EBU

OPERATING EUROVISION AND EURORADIO

TECH 3353

DEVELOPMENT OF A “STANDARD” TELEVISION CAMERA MODEL IMPLEMENTED IN THE TLCI-2012

Source: FTV-LED

Geneva
November 2012

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Development of a 'Standard' Television Camera Colour Model implemented in the TLCI-2012

EBU Committee	*First Issued*	*Revised*	*Re-issued*
TC	2012		

Keywords: TLCI-2012, TV Camera Colour Model.

1. Introduction

The introduction of high efficiency light sources such as LEDs, both in TV and film production studios, has revitalised the earlier work done in the 1970s of W.N. Sproson and E.W. Taylor (BBC) on the effects of lighting for television.

Uncritically introducing LED based studio lighting (or other high efficiency non-incandescent light sources) into programme production may introduce colorimetric problems that would need colour correction in post-production. Reports of the current work at IBC 2011 [1] and on the updated work at IBC 2012 [2] gave well-informed insights into what may well be the consequences of using problem luminaires in programme production.

In order to fully realise the proposed Television Lighting Consistency Index, 2012 (TLCI-2012) [3], it is necessary to have information about the spectral sensitivity in modern CCD or CMOS based TV cameras. Work has been undertaken to measure the spectral sensitivity properties of such modern HDTV cameras. The results have enabled the development of the proposal for a 'Standard' Television Camera Colour Model, presented in this document.

Other than requesting data directly from camera manufacturers, the only reliable alternative for obtaining information on the spectral sensitivity for modern CCD/CMOS based broadcast HDTV cameras is to measure the response of the three (RGB) camera channels. This document briefly explains the principles and some details of these measurements and then shows how the results have been used to develop the proposed 'Standard' camera colour model.

2. The 'Fundamental' Measurement Tool

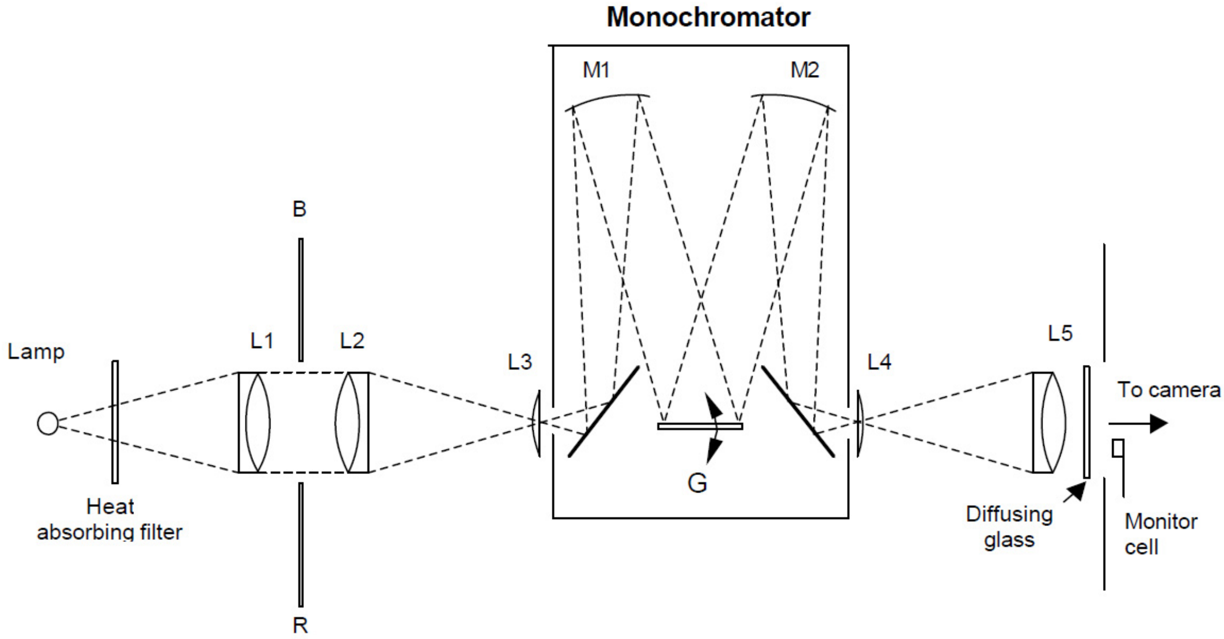

Figure 1: Apparatus for spectrophotometric measurements

Figure 1 illustrates the optical arrangement needed for the spectrophotometer, which can be built from standard optical components. An ordinary Tungsten Halogen lamp and a grating-monochromator make up a tuneable light source that produces a narrow-band beam of light (almost pure spectral colour) from the output slit. This beam illuminates a small piece of ground glass for the camera to "see". A photocell attached to the diffusing glass measures the (relative) intensity of the illuminated spot. This information is essential for the subsequent calculations. The responsivity of this monitoring cell has been established by comparing its output with that from a calibrated silicon photodiode, illustrated in Figure 2.

