



Bismuth color calibration

- Z1 retrofit with Bismuth lens
- 3x Warm gold calibration

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Z1 with Bismuth lens calibration test setup

- 4x Z1 systems with 3D printed housing and 3x Warm gold Bismuth lenses are prepared
 - Calibration process : [LINK](#)
- Measurement for demonstration
 - Measure Native R,G,B,W, NR(Nest Red), NB(Nest Blue)
 - Propose calibration target based on the 4x distribution data
 - Measure Post-Cal R,G,B,W, NR(Nest Red), NB(Nest Blue) after calibration
 - Propose per-Device UX color : NR, NB



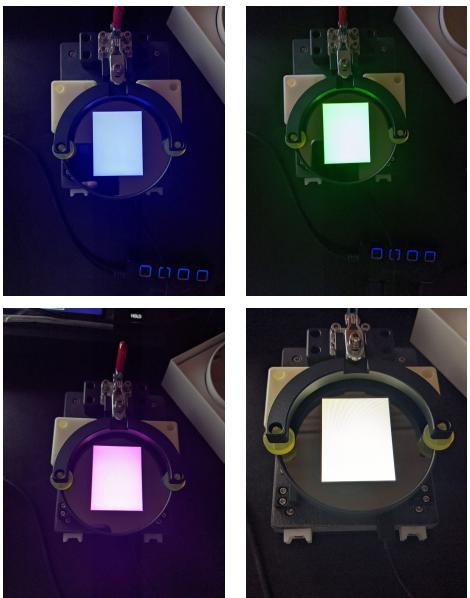
Recap: Primary and White point calibration POC

Calibrated color primary

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\text{Adjusted RGB}} = \begin{matrix} \text{XYZ-to-R'G'B'} \\ \text{3x3 Matrix} \\ \text{Device Specific} \end{matrix} \quad \begin{matrix} \text{RGB-To-XYZ} \\ \text{3x3 Matrix} \\ \text{Standard color space} \end{matrix} \quad \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\text{Native RGB}}$$

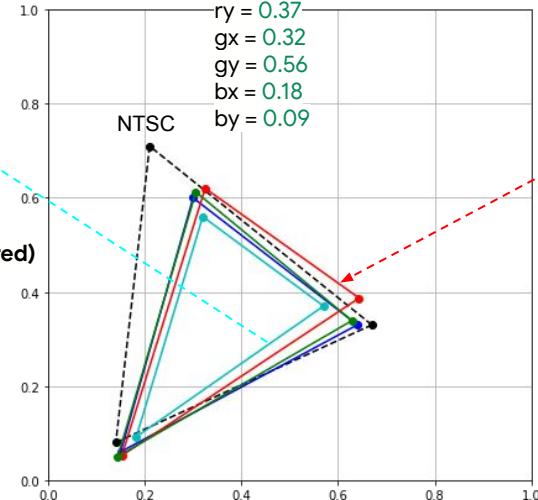
Original color primary (Z1 black)

Calibration error < 0.01 in RGB 5,6,5 bit format
FYI, Bismuth RGB is 8,8,8 bit format, higher res



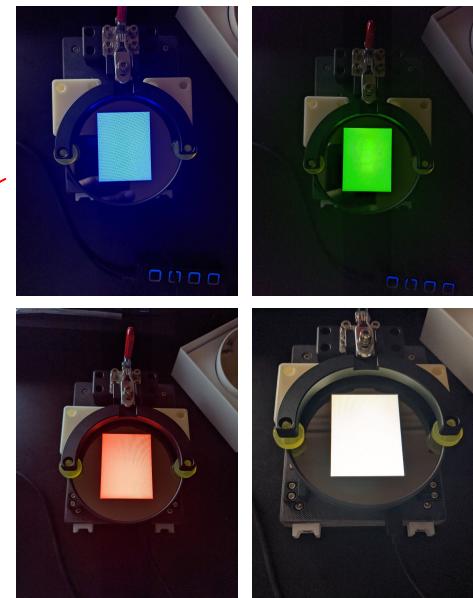
Post-cal(Measured)

Wx = 0.3122
Wy = 0.326
rx = 0.569
ry = 0.365
gx = 0.32
gy = 0.56
bx = 0.18
by = 0.09

