

# 2018 Value Electronics TV Shootout

## Out of the Box vs. Professional Calibration and the Comparison of DeltaE 2000 & Delta ICtCp

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Calibrator ISF Level-3  
9/23/2018



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# Presentation Goals

- Define calibration and its benefits
- How do we measure calibration accuracy?
- What is color difference and how is it measured?
- DeltaE 2000 vs Delta ICtCp
- Typical out of the box calibration scans
- Comparisons of DeltaE 2000 and Delta ICtCP measurements
- Typical improvements with proper calibration

# What is Calibration?

- Calibration is matching a device to a standard
  - White Point
    - D65  $x=.313$   $y=.329$  or Custom White Point
  - Gamma
    - 2.2, 2.4, BT1886 for SDR
    - Light output curve based on CRT physics
  - Electro Optical Transfer Function (EOTF) HDR & Dolby Vision
    - SMPTE ST2084 defines the process by which digital code words are converted into visible light
  - Color
    - Rec.709, DCI/P3, REC.2020

# What are the Benefits of Calibration?

- Achieving the most accurate viewing experience so that all colors are the same across all platforms from content creation, to production, to consumer displays
  - Full picture details in the darkest and brightest parts of all scenes
  - Eliminating or minimizing Crushing of Blacks and Clipping of Whites and picture Artifacts (Distortions)
  - Accurate production of the full range of colors without exaggeration

# How Do We Measure Calibration Accuracy?

## ➤ Perceptual Color Difference Metrics

- Predict color differences as closely as possible to the way humans see them.

## ➤ Just Noticeable Difference

- Threshold where humans can perceive a difference between two colors and where two colors appear identical.

# Color Difference

- Measure of change in visual perception of two given colors
  - How the human eye perceives the difference between two colors
- Color Difference Metrics
  - DeltaE 2000 (CIE)
  - Delta ICtCp (created by Dolby Labs)
  - Designed to match how humans see color
  - Based on mathematical formulas to compensate for the human eye's sensitivity to some areas of color and less sensitivity to others
  - Has to be repeatable and user independent

# DeltaE 2000 vs. Delta ICtCp

## ➤ DeltaE 2000

- Commonly used Industry Standard
- Formula assumes the human visual system is adapted to white, so you see smaller errors and more inaccurate measurements near black
- Inaccuracies with HDR and WCG displays because data set does not cover this expanded color range.

# DeltaE 2000 vs. Delta ICtCp, continued

## ➤ Delta ICtCp

- Formula assumes unlimited adaption states so the human visual system is adapted to each color for the patch you are measuring
- Predicts gamma and grayscale errors more accurately at the low end (closest to black) and at the high end (closest to white)
- Designed for HDR and WCG displays
- Works for SDR displays as well

# Calibration Accuracy Considerations

- It is important to consider how well a metric adheres to human vision across a wide range of colors and luminance levels
- Some metrics perform accurately for certain colors and poorly for others
- Depending on the metric used, calibrated displays could appear not to match visually even though their color difference values agree
  - DeltaE 2000 may significantly over or under predict color differences
  - One display's blue may trend toward red and another display's toward green making the sets look perceptually different

# ICtCp vs. Delta ICtCp

- ICtCp is an encoding space similar to YCbCr
- Delta ICtCp is a Color Difference Metric

# ICtCp New Color Encoding Model - Reference

## ➤ ICtCp

- A color representation model designed for HDR and WCG displays which challenges existing image and video data processing algorithms such as YCbCr in terms of compression and accuracy
  - New non-linear encoding curves, EOTF
  - New color primaries, more saturated colors
  - Increased bit depth

# ICtCp New Color Encoding Model - Reference

## ➤ ICtCp, continued

- More perceptually uniform color representation that is based on the human visual system by decorrelating Saturation, Hue and Intensity
  - I - Intensity: Black/White intensity
  - Ct- Tritan: Blue-Yellow axis of human vision
  - Cp- Protan: Red-Green axis of human vision
- Ct/Cp in ICtCp like Cb/CR in EOTF encoded Y'C'bC'r are the color difference channels
- Defined from Rec. 2100
- Proposed for ATSC 3.0; Used by Netflix DV content

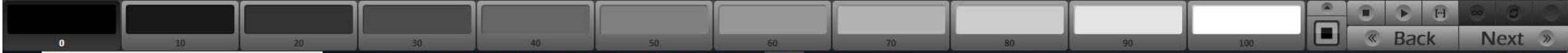
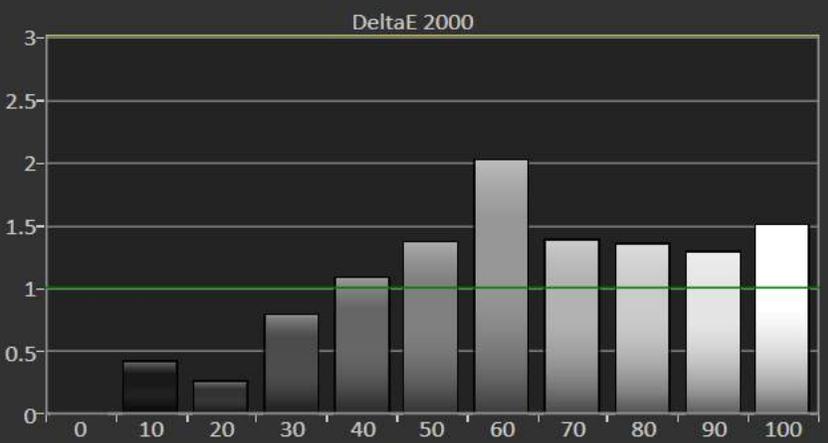
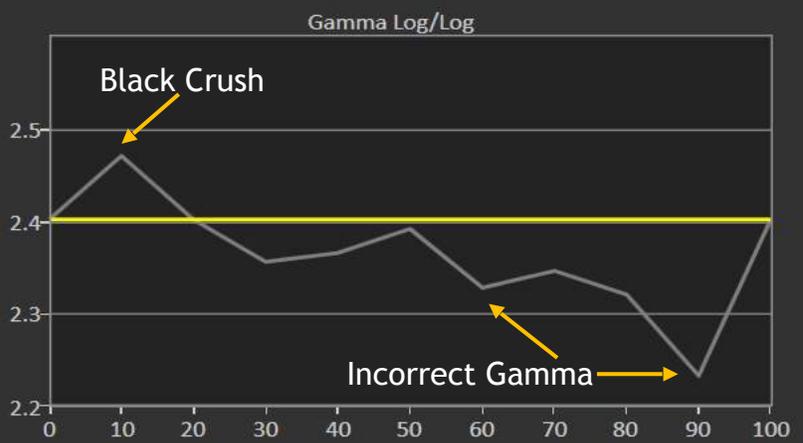
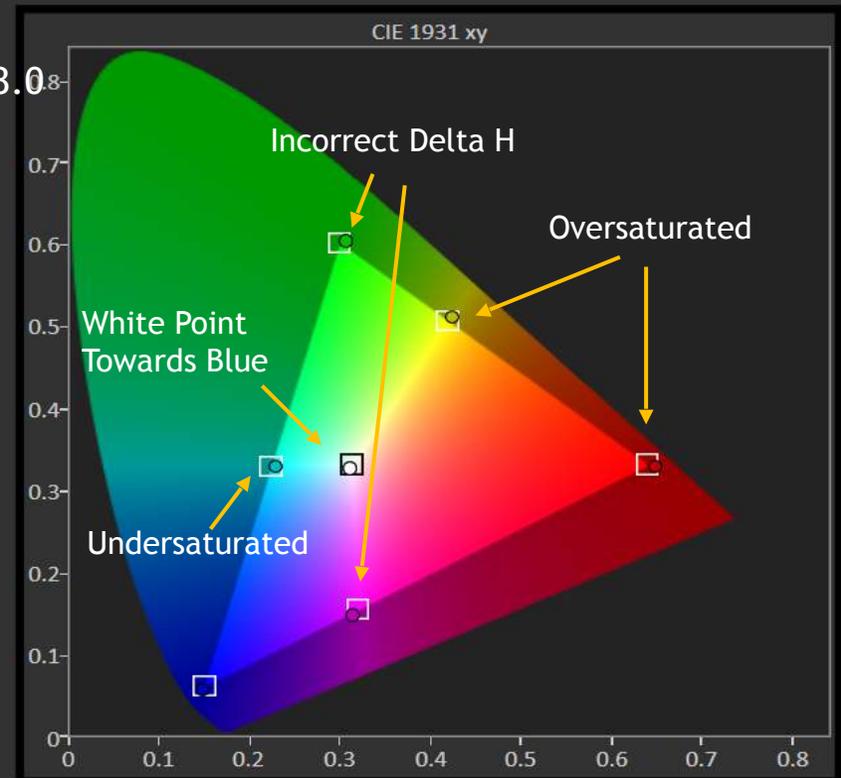
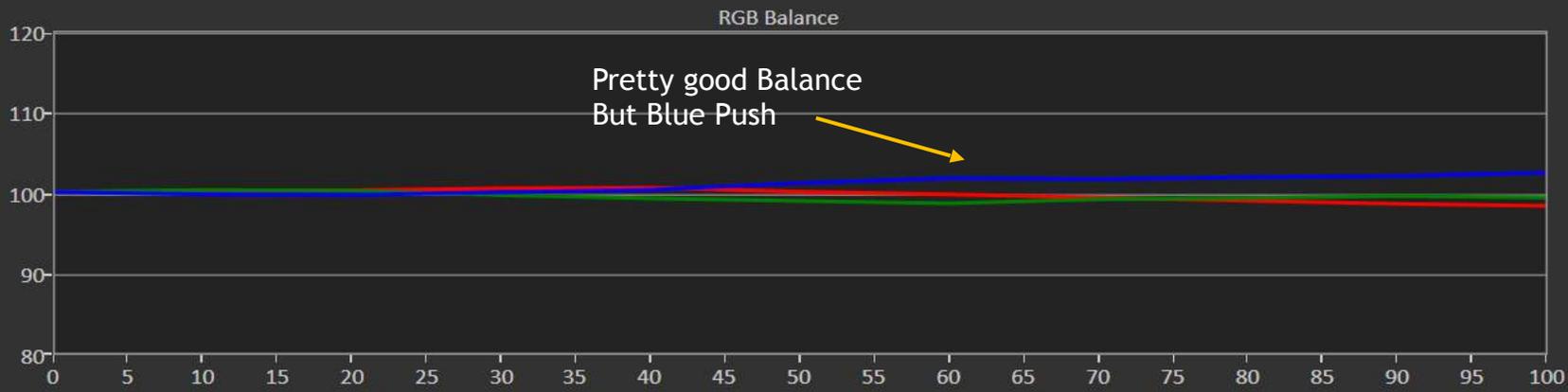
# ICtCp vs. YCbCr - Reference