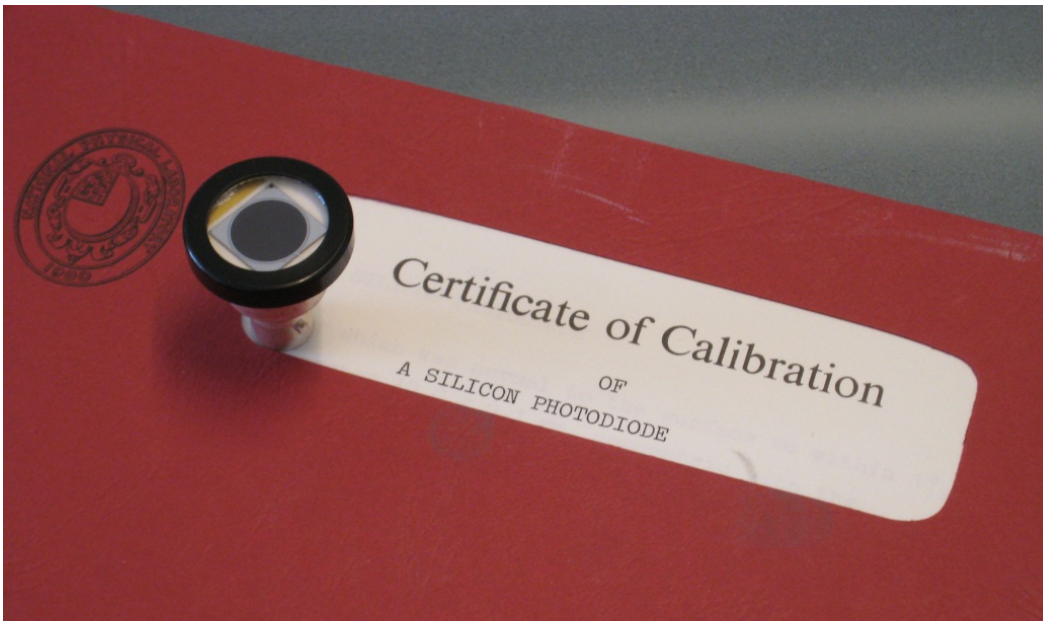

Figure 2: The reference photodiode and calibration data

A stroke of luck was that such an 'instrument' had been built by the NRK many years ago (late 1970s) in connection with EBU work regarding the characterisation of the colour reproduction properties of TV cameras [4]. It was known from experience of this work that such a setup gave the required information about the spectral sensitivity of cameras, and with the required precision. In addition it should be mentioned that this gear had not been disposed of decades ago after the EBU work on camera colorimetry was completed.

However, at the time this 'instrument' was first put into use there were no computers or automation tools easily available to make these kinds of measurement automatically. And with the resurrection of this device in 2011 it was not worth the time, cost and effort to redesign it into an automated instrument. Figures 3 and 4 give an impression of the setup.

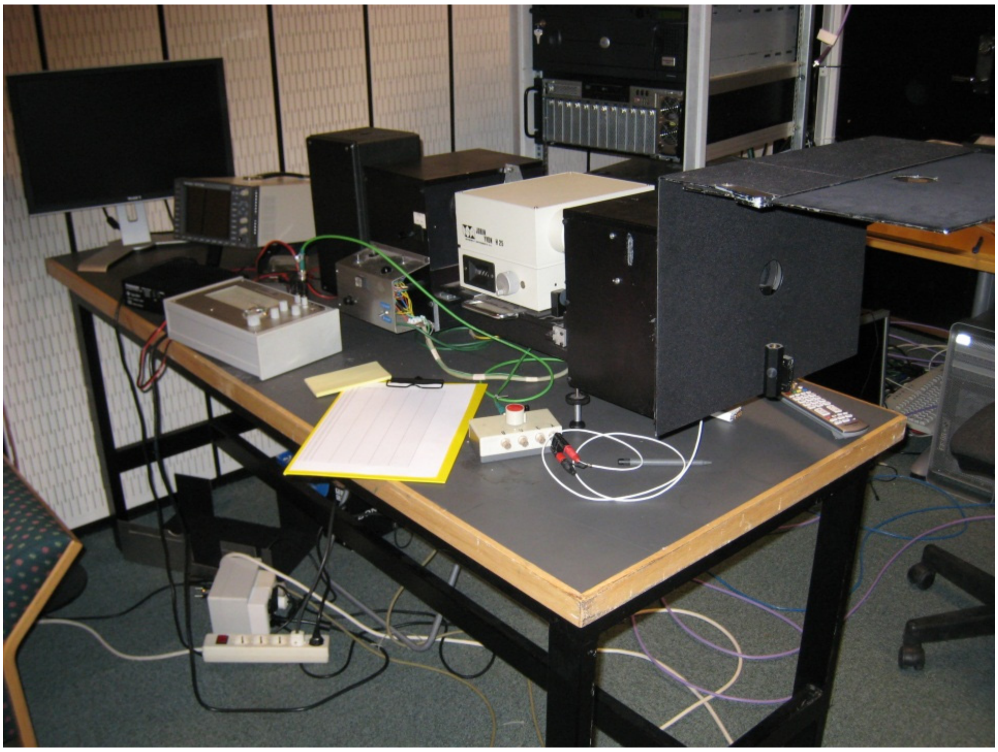

Figure 3: Camera measurement "rig"

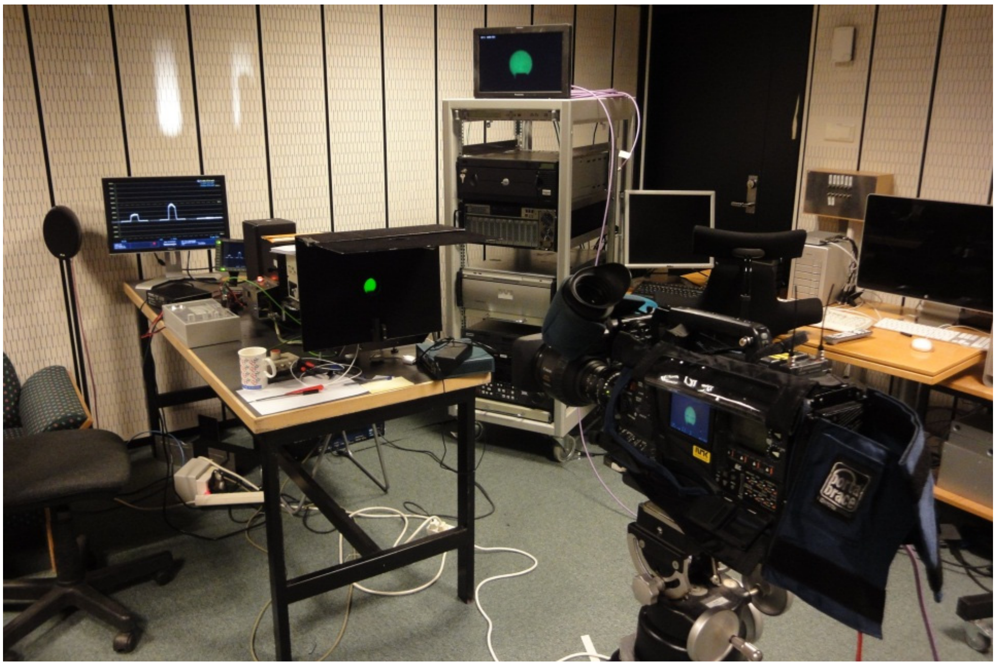

Figure 4: A camera being measured

3. General spectrophotometric properties in TV cameras

In referring to the papers presented at IBC 2011 by A. Roberts [1] and at IBC 2012 by P. Böhler [2], a repetition of the TLCI block diagram, shown in Figure 5, will be useful for the subsequent descriptions.