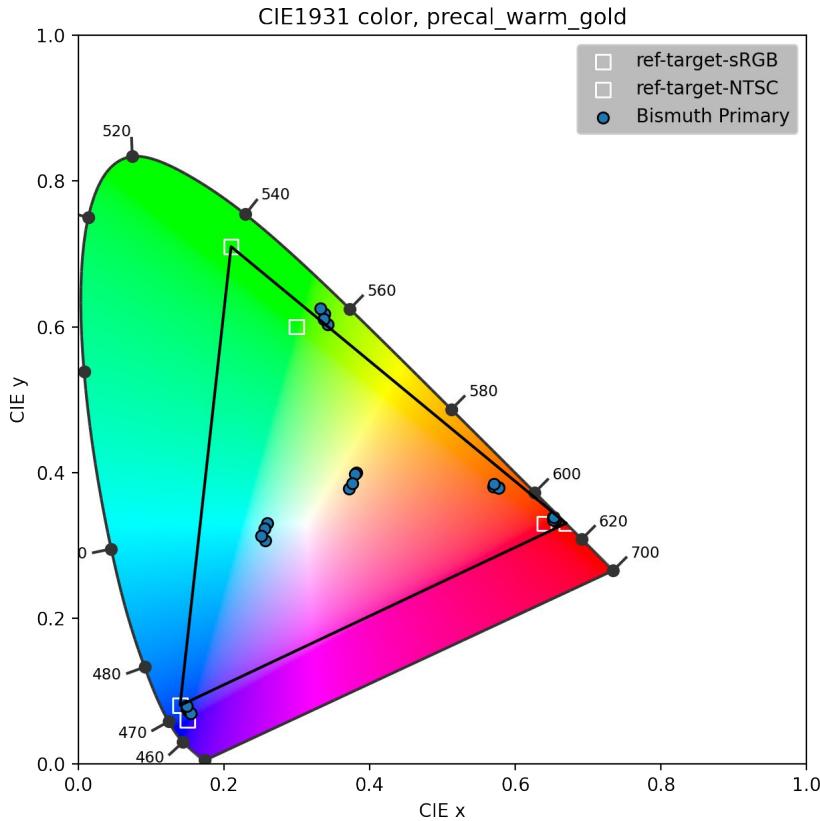
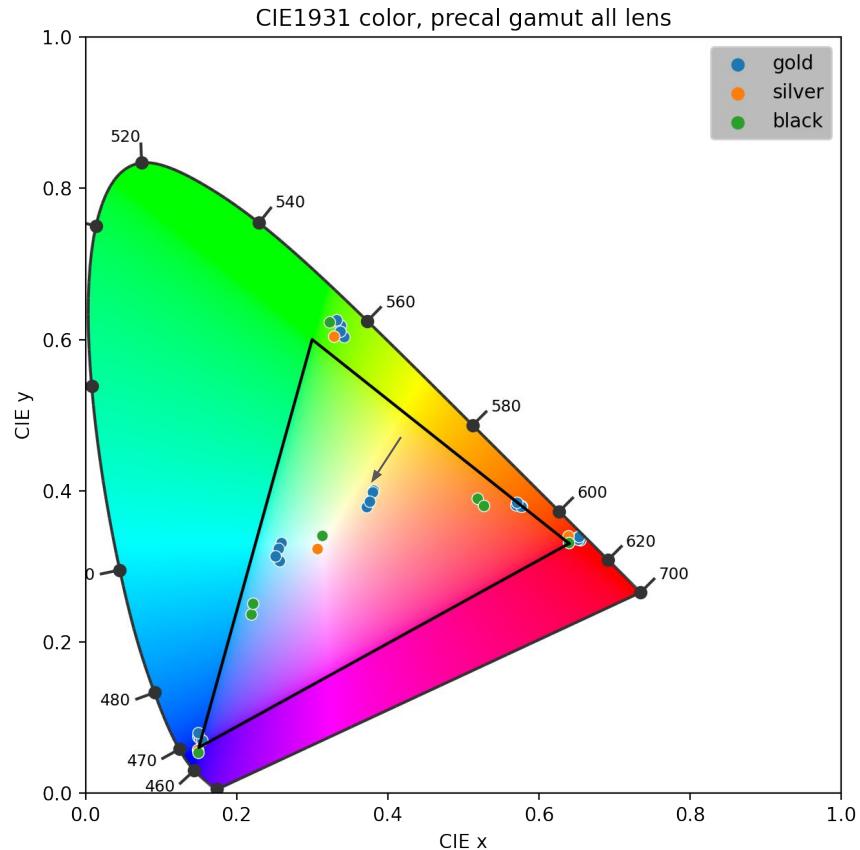


Native

Wx = 0.3145
Wy = 0.333
rx = 0.644
ry = 0.387
gx = 0.325
gy = 0.620
bx = 0.152
by = 0.052