- ICtCP can replace YCbCr
  - Improved chroma subsampling and gamut mapping
  - Less distortions than YCbCr for HDR and WCG; less color “leakage” into luminance channel
  - Better overall image quality and perceptual uniformity
  - Better compression requires lower bit rates

# Pre-Calibration View

Out of the Box Expert PM  
Gamma 2.4, D65

Avg Gamma: 2.36 ← Pretty Close to 2.4  
Avg dE2000: 1.16 ← Perceptual Errors OK < 3.0  
Avg CCT: 6551 ← Avg White Point OK

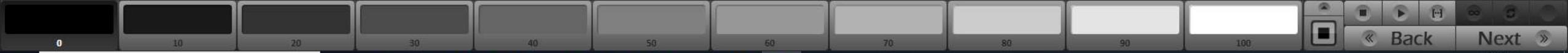
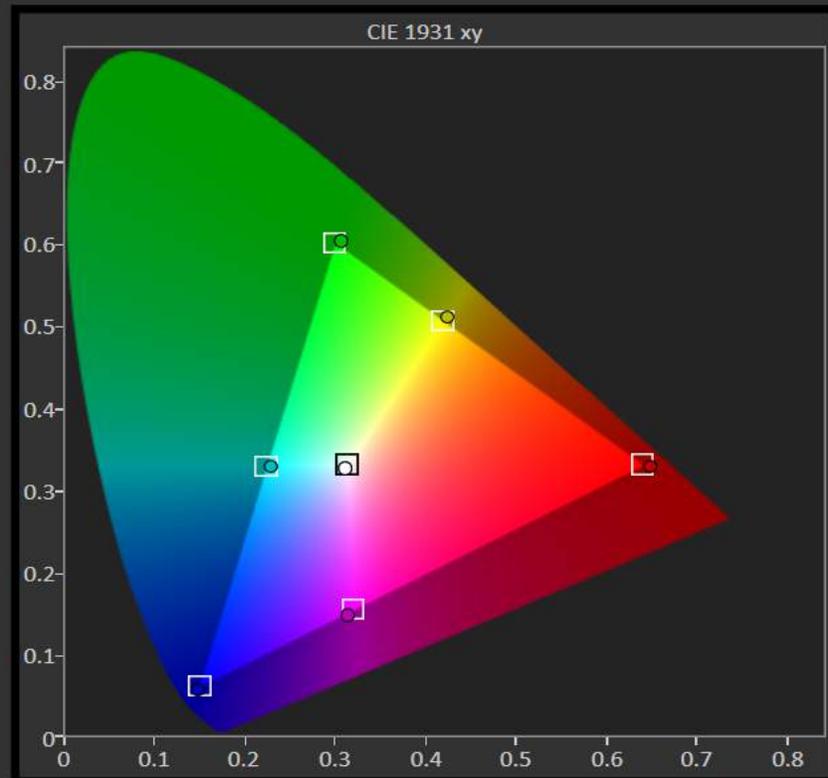
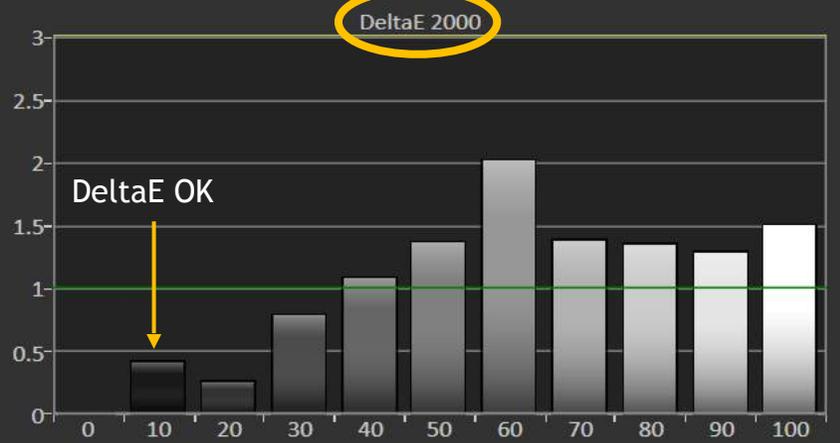
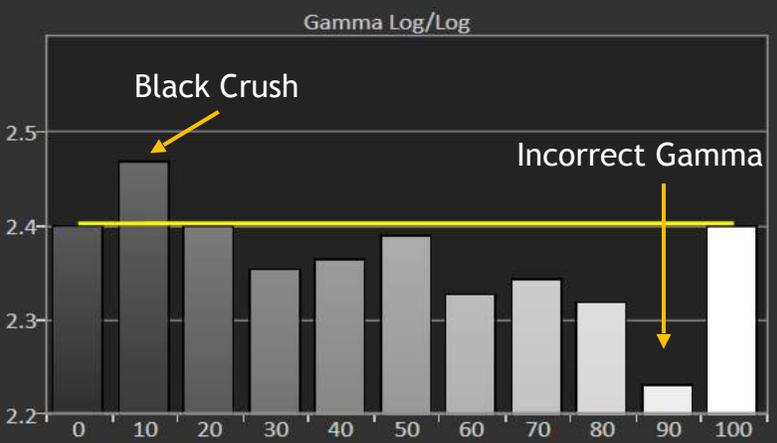


