Full Gamut Colorimetry Proposal for DC28.2

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Background

Photometric response is described and plotted on the CIE (x,y) diagrams or converted to u'v' space. A plot of the spectral points is shown along with various tri-stimulus points enclosing increasing amounts of the visible color space.

The full gamut is described by the line connecting the spectral locus and is closed by the "line of Purples". All colors, within the range of human vision as defined by the CIE standard observer, lie within this horseshoe shaped curve.

Tri-stimulus response is referenced from defined primary reference points are used to describe any point that is within the horseshoe range of visible colors. The most commonly used reference points are the points described in ITU-R BT. 709-2 "709" recommendation for High Definition Television (HDTV). Older television systems use tri-stimulus point RGB that lie close to the 709 primaries.

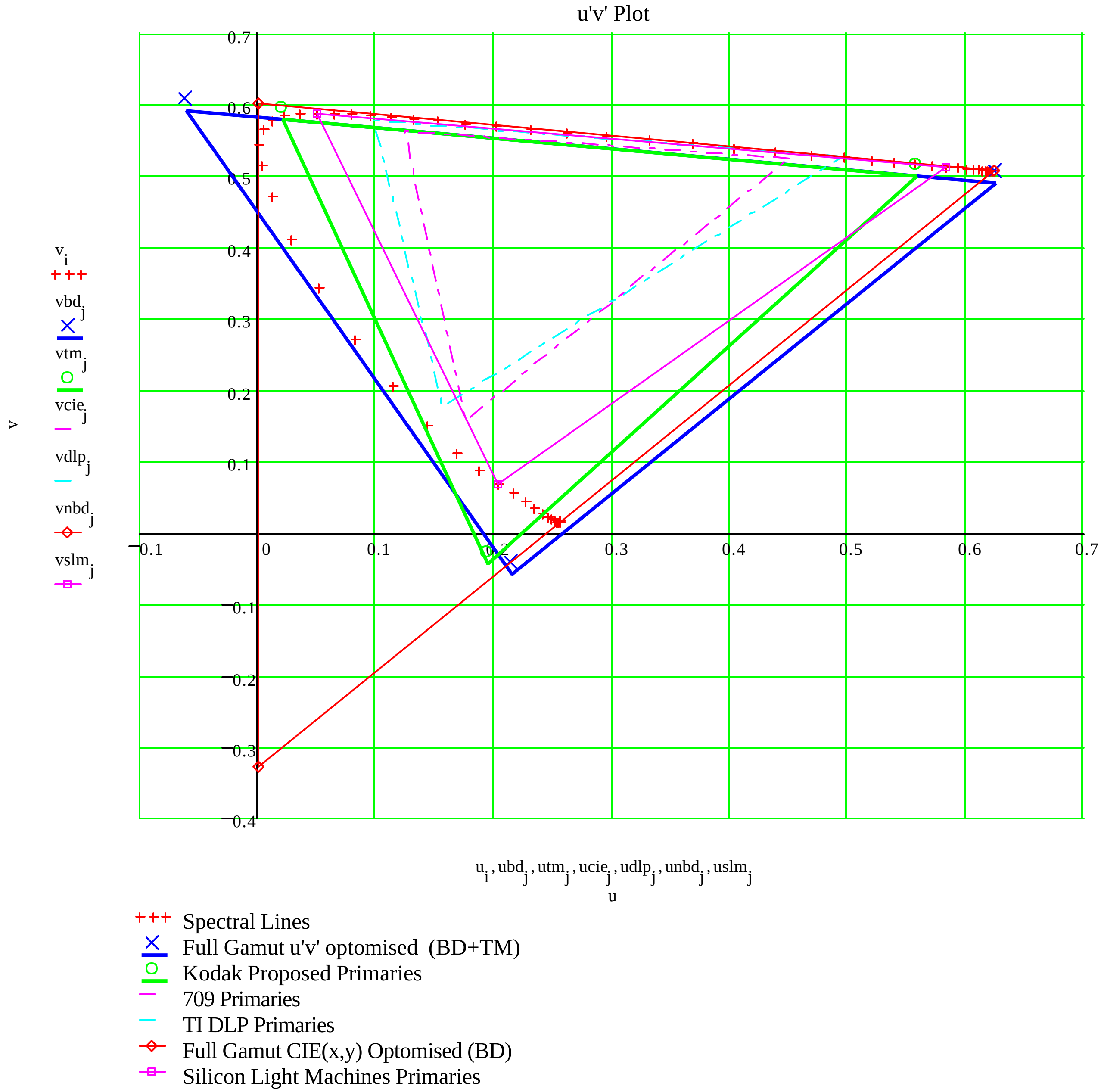
Color film's gamut slightly exceeds the 709's gamut as shown by Chuck Harrison in his well written earlier paper on the subject.