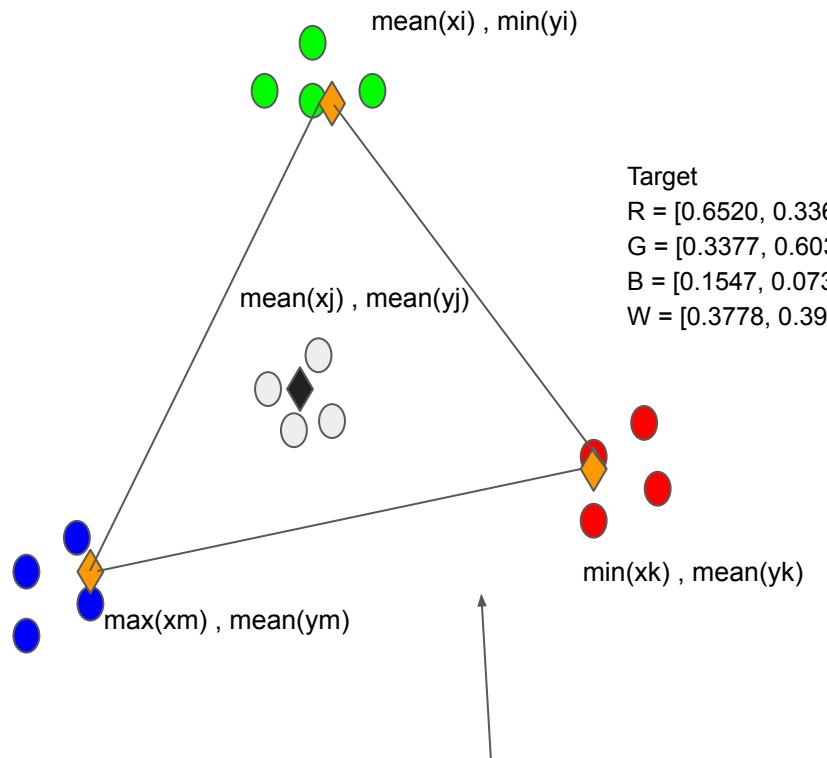


Native R, G, B, W, NR, NB color distribution



Proposed R, G, B, W for warm gold primary calibration

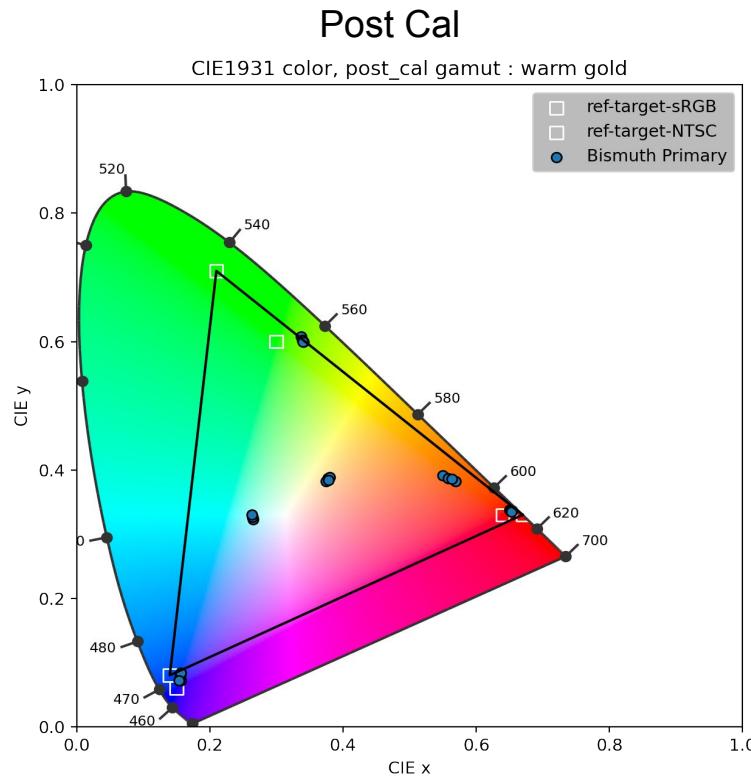
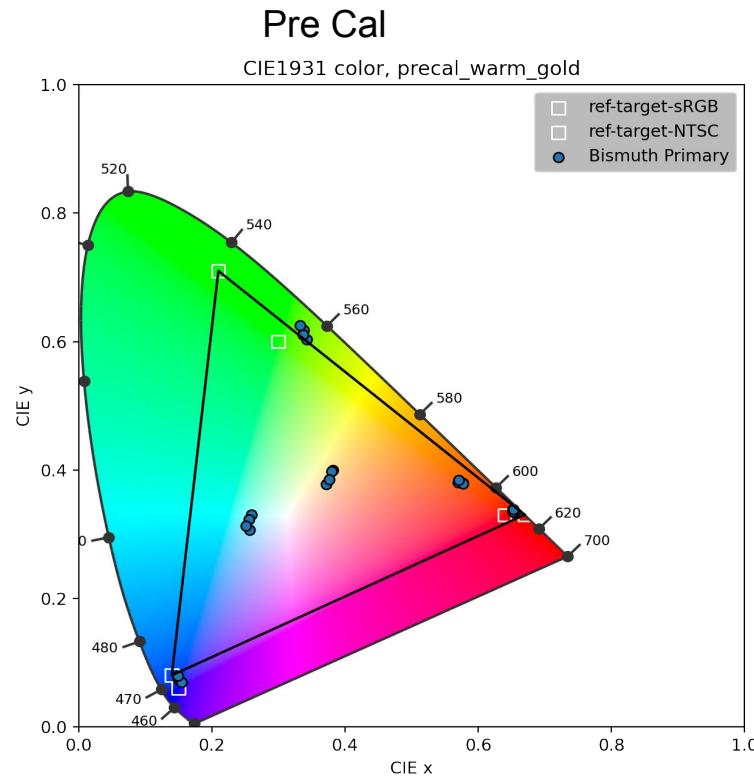
◆ Proposed color primary



Color		x	y	Y
R		0.65325	0.3366	80.27425
	mean	0.00138684293751	0.00227303028283	12.0638658363
	std	0.652	0.3343	73.23
	min	0.6523	0.334825	73.2825
	25%	0.6539	0.338475	81.80525
	75%	0.6551	0.3387	98.24
G	max	0.337725	0.61425	233.7425
	mean	0.00405	0.00965832973828	23.9802646288
	std	0.3327	0.6031	215.48
	min	0.3363	0.6085	220.37
	25%	0.339225	0.62	238.7225
	75%	0.3426	0.6254	268.79
B	max	0.15135	0.073525	16.794
	mean	0.00246373699895	0.00424057779082	4.04127710837
	std	0.1494	0.0692	13.725
	min	0.14955	0.071	13.7325
	25%	0.15245	0.075425	18.662
	75%	0.1547	0.0791	22.25

