



## ENGINEERING SPECIFICATION

### Bismuth Display ACR ERS

OBJECTIVES:	Detail the Engineering Requirements Specification (ERS) for the Bismuth display Ambient Contrast Ratio(ACR) test including the technical and design conditions to be met.  The ERS is used in conjunction with Reliability Requirements, Mechanical Control Outline (MCO), Outgoing Quality Control, and First Article Inspection documents for a comprehensive view of the adapter requirements.
BUILD LEVEL:	MP
AUTHORS:	Peter Kim ( <a href="mailto:hckim@google.com">hckim@google.com</a> ) Yun Shuai ( <a href="mailto:yshuai@google.com">yshuai@google.com</a> ) Sathya (skurcharlapati@google.com)
APPROVED BY:	Steven Lee ( <a href="mailto:seungjunlee@google.com">seungjunlee@google.com</a> )
REVISION:	00
RELEASE DATE:	xx/xx/2021
AGILE CONTROL:	G860-00212-01-ERS (example) ECO-A21142(example)
NOTES:	This specification assumes that the reader has some familiarity with display test methodology, design and manufacturing. This document is intended for:  Contract manufacturers who are involved in the design, assembly, and test of the display panel.  Google engineers who are designing the display for Bismuth.  Google engineers who are designing electrical or mechanical assemblies connecting to, or interacting with, the display system.

All information in this specification is confidential and the sole property of Google. This document is subject to change without notice. The latest released version of this document is available on the Agile system for authorized users.

This documents falls under the control of Google's non-disclosure agreements. Do not transmit, copy, or change information in this specification without explicit permission from Google.

## Revision History

Date	Rev. No	Contents	Remarks
09/20/2021	A	Initial	skurcharlapati@ hckim@
03/05/2022	B	P1 coverage	skurcharlapati@
08/23/2022	C	P2 coverage	skurcharlapati@
02/28/2023	D	P2.1 Coverage added	skurcharlapati@

## **Table of Contents**

1. Reference Documents
2. Introduction
3. ACR measurement setup requirement

## 1. Reference Documents

- [ACR justification](#)
- [Bismuth UX: Lens/Display Legibility](#)
- [ACR process and improvement plan](#)

## 2. Introduction

Bismuth targets to launch three different color SKUs and each lenses will be tinted to holistically match with the ring colors and Ambient Contrast Ratio is the UX performance evaluation metric that informs legibility of graphics. Bismuth has dome shaped mirrored lens, with low transmissivity, high reflectivity and severe off-angle color & luminance drop (particularly warm gold lens color). All these features combined together makes Bismuth more challenging in legibility over Z1. Also lens and display process variation makes color and luminance variation wider than any other products which requires large volume measurement to make sure all displays have proper ACR values.



Fig. Three different color SKU in Bismuth

Spec related to ACR measurement station

## 2.1 P1 ACR Spec

Lux condition	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR Spec Low BS (LSL)	ACR Spec High BS (LSL)	Note (Priority)
0	White #FFFFFF	35	55	4.5	4.5	Subject to change P1*
10		47	63	4.5	4.5	Subject to change P1
100		60	76	4.5	4.5	Subject to change P0
300		80	100	4.5	4.5	Subject to change P0
600		100	100	4.5	4.5	Subject to change P0
0	Orange #FF6E40	35	55	4.5	4.5	Subject to change P1
10		47	63	4.5	4.5	Subject to change P1
100		60	76	4.5	4.5	Subject to change P0
300		80	100	4.5	4.5	Subject to change P0
600		100	100	4.5	4.5	Subject to change P0
0	Blue #4AA8FE	35	55	4.5	4.5	Subject to change P1
10		47	63	4.5	4.5	Subject to change P1
100		60	76	4.5	4.5	Subject to change P0
300		80	100	4.5	4.5	Subject to change P0
600		100	100	4.5	4.5	Subject to change

							P0
--	--	--	--	--	--	--	----

\*Note: P1 is data collection only and P0 is for pass/fail.