# Pre-Calibration View

Avg Gamma: 2.36

Avg dE2000: 1.16

Avg CCT: 6551

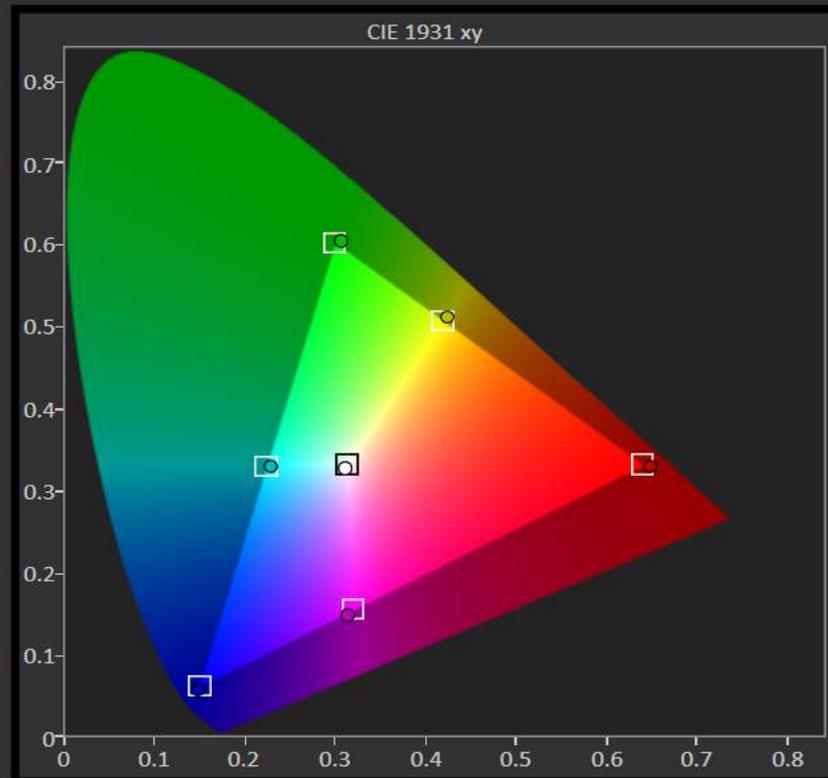
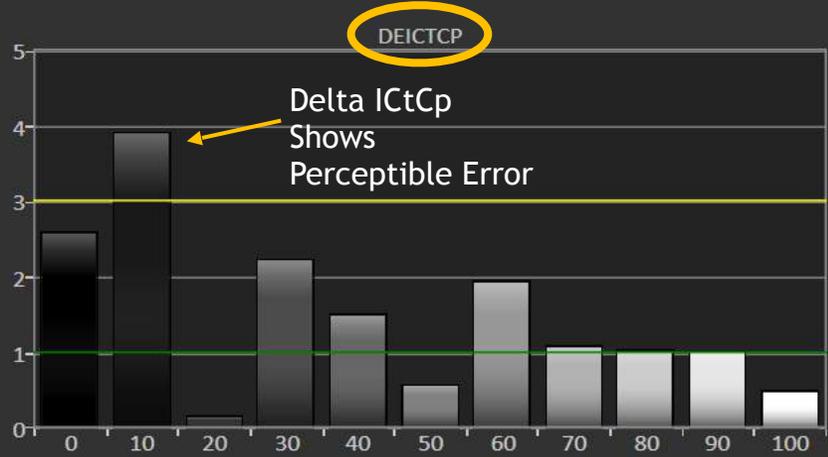
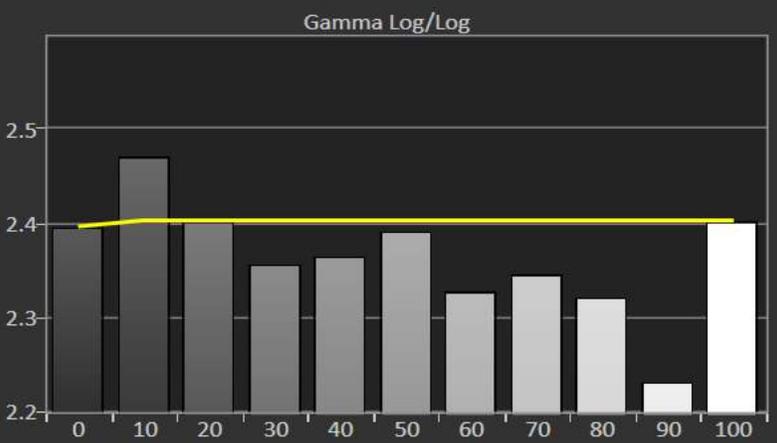


# Pre-Calibration View

Avg Gamma: 2.36

Avg dE2000: 1.16 Avg dE ICtCp: 1.4

Avg CCT: 6551



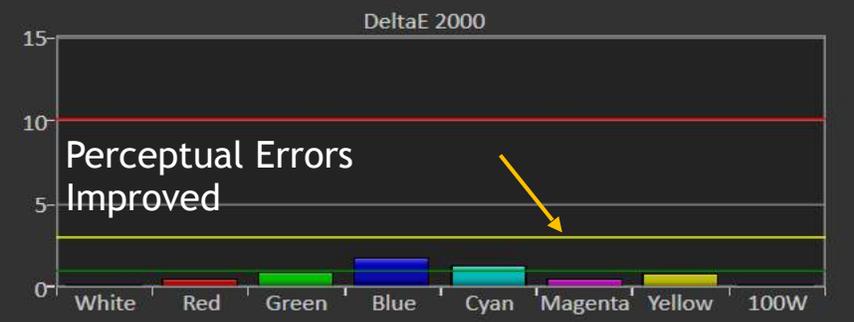
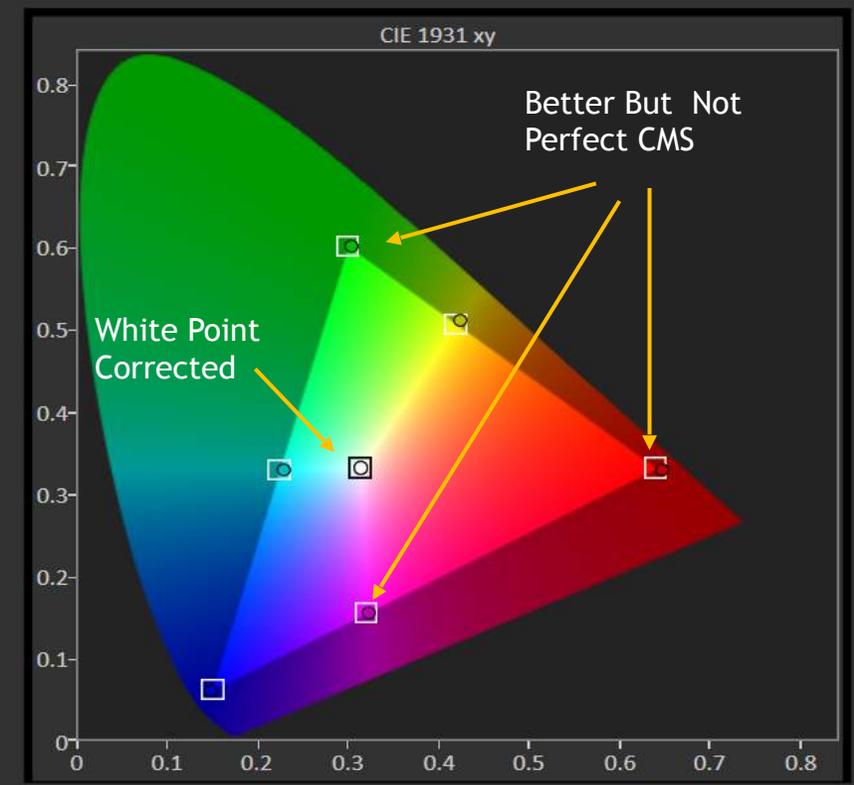
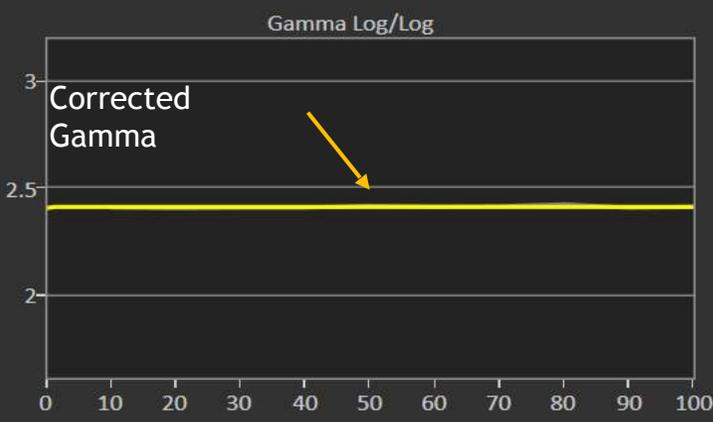
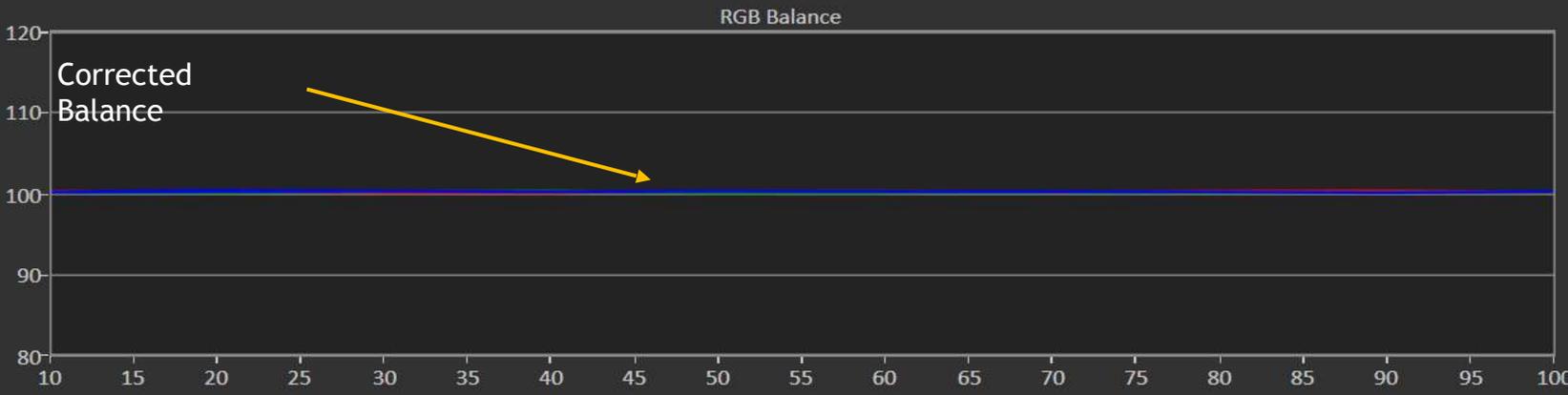
0 10 20 30 40 50 60 70 80 90 100