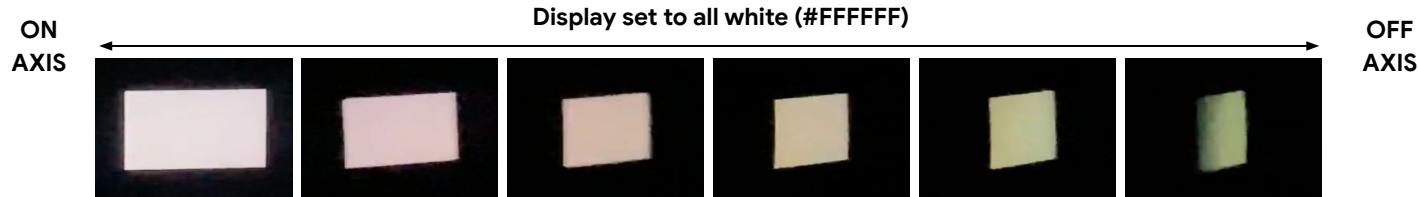
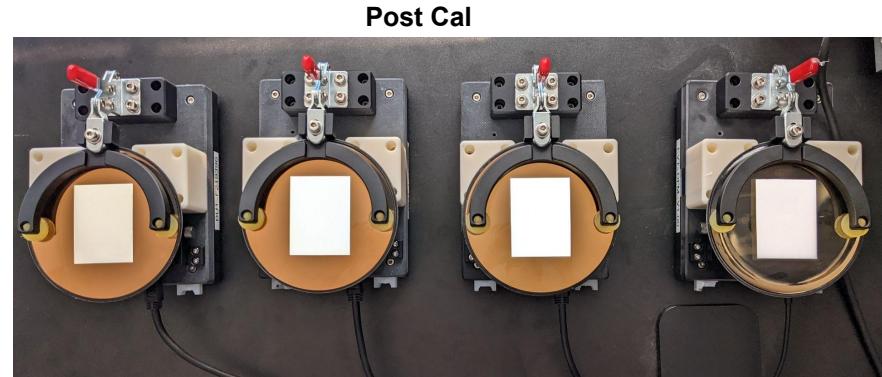
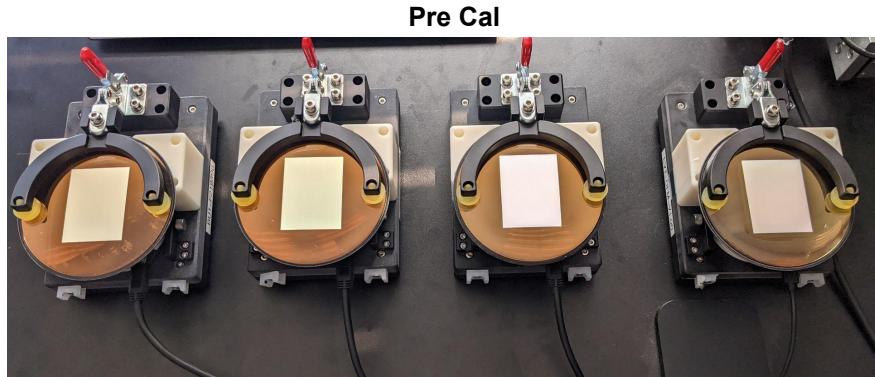
Pre vs Post Calibration result comparison

- After calibration, color distribution becomes smaller

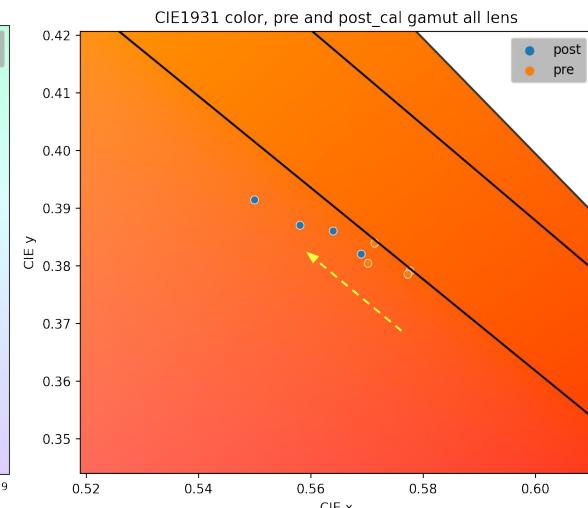
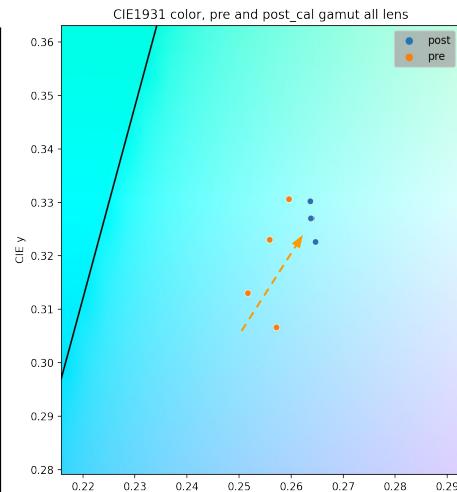
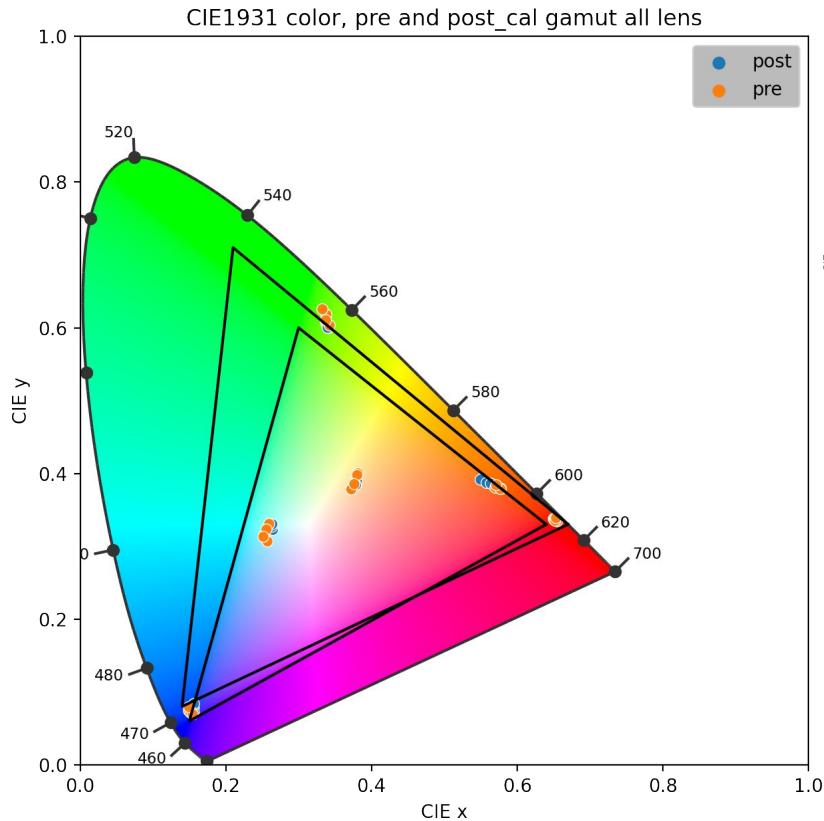


