CREATE

Overcoming metamerism when calibrating colorimeters used for display measurement

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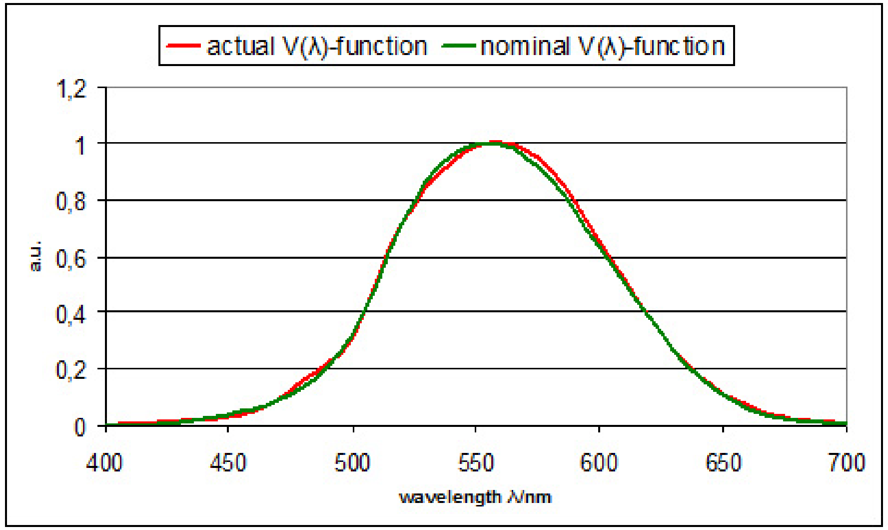
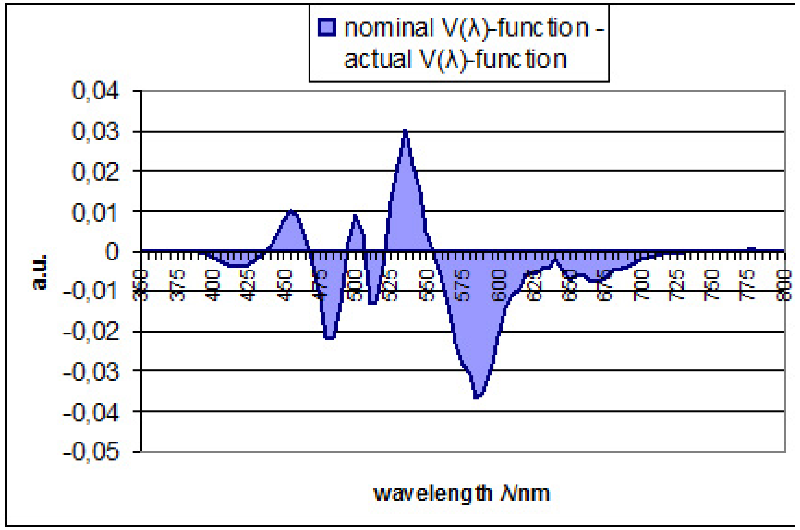
Display Measurement Challenges

- Tristimulus colorimeters comprised of three or four detector channels are, in general, not amenable to accurate calibration that holds for all manner of usage with different illuminated devices and objects.
- This is because the spectral responsivities of their filtered detector channels do not exactly match the defined CIE $\bar{x}$, $\bar{y}$, $\bar{z}$ functions.
- Tristimulus colorimeters may be optimized for use of measuring displays providing better accuracy with that device than its more general calibration provides.
- Closer to ideal requires optimization matrix that transforms the measured CIE *X, Y, Z* values into adjusted *X, Y, Z* values.

Photometer Response Metric





$$M = \frac{\int_a^b E(\lambda)R(\lambda)d\lambda}{\int_c^d E(\lambda)R_r(\lambda)d\lambda} \times \frac{\int_c^d E_0(\lambda)R_r(\lambda)d\lambda}{\int_a^b E_0(\lambda)R_t(\lambda)d\lambda}$$

where:

M = spectral mismatch parameter;

E(λ) = spectral irradiance (Wm^{-2}/nm);

$E_0(\lambda)$ = reference spectral irradiance (Wm^{-2}/nm);

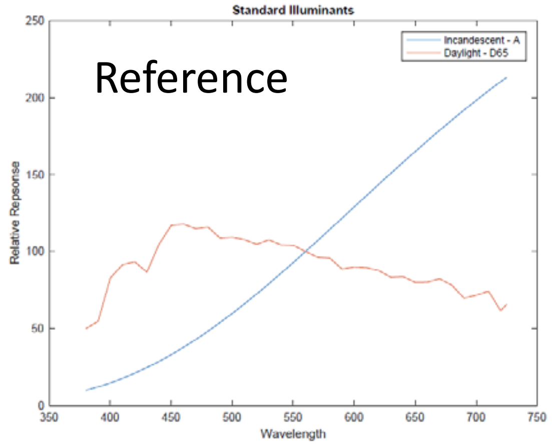
$R_r(\lambda)$ = spectral response of reference cell (A/W);