The TI DLP projector, with its primaries, exceed the 709 gamut as shown in the u'v' and xy plots in the attached figures. The Silicon Light Machine's stated primaries cover almost twice the area (gamut) covered by 709 primaries as can be seen in the figures.

Tom Maier, Glen Kennel and Mitch Bogdanowicz of Eastman Kodak extended the gamut farther in their proposal "Colorimetry for Digital Cinema" dated March 14, 2000 and presented to DC28.2 at the March 20 meeting. This extension covered a still larger gamut but does not include some of the colors that can be produced by the Silicon Light Machines projector.

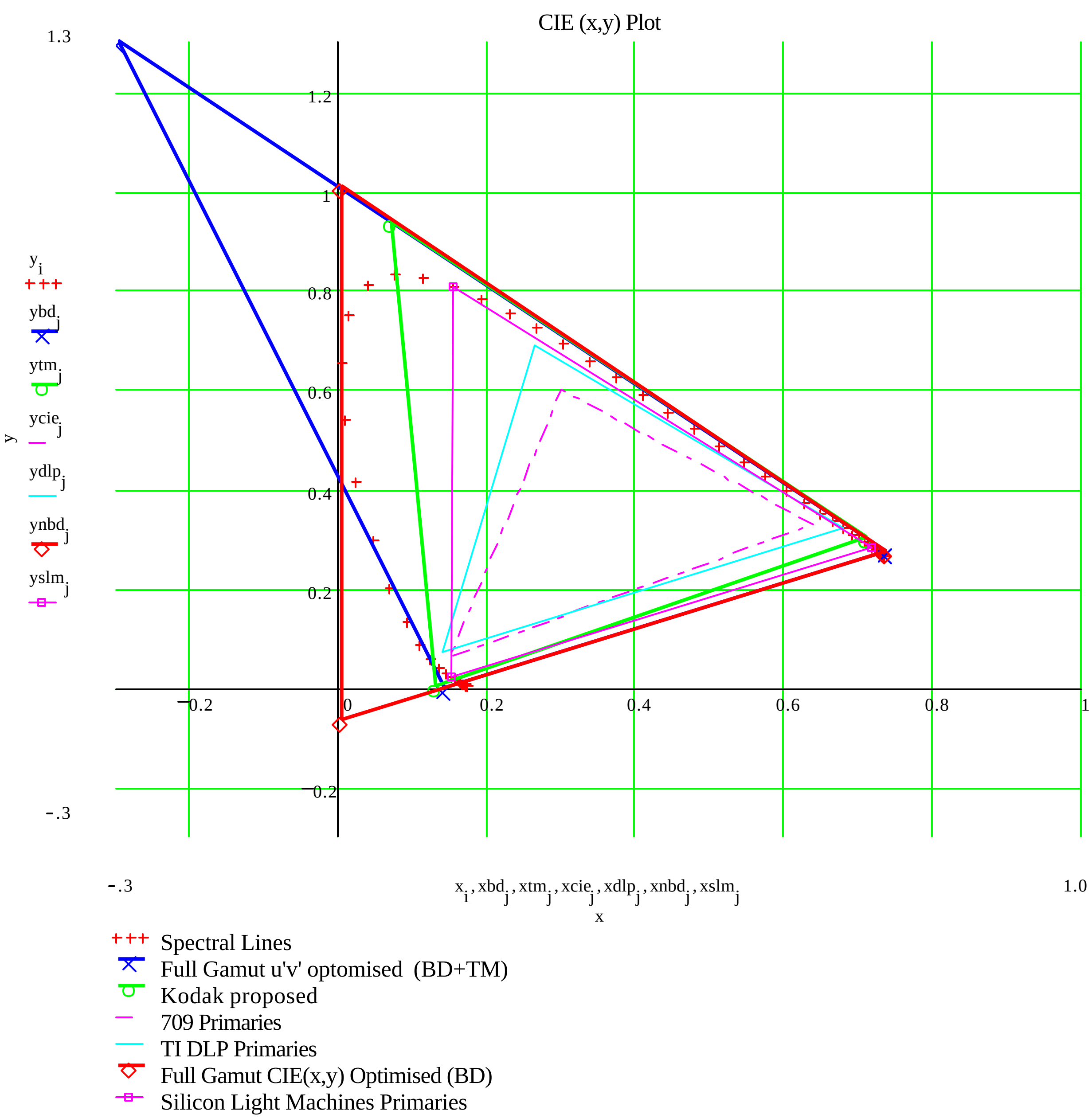
Continued Developments

Following the Kodak presentation, I asked Tom Maier about extending his red-green line to intersect the red-blue "line of purples" and to create a line tangential to the green–blue line of spectral locus points to cover the entire visible gamut with minimum area external to the area of visible color. This he did and his result is plotted in with the "x" point or blue on the color graph. This area is slightly larger than Kodak's proposal and is the minimum tri-stimulus primaries that can display the visible color space to the CIE standard observer.



In converting this set of u'v' primaries back to CIE (x,y) space, the resulting area appears to cover more area outside of the full set of visible colors although the this is a simple mathematical transform. Plotting the minimum space in the CIE (x,y) diagram shows the more optimum points makes use of the y axis as the green-blue line. Using the vertical axis in the CIE (x,y) diagram should provide easier transforms to projector color space.