Pre vs Post Calibration result comparison

- White color test result
- On-axis calibration improves off-axis color shift ([LINK](#)) by minimizing the offset at on-axis color diff
 - Large on-axis color shift worsen the off-angle color shift



Pre vs Post Calibration result comparison

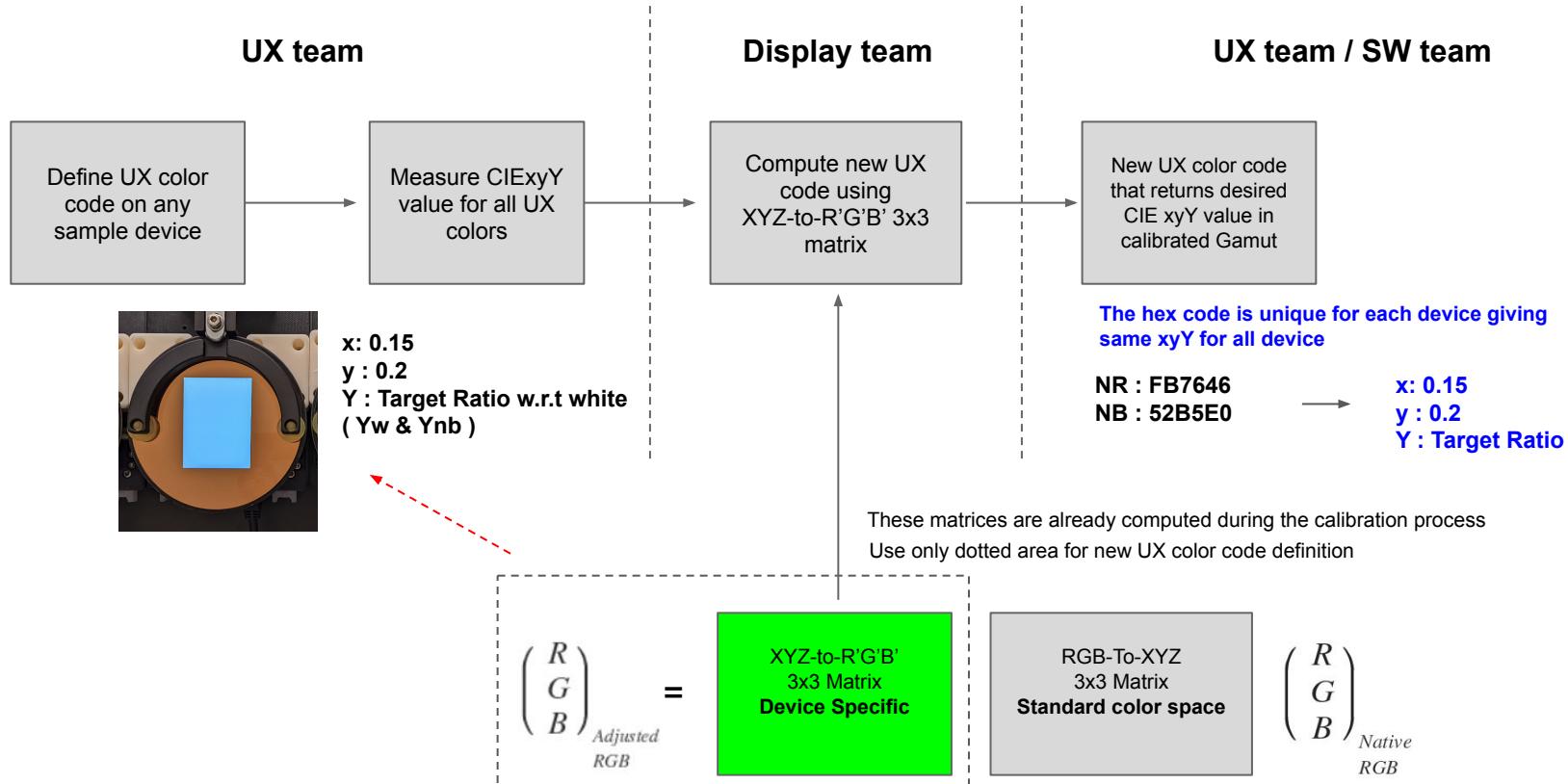


After Calibration, NR & NB shifts toward less saturated color coordinate

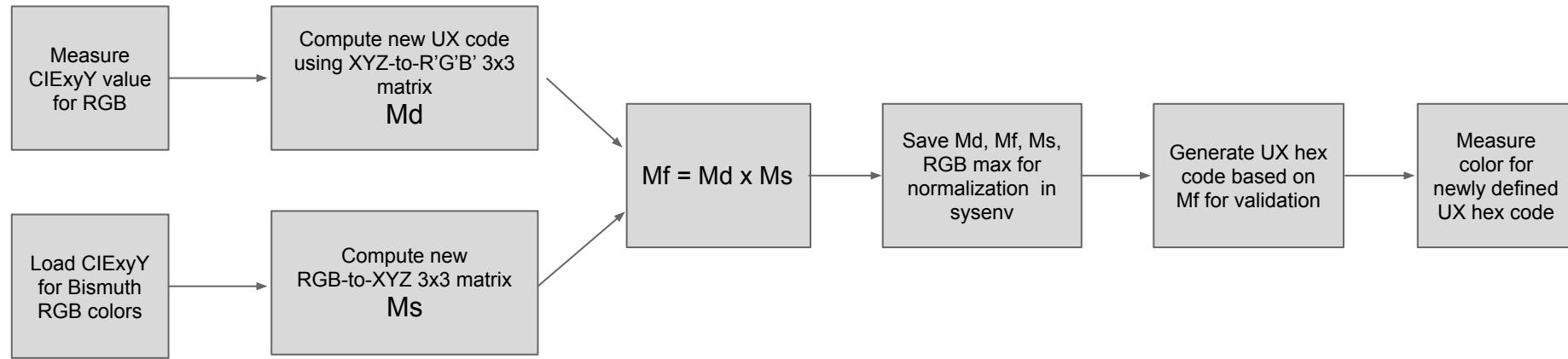
We can't use same UX color code for all devices