### Contrast Ratio Target

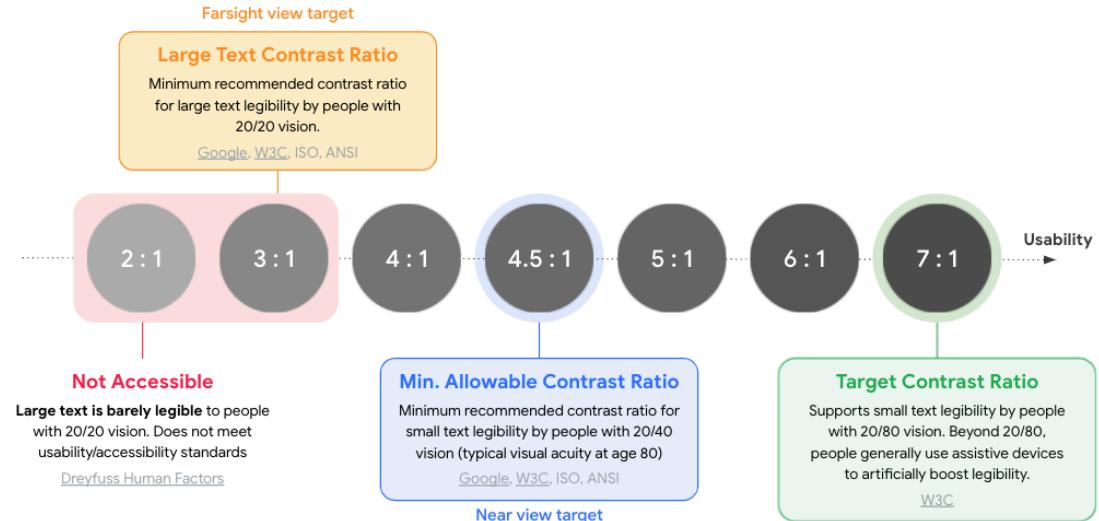


Fig. Legibility of UX on different ACR level

Lux	Measured Nits	Current Setting LSL		Measured Nits LSL		Current Setting USL		Measured Nits USL		Calculated Contrast LSL		Calculated Contrast USL		<b>Avg contrast</b>
		Black	White	Black	White	Black	White	Black	White	Black	White	Black	White	
8/23 GOLD Selen POR1 Comp polarizer	0	0.01442	35	2.82	55	12.66	195.56	877.95	536.755					
	10	2.452	47	26.62	63	82.16	10.86	33.51	22.185					
	100	24.39	60	87.57	76	229.4	3.59	9.41	6.5					
	300	72.91	80	340.5	100	1130	4.67	15.5	10.085					
	600	146.1	100	1185	100	1201	8.11	8.22	8.165					
		Orange - #FF6E40												
	0	0.01442	35	1.021	55	4.606	70.8	319.42	195.11					
	10	2.452	47	11.25	63	31.44	4.59	12.82	8.705					
	100	24.39	60	47.22	76	98.78	1.94	4.05	2.995					
	300	72.91	80	169.5	100	452.3	2.32	6.2	4.26					
	600	146.1	100	518.5	100	524.7	3.55	3.59	3.57					
		Blue - #4AA8FE												
	0	0.01442	35	1.092	55	4.899	75.73	339.74	207.735					
	10	2.452	47	11.82	63	33.23	4.82	13.55	9.185					
	100	24.39	60	48.65	76	103	1.99	4.22	3.105					
	300	72.91	80	175.4	100	474	2.41	6.5	4.455					
	600	146.1	100	541.2	100	545.9	3.7	3.74	3.72					

Fig. MTV lab measurement data. Z1 system with Bismuth lens.