Full Gamut Colorimetry Proposal



Proposal

For Digital Cinema using tri-stimulus system, the three primary points be defined in CIE (x,y) diagram as follows:

Digital Cinema Primaries	x	y	u’ equiv	v’ equiv
DCRed	0.7348	0.2653	0.6235	0.50651
DCGreen	0.0000	1.0000	0.0000	0.60000
DCBlue	0.0000	-0.0758	0.0000	-0.32635
White – Director Choice	-	-	-	-

Should the DC28.2 Colorimetry subcommittee choose to use the u'v' plotting space as the definition of the color space then the choice should be optimized for that space as follows:

Digital Cinema Primaries	u'	v'	x equiv	y equiv
DCRed	0.62341	0.50652	0.7348	0.2653
DCGreen	-0.06255	0.60887	-0.2990	1.2936
DCBlue	0.21455	-0.04011	0.1386	-0.0115
White – Directors Choice	-	-	-	-

This proposal provides for the description using tri-stimulus system for all light visible to the CIE standard observer. The gamut of the various projection and display systems are improving and will surely cover the entire space in the near future.

Either of these systems will enable the Digital Cinema to pass the Hummingbird test.

Radiometric and Photometric Domains

The difference between radiometric, spectral power distribution, and photometric, tri-stimulus, image information is the application of CIE eye response estimations to radiometric data converting it to the CIE photometric responses.

The human eye converts radiometric energy inputs to optical nerve response as part of the seeing process. The reason for conversion from radiometric to photometric quantities is to limit the amount of stored and transported information to that most likely to be perceived by the eye as determined by the CIE standard observer research.