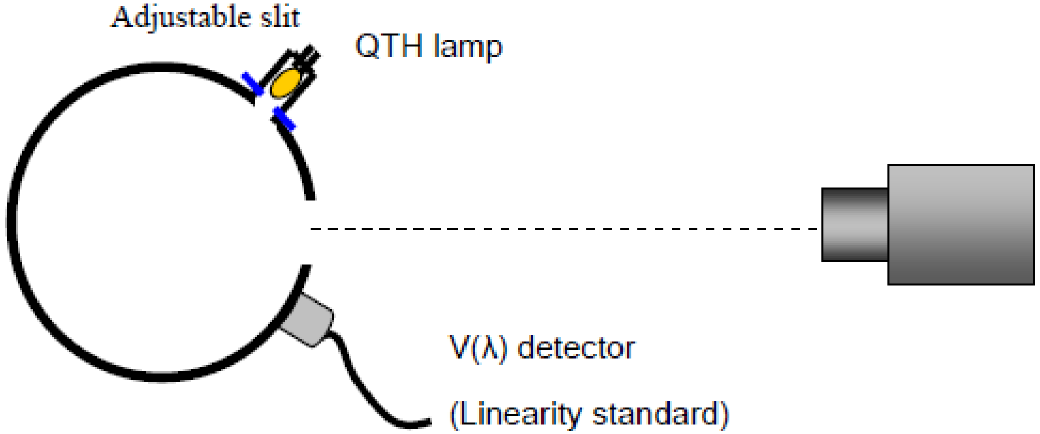
$R_t(\lambda)$ = spectral response of photovoltaic device (A/W).

M = 1 if the reference device is matched with the test device

M = 1 if test spectrum is matched with the reference spectrum

Typical Filtered Colorimeter Calibration with Standard Illuminant



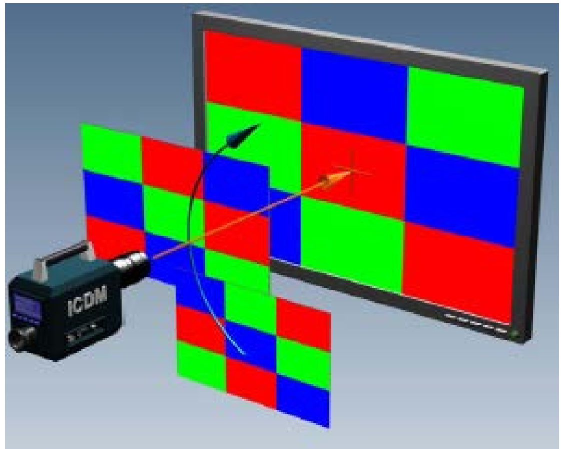


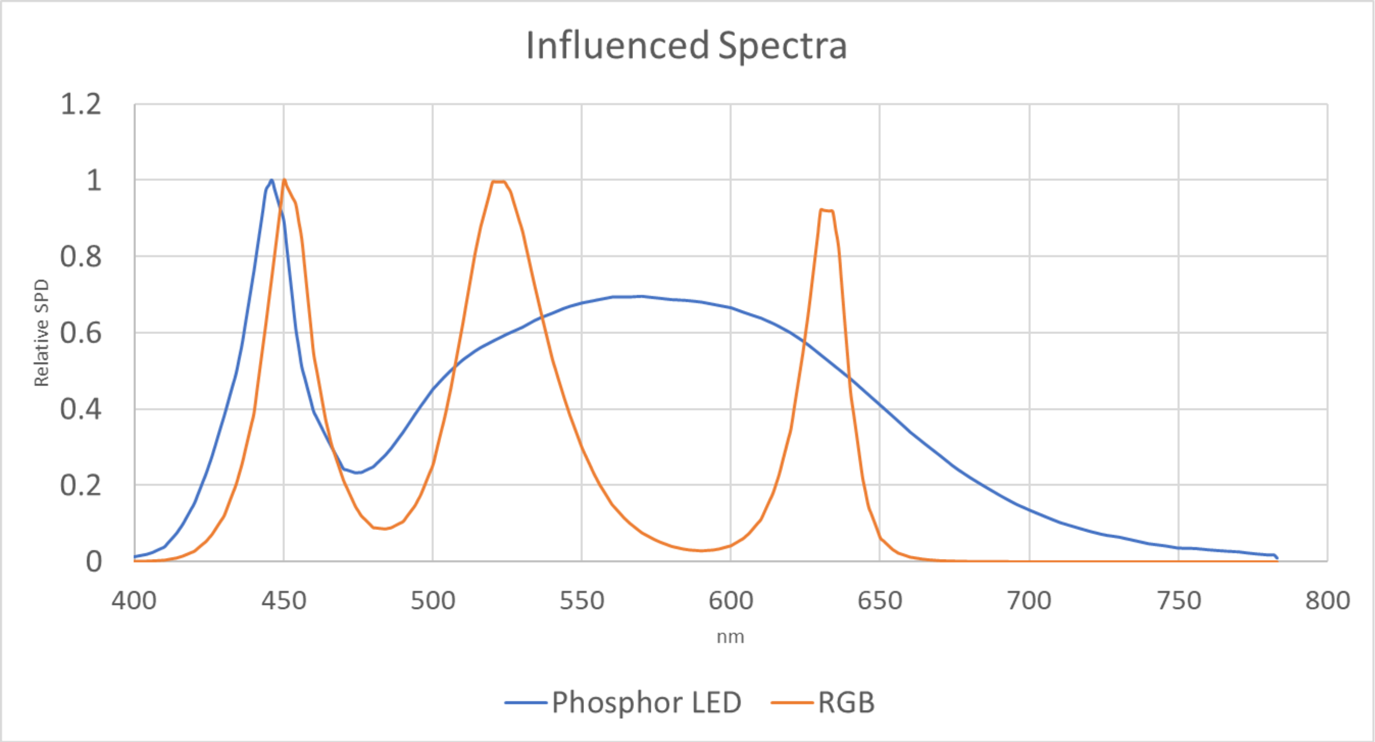
Ideal if Standard Illuminant spectra is what will be measured.