In 2011, the only available camera curves were those obtained from Plumbicon tube cameras and CCD cameras in the 1980s. It must be noted that the ideal camera spectral sensitivity curves are defined by the display primaries, but that such curves are not easily achieved in practice. In order to have consistent colour reproduction properties in colour TV the display primaries were standardised at an early stage in the development of colour television. Much of the work leading up to this standardisation of European Colour TV took place within the BBC around 1970 and later in the 1980s [5], [6] and [7]. Reference [5] shows a set of 'ideal' camera spectral analysis curves.

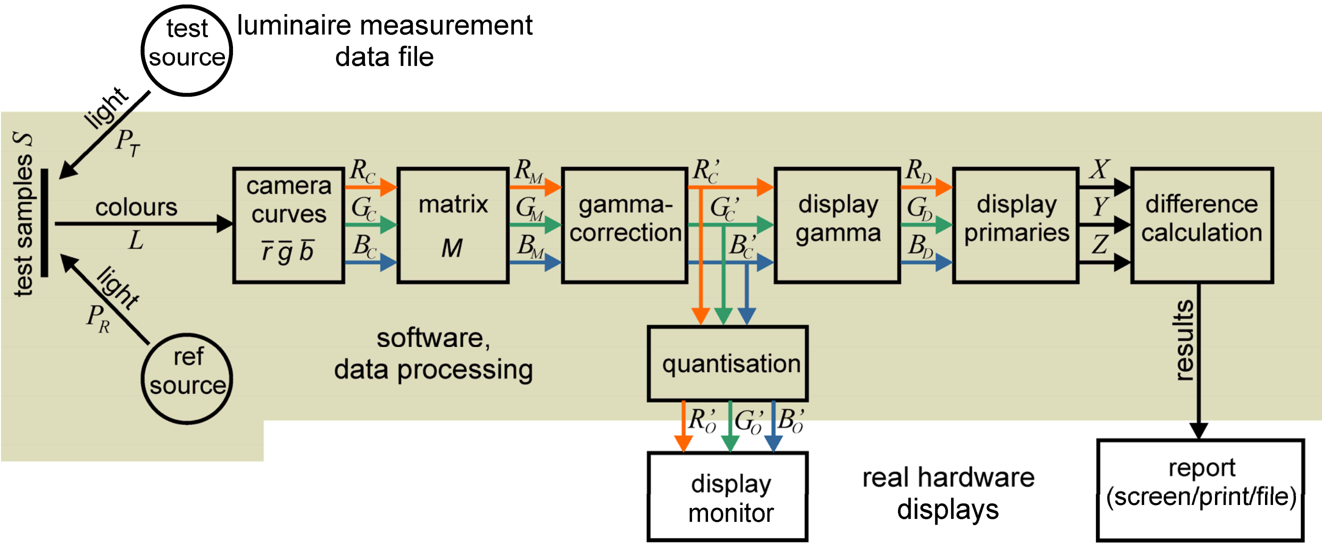

Figure 5: "TLCI" block diagram

Consequently all TV programme archives around the world hold programme material produced with such cameras. For this reason it is important that modern cameras have the same colour reproduction properties. Today however, the sensors used in TV cameras are based on silicon using either CCD or CMOS technologies.

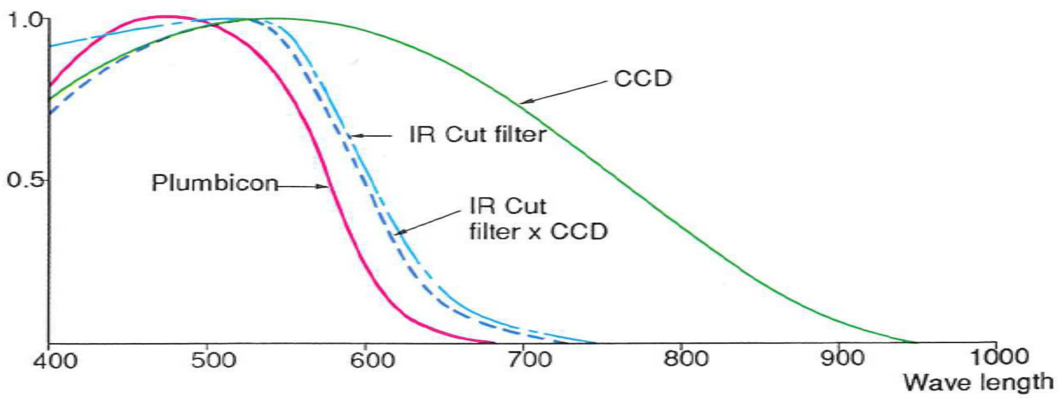

Figure 6: Spectral sensitivity of camera tubes vs. CCD sensors

As Figure 6 shows, there is a considerable difference in spectral sensitivity between Plumbicon tubes and the current sensors. Consequently the colour separation system (colour filtering) in modern TV cameras will have to be quite different from the older technology in order to approximate to the ideal response characteristics for our TV system. In order to be as close as possible to the practical world in our proposal for a TLCI [2] it has been necessary to investigate modern HDTV cameras and measure their spectral sensitivity properties. In particular the

CCD/CMOS sensors are highly sensitive to the near infrared part of the spectrum, and so it is crucially important to carefully control this part of the spectrum in any high quality camera for a controlled colour reproduction and to avoid "false colours".

