Theory and Application of an Alternative Method to Integrating Sphere Photometry

CORM 2009
May 6, 2009

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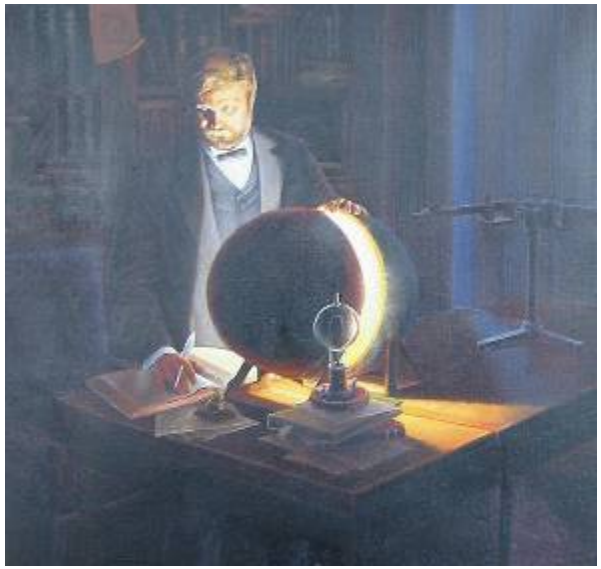
Brief History of Integrating Sphere Technology

- 1892 — W.E. Sumpner (UK) describes integrating sphere theory
- 1894 — R. Ulbricht (Germany) builds first working integrating sphere
- 1920 — A.H. Taylor (NBS) develops methods for measuring reflectance using integrating spheres.
- 1933 — A.C. Hardy (MIT) designs first integrating sphere for a commercial spectrometer.
- 1968 — F. Grum and G.W. Luckey (Kodak) develop $BaSO_4$ sphere paint
- 1979 — D.J. Lovell (Labsphere) codifies sphere design principles