$$\begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} = \begin{bmatrix} C_{X1} & C_{X2} & 0 & 0 \\ 0 & 0 & C_{Y3} & 0 \\ 0 & 0 & 0 & C_{Z4} \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}$$

Corrections Applied

Display Test Applications More Unique SPDs





Sources: IDMS

Common Approach: Match a "Good" Display

Measure spectral radiance of display with spectroradiometer and apply additional corrections. Often requires a series of "Golden Displays" as unstable reference source

Results are Golden Displays to try to match when testing

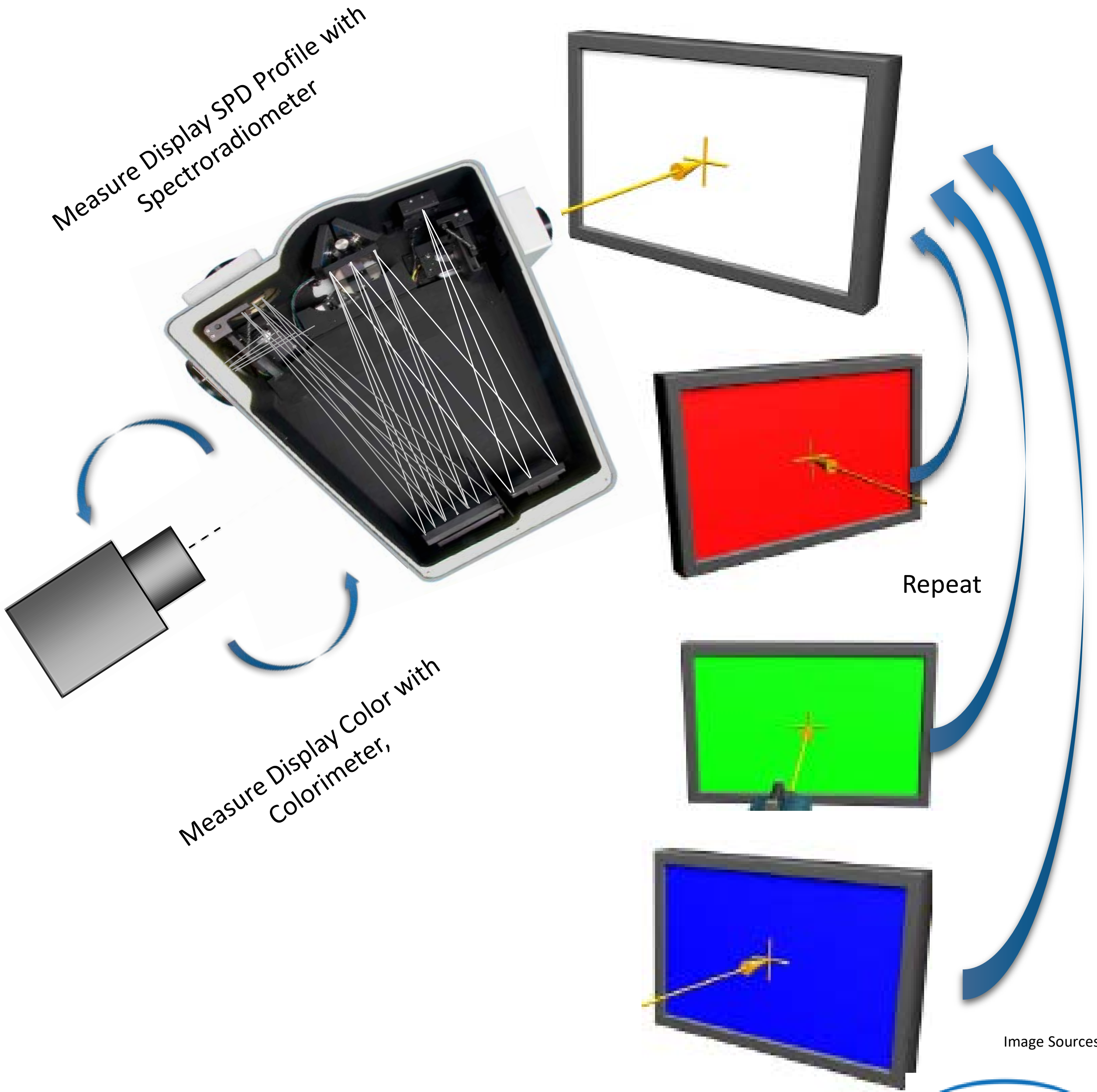


Image Sources: IDMS

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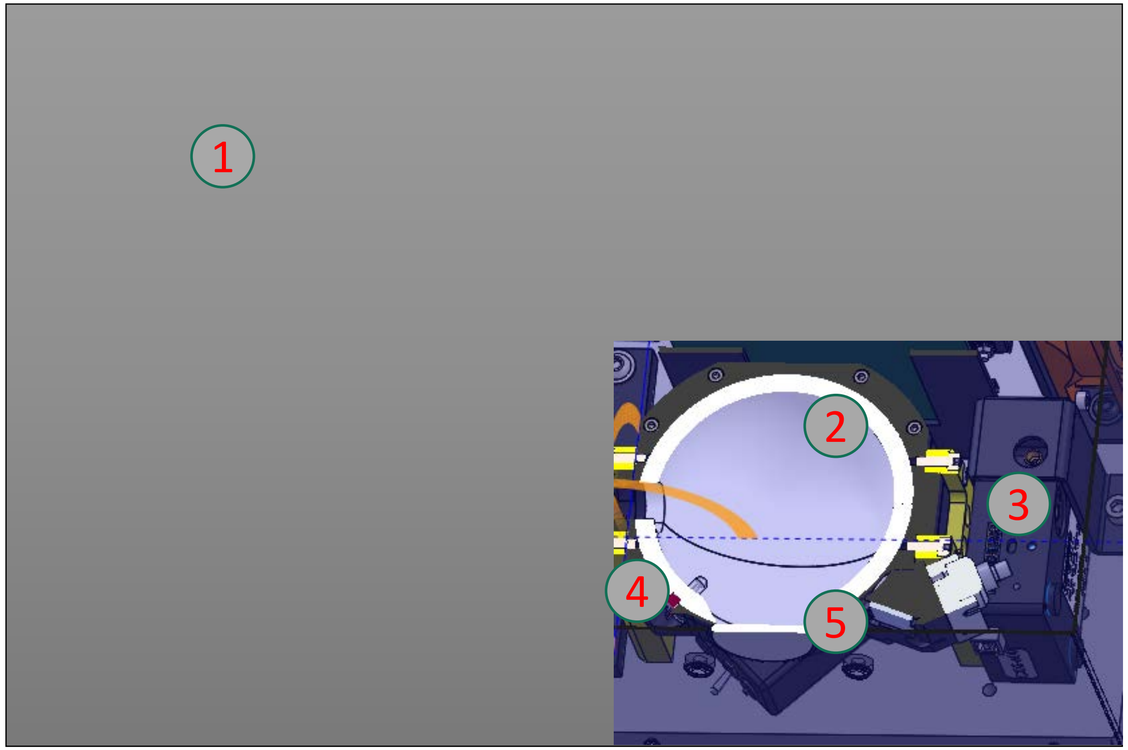
What if

- What if you could measure the SPDs of a display, reproduce it with high fidelity and uniformity, and correct the measuring tristimulus colorimeters performance?
- What if you could correct every colorimeter used to produce repeatable display color results.
- What if you could tune every display to have the same color appearance no matter what colorimeter was used?
- How would this effect the display users color experience?

Differentiating Approach

1. Polychromatic Source breaks light into constituent wavelengths and control intensity levels
2. Sphere integrates the Light
3. Spectrometer provides spectral radiance measurements and feedback to DMD control to establish target spectra matching
4. QTH enables user spectral radiance monitor calibration
5. Top down view or side view