4. Optical systems in modern cameras

Figure 7 illustrates in some detail the optical design and the elements that influence the final spectral response in each of the RGB signal channels. The main elements shaping the response curves in each channel are the dichroic coating reflection filters for blue and red in combination with the trimming filters in front of each sensor. In addition the infrared cut filter shapes the red response at the long wavelength end for the reason described above. For a more detailed description, see [8].

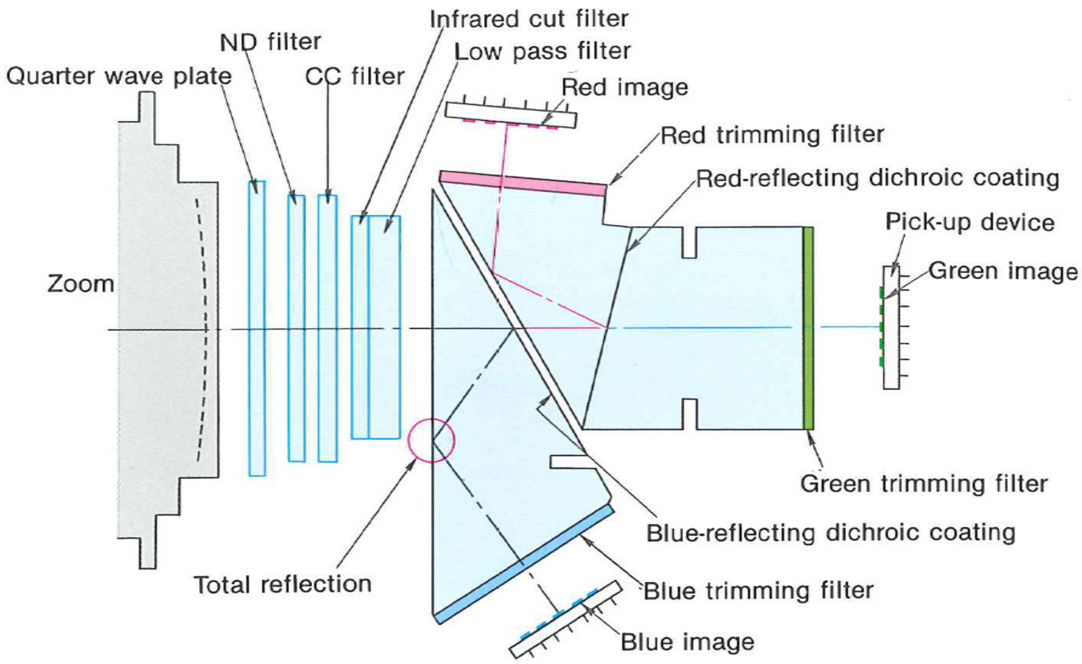

Figure 7: Optical elements in a modern TV camera

5. Measurements and computations

Due to the "spiky" nature of LED spectra, all measurements are taken at 5nm intervals. In addition to the RGB video outputs the spectral power output from the monochromator is measured on the diffusing glass (on the "camera side"). The calibration values for this monitoring photocell is related to the responsivity of another photodiode calibrated by NPL (Teddington, UK) and a "Power Correction Factor" ($Pcf_{(\lambda)}$) for the monitoring photocell can be worked out [1; Supplement 1].

During the process of establishing the $P_{cf(\lambda)}$ the calibrated photocell is placed on the diffusing glass and readings are taken from both photocells simultaneously.

$$P_{cf(\lambda)} = Cal_{(\lambda)} * M_{cal(\lambda)}/Ref_{c(\lambda)}$$

Where $Cal_{(\lambda)}$, $M_{cal(\lambda)}$ and $Ref_{c(\lambda)}$ are respectively relative Calibration values, Monitoring cell outputs and Reference photodiode outputs.

The measured camera signals $R_{m(\lambda)}$, $G_{m(\lambda)}$, $B_{m(\lambda)}$ for the monochromatic radiations are corrected for zero lift (black level) conditions.

$$R_{l(\lambda)} = R_{m(\lambda)} - R(b)\ ,\ \ G_{l(\lambda)} = G_{m(\lambda)} - G(b)\ ,\ \ B_{l(\lambda)} = B_{m(\lambda)} - B(b)$$

Where R(b), G(b), B(b) are the measured black level values. These corrected values are then further corrected for variation of power level with wavelength at the monochromator output ($R_{corr(\lambda)}$, $G_{corr(\lambda)}$, $B_{corr(\lambda)}$) and the calculated output from each of the camera channels for an equal energy spectrum then becomes:

$$R_{corr(\lambda)} = R * P_{cf(\lambda)} / M_{c(\lambda)}$$

$$G_{corr(\lambda)} = G_{I(\lambda)} * P_{cf(\lambda)} / M_{c(\lambda)}$$

$$B_{corr(\lambda)} = B_{I(\lambda)} * P_{cf(\lambda)}) / M_{c(\lambda)}$$

Where $M_{c(\lambda)}$ is the monochromator output power during camera measurements taking into account the variations in radiated power from the lamp due to lamp aging and differences between individual lamps.

The normalised values for Rn, Gn and Bn outputs respectively are:

$$Rn(\lambda) = \frac{Rcorr(\lambda)}{\sum_{\lambda=380nm}^{770nm} Rcorr(\lambda)}$$

$$Gn(\lambda) = \frac{Gcorr(\lambda)}{\sum_{\lambda=380nm}^{770nm} Gcorr(\lambda)}$$

$$Bn(\lambda) = \frac{Bcorr(\lambda)}{\sum_{\lambda=380nm}^{770nm} Bcorr(\lambda)}$$

Figure 8 shows results after the described process for a typical HDTV camera used today by broadcasters and production houses all over the world.

