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SMPTE ENGINEERING GUIDELINE

Transformations Between Television Component Color Signals



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1 Introduction

The colorimetric characteristics of television component color signals are determined by three separate sets of parameters. They are:

- a) Color primaries and reference white: These characteristics are specified by CIE colorimetric parameters and define the relationship between scene color and the linear RGB video signals. The primaries also define the maximum gamut of color that can be transmitted with all-positive RGB signals.
- b) Opto-electronic transfer characteristics (gamma) used to derive the $R'G'B'$ gamma-corrected signals from the linear RGB values.
- c) The luminance equation and the color channel coding matrix derived using that luminance equation. This coding matrix defines the relationship between the gamma corrected $R'G'B'$ values and the component color signals $Y' PB' PR'$ (analog) or $Y' CB' CR'$ (digital).

In current practice, the differences between the first two colorimetric characteristics are small and can usually be ignored. This guideline is concerned only with the third of these characteristics and assumes the first two to be identical. The analog and digital cases are treated separately because their color-difference gains differ slightly.

2 Scope

Existing television interface standards utilize at least two different color channel coding matrices to derive their corresponding analog $Y' PB' PR'$ or digital $Y' CB' CR'$ component color signals. Clearly, it will be necessary to perform transformations between these color component signal sets. This guideline describes the derivation of the transformation matrices and lists example transformations between color component signals adopting ITU-R BT.601 (see note 1) and ITU-R BT.709 (HD-CIF and 1125/60 [see note 2]) luma/chroma equations for both the digital and analog component signal sets. A parametric form of conversion matrix is derived for converting between signal sets with arbitrary source and target luma coefficients.

3 Derivation of transform matrices

A general form of the transform matrix for converting between arbitrary sets of luma/chroma coefficients is now derived.

3.1 Luma equations

The derivation starts with luma equations (1) and (2) for the source and target systems:

$$E'_{YS} = Y_{RS} \cdot E'_R + Y_{GS} \cdot E'_G + Y_{BS} \cdot E'_B \quad (1)$$

$$E'_{YT} = Y_{RT} \cdot E'_R + Y_{GT} \cdot E'_G + Y_{BT} \cdot E'_B \quad (2)$$

where Y_{RS} , Y_{GS} , and Y_{BS} are the source set of coefficients, and Y_{RT} , Y_{GT} , and Y_{BT} are the target set. Using these coefficients, along with the required chroma scalings, separate coding matrices and the final source-to-target transform matrices are derived for the analog and digital component cases.

3.2 Analog derivation

Subscripted E' variables, used for the analog representation, represent gamma-corrected component signals in the source and target luma equation sets. For E'_Y , E'_R , E'_G , and E'_B , black is at 0 and white at 1.0. E'_{PB} and E'_{PR} have 100% color ranges of $-1/2$ to $+1/2$. (Alternatively, the ranges could have been chosen to represent the common analog range, 0-700 mV for E'_Y , E'_R , E'_G , and E'_B , and ± 350 mV for E'_{PB} and E'_{PR} .)

AMTX signifies the coding matrix used for analog component transformations (DMTX is used later for the corresponding digital component transformations).

The conversion from the source to target luma/chroma equations is performed in equations (3)-(5). The source component signal is first converted to E'_{RS} , E'_{GS} , and E'_{BS} , by multiplying it by the inverse coding matrix for the source signal:

$$\begin{bmatrix} E'_R \\ E'_G \\ E'_B \end{bmatrix}_S = [AMTX_S]^{-1} \cdot \begin{bmatrix} E'_Y \\ E'_{PB} \\ E'_{PR} \end{bmatrix}_S \quad (3)$$

Premultiplying both sides of equation (3) by the target coding matrix, $[AMTX_T]$, and assuming that the E'_R , E'_G and E'_B values for the source and target sets are identical, yields

$$\begin{bmatrix} E'_Y \\ E'_{PB} \\ E'_{PR} \end{bmatrix}_T = [AMTX_{S \text{ to } T}] \cdot \begin{bmatrix} E'_Y \\ E'_{PB} \\ E'_{PR} \end{bmatrix}_S = [AMTX_T] \cdot [AMTX_S]^{-1} \cdot \begin{bmatrix} E'_Y \\ E'_{PB} \\ E'_{PR} \end{bmatrix}_S \quad (4)$$

with the overall conversion from the source to target being

$$[AMTX_{S \text{ to } T}] = [AMTX_T] \cdot [AMTX_S]^{-1} \quad (5)$$

Essentially, the source component has been decoded back to $R'G'B'$ using the source luma coefficients and then reencoded to the target component signal using the forward matrix for the target luma coefficients.

3.3 Digital representation

For the component digital treatment, subscripted D' variables are used, and all coding and transform matrices begin with the letter D. The digital representation uses the component definitions of ITU-R BT.601 which are commonly used in many subsequent digital video standards. The differences between the digital and analog cases are that

- The digital D'_R , D'_G , D'_B , and D'_Y , and D'_{CB} and D'_{CR} have different peak-to-peak signal levels of $219 \cdot 2^{n-8}$ and $224 \cdot 2^{n-8}$, where $n \geq 8$, respectively, whereas in the analog case treated here, the two ranges are the same. This causes the transform matrices to be scaled differently, by the factor $224/219$, in a few of the terms.
- D'_R , D'_G , D'_B , and D'_Y have black-and-white reference levels of $16 \cdot 2^{n-8}$ and $235 \cdot 2^{n-8}$ respectively, and