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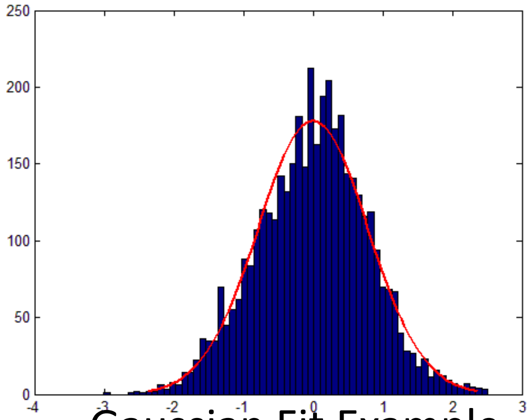
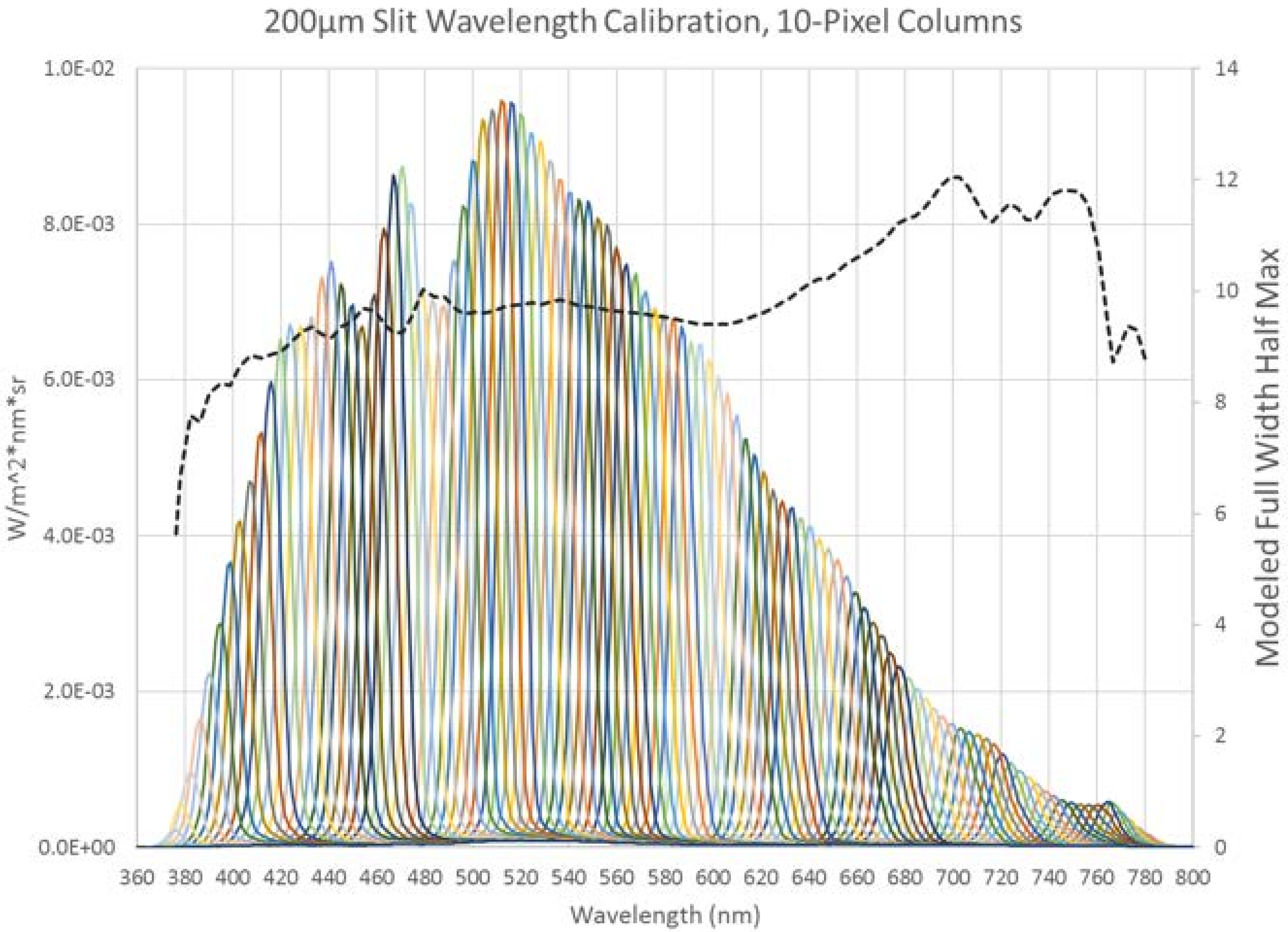
Wavelength Calibration

Each curve is generated by a 10-pixel wide "column" of the DMD mirrors. A curve is generated every 10 pixels. A gaussian fit is given to each, and the FWHM of each gaussian fit is show by the dotted black line.



