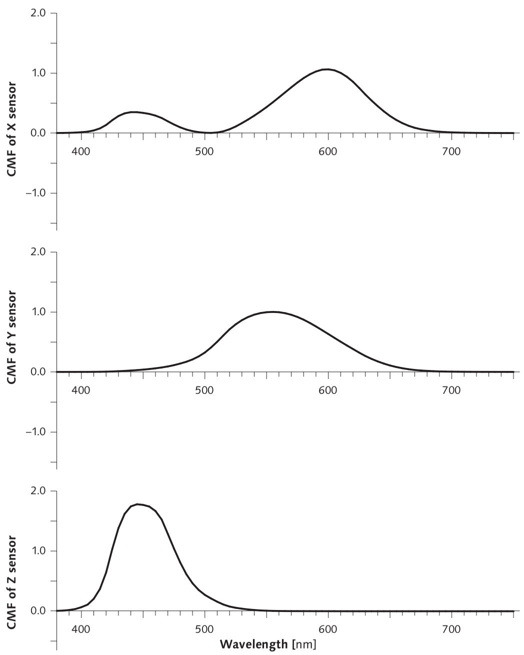
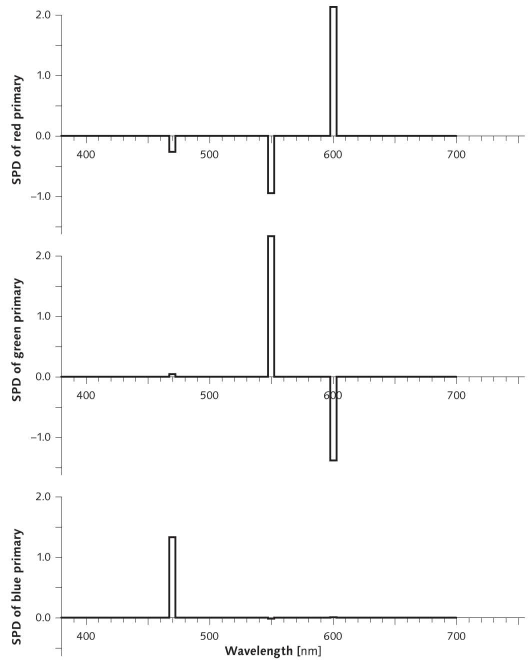
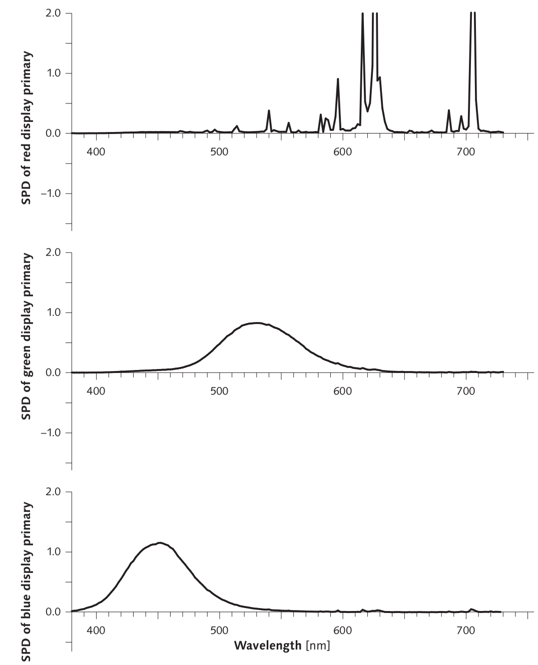