## 2.1 P2 ACR Spec

### Warm Gold

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
0	Black #000000	White #FFFFFF	7	12	4.5	P0
10			48	67	4.5	P0
100			66	83	4.5	P0
300			83	98	4.5	P0
600			90	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	7	12	-	P1
10			48	67	-	P1
100			66	83	-	P1
300			83	98	-	P1
600			90	100	-	P1
0	Blue #1D427F	White #FFFFFF	7	12	-	P1
10			48	67	-	P1
100			66	83	-	P1
300			83	98	-	P1
600			90	100	-	P1

### Silver

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
0	Black #000000	White #FFFFFF	12	16	4.5	P0
10			39	62	4.5	P0
100			61	82	4.5	P0
300			73	93	4.5	P0
600			86	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	12	16	-	P1
10			39	62	-	P1
100			61	82	-	P1
300			73	93	-	P1
600			86	100	-	P1
0	Blue #1D427F	White #FFFFFF	12	16	-	P1
10			39	62	-	P1
100			61	82	-	P1
300			73	93	-	P1
600			86	100	-	P1

## Black

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
0	Black #000000	White #FFFFFF	25	33	4.5	P0
10			50	69	4.5	P0
100			65	83	4.5	P0
300			76	94	4.5	P0
600			85	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	25	33	-	P1
10			50	69	-	P1
100			65	83	-	P1
300			76	94	-	P1
600			85	100	-	P1
0	Blue #1D427F	White #FFFFFF	25	33	-	P1
10			50	69	-	P1
100			65	83	-	P1
300			76	94	-	P1
600			85	100	-	P1

## Example ACR test

Lux	Measured nits LL	Measured nits UL	Brightness Setting Low (%)	Measured Nits LSL	Brightness Setting High (%)	Measured Nits USL	Calculated Contrast LSL	Calculated Contrast USL	Avg contrast
Black									
0	0.015	0.0163	38	0.806	50	1.96	53.73	120.25	86.99
10	0.1799	0.1894	55	2.936	70	8.759	16.32	46.25	31.285
100	1.664	1.68	69	9.547	90	36.35	5.74	21.64	13.69
300	4.903	4.94	80	21.89	97	59.96	4.46	12.14	8.3
600	9.821	9.82	88	39.45	100	78.4	4.02	7.98	6
Orange - #A04A2E									
0	0.1459	0.3198	38	0.806	50	1.96	5.52	6.13	5.825
10	0.6197	1.477	55	2.936	70	8.759	4.74	5.93	5.335
100	2.865	6.957	69	9.547	90	36.35	3.33	5.22	4.275
300	7.519	13.34	80	21.89	97	59.96	2.91	4.49	3.7
600	14.41	20.49	88	39.45	100	78.4	2.74	3.83	3.285
Blue - #5A7096									
0	0.1609	0.3664	38	0.806	50	1.96	5.01	5.35	5.18
10	0.6251	1.566	55	2.936	70	8.759	4.7	5.59	5.145
100	2.928	7.316	69	9.547	90	36.35	3.26	4.97	4.115
300	7.725	14	80	21.89	97	59.96	2.83	4.28	3.555
600	14.73	21.3	88	39.45	100	78.4	2.68	3.68	3.18

## 2.2 P2.1 ACR spec

### Warm Gold

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
---------------	------------------	------------	----------------------------	-----------------------------	--------------	-----------------

0	Black #000000	White #FFFFFF	7	12	4.5	P0
10			48	67	4.5	P0
100			66	83	4.5	P0
300			83	98	4.5	P0
600			90	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	7	12	-	P1
10			48	67	-	P1
100			66	83	-	P1
300			83	98	-	P1
600			90	100	-	P1
0	Blue #1D427F	White #FFFFFF	7	12	-	P1
10			48	67	-	P1
100			66	83	-	P1
300			83	98	-	P1
600			90	100	-	P1

### Silver

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
0	Black #000000	White #FFFFFF	12	16	4.5	P0
10			39	62	4.5	P0
100			61	82	4.5	P0
300			73	93	4.5	P0
600			86	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	12	16	-	P1
10			39	62	-	P1
100			61	82	-	P1
300			73	93	-	P1
600			86	100	-	P1
0	Blue #1D427F	White #FFFFFF	12	16	-	P1
10			39	62	-	P1
100			61	82	-	P1
300			73	93	-	P1
600			86	100	-	P1

### Black

Lux condition	Background color	Test color	Brightness Setting Low (%)	Brightness Setting High (%)	ACR spec Avg	Note (Priority)
0	Black #000000	White #FFFFFF	25	33	4.5	P0
10			50	69	4.5	P0
100			65	83	4.5	P0
300			76	94	4.5	P0
600			85	100	4.5	P0