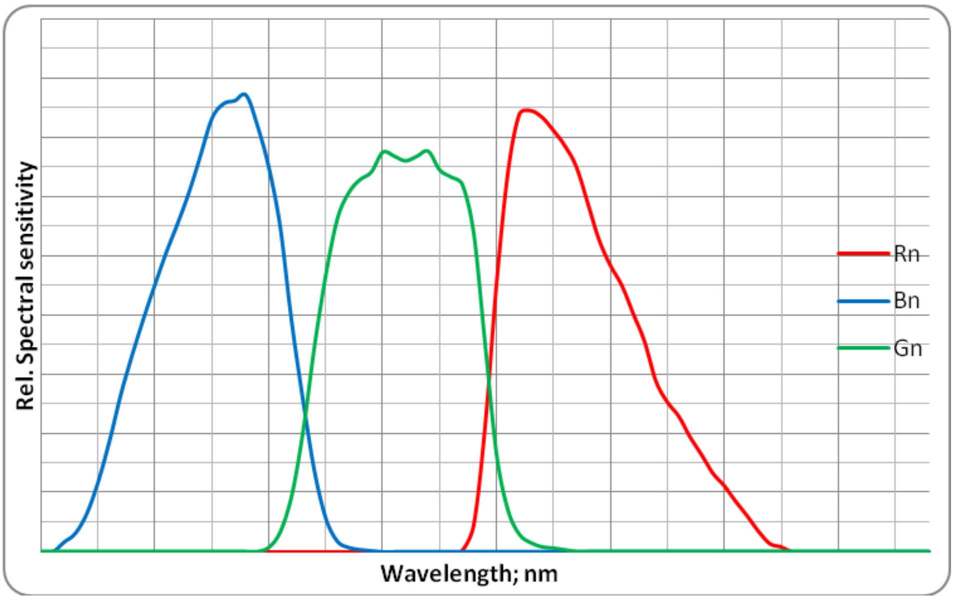

Figure 8: Typical normalised spectral response in a modern HDTV camera

6. Towards a Standard Television Camera Colour Model

Currently nine different camera models have been measured. They are all professional broadcast HDTV cameras with 3 CCD sensors and they are from several different manufacturers. Where possible, several different cameras of each model have been measured more than once in order to detect measurement errors, but also to make averages for "smoother" value sets. For obvious reasons, no camera will be identified here either by type or by manufacturer, see Figure 9.

From all the data collected to date it has become clear that there are only relatively small differences between types and manufacturers. In many respects this is reassuring in the sense that the proposed "camera model" has almost negligible differences from the practical cameras that broadcasters use. Indeed, the calculations and subjective tests with the most suitable CIE (Commission international d`éclairage/International commission on illumination) colour difference metrics (CIEDE2000) confirm this.

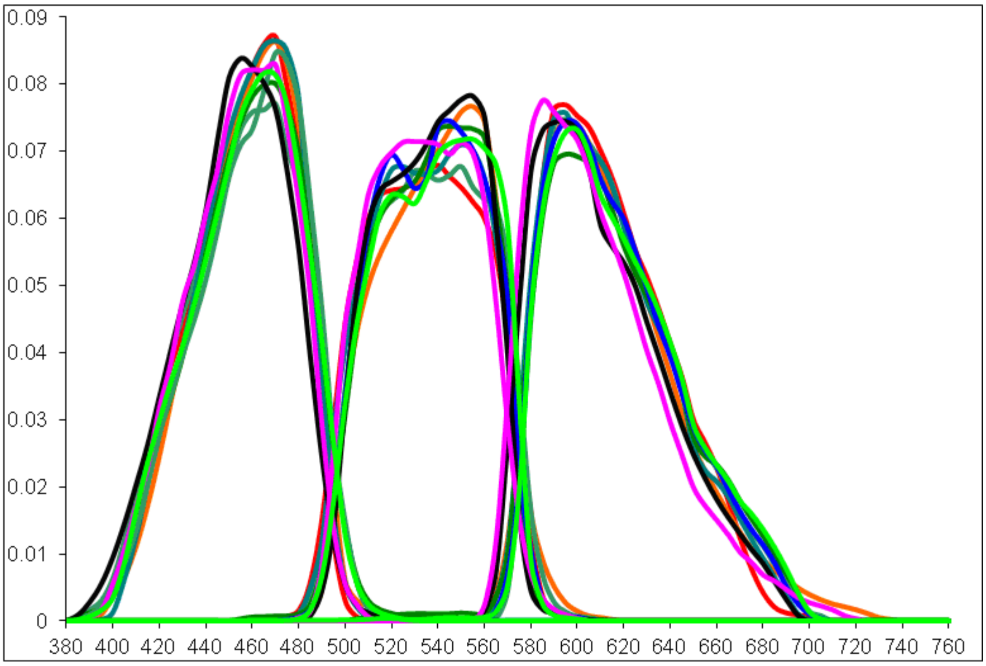

Figure 9: Spectral sensitivity of nine different cameras from three manufacturers

From the work described in references [5] and [7] some critical parameters for the camera spectral sensitivity curves are the wavelengths for the crossover points of the blue/green and the green/red sensitivities and the wavelength for maximum sensitivity in the RGB channels. The crossover wavelength for Blue-Green is 492 ± 2nm and 570 ± 2nm for Green-Red. The peaks should be at 604 ± 5nm, 535 ± 5nm and 452 ± 5nm for RGB respectively. All tested cameras are within these ranges or nearly so. The deviations, where they occur, do not create problems of a significant nature. Subsequent calculations on individual camera responses have verified this assumption. It is on this background and on the basis of the calculated colour errors that the standard camera model can be represented by the "smoothed" average of all measured cameras, including data from single chip CMOS cameras, as shown in Figure 10.