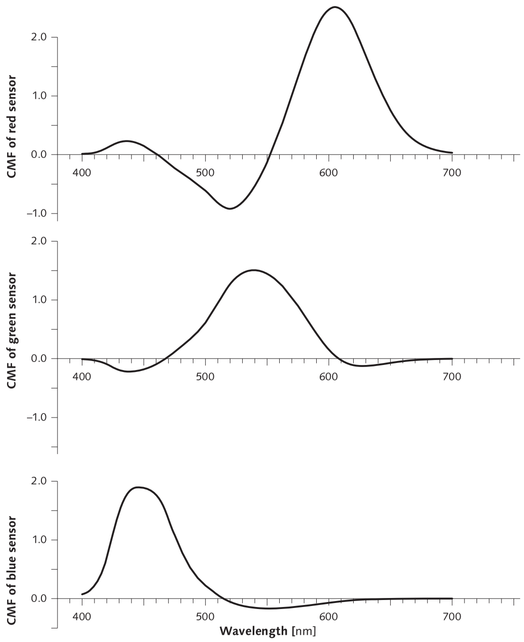




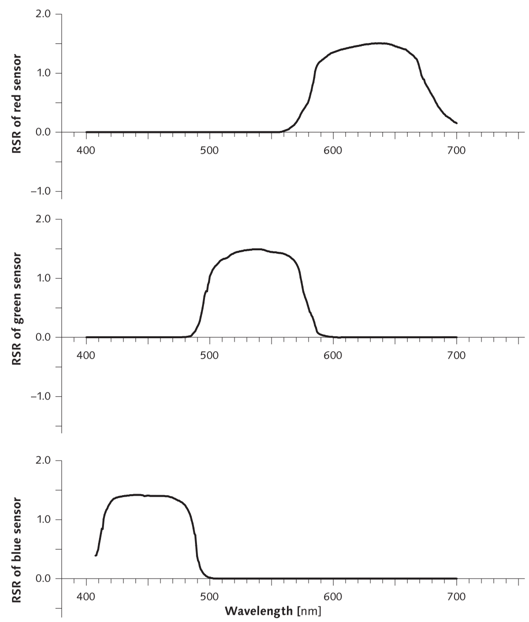
CMFs for CIE *XYZ* primaries. To acquire all colors in a scene requires filters having the CIE *X*(λ), *Y*(λ), and *Z*(λ) spectral sensitivities. The functions are nonnegative, and therefore could be realized in practice. However, these functions are seldom used in actual cameras or scanners, for various engineering reasons.

SPDs for CIE *XYZ* primaries. To directly reproduce a scene that has been analyzed using the CIE colour-matching functions requires *nonphysical* primaries having negative excursions, which cannot be realized in practice. Many different sets are possible. In this hypothetical example, the power in each primary is concentrated at the same three discrete wavelengths, 470, 550, and 600 nm.

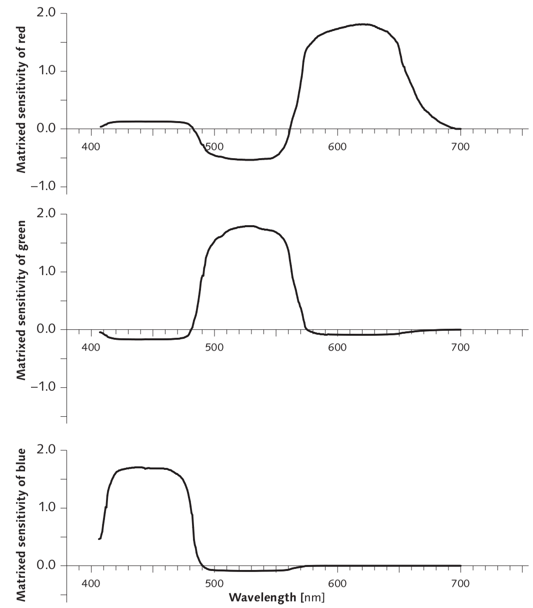
SPDs for BT.709 primaries. This set of SPDs has chromaticity coordinates that conform to SMPTE RP 145, similar to BT.709. Many SPDs could produce the same chromaticity coordinates; this particular set is produced by a Sony Trinitron monitor. The red primary uses *rare earth* phosphors that produce very narrow spectral distributions, different from the phosphors used for green or blue.



CMFs for BT.709 primaries. These analysis functions are theoretically correct to acquire *RGB* components for display using BT.709 primaries. The functions are not directly realizable in a camera or a scanner, due to their negative lobes; however, they can be realized by a 3×3 matrix transformation of the CIE *XYZ* color-matching functions.



Analysis functions for a real camera. This set of spectral sensitivity functions is produced by the dichroic color separation filters (*prism*) of a contemporary studio HDTV CCD camera.