Back Next

# Post-Calibration View

Calibrated Expert PM  
Gamma 2.4, D65

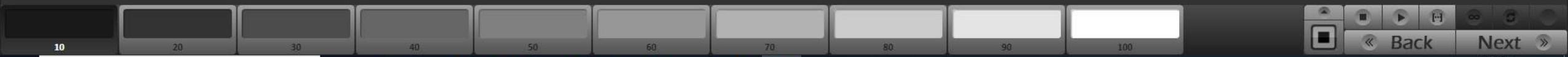
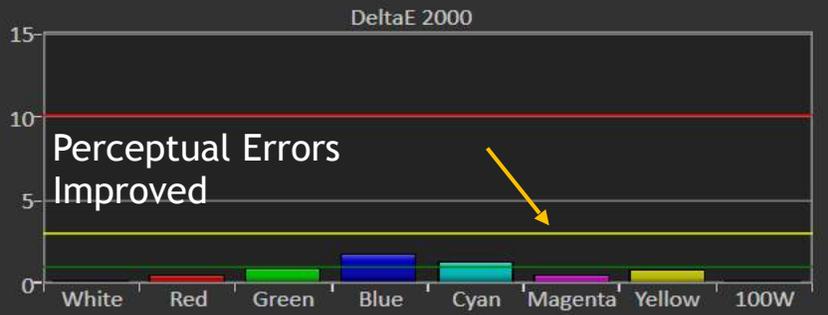
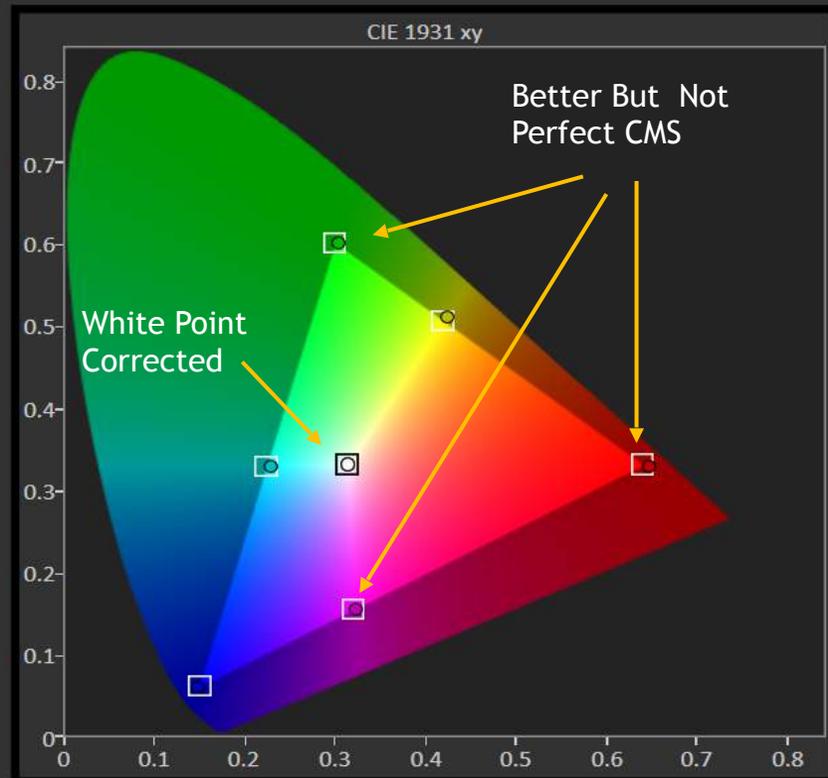
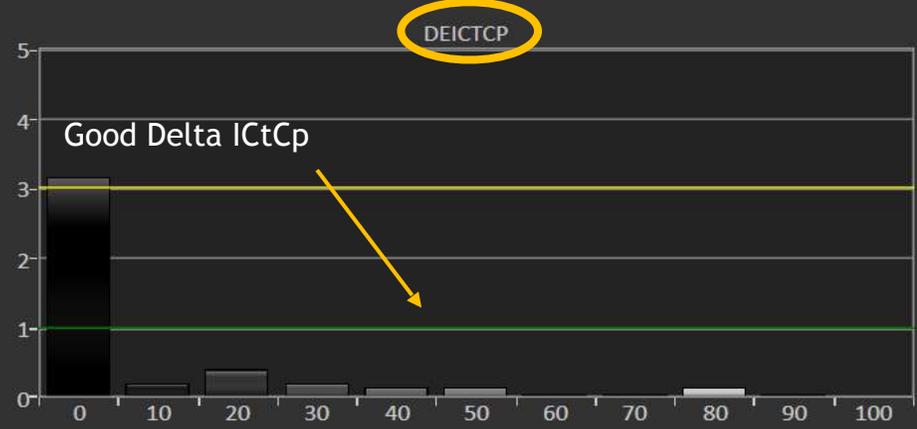
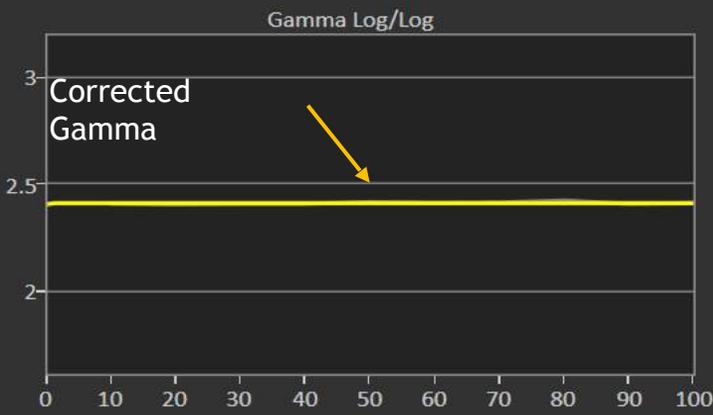
Avg Gamma: 2.4 ← Correct Gamma  
Avg dE2000: 0.12 → Low Errors  
Avg dE ICTcp: 0.14  
Avg CCT: 6505 ← Good Avg White Point



# Post-Calibration View

Calibrated Expert PM  
Gamma 2.4, D65

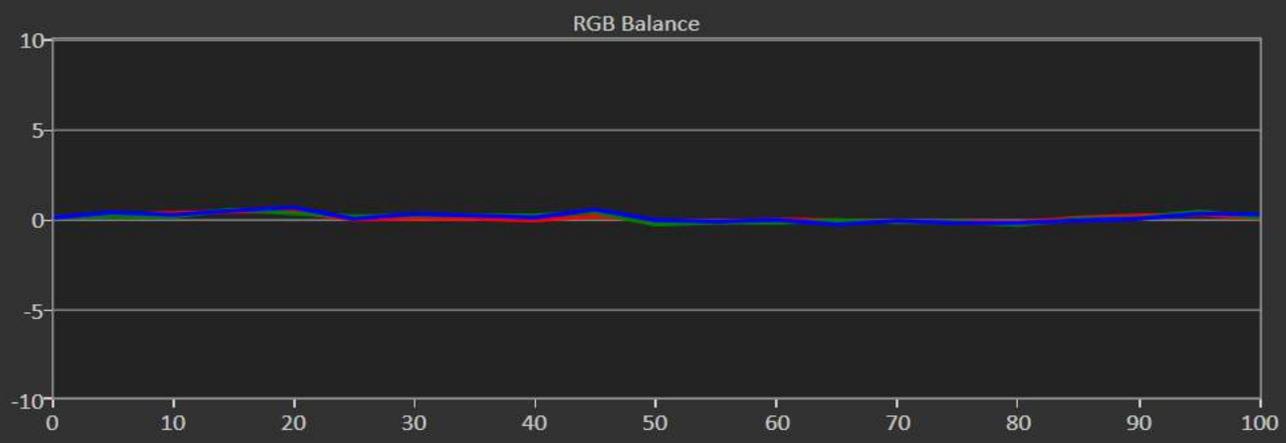
Avg Gamma: 2.4 ← Correct Gamma  
Avg dE2000: 0.12 ← Low Errors  
Avg dE ICtCp: 0.14  
Avg CCT: 6505 ← Good Avg White Point



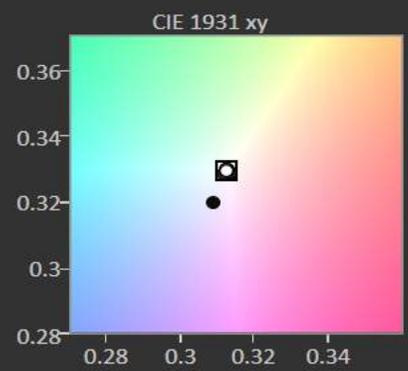
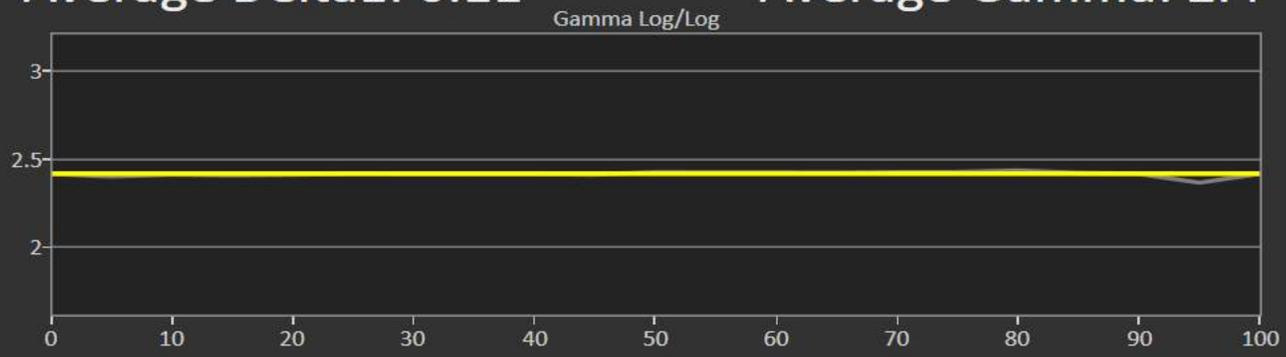
# Adjust Multipoint Grayscale & Gamma