Key Integrating Sphere Photometer Features

Diffusely reflecting coating

High reflectance coating

Baffle(s) to screen direct view between sample or light source and detector

Ports to let light in or out

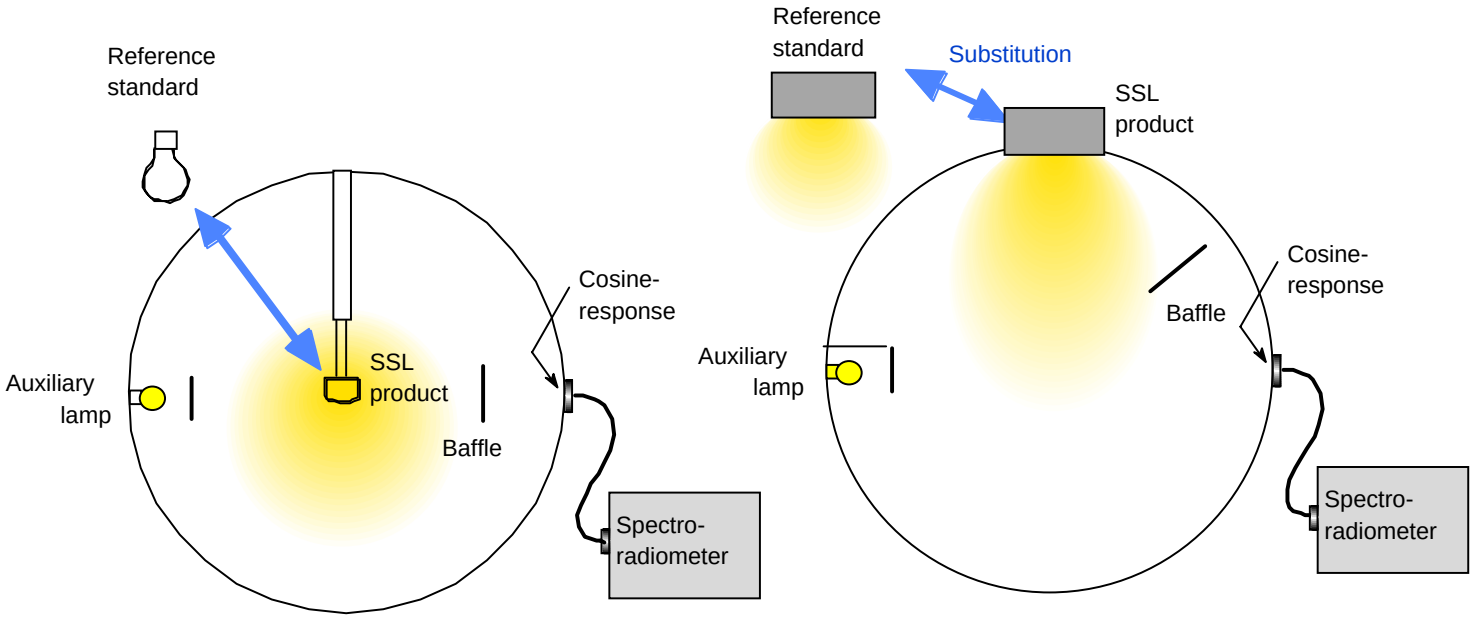
Substitution Method