CMFs of an actual camera after matrixing for BT.709 primaries. These curves result from the analysis functions of a real camera being processed through a suitable 3×3 matrix. Colors as "seen" by this camera will be accurate to the extent that these curves match the ideal CMFs for BT.709 primaries.

$$\boldsymbol{C} = \begin{bmatrix} x_R & x_G & x_B \\ y_R & y_G & y_B \\ z_R & z_G & z_B \end{bmatrix} \qquad \begin{bmatrix} J_R \\ J_G \\ J_B \end{bmatrix} = \boldsymbol{C}^{-1} \cdot \begin{bmatrix} x_W \\ y_W \\ z_W \end{bmatrix} \cdot \frac{1}{y_W}$$

Luminance coefficients are computed based upon primary chromaticities (shown here at the left, in matrix form) and the white reference, which is used to compute three scaling coefficients.

$$Y = \begin{bmatrix} J_R y_R & J_G y_G & J_B y_B \end{bmatrix} \bullet \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\boldsymbol{T} = \boldsymbol{C} \bullet \begin{bmatrix} J_R & 0 & 0 \\ 0 & J_G & 0 \\ 0 & 0 & J_B \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \boldsymbol{T} \bullet \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Transform from *RGB* to *XYZ* is based upon a matrix computed from the primary chromaticities, with its columns scaled by the scaling coefficients. The transform is accomplished by placing the matrix ***T*** to the left of the *RGB* column vector.

$$\begin{bmatrix} R_D \\ G_D \\ B_D \end{bmatrix} = \boldsymbol{T}_D^{-1} \bullet \boldsymbol{T}_S \bullet \begin{bmatrix} R_S \\ G_S \\ B_S \end{bmatrix}$$

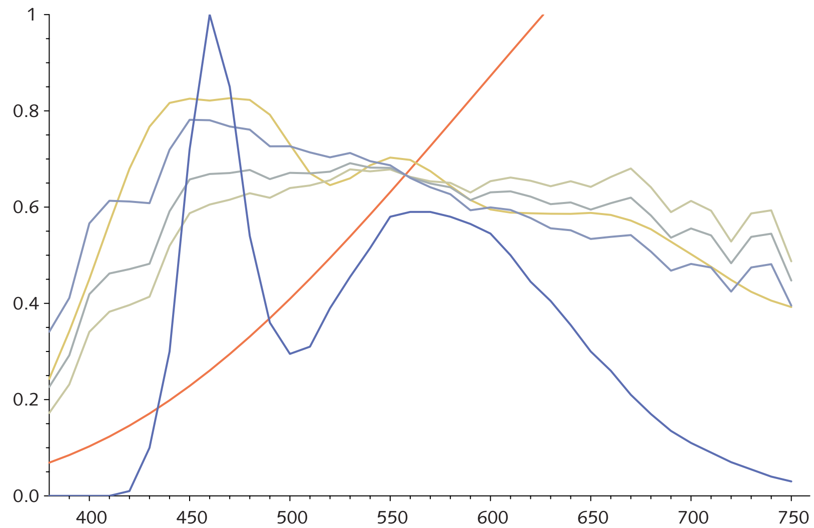
RGB_D is obtained from RGB_S (reading from right to left) by applying the matrix $\boldsymbol{T}_S$ (to produce *XYZ*), then applying matrix $\boldsymbol{T}_D^{-1}$ (to produce RGB_D). The matrix product $\boldsymbol{T}_D^{-1} \cdot \boldsymbol{T}_S$ can be precomputed.

$$\begin{bmatrix} R_{709} \\ G_{709} \\ B_{709} \end{bmatrix} = \begin{bmatrix} 0.939555 & 0.050173 & 0.010272 \\ 0.017775 & 0.965795 & 0.016430 \\ -0.001622 & -0.004371 & 1.005993 \end{bmatrix} \bullet \begin{bmatrix} R_{145} \\ G_{145} \\ B_{145} \end{bmatrix}$$