Use the charts below to adjust both the best color balance and the target luminance level for each point along the luminance response to obtain a DeltaE of less than 3.\*

Avg CCT: 6520.9  
Max Nits: 268.71  
Max fL: 78.43



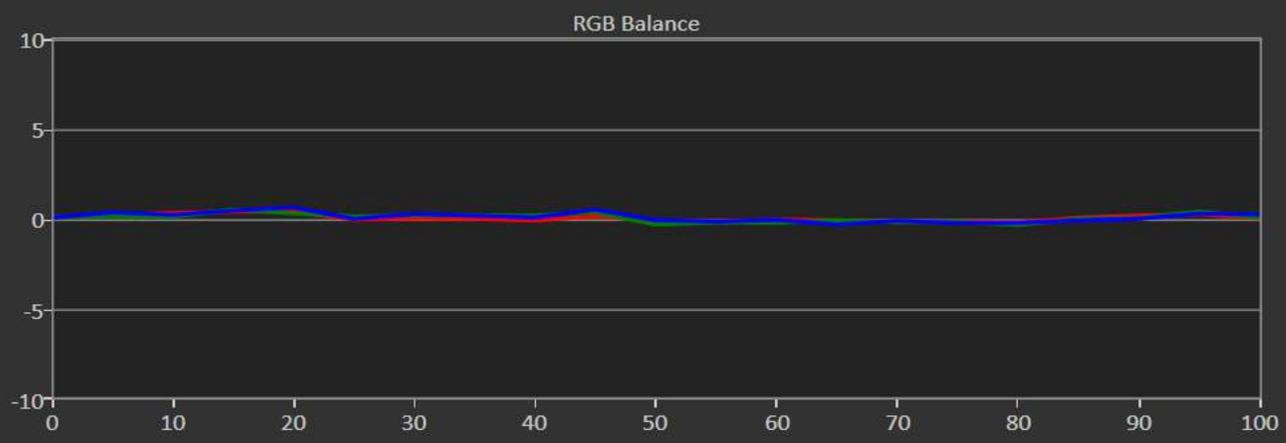
Average DeltaE: 0.11      Average Gamma: 2.4



# Adjust Multipoint Grayscale & Gamma

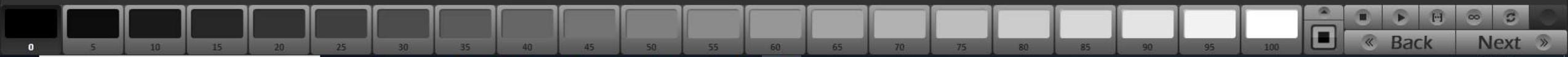
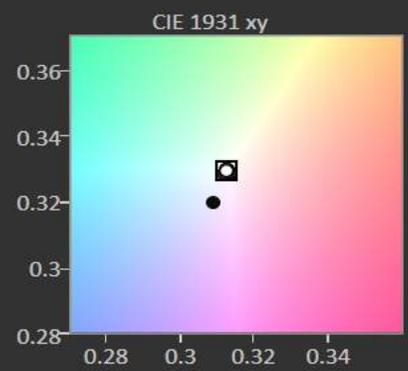
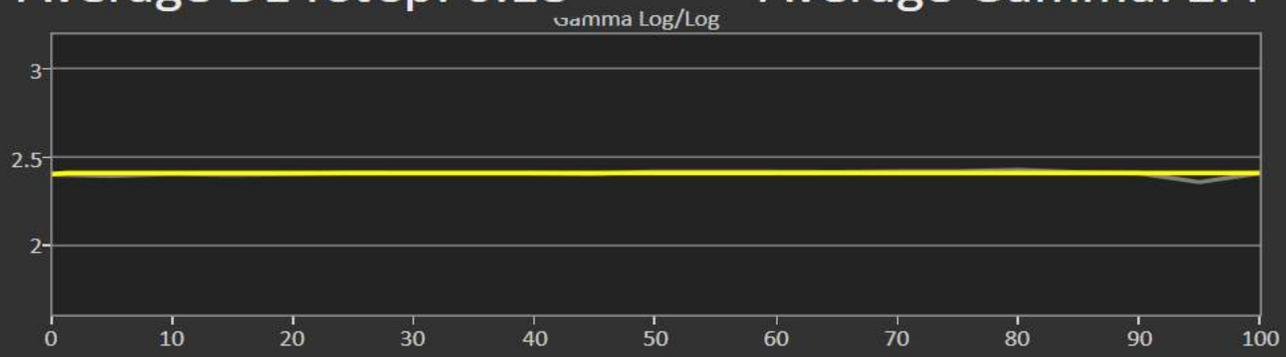
Use the charts below to adjust both the best color balance and the target luminance level for each point along the luminance response to obtain a DeltaE of less than 3.\*

Avg CCT: 6520.9  
Max Nits: 268.71  
Max fL: 78.43



Average DE ICtCp: 0.18

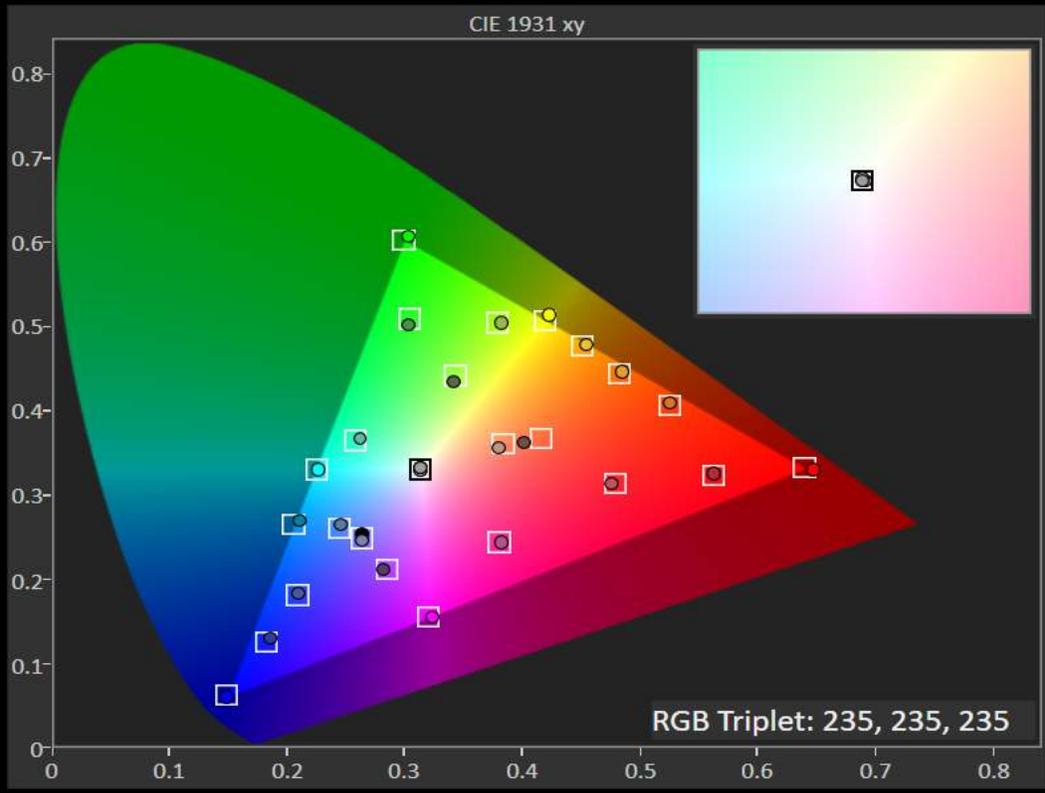
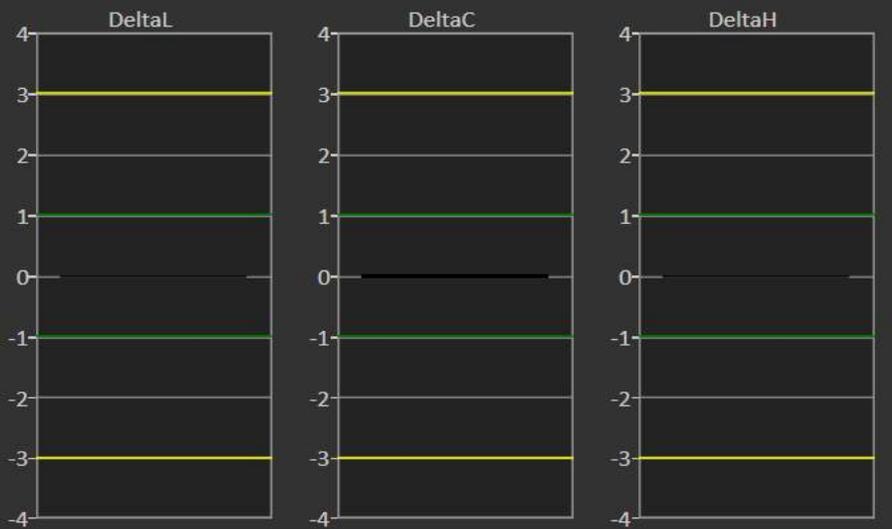
Average Gamma: 2.4