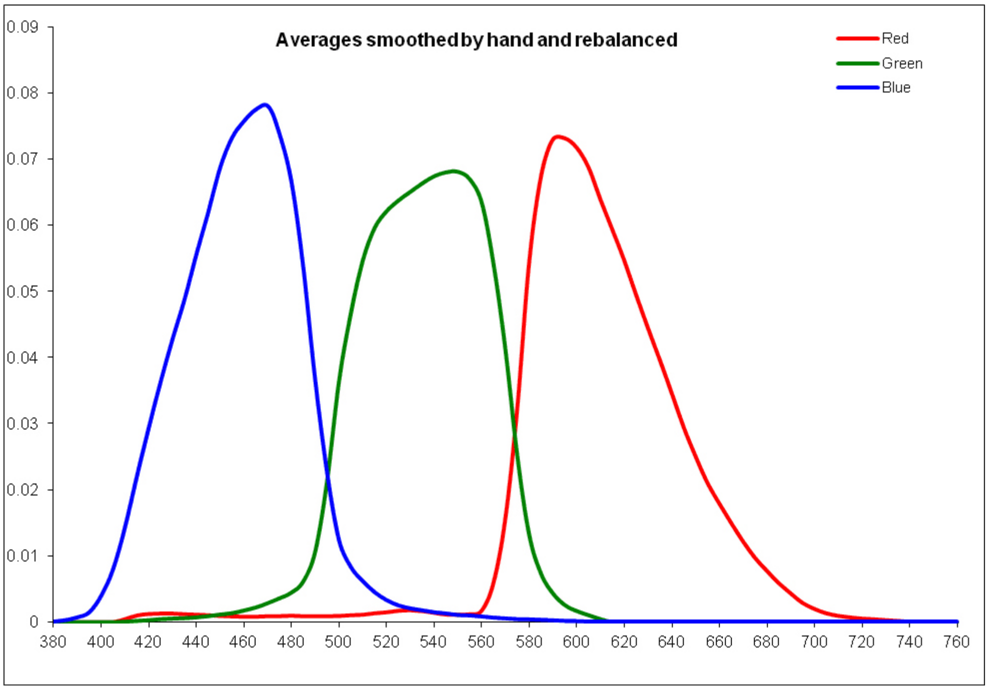

Figure 10: Proposed "Standard" Television Camera Colour Model

The curves shown include the effect of the lens and represent the spectral responsivity (without any colour matrixing) being computationally balanced for an equal energy spectrum. The effect of the lens (any modern lens) is negligible as today's multilayer anti reflection coatings for all practical purposes give a 'flat' spectral transmission curve in the visible part of the spectrum [8].

Normally cameras need a linear colour correction matrix to improve colour rendition. In Figure 11 the spectral sensitivity is shown after a linear matrix has been applied to the "Standard" camera. Figure 12 shows the resulting chromaticity diagram for a ColorChecker® test chart, for an assumed-linear camera and display.

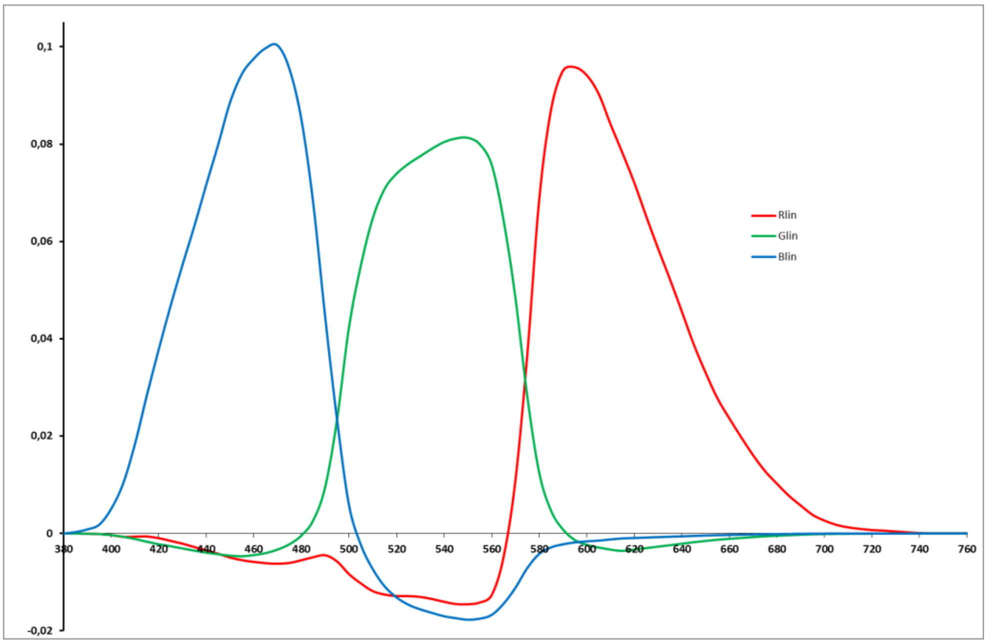

Figure 11: TLCI-2012 camera with linear matrix

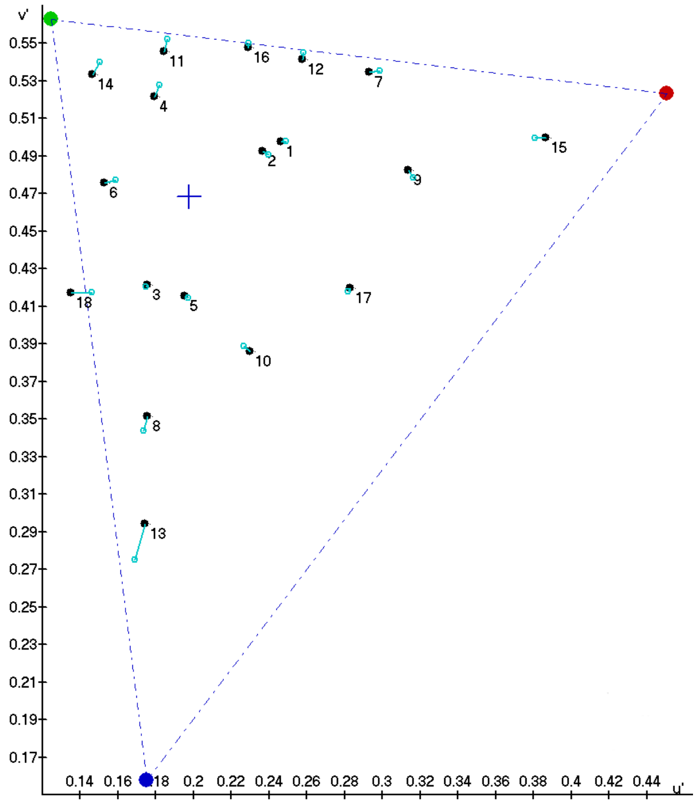

Figure 12: Colour Rendition with linear Matrix

However, in a camera set-up for programme production, gamma correction is introduced after the linear matrix. In addition the display has a non-linear electro-optic transfer function. These facts cause changes in the colour reproduction properties; the saturation for most colours increases significantly, and hue errors are introduced. Figure 13 illustrates this.