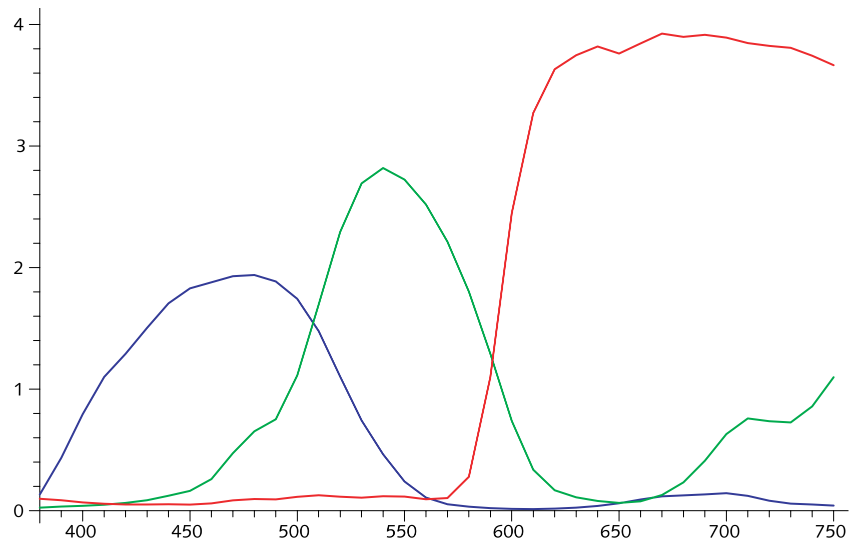
Transforms among *RGB* systems. *RGB* values in a system employing one set of primaries can be transformed to another set by a 3×3 linear-light matrix (affine) transform. Generally these matrices are normalized for a white point luminance of unity. This is the transform from SMPTE RP 145 *RGB* to BT.709 *RGB.* Transforming among *RGB* systems may lead to an *out of gamut RGB* result, where one or more *RGB* components are negative or greater than unity.

The "Macbeth" ColorChecker chart is now manufactured and distributed by X-Rite. The chart measures approximately 330 mm by 230 mm (13 inches by 9 inches); it contains 24 colored patches arranged in a 6 by 4 array.

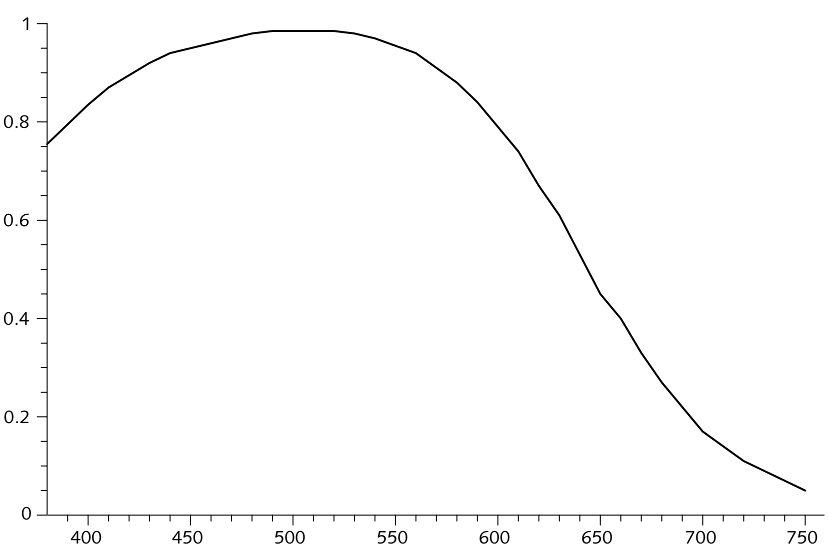
SPDs of various illuminants are graphed here. Illuminant A, shown in orange, is representative of tungsten light sources; it is deficient in short-wave power, and may cause errors in sensing blue colors. The blue line graphs the SPD of a Nichia white LED. The other four lines represent CIE standard illuminants C, D_{50}, D_{55}, and D_{65}. The “white“ LED itself produces narrowband blue; part of this light is emitted, and part pumps a phosphor that emits a broadband yellow. There is a peak in the blue portion of the spectrum: a sensor is liable to report excessive blue values for certain blue reflectance spectra.