New UX Color Code definition process after primary calibration

Not valid



FATP process

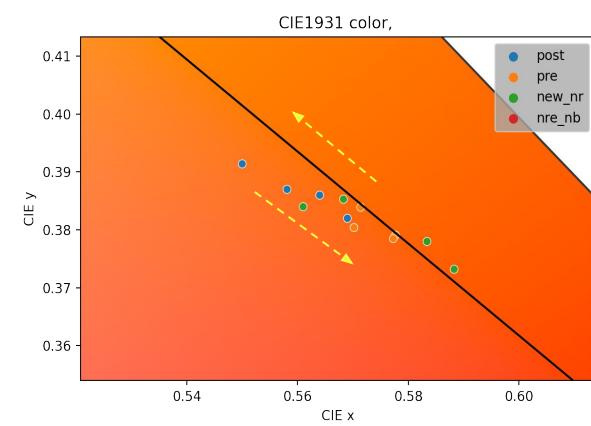
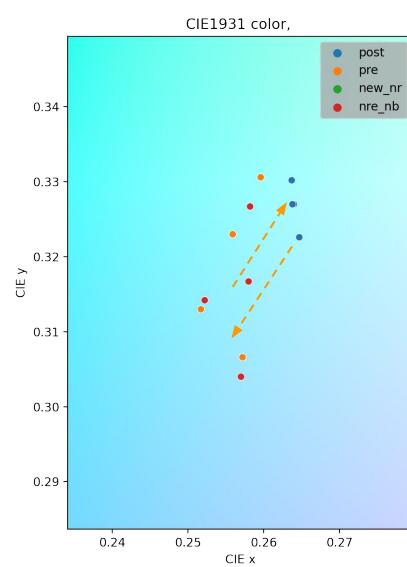
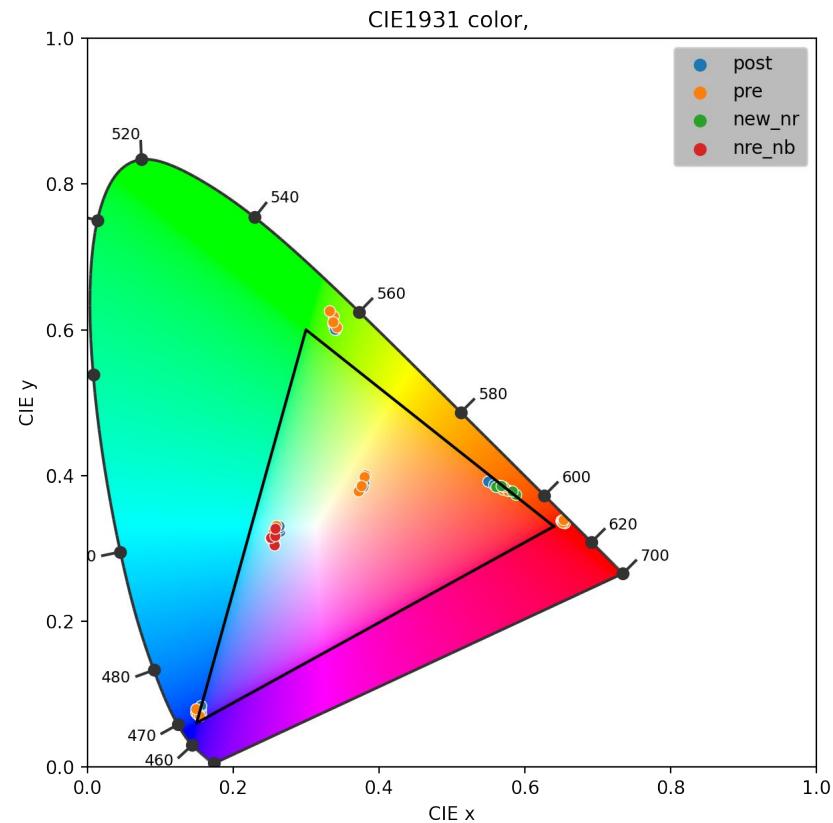


New UX Color Code definition process after primary calibration

- Deliverable to SW team
 - New hex code for each color
 - 3x3 matrix for new UX color introduction for future use
 - Need discussion with SW team for data formatting

unit_#	color	Pre			Post				New_NR/NB (Stored in Device)				
		hex	x	y	Y	hex	x	y	Y	hex	x	y	Y
0	NR	ff6240	0.5702	0.3804	115.4	fb7646	0.55	0.3914	118	ff7142	0.561	0.384	114.23
	NB	4aa8ee	0.2572	0.3066	111.7	52b5e0	0.264	0.327	125	55abe8	0.257	0.304	114
2	NR	ff6240	0.5773	0.3785	110.3	f8724a	0.569	0.382	110	fe7341	0.5683	0.3853	145
	NB	4aa8ee	0.2559	0.3230	100.62	59aeee	0.2647	0.3226	109.7	4dacec	0.2522	0.3142	142
1	NR	ff6240	0.5714	0.3839	146.8	fa774a	0.5581	0.387	153	f8663f	0.5883	0.3732	106
	NB	4aa8ee	0.2517	0.313	140.1	59b5e8	0.2638	0.327	161	489ddd	0.258	0.3167	88.7
3	NR	ff6240	0.5777	0.3791	111.6	f3704b	0.564	0.386	106.7	f4653f	0.5834	0.378	100.6
	NB	4aa8ee	0.2596	0.3306	106.7	54a9ee	0.2637	0.3302	108.3	479cdd	0.2582	0.3267	90.4