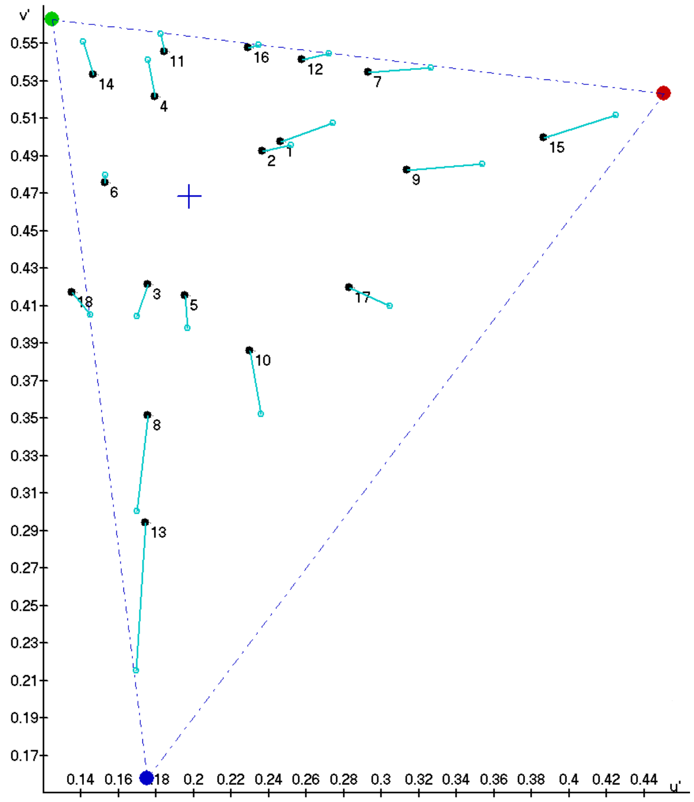

Figure 13: Colour Rendition with linear Matrix and Gamma

These effects can be dealt with by adjusting the matrix in a way that reduces the oversaturation to acceptable levels.

Figure 14 shows the resulting camera response after gamma correction and with an adjusted matrix. Figure 15 shows the resulting chromaticity diagram.