Gaussian Fit Example



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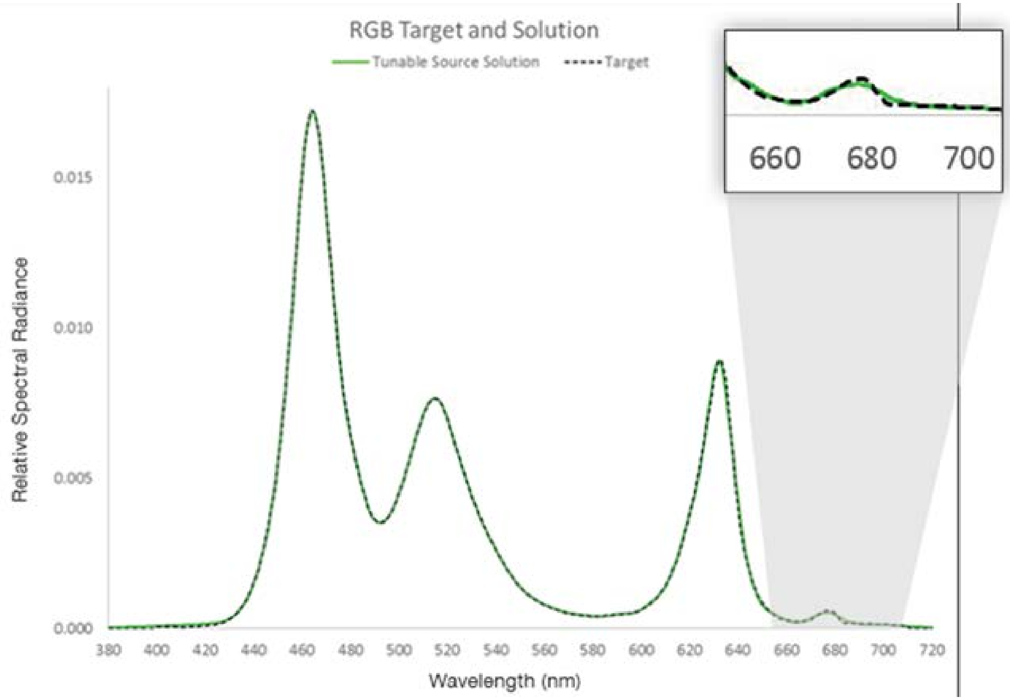
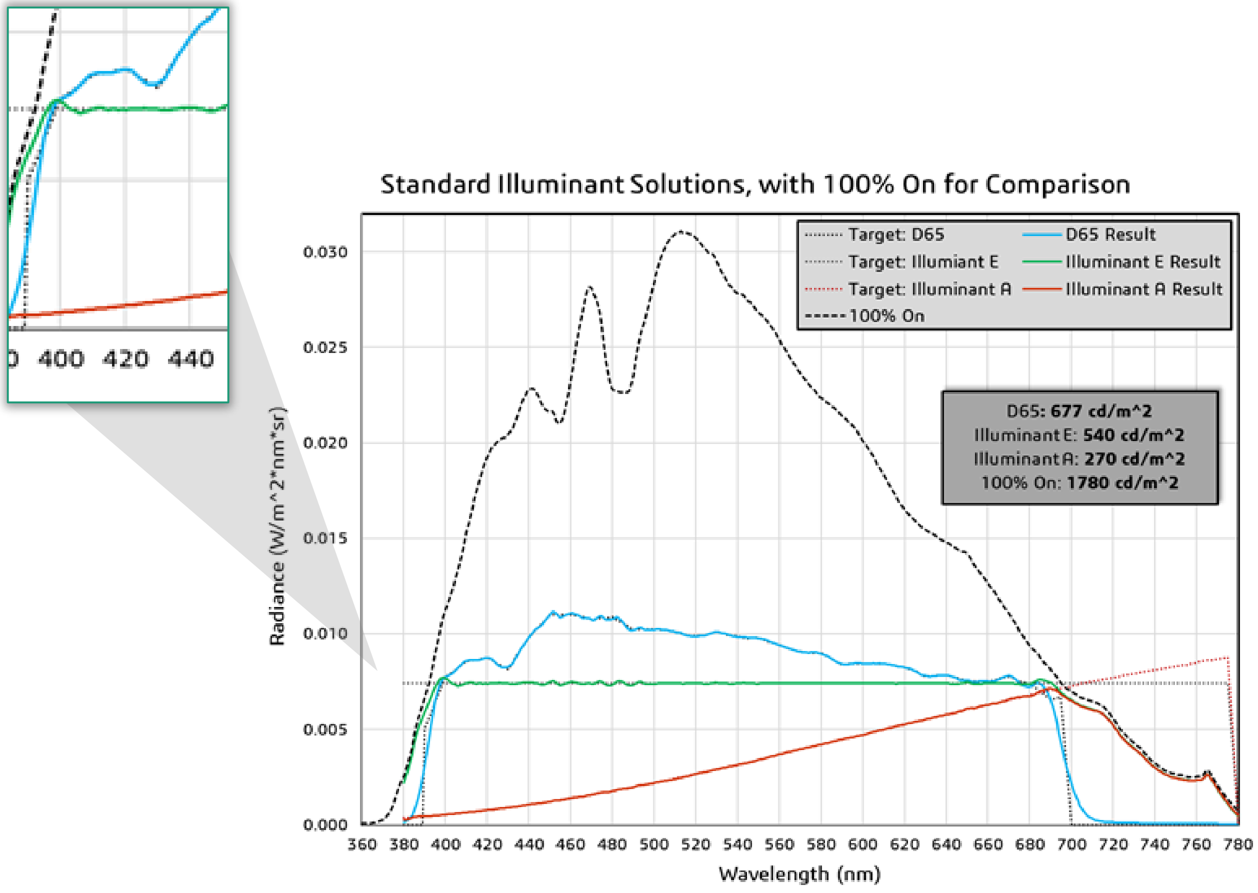
Enabled Spectral Distribution Matching with Traceable Results