# ColorChecker



Avg dE2000: 0.71  
Max dE2000: 2.62



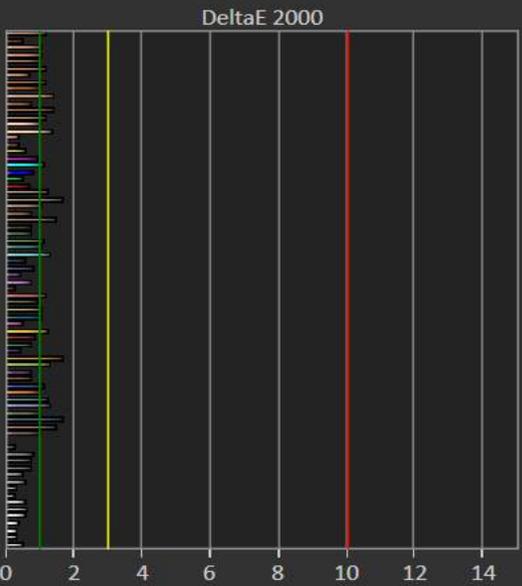
## Current Reading

x: 0.3127  
y: 0.329  
fL: 77.9  
cd/m<sup>2</sup>: 266.89

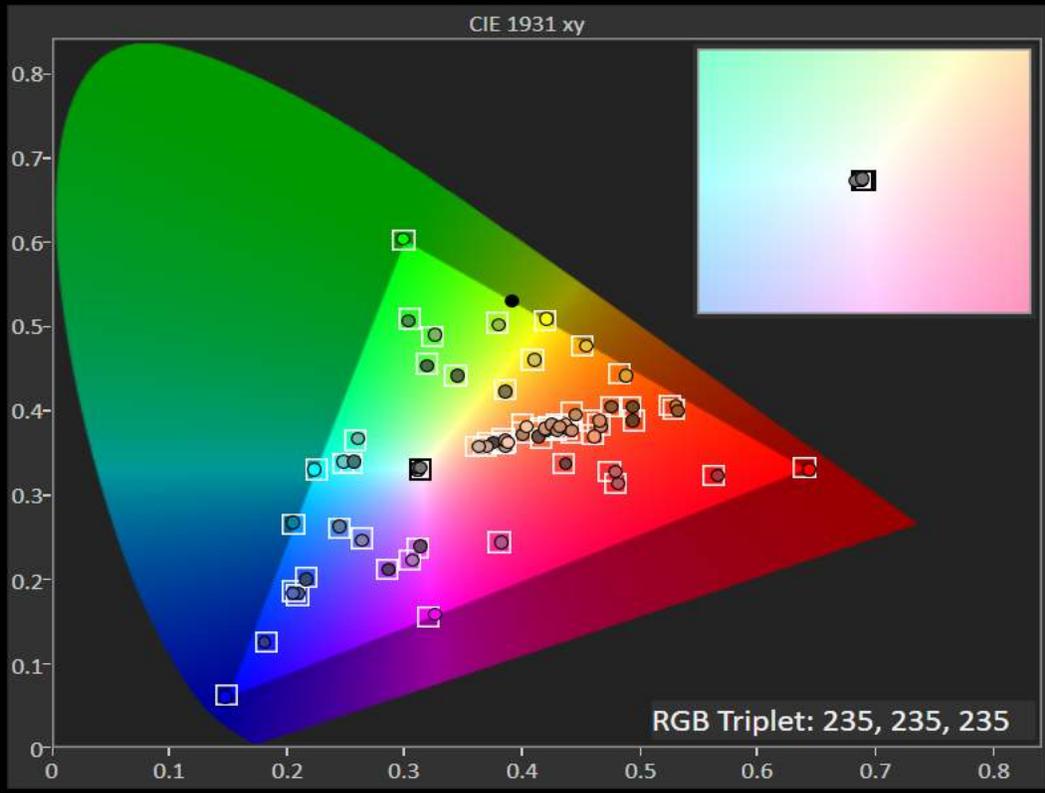
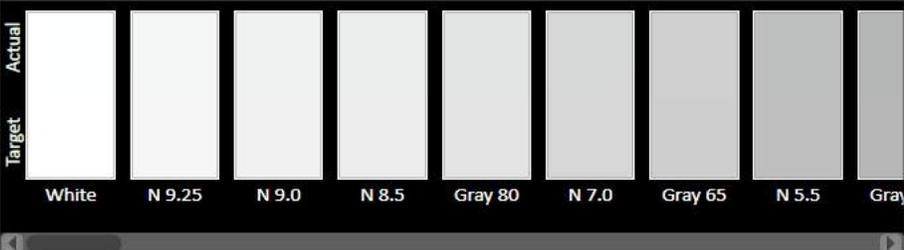
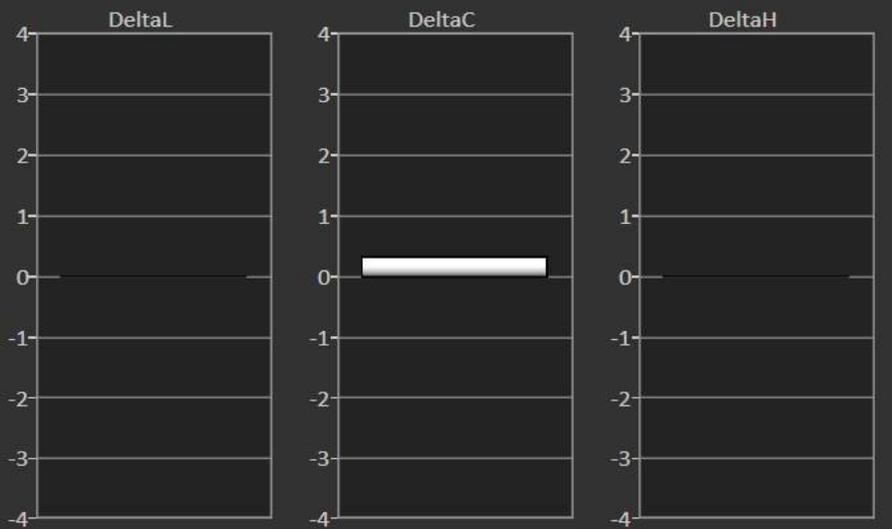
	White	Gray 80	Gray 65	Gray 50	Gray 35	Black	Dark Skin	Light Skin	Blue Sky	Foliage	Blue Flower	Bluish Green	Orange	Purplish
x: CIE31	0.3127	0.3129	0.3128	0.3127	0.3127	0.2637	0.4025	0.3800	0.2471	0.3420	0.2643	0.2613	0.5245	0.2095
y: CIE31	0.3290	0.3291	0.3290	0.3292	0.3291	0.2501	0.3598	0.3532	0.2627	0.4332	0.2454	0.3649	0.4079	0.1816
Y	266.8931	206.7772	166.8488	125.4576	85.3082	0.0008	21.1812	85.9069	43.4089	28.6252	55.6363	102.2262	69.9159	26.1311
Target x:CIE31	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.4154	0.3845	0.2442	0.3430	0.2646	0.2593	0.5260	0.2083
Target y:CIE31	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3662	0.3580	0.2593	0.4398	0.2460	0.3624	0.4054	0.1782
Target Y	266.8931	207.0095	166.6961	125.6491	85.0677	0.0000	21.5612	86.6323	43.8404	29.1908	55.8063	105.5953	69.8112	26.0652
ΔE 2000	0.0305	0.1019	0.0887	0.1366	0.0843	0.0043	1.6151	1.4088	0.6167	0.8580	0.1091	0.9543	0.7048	0.5347



