined by the DCI) - It'll be a while before ANY display device can faithfully reproduce that gamut.

red: 0.708, 0.292

green: 0.170, 0.797

blue: 0.131, 0.046

white: 0.3127, 0.3290

The new luma transfer function
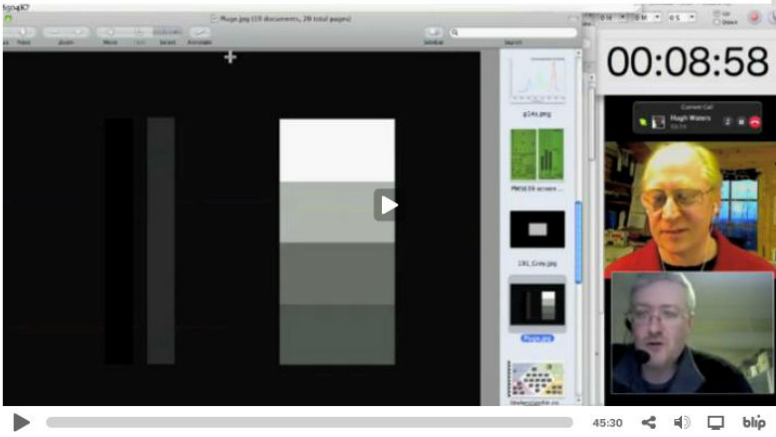
$Y' = 0.2627\ R = 0.6780\ G + 0.0593\ B$

For the first time ever in television an allowance for constant luminance is included.

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Resources

Phil's technical blog

Broadcast engineering and IT related links and stuff. Maybe some music, films and other things.

Friday, March 23, 2012

Colourimetry 2 - Calibrating monitors for TV

00:08:58

Links

Places to find Phil on the web

@IsItBroke on Twitter

Phil's broadcast engineer podcasts

When you can measure what you are speaking about, and express it in numbers, you can know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science.

William Thompson, Lord Kelvin.

After the intro to colourimetry Hugh and I talk about calibrating monitors for film and TV use. Also on iTunes.

Posted by Phil Crawley at 00:07
Labels: colourimetry, EngineersBench, podcasts, television

Twitter feed

`http://tinyurl.com/TVcolour`

Video podcasts and notes from your truly.

`http://www.belle-nuit.com/test-chart`

An excellent colour workflow tool.

`http://tinyurl.com/EizoColour`

Eizo colour handbook – free download.

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