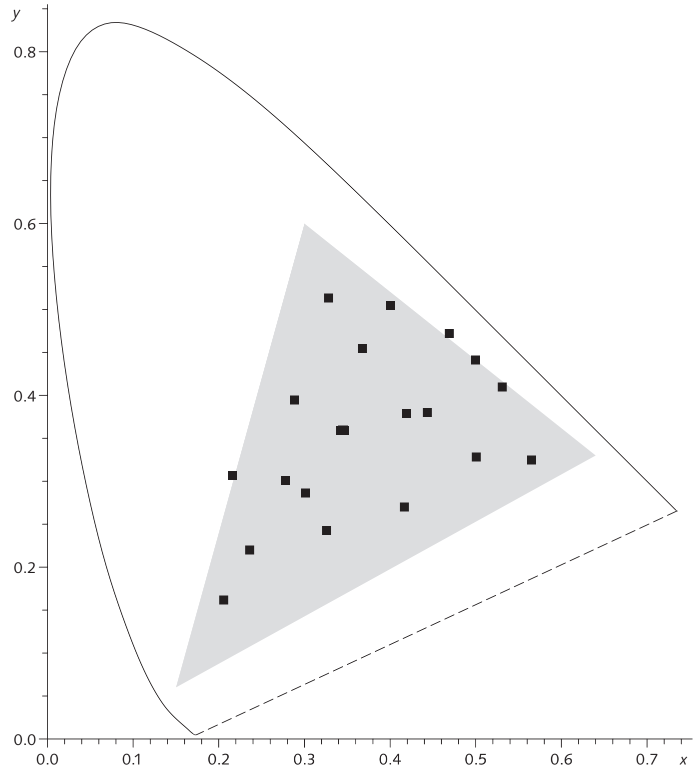


Spectral responsivity functions of a typical digital still camera (DSC) are graphed here. The red, green, and blue channels are graphed in the corresponding colors. Because these responses are different from the CIE standard observer, the values reported by the camera are not colorimetric. However, suitable signal processing yields color information that is sufficiently accurate for commercial imaging.

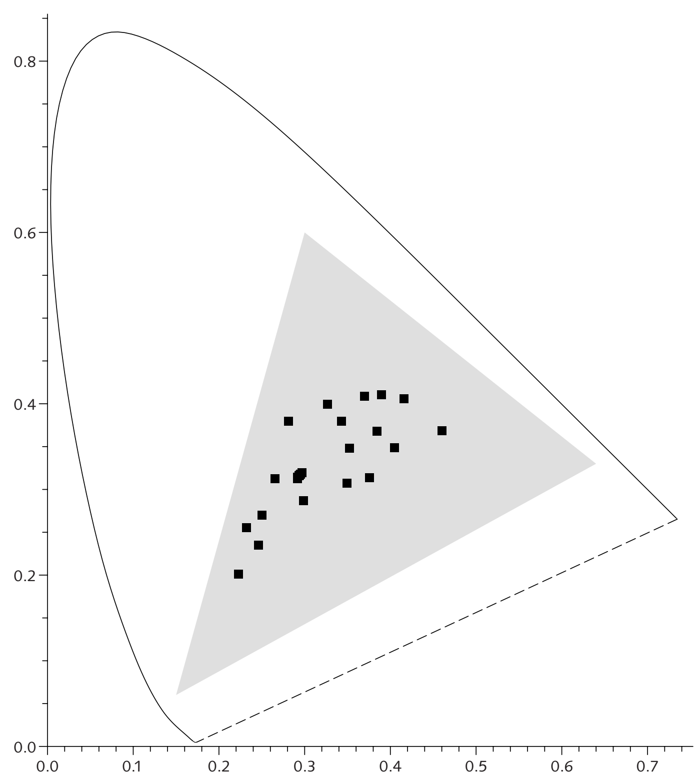


An IR cut filter is necessary in most sensor systems. Most silicon sensors are sensitive to IR, most light sources emit substantial amounts of power in the IR region, and many colored objects reflect in the IR range. If IR response were left unattenuated, the sensor would report an excessively high red component value. A colourful blue flower in the scene might reflect invisible infrared power; but if that power is sensed by the camera, the blue flower would turn purple in the image.