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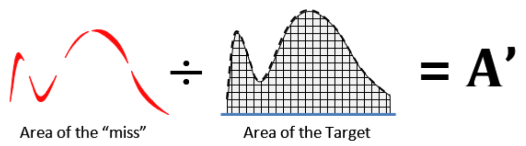
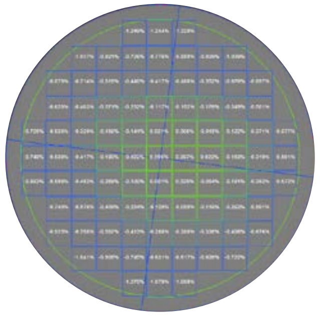
Performance Metrics



- Spectral Matching A’ <1% from target SPD

$$A' = \frac{\int_{\lambda Low}^{\lambda High} |Target - Solution|}{\int_{\lambda Low}^{\lambda High} Target}$$

- Uniformity: across a 30mm port: 99% or greater



$$U_{CoV} = 1 - \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(L-\bar{L})^2}}{\bar{L}}$$

- Reproducibility:
  - cd/m2 CoV - <0.5%

Measured using high resolution spectrometer, with full power cycling and feedback

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RGB Test Colors

R: 255 G: 0 B: 0	R: 0 G: 255 B: 0	R: 0 G: 0 B: 255	R: 255 G: 255 B: 255

Process

Measure Display with
Spectroradiometer and
Commercial Imaging Colorimeter

Transfer from Spectroradiometer
to Digital Polychromator.

Polychromator reproduces
display SPD

Measure digital polychromator

Compute and apply color
Correction to Colorimeter

Remeasure Display and
Compare

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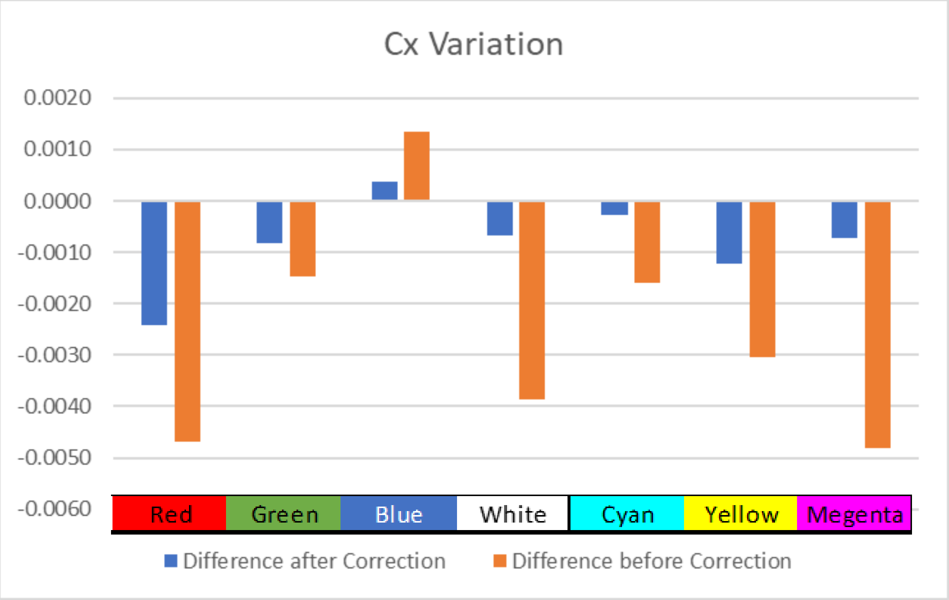
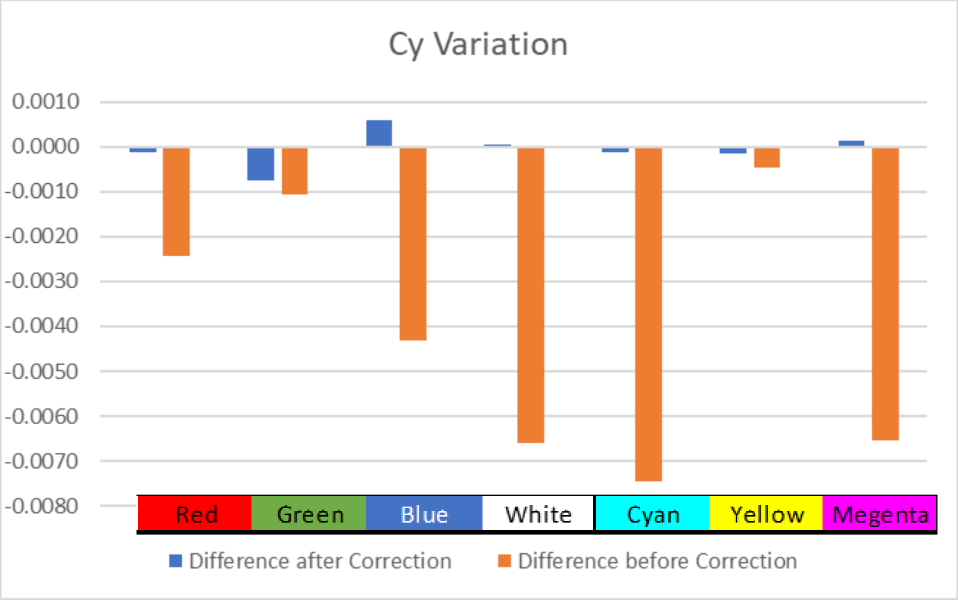
Corrected Results