New UX Color Code definition process after primary calibration

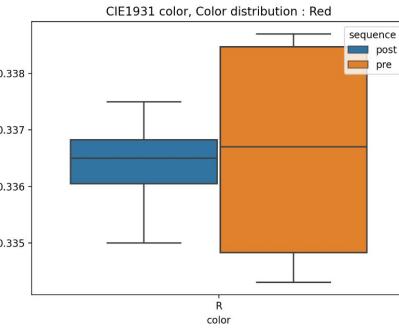
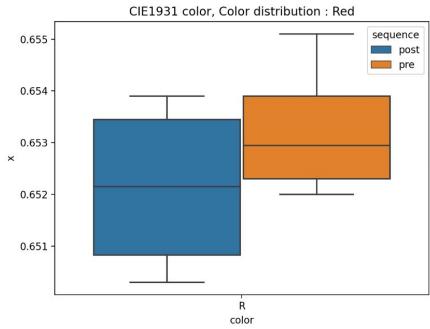


Same color is maintained with device specific color code

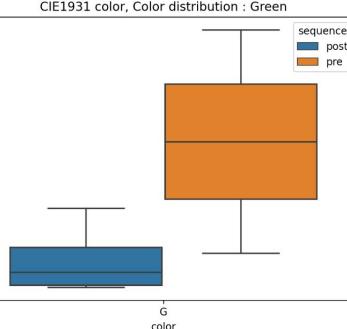
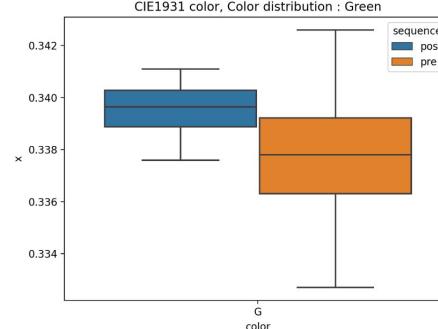
Pre vs Post Cal Color distribution : R,G,B

- Post calibration color (blue) distribution is improved overall for all primary and white colors

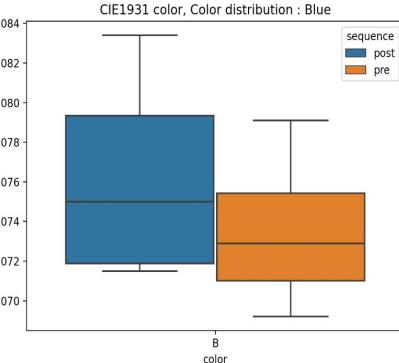
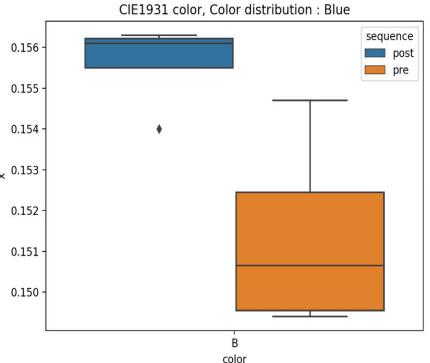
Red



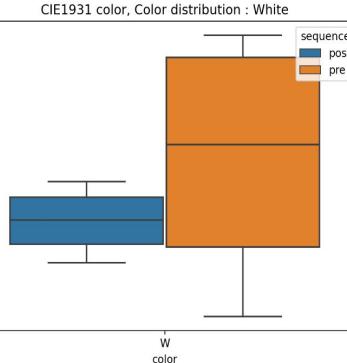
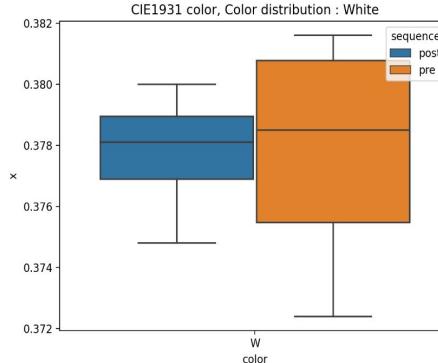
Green