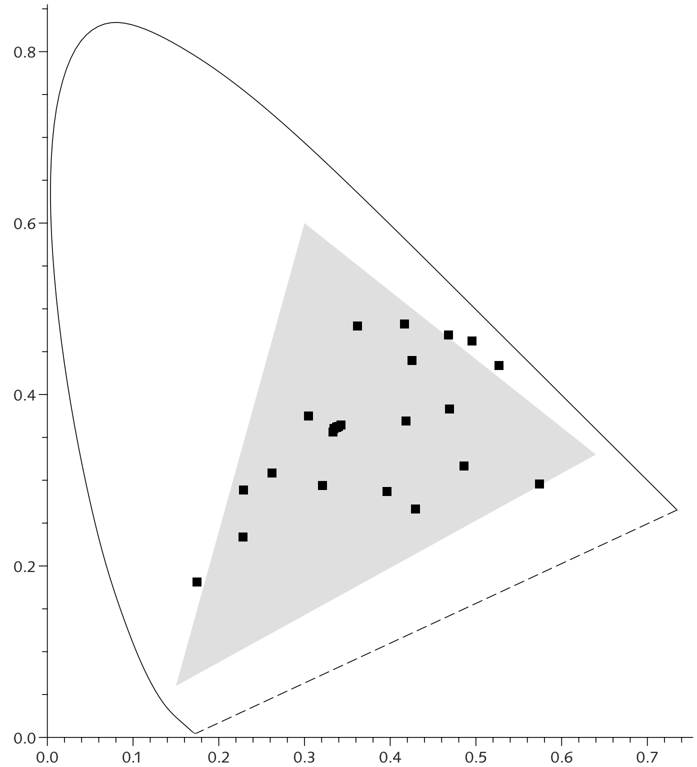


ColorChecker patches, illuminated by CIE Illuminant D_{65}, are graphed here on the CIE [*x*, *y*] chromaticity diagram. Chromaticity values of the white and gray patches are clustered near the center of the chart.

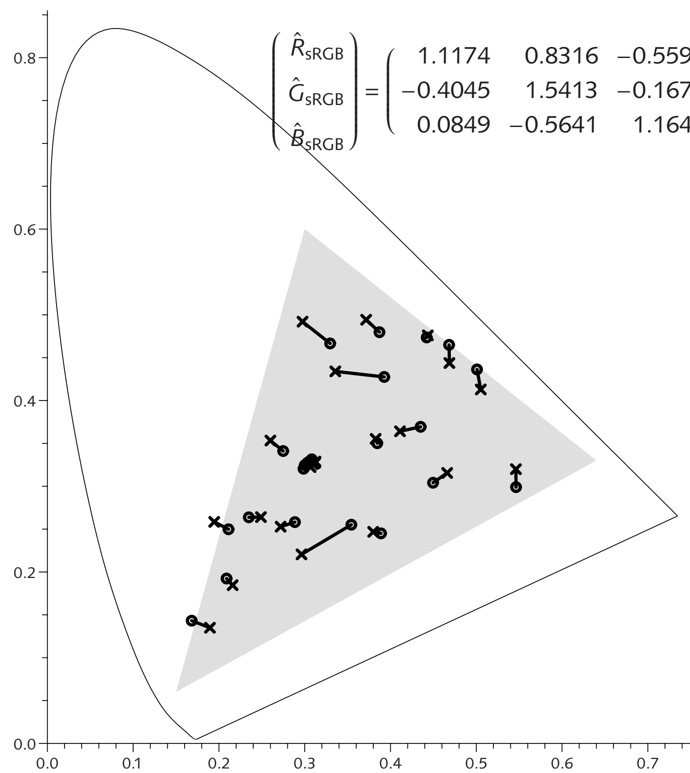


Uncorrected device values, illuminated by CIE Illuminant D_{65}, are graphed here according to the colours that they would represent if the device *RGB* values were interpreted directly as linear sRGB component values. The most obvious problem is that the patches are apparently desaturated. Signal processing can be used to bring these values into closer agreement with the values obtained using the CIE Standard Observer.

Corrected device values are graphed here. These values are obtained by transforming device values through an optimum 3×3 matrix obtained through the pseudoinverse procedure that minimizes the average error in *XYZ* cordinates. The chromaticity values are reasonably close to the colorimetric values graphed earlier.



Residual error between the colorimetric values and the estimates obtained through the optimum 3×3 matrix are graphed; the optimum 3×3 matrix is shown.



$$\begin{pmatrix} \hat{R}_{\text{sRGB}} \\ \hat{G}_{\text{sRGB}} \\ \hat{B}_{\text{sRGB}} \end{pmatrix} = \begin{pmatrix} 1.1174 & 0.8316 & -0.5594 \\ -0.4045 & 1.5413 & -0.1671 \\ 0.0849 & -0.5641 & 1.1642 \end{pmatrix} \bullet \begin{pmatrix} R_{\text{DEVICE}} \\ G_{\text{DEVICE}} \\ B_{\text{DEVICE}} \end{pmatrix}$$