$$\Phi_t = \Phi_s \frac{D_t}{D_s} \frac{A_s}{A_t} k$$

SSL Test Methods

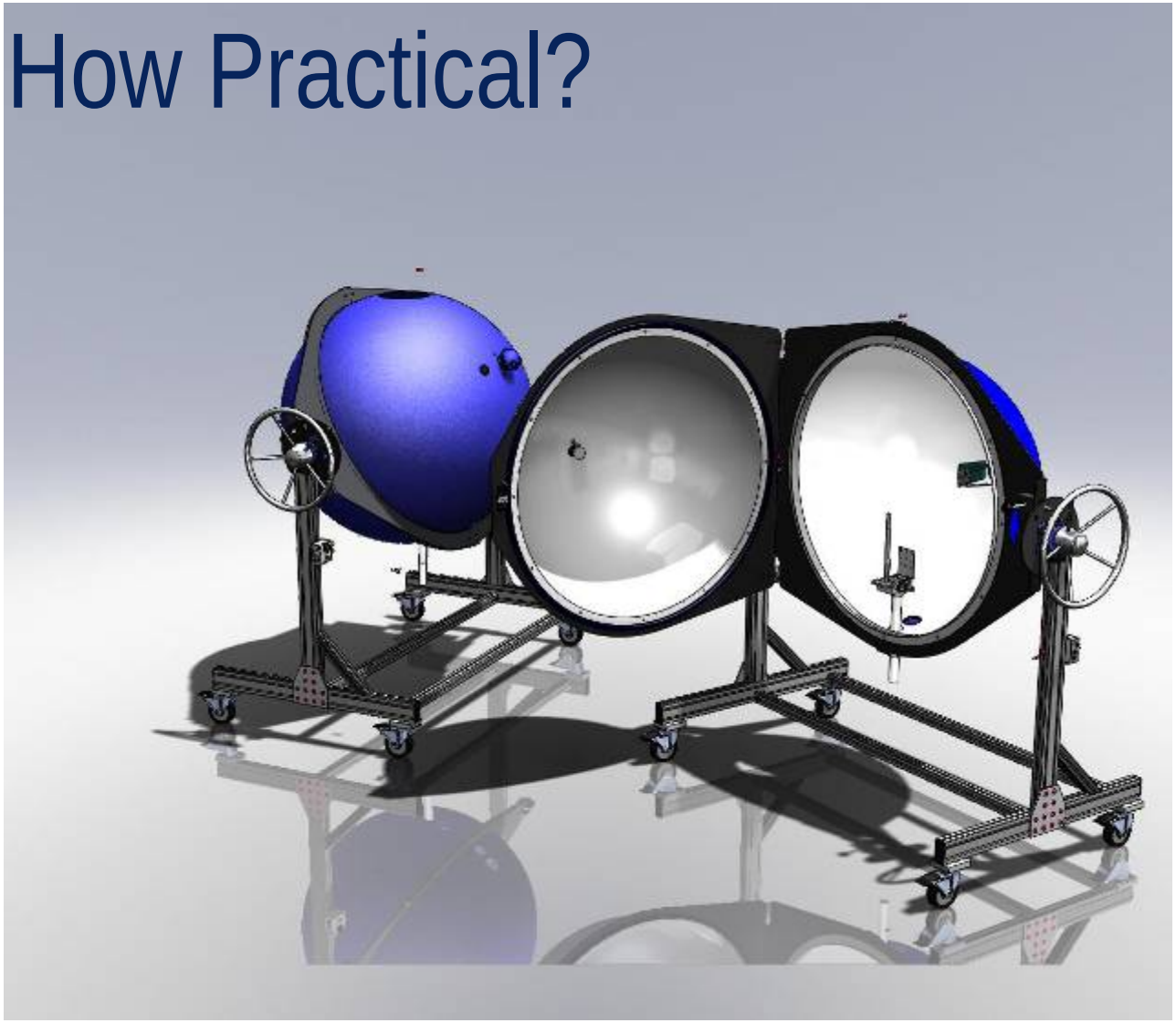
4π Substitution Method

2π Substitution Method

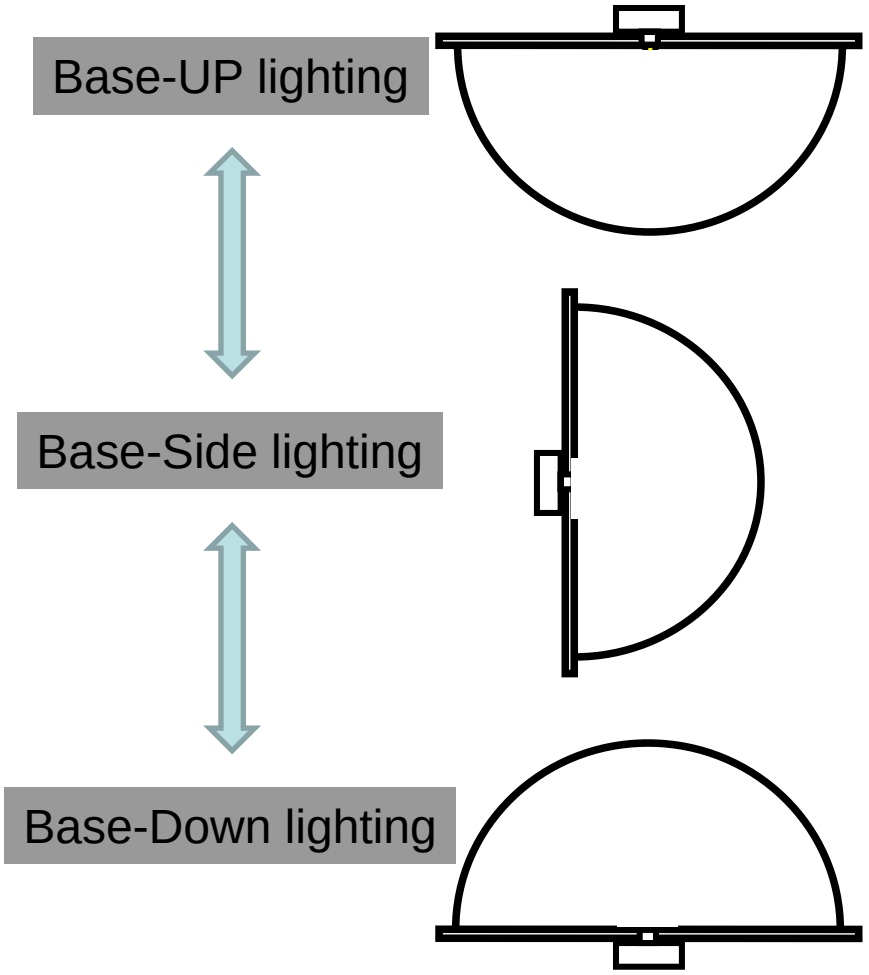


Source: IESNA LM 79

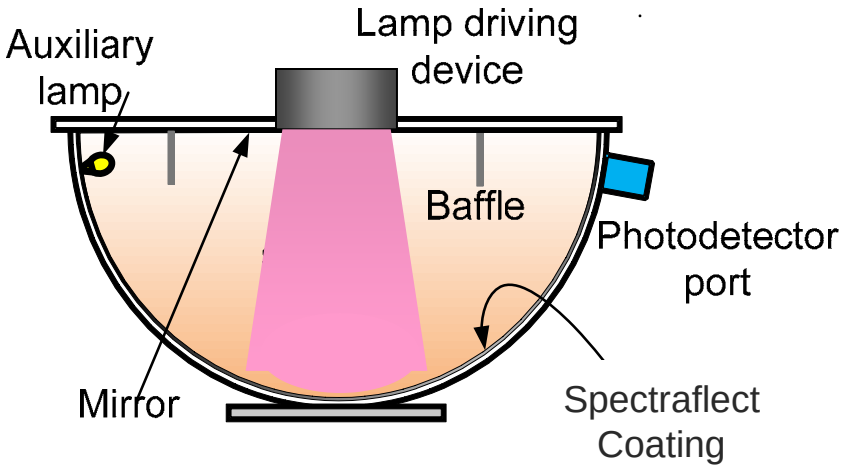
How Practical?