Blue

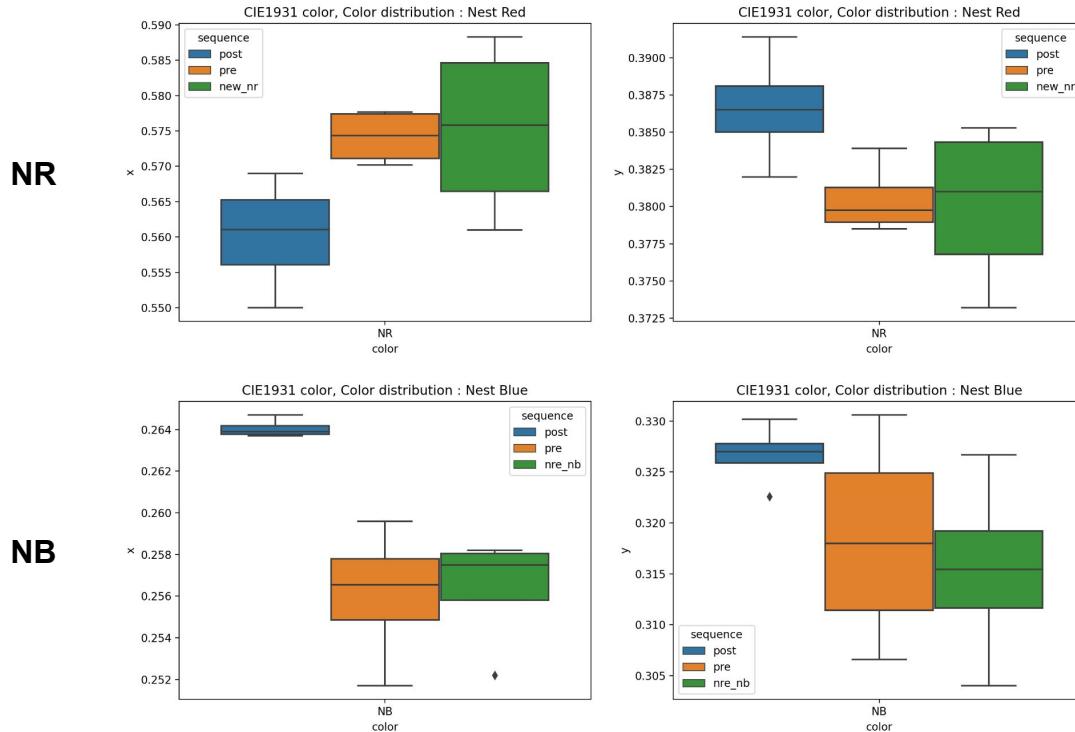


White



Pre vs Post Cal Color distribution : NR, NB

- Chose Native NR/NB color as target so new NR/NB distribution is larger than Pre-cal color
 - Expect narrower distribution once adopting single NR/NB color target



Conclusion

- Post calibration result shows much narrower color distribution
- Defined new UX hex code generation process
- Limitation: Z1 system use only 5,5,6 bit resolution for R,G,B channel while Bismuth use 8,8,8 bit resolution
 - Expect better performance on Bismuth system
- Next step: Choose tentative P1 POR color coordinate for each lens config and UX color per display team recommendation
- Monitor P1 build for POR color decision



Color Conversion matrix

New UX Color Code definition process after primary calibration

This matrix will be computed in FATP Display Cal station

To construct this matrix, XYZ value of UX color codes are required

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\text{Adjusted RGB}} = \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\text{Native RGB}}$$

XYZ-to-R'G'B'
3x3 Matrix
Device Specific

RGB-To-XYZ
3x3 Matrix
Standard color space

The diagram illustrates the mathematical equation for calculating a device-specific 3x3 matrix. It shows three components: a vector of Adjusted RGB values, a 3x3 matrix labeled 'XYZ-to-R'G'B' 3x3 Matrix Device Specific', and another 3x3 matrix labeled 'RGB-To-XYZ 3x3 Matrix Standard color space'. Arrows point from the Adjusted RGB vector and the second matrix to the equals sign. A brace underneath groups the 'XYZ-to-R'G'B' matrix and the 'RGB-To-XYZ' matrix.

Two 3x3 matrices or potentially combined version of single 3x3 matrix will be saved in the sysenv

Lens info.	Tongda Selen Silver	CIExy	Tongda Selen Black	CIExy	Tongda Selen Gold	CIExy
Colors	Silver		Black		Warm Gold	
White	#FFFFFF		#FFFFFF		#FFFFFF	
Orange	#FF7343		#FF6632		#FF905C	
Blue	#45A6FF		#56AEFE		#4EAAFF	
Green	#40D267		#3CDF68		#40D267	
Green - Apollo	#28FF8B		#28FF8B		#00F17A	
Red	#F83538		#FF4548		#F83538	
Yellow	#FFDB55		#FFDB55		#F6D455	
Maroon (Air)	#CA293A		#E94052		#B12D2D	
Purple (Air)	#BB3E90		#D445A3		#A53E90	
Gray - Light	#969DA5		#A0A7AF		#A0A7AF	
Gray - Dark	#79838C		#86919B		#80868B	
Black	#000000		#000000		#000000	

New UX Color Code definition process after primary calibration

Two 3x3 matrices and potentially combined version of single 3x3 matrix will be saved in the sysenv in engineering build.

$$\text{Eq 1)} \quad \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\substack{\text{Adjusted} \\ \text{RGB}}} = \underbrace{\begin{matrix} \text{XYZ-to-R'G'B'} \\ \text{3x3 Matrix} \\ \text{Device Specific} \end{matrix}}_{\substack{\text{Md} \\ \text{Matrix Device Specific}}} \quad \underbrace{\begin{matrix} \text{RGB-To-XYZ} \\ \text{3x3 Matrix} \\ \text{Standard color space} \end{matrix}}_{\substack{\text{Ms} \\ \text{Matrix Standard color space}}} \quad \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\substack{\text{Native} \\ \text{RGB}}}$$

M_f

$$\text{Eq 2)} \quad \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\substack{\text{UX code}}} = \frac{255}{\text{RGB}_{\max}} \times \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\substack{\text{Adjusted RGB}}}^{1/(2.2)}$$

, Where $\text{RGB}_{\max} = \max \left(M_f \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}_{\substack{\text{Native RGB}}} \right)^{1/(2.2)}$

Backup

Lens sample selection

Display_only	unit1	unit2	unit3	unit4
With Lens	3	2		1
sn	ss5su9	ndnfb5	3leac3	ufkk18
	01180exdb01303	01140exdb0141r		01170exdb014na
housing color	white	pink	pink	blue
ciexy	left bottom	top bottom		center
wY	1558	1299	1254	1267
wx	0.2883	0.2954	0.2937	0.2919
xy	0.3053	0.3268	0.3173	0.3191
rY	261.3	199.9	199.8	200
rx	0.635	0.632	0.6312	0.6301
ry	0.339	0.3283	0.3279	0.3287
gY	1152	989	952	986
gx	0.3184	0.3138	0.3148	0.315
gy	0.6087	0.6318	0.6273	0.624
bY	128.38	80.58	85	83.939
bx	0.1489	0.1528	0.15	0.149
by	0.0537	0.0486	0.0495	0.0491
blackY	1.084	0.8765	0.876	0.949
blackx	0.2477	0.2472	0.2473	0.2455
blacky	0.2384	0.2462	0.2467	0.2451