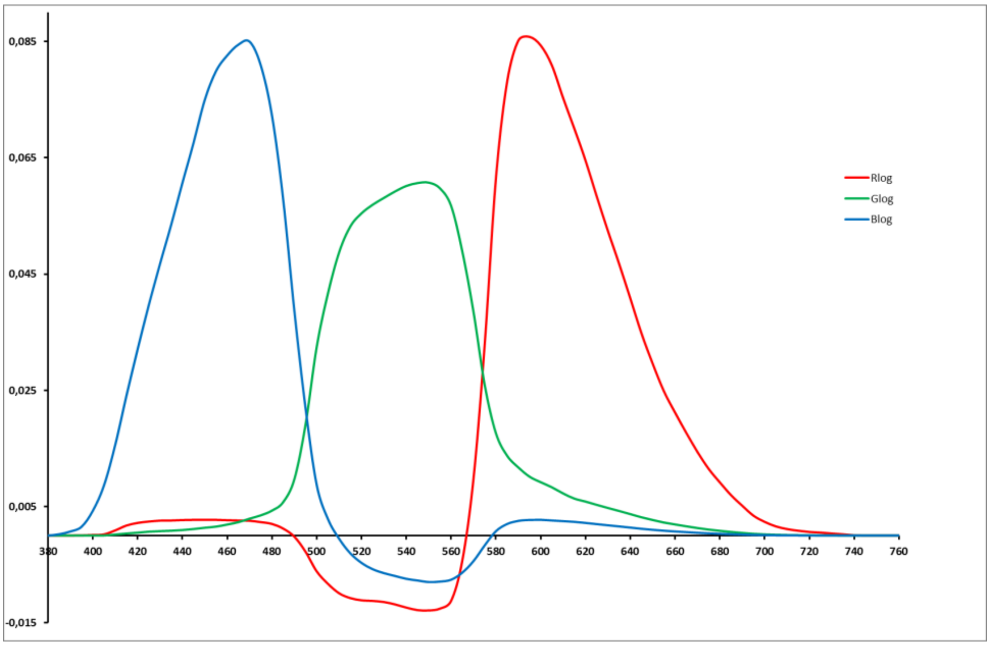

Figure 14: TLCI-2012 Camera with adjusted Matrix

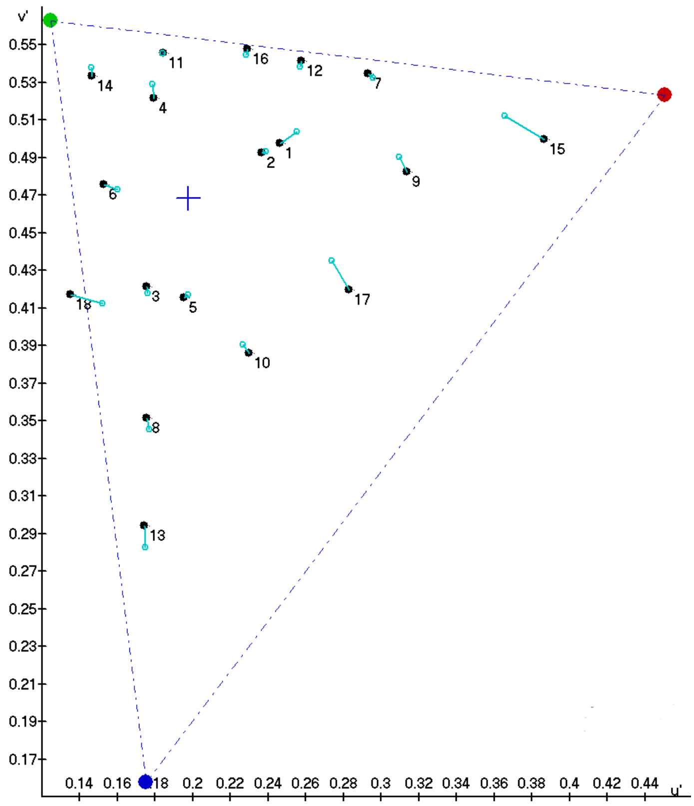

Figure 15: Resulting colour rendition with adjusted Matrix

The matrix adjustments are deliberately calculated to avoid oversaturation, thereby allowing space for errant lighting to oversaturate without clipping (as shown in Figure 15). It is not normally recommended to use such a matrix for broadcast purposes, since the 'look' it gives is more like film than video. The matrix was optimized to keep skin tones reasonably accurate but leave space around the most saturated colours. This should explain why people 'like' having the yellows and oranges a little under-saturated.

7. Conclusions

In 1927, the CIE created a model of human vision with the aid of just 17 subjects, and in a slightly modified form one still employs this model today.

It does look from the work described above that a similar model is possible for cameras, and in view of the recent technology convergence of still, television and film cameras, such a model could well have a lasting effect on the industry.

The application of such a model will not only be of assistance in the design of cameras, as the lighting conditions under which cameras are used has proved to be more demanding than for the human visual model. Most of this difference is down to the non-human attribute of cameras when white balancing, as this action cement errors into the picture data. However, significant errors have also been observed that are simply down to poor out-of-band sensor filtering, especially in the infrared zone of the spectrum.

There is nothing actually new in this, because for many decades colour photography was plagued by errors due to the basic silver halide having more sensitivity to the ultra violet compared to the human eye. The shift in emphasis in the new universal world of silicon based imaging, now lies towards problems in the zone lying between 750nm and 1100nm wavelengths. This zone has been exploited in consumer cameras as it increases the apparent sensitivity in low light conditions. Unfortunately this is to the detriment of the colorimetry as lighting sources of a similar eye response may well have vastly different infrared contents. In particular the current television studio standard of 3200K (degrees Kelvin) tungsten lighting, compared with visual LED equivalents.

8. References

[1] Alan Roberts: A Television Lighting Consistency Index. IBC 2011

[2] Per Böhler: Towards A 'Standard' Television Camera Colour Model. IBC 2012

[3] EBU Tech 3355: Method for the Assessment of the colorimetric properties of luminaires, the Television Lighting Consistency Index (TLCI-2012), October 2012

[4] EBU Tech 3237: Methods of the Measurement of the Colorimetric Fidelity of Television Cameras, May 1983 (incl. EBU Tech 3237 Supplement 1, November 1989)

[5] Wood C.B.B. and Sproson W.N. (1971), The Choice of Primary Colours for Television: Part II. BBC Engineering No.85 (Jan. 1971).

[6] EBU Tech 3212: EBU Standard for Chromaticity Tolerances for Studio Monitors, August 1975

[7] BBC Engineering, 1984. Colour television cameras. BBC Specification TV2248, September 1984

[8] TV OPTICS II/III; The CANON Guide Book of Optics for Television System. Canon Inc, June1992/ 2007.

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Annex 1: Glossary

TLCI	Television Lighting Consistency Index
CRI	Colour Rendering Index
R_C G_C B_C	Television signals, linear
R_M G_M B_M	Television signals, linear after matrix
Q	TLCI result value for a luminaire
$R_C'G_C'B_C'$	Television signals, gamma-corrected
CCT	Correlated Colour Temperature
λ	Wavelength of light, nanometers, nm
P_λ	Spectral power distribution of a Planckian luminaire
$P_{T,\lambda}$ $P_{R,\lambda}$	Spectral power distribution of Test and Reference luminaires
$\overline{x_\lambda}, \overline{y_\lambda}, \overline{z_\lambda}$	CIE 1931 colour-matching functions
X,Y,Z	CIE 1931 tri-stimulus values
X_T, Y_T, Z_T X_R, Y_R, Z_R X_w Y_w Z_w	CIE 1931 tri-stimulus values for Test and Reference luminaires, and system white point
x,y,z	CIE 1931 chromaticity coordinates
x_D, y_D, z_D	CIE chromaticity coordinates of Daylight luminaire
u,v	CIE 1960 chromaticity coordinates
d	Chromaticity distance from a luminaire to its CCT, in CIE1960 uv values, normalised to 0.00541
T	Colour temperature of an illuminant, Kelvin
D_λ	Spectral power distribution of Daylight luminaire
S_0,S_1,S_2	Spectral power distributions of Daylight components
M_1,M_2	Multipliers for the generation of spectral power distribution of a Daylight luminaire
M_λ	Spectral power distribution of Mixed-lighting luminaire
L_λ	Spectral power distribution of light reaching the camera sensor(s)
S_λ	Spectral reflectance distribution (reflectivity) of a colour sample
$\overline{r_\lambda}$ $\overline{g_\lambda}$ $\overline{b_\lambda}$	Spectral response distributions (responsivities) of the standard camera sensor(s)
γ	Assumed power-law electro-optic transfer function for the standard display
ΔL	CIEDE2000 lightness difference
ΔL	CIEDE2000 chroma difference
ΔH	CIEDE2000 hue difference
ΔE^*	CIEDE2000 total difference
R_a	CRI value
k p	Weighting factors in the calculation of Q
$R_O'G_O'B_O'$	Television signals, gamma-corrected and quantised for output
R_d G_d B_d	Television display signals, in 'linear light' conditions
V_C V_D	General signal voltages from the camera and display