# ColorChecker



Avg dE2000: 0.9  
Max dE2000: 1.7



## Current Reading

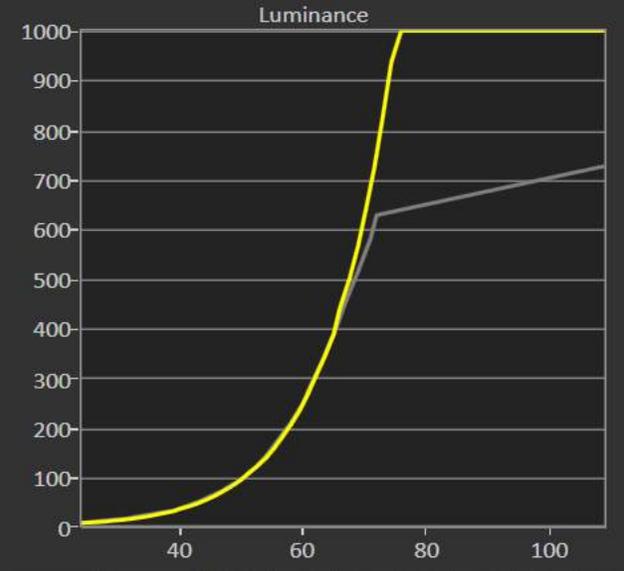
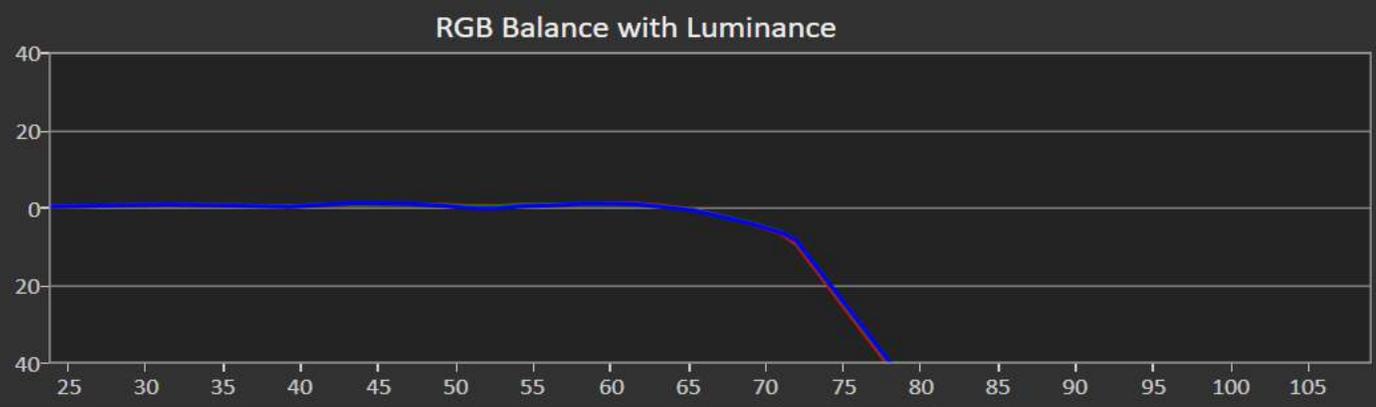
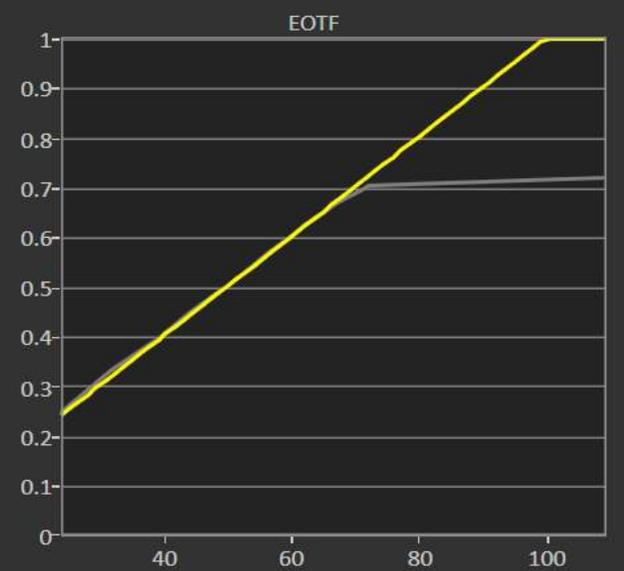
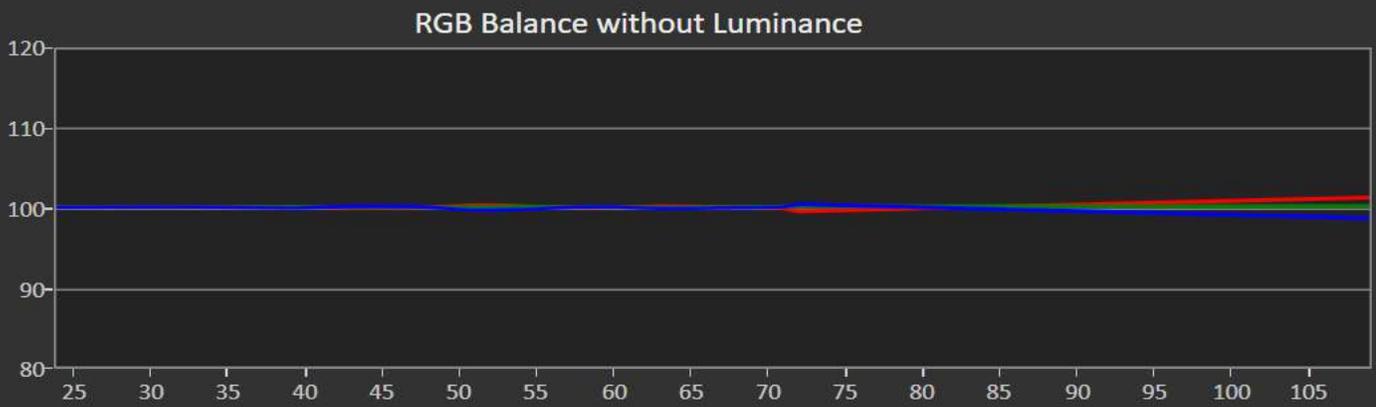
x: 0.3123  
y: 0.3292  
fL: 78.77  
cd/m<sup>2</sup>: 269.9

	White	N 9.25	N 9.0	N 8.5	Gray 80	N 7.0	Gray 65	N 5.5	Gray 50	Gray 35	N 3.0	N 2.5	N 2.25	N 2.0
x: CIE31	0.3123	0.3124	0.3123	0.3122	0.3119	0.3119	0.3120	0.3123	0.3123	0.3122	0.3120	0.3118	0.3119	0.3116
y: CIE31	0.3292	0.3290	0.3291	0.3290	0.3290	0.3290	0.3292	0.3290	0.3291	0.3296	0.3293	0.3292	0.3294	0.3291
Y	269.8986	247.4780	237.2862	226.2764	210.9349	183.3371	168.9823	138.3973	125.8068	86.4265	73.7178	60.2204	55.3630	47.6875
Target x:CIE31	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127	0.3127
Target y:CIE31	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290	0.3290
Target Y	269.8986	249.6553	238.4992	227.6393	209.3408	182.3754	168.5735	138.8018	127.0643	86.0260	72.9904	58.7268	53.9834	46.2372
ΔE 2000	0.5081	0.3405	0.3513	0.4102	0.6087	0.6150	0.5714	0.3042	0.3552	0.5519	0.5349	0.7433	0.7864	0.8446

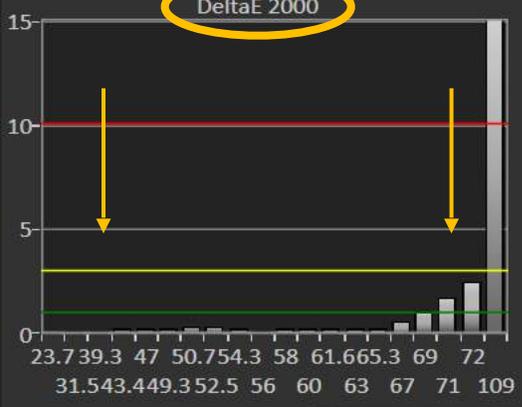
Color calibration bar with patches: White, N 9.25, N 9.0, N 8.5, Gray 80, N 7.0, Gray 65, N 5.5, Gray 50, Gray 35, N 3.0, N 2.5, N 2.25, N 2.0, N 1.8, Black, Dark Skin, Light Skin, Blue Sky, Foliage, Blue Flower, Bluish Green, Orange, Purplish Blue, Moderate Red, Purple, Yellow Green, Orange Yellow, Blue, Green, Red.

# Grayscale

Avg dE2000: 3.16  
 Max dE2000: 9.5  
 Color Temperature Avg: 6504  
 Max White Level Nits: 10000  
 Black Level Nits: 0