Data Collection only for below

0	Orange #8D4027	White #FFFFFF	25	33	-	P1
10			50	69	-	P1
100			65	83	-	P1
300			76	94	-	P1
600			85	100	-	P1
0	Blue #1D427F	White #FFFFFF	25	33	-	P1
10			50	69	-	P1
100			65	83	-	P1
300			76	94	-	P1
600			85	100	-	P1

### P2.1 - test items - Additional test items

white_0lux_10_Y
white_0lux_25_Y
white_0lux_50_Y
white_0lux_75_Y
white_0lux_85_Y
white_0lux_90_Y
white_0lux_95_Y
white_0lux_97_Y
white_0lux_98_Y
black_0lux_100_Y

white_0lux_100_Y
white_0lux_100_x
white_0lux_100_y
off_10lux_off_Y
off_600lux_off_Y

## 2.3 ACR station coverage

ACR station test coverage is mentioned in this [link](#)

## 3. ACR measurement setup requirement

### 3.1 Measurement setup

ACR measurement station should be placed after ALS, Backlight, and Color calibration in FATP. The following figure describe the measurement setup in MTV and geometry of measurement setup.

### System requirement

1. **Spectroradiometer** - measures light (brightness, color wavelength) [replace with hyperion colorimeter \(WD limitation? 100mm\)](#)
2. **Reflector wall** - simulates worse case scenario for contrast ratio (Add color code)
  - a. 40 inch x 40 inch in MTV setup but it can be smaller than this.
  - b. 30 cm x 30 cm for size can be used in factory
  - c. Paint color: swiss color (Peter to provide color coordinates)
  - d. Finish: matt (reflectance %?)
3. **Smart bulbs** - connected to a local network, changes ambient brightness [replace with light panel](#)
4. Lights color temperature - [4000K](#)
5. **Lux meters** - measures ambient lux at the reflector wall and Z1 unit to set ambient brightness accurately. [what is the position of the lx meter](#)
  - a. Lux accuracy +- 1%
6. **Device Under Testing**

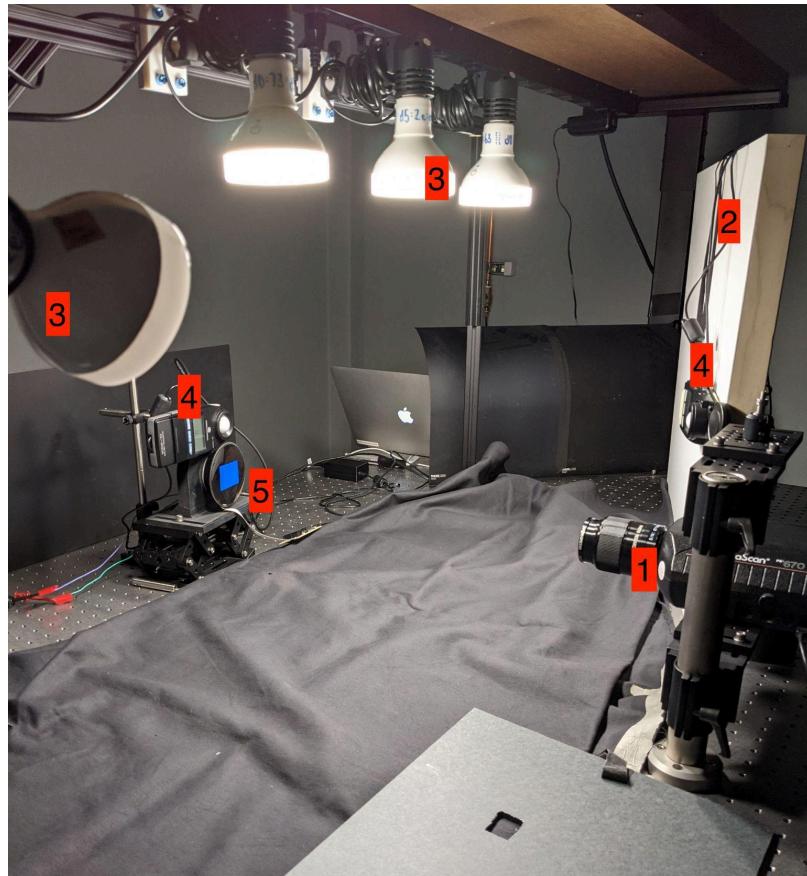
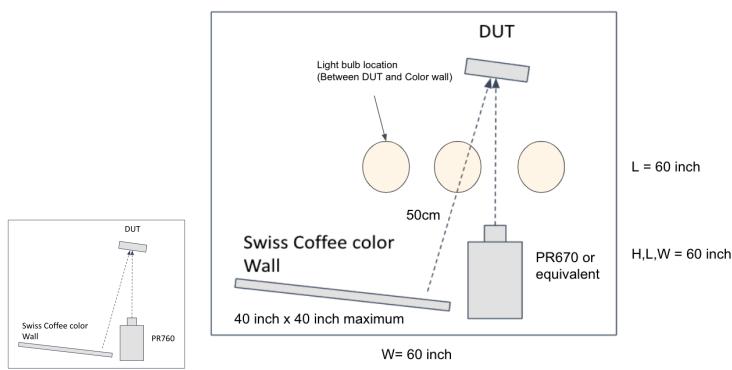