While expanding the color gamut, we should also expand the representation of the data to better represent the illuminant in either tri-stimulus or radiometric measurements. Previous tri-stimulus systems for television used 8 bit representations for each of the RBG primaries. Some of the home systems compressed this down to 16 bits total for all three primaries. Current HDTV systems are standardized at 10 bits each for RGB converted to Non-linear DC offset R'G'B' to save bandwidth. Sub-sampling of the Chroma to 4:2:2 is used for SMPTE 274M/292M again to save bandwidth by throwing away half of the color information.

Film conversions via telecine now read up to 14 bit linear conversions. Although most CCD scanners could do more it would probably not be useful based on the chemistry of the film.

The Cineon scale covers a film density range of a little more than 100:1 with a D=2.048, the soft clip range on each end of the scale gives us a 90% white at 685 and 1% black at 95 for a 595 code values for majority of the range. Including the effects of soft clipping, the formula for the center of this curve is approximately codevalue = -500(Log(Density)). This is considered to be full coverage for the density of the motion picture film. A range of 100:1 is a 40db range.

The CCD cameras, and other new sensors that will be used in Digital Cinema, currently have a dynamic range from 70 to 87db Signal+Noise/Noise ratio for the light incident on the sensor. If some of the noise can be removed, with new designs and techniques, the signal to noise ratio will extend beyond 100db. CCD's, or other sensors, can also be calibrated in units of illumination and provide better information than film can about the scene. To linearly represent the dynamic range of the new CCD cameras would require a 20+ bit linear converter. Technology will only improve this camera capability. Sensitivities in many of these camera devices is measured in individual electrons at 10 to 15 uV per electron and with a average quantum efficiency in the 33% range from the photons providing the ultimate low end of the potential light range available now.

A linear response from a camera will grow from the current 12-14 bits to more than 20 bits with time; we should consider the dynamic range of the video signal to be potentially greater than 100db possibly more than 120db. If we restrict the data to 16 bits, initially, for processing ease, we can approach and exceed the capabilities of the human eye to view a scene with eye adaptation. Using a log representation keeps an equal set of potential code values within each decade as was mostly implemented by the Cineon scale with 500 log code values to each decade of density. Using 16 bits for the value and covering 10 decades of signal we can achieve 65536/10 code values per decade, or about 13 times the resolution of the Cineon scale. With these code values referenced to micro-lumens an appropriate scale for spectral power distribution is created for use in recording the information from the camera prior to post production lighting modifications and CGI manipulations.

Proposal for coding values of light intensity for Digital Cinema:

Linear coding using a 16 bit (two byte) value initially with extension to 24 bit, or larger field, as needed in the future. This coding would be used in the same way that the current 8, 10 and 12 bit coding is used.

Log coding should be used for extended dynamic range using 16 bit binary code value defined as the Log of the illuminance as measured in Lumens x 10^{-6} (micro-lumens). This provides a method of recording the spectral power distribution radiometric measurements as well as Tri-stimulus photometric values

DCilluminance (0-FFFF) = 6553.6(Log(Illuminance in micro-Lumens)).

This set of DCilluminance values will provide a linear mode for calculations and a log mode that can be used for absolute reference level for interchange.

Appendix

The following calculations do not include the effect of lenses, filters, splitters, irises, or other real world attachments and are solely to show the present capabilities of the camera CCD devices. Using Kodak's KAF-6303E 6megapixel CCD, as an example of a slower device, the calculations for a photon/sec/pixel is: 3.58xe-19 joules per photon(555nm) x 673 lumens/watt x 1.23e+10 pixel/meter^2 = 2.97e-6 lumens/meter^2. Saturation would be 0.3 Lumens/meter^2. Clearly at high frame rates these numbers change with the frame rate. The calculations are similar for the 1920x1080 arrays except for the 24/48 frame per second rate the raises the saturation range by 48.