		Red	Green	Blue	White	Cyan	Yellow	Megenta
Display Measured SPD	x	0.5712	0.3301	0.1584	0.2948	0.2326	0.4130	0.2750
	y	0.3398	0.5599	0.0964	0.3053	0.2973	0.4865	0.1649
Commercial Colorimeter	x	0.5665	0.3286	0.1597	0.2909	0.2310	0.4100	0.2702
	y	0.3374	0.5588	0.0921	0.2987	0.2898	0.4860	0.1584
Corrected Colorimeter	x	0.5688	0.3292	0.1587	0.2941	0.2323	0.4118	0.2743
	y	0.3397	0.5591	0.0970	0.3054	0.2971	0.4863	0.1651
Difference before Correction	Dx	-0.0047	-0.0015	0.0014	-0.0039	-0.0016	-0.0030	-0.0048
	Dy	-0.0024	-0.0011	-0.0043	-0.0066	-0.0075	-0.0005	-0.0065
Difference after Correction	Dx	-0.0024	-0.0008	0.0004	-0.0007	-0.0003	-0.0012	-0.0007
	Dy	-0.0001	-0.0007	0.0006	0.0001	-0.0001	-0.0002	0.0001

Substantial improvement, particularly in the secondary colors

Chromaticity Correction per ASTM E1455-03





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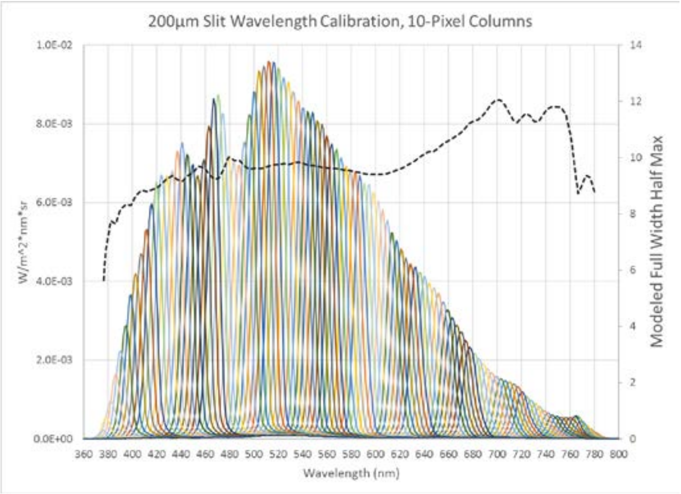
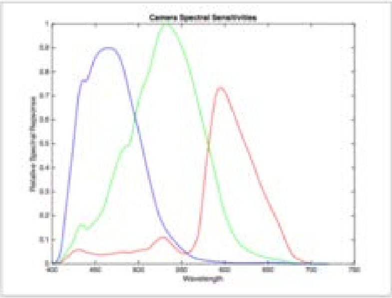
RGB Camera Response Application

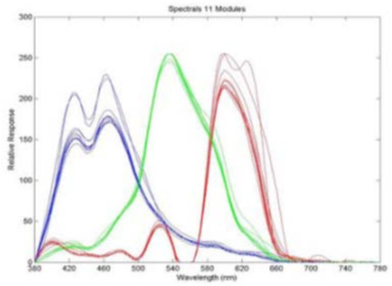


Monochromatic Output

Image Capture/Wavelength



Spectral Response Single



Spectral Response Class

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Summary

- Presented was technology the provides the ability to reproduce virtually any band pass source >10nm through the visible spectra
- Labsphere believes this technology can enable more accurate filter based metering with improved accuracy and lower uncertainty
- This technology can apply to calibration and correction of other visible RGB devices:
  - RGB images sensors response
  - Camera RGB response correction
  - Visible sensor quantum efficiency
  - Hyperspectral System Calibration

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