Fig. Measurement setup overview



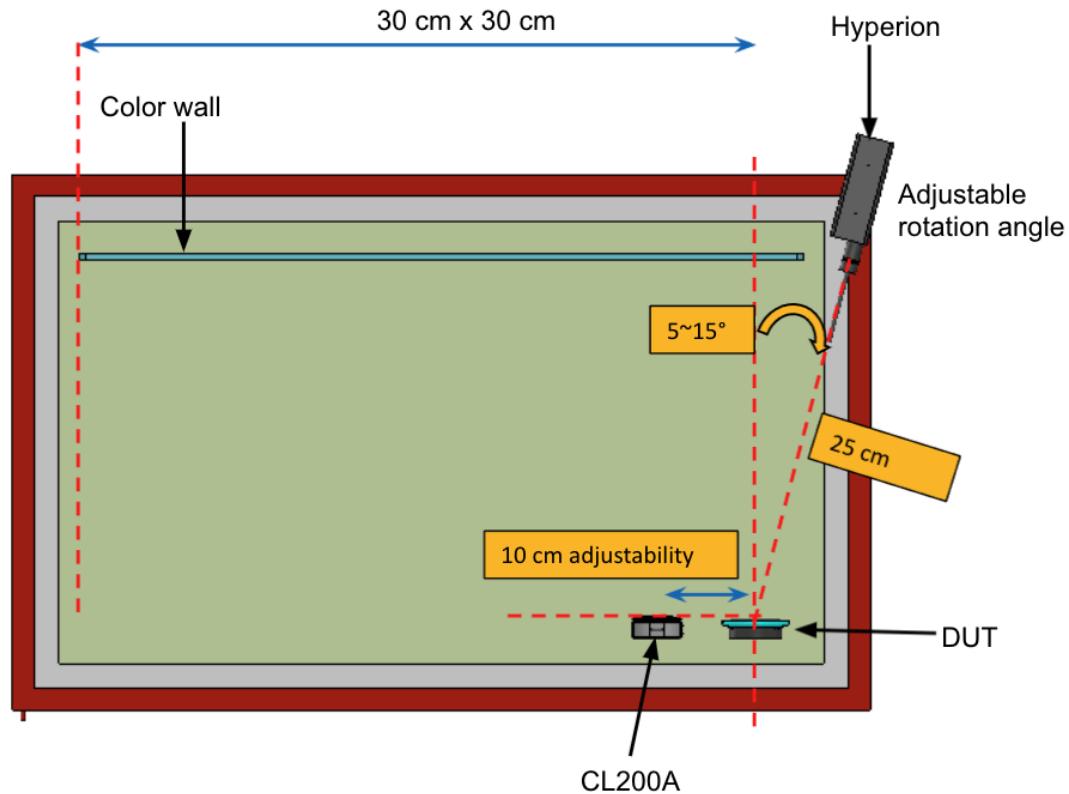


Fig. Measurement setup top view . PR670 can be replaced by any other spectrophotometer or colorimeter with equivalent measurement accuracy and working distance