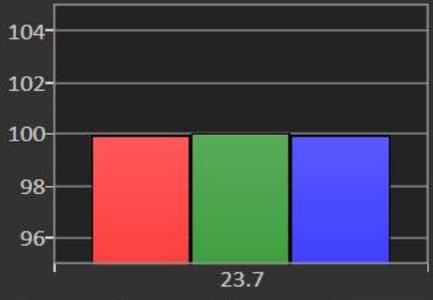


DeltaE 2000



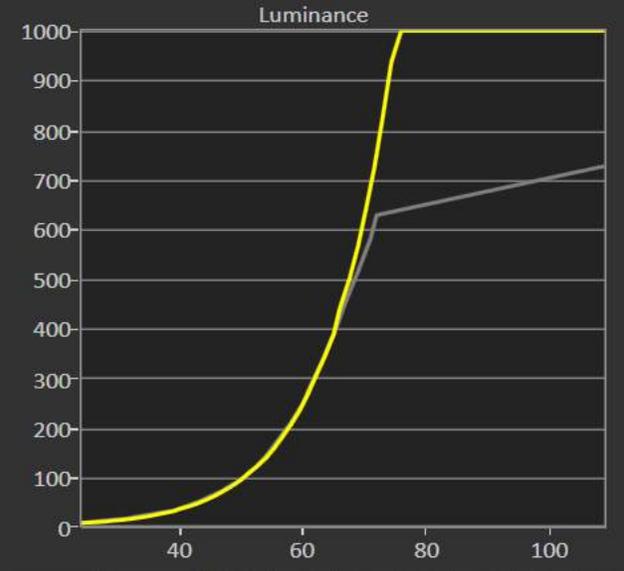
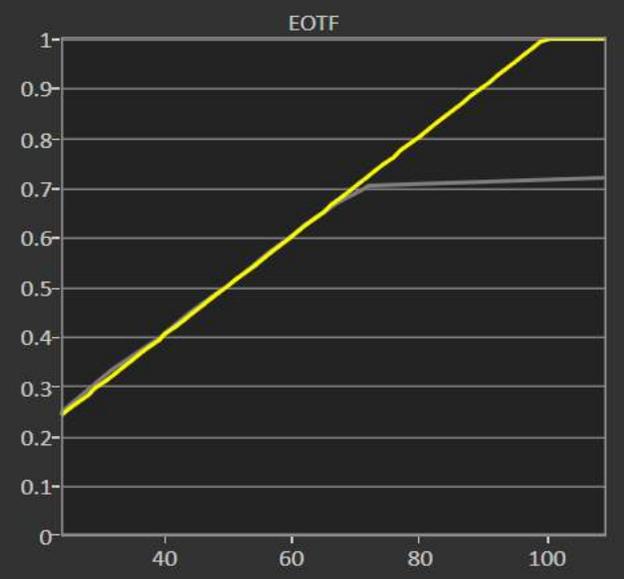
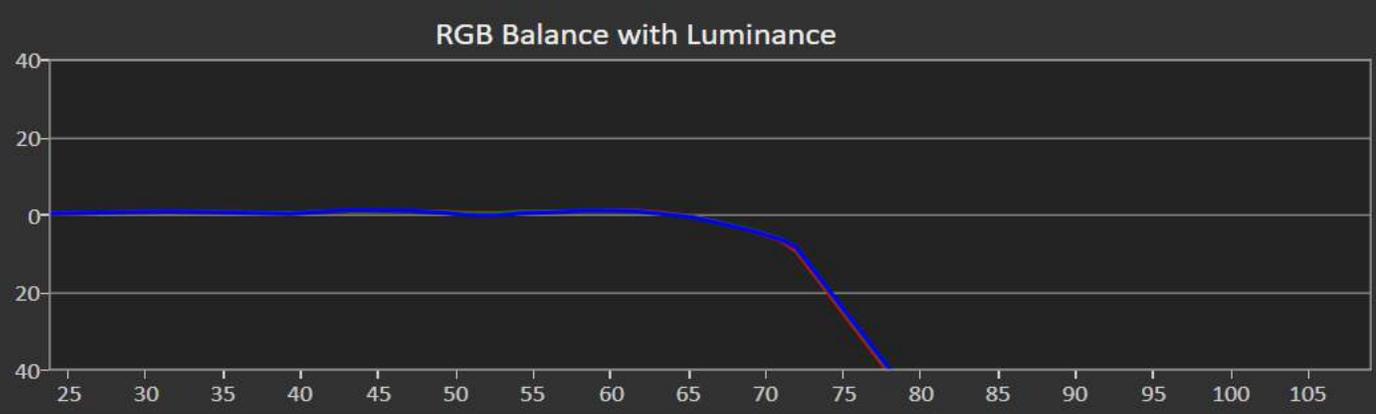
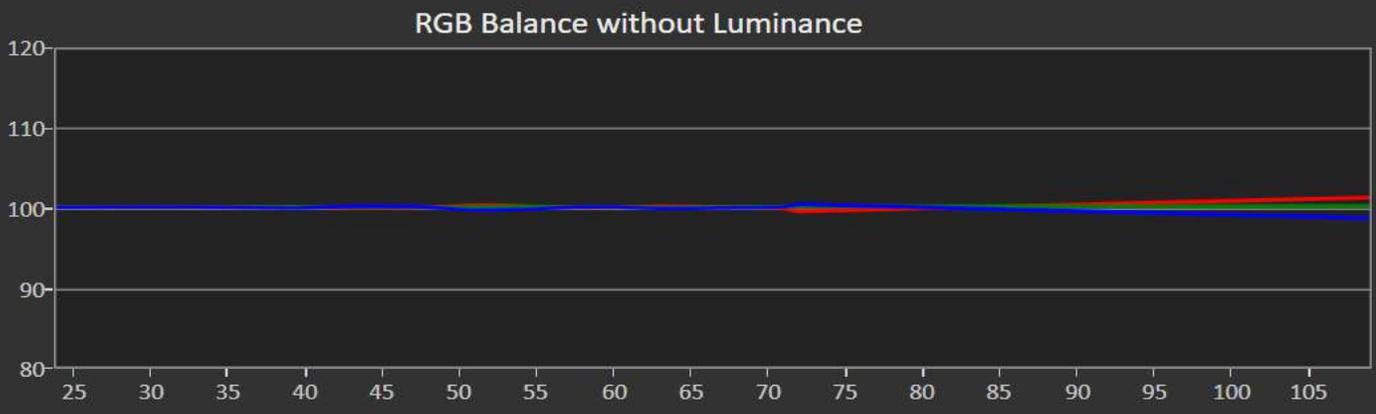
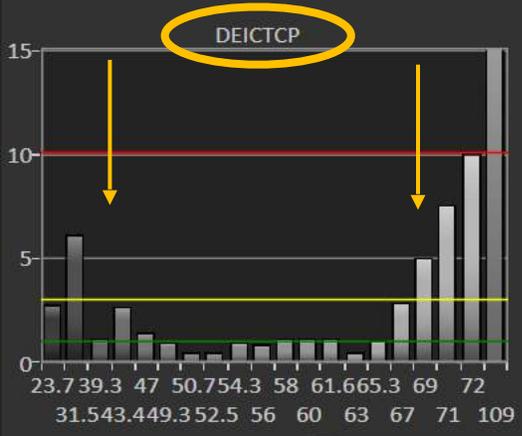
Current Reading  
 x: 0.3135  
 y: 0.3337  
 fL: 1.36  
 cd/m<sup>2</sup>: 4.68

	23.7	31.5	39.3	43.4	47	49.3	50.7	52.5	54.3	56	58
x: CIE31	0.313	0.312	0.314	0.311	0.312	0.314	0.315	0.315	0.314	0.313	0.312
y: CIE31	0.334	0.327	0.332	0.327	0.328	0.330	0.331	0.331	0.331	0.330	0.329
Y	4.675	14.143	30.692	49.416	70.343	87.790	99.371	118.723	144.230	171.884	206.0
Target x:CIE31	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313
Target y:CIE31	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329
Target Y	4.307	12.120	29.940	46.690	68.292	86.113	98.782	118.388	141.597	169.047	201.4
ΔE 2000	0.043	0.113	0.139	0.194	0.148	0.159	0.266	0.300	0.235	0.142	0.170



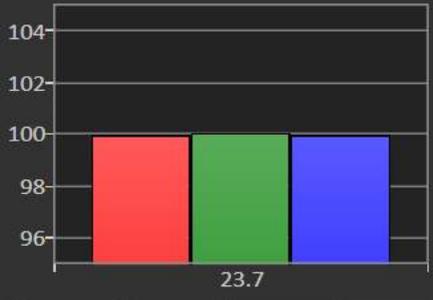
# Grayscale

Avg dE2000: 3.16  
 Max dE2000: 9.5  
 Color Temperature Avg: 6504  
 Max White Level Nits: 10000  
 Black Level Nits: 0



Current Reading  
 x: 0.3135  
 y: 0.3337  
 fL: 1.36  
 cd/m<sup>2</sup>: 4.68

	23.7	31.5	39.3	43.4	47	49.3	50.7	52.5	54.3	56	58
x: CIE31	0.313	0.312	0.314	0.311	0.312	0.314	0.315	0.315	0.314	0.313	0.312
y: CIE31	0.334	0.327	0.332	0.327	0.328	0.330	0.331	0.331	0.331	0.330	0.329
Y	4.675	14.143	30.692	49.416	70.343	87.790	99.371	118.723	144.230	171.884	206.0
Target x:CIE31	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313
Target y:CIE31	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329	0.329
Target Y	4.307	12.120	29.940	46.690	68.292	86.113	98.782	118.388	141.597	169.047	201.4
ΔE 2000	0.043	0.113	0.139	0.194	0.148	0.159	0.266	0.300	0.235	0.142	0.170



# References

1. How Close Is Close Enough? Specifying Color Tolerances For HDR AND WCG Displays
  - Jaclyn A. Pytlarz, Elizabeth G. Pieri
  - Dolby Laboratories Inc., USA
2. ICtCp White Paper
  - Dolby Laboratories
3. Dolby Demonstrates ICtCp Color Model at SMPTE 2017
  - Scott Wilkinson, AVS, October 31, 2017
4. Hitting the Mark - A New Color Difference Metric
  - Jaclyn Pytlarz, SMPTE 2017