#### Details on the device/equipment placement

##### Spectrascan - PR670 or equivalent

- SS (PR670) is kept at a distance of 50cm from the DUT display. SS lens and DUT display needs to be on axis.
- **Measurement angle: 5~15 degree adjustability**
- **Distance from DUT to Hyperion: 25cm at 5 degree**

##### DUT

- DUT needs to be slightly angled (current angle at MTV is "15 deg") to reflect the canvas wall on the lens surface. This angle can vary depending on the condition if the viewpoint from SS can see a reflection of the wall covering the complete lens (specifically the display and ALS region). Suggestion to have capability to move DUT 10 - 20 deg for better adjustments until lens is finalized.

##### White canvas wall

- White canvas wall surface distance to DUT lens needs to be 50cm or higher. This is defined by the lux meter reference on the white canvas wall to have the same values (within tolerance spec +/-1%) as the lux meter reference on the DUT. Current size of canvas is 24inch x 24 inch (2ft x 2ft). Suggestion for the canvas wall minimum size will be 12 inch x 12 inch (1ft x 1ft).
- **Size: 30cmx30cm**
- **Distance from DUT: > 25cm**

- Reflectance of color wall : [LINK](#)
- XYZ value of color wall at D65 : [LINK](#)
  - The color of swiss coffee color wall is close to the plain white color in Pantone checker pattern.
- FATP white wall data: [LINK](#)



The data below is intended to be an average measurement of all ColorChecker Charts. ColorChecker Charts should be replaced every two years as fading of the colors will alter the values of the chart.

No.	Number	sRGB			CIE L*a*b*			Munsell Notation	
		R	G	B	L*	a*	b*	Hue Value / Chroma	
1.	dark skin	115	82	68	37.986	13.555	14.059	3 YR	3.7 / 3.2
2.	light skin	194	150	130	65.711	18.13	17.81	2.2 YR	6.47 / 4.1
3.	blue sky	98	122	157	49.927	-4.88	-21.925	4.3 PB	4.95 / 5.5
4.	foliage	87	108	67	43.139	-13.095	21.905	6.7 GY	4.2 / 4.1
5.	blue flower	133	128	177	55.112	8.844	-25.399	9.7 PB	5.47 / 6.7
6.	bluish green	103	189	170	70.719	-33.397	-0.199	2.5 BG	7 / 6
7.	orange	214	126	44	62.661	36.067	57.096	5 YR	6 / 11
8.	purplish blue	80	91	166	40.02	10.41	-45.964	7.5 PB	4 / 10.7
9.	moderate red	193	90	99	51.124	48.239	16.248	2.5 R	5 / 10
10.	purple	94	60	108	30.325	22.976	-21.587	5 P	3 / 7
11.	yellow green	157	188	64	72.532	-23.709	57.255	5 GY	7.1 / 9.1
12.	orange yellow	224	163	46	71.941	19.363	67.857	10 YR	7 / 10.5
13.	blue	56	61	150	28.778	14.179	-50.297	7.5 PB	2.9 / 12.7
14.	green	70	148	73	55.261	-38.342	31.37	0.25 G	5.4 / 8.65
15.	red	175	54	60	42.101	53.378	28.19	5 R	4 / 12
16.	yellow	231	199	31	81.733	4.039	79.819	5 Y	8 / 11.1
17.	magenta	187	86	149	51.935	49.986	-14.574	2.5 RP	5 / 12
18.	cyan	8	133	161	51.038	-28.631	-28.638	5 B	5 / 8
19.	white (.05*)	243	243	242	96.539	-0.425	1.186	N	9.5 /
20.	neutral 8 (.23*)	200	200	200	81.257	-0.638	-0.335	N	8 /
21.	neutral 6.5 (.44*)	160	160	160	66.766	-0.734	-0.504	N	6.5 /
22.	neutral 5 (.70*)	122	122	121	50.867	-0.153	-0.27	N	5 /
23.	neutral 3.5 (.1.05*)	85	85	85	35.656	-0.421	-1.231	N	3.5 /
24.	black (1.50*)	52	52	52	20.461	-0.079	-0.973	N	2 /

Cie L\*a\*b\* values use Illuminant D50 2 degree observer sRGB values for illuminate D65.

Reference: [LINK](#)

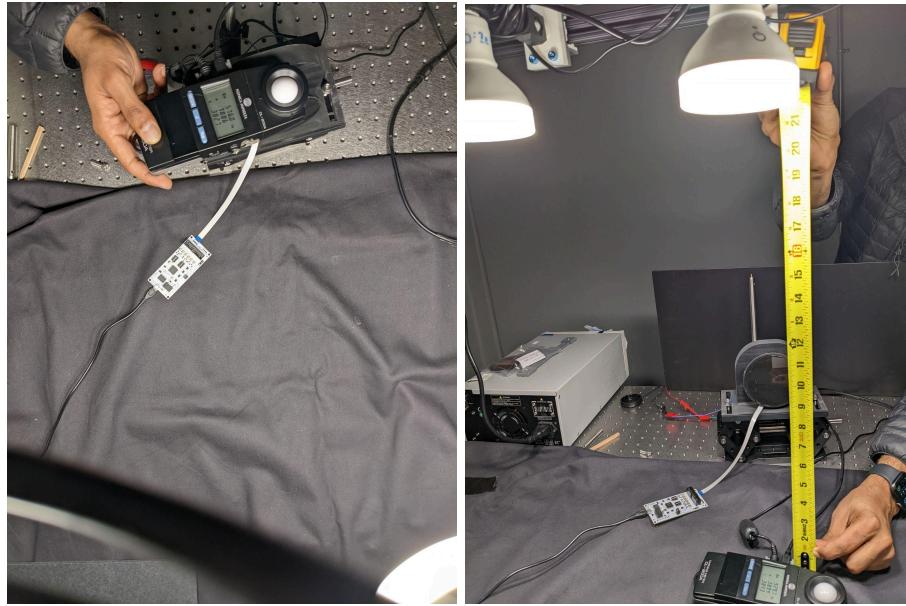
White in the checker corresponds to 243,243,242 in sRGB space which is  $x,y = (0.313, 0.3295)$  at D65. This is close enough to  $x,y = (0.3136, 0.3365)$  of Swiss coffee color wall. So standard white from color checker can be used instead of coffee color wall

### Lights (light panel)

- To be placed in the mid point of the distance between DUT and canvas wall.
- Size: **30cm x 30cm**
- Distance above DUT: 20-30cm

### Lux meter

- Position w.r.t DUT: Right next to DUT (See drawing)



- Lux condition
- (21 inch below light source) 880 lux (600 lux at position 4 )
- 90 degree rotated at original location: 576 lux (set as 600 lux before rotation)
- 

### 3.2 Test procedure

1. Set ambient brightness to target lux at DUT(4a) and Reflector Wall (4b) location
  - a. There are 3 light bulbs for high brightness range control (3a,3b)
  - b. There is a 1 light bulb for low brightness range control (3c)
  - c. Adjust individual bulb intensity to make 4a and 4b lux meter reading similar to each other : delta < 1 lux : **Need updates. One lux meter next to DUT is required**
    - i. Target lux range: 600 lux to 0 lux
    - ii. Currently this process is all handled manually and can be further optimized considering the fixture design limitation and TACT time
  - d. Note: Light bulb configs in a & b can be replaced by any other equivalent lightning config such as single light and diffuser considering the FATP process and fixture design.
2. Make sure DUT orientation to make the worst case ACR scenario
  - a. Looking through spectrophotometer, the DUT should see wall reflection (Fig 2)
  - b. Check the wall reflection through web camera in PR760, wall color would be visible through web camera
    - i. The fixture should provide adjustability of DUT orientation angle to determine worst case scenario angle
3. Adjust backlight current to make backlight brightness match display bezel and measure black and white color luminance to compute ACR (See picture below)
  - a. In actual process, device will load predefined current level at each Lux condition

since device is on FCT.