Alternate Solution



Alternate Solution



Sphere Multiplier

a flat diffuse surface

$$L = \frac{\Phi_i \rho}{\pi A}$$

the integrating sphere

$$L_s = \frac{\Phi_i}{\pi A_s} * M$$

where;

$$M = \frac{\rho}{1 - \rho(1 - f)}$$

Surface Radiance

$$L_s \cong \frac{\Phi_i}{\pi A} M$$

Integrating Sphere (IS)

$$M = \frac{\rho}{1-\rho(1-f)}$$

Integrating Hemisphere (IH)

$$M = \left\{ \frac{\rho}{1-\rho(1-2f)} + \frac{\rho\rho_m}{1-\rho\rho_m(1-2f)} \right\}$$

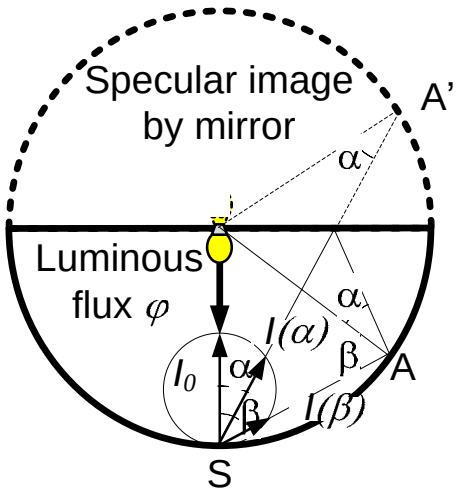
Surface Radiance of Integrating Hemisphere

1) $I_0 = \dfrac{\phi\rho}{\pi}$

2) $I_\alpha = I_0 \cos\alpha = \dfrac{\phi\rho}{\pi}\cos\alpha$

3) $d = 2r \cdot \cos\alpha$

4) $E_{a0} = \dfrac{I_\alpha}{d^2} = \dfrac{\phi\rho\rho_m}{4\pi r^2}$



5) $E_{b0} = \dfrac{\phi\rho}{4\pi r^2}$

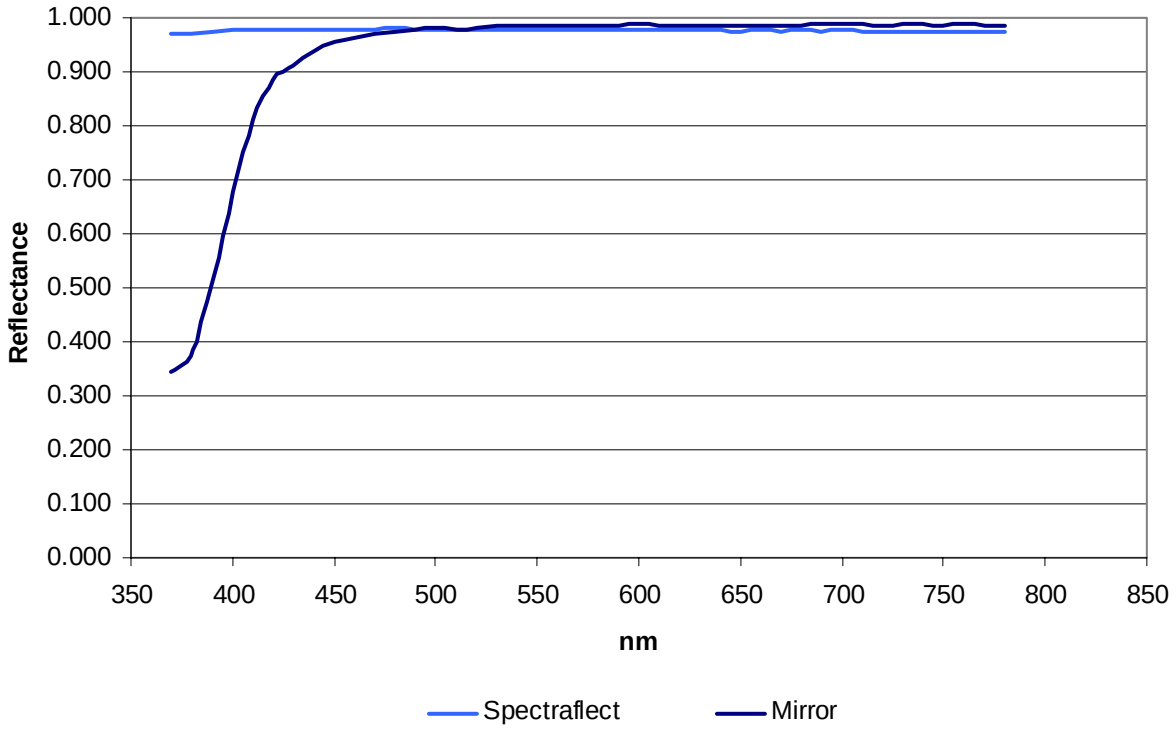
6) $E_{ab} = \dfrac{\phi}{4\pi r^2}\left(\dfrac{\rho}{1-\rho} + \dfrac{\rho\rho_m}{1-\rho\rho_m}\right)$

7) $L = \dfrac{\phi}{A_S\pi}\left\{\dfrac{\rho}{1-\rho(1-2f)} + \dfrac{\rho\rho_m}{1-\rho\rho_m(1-2f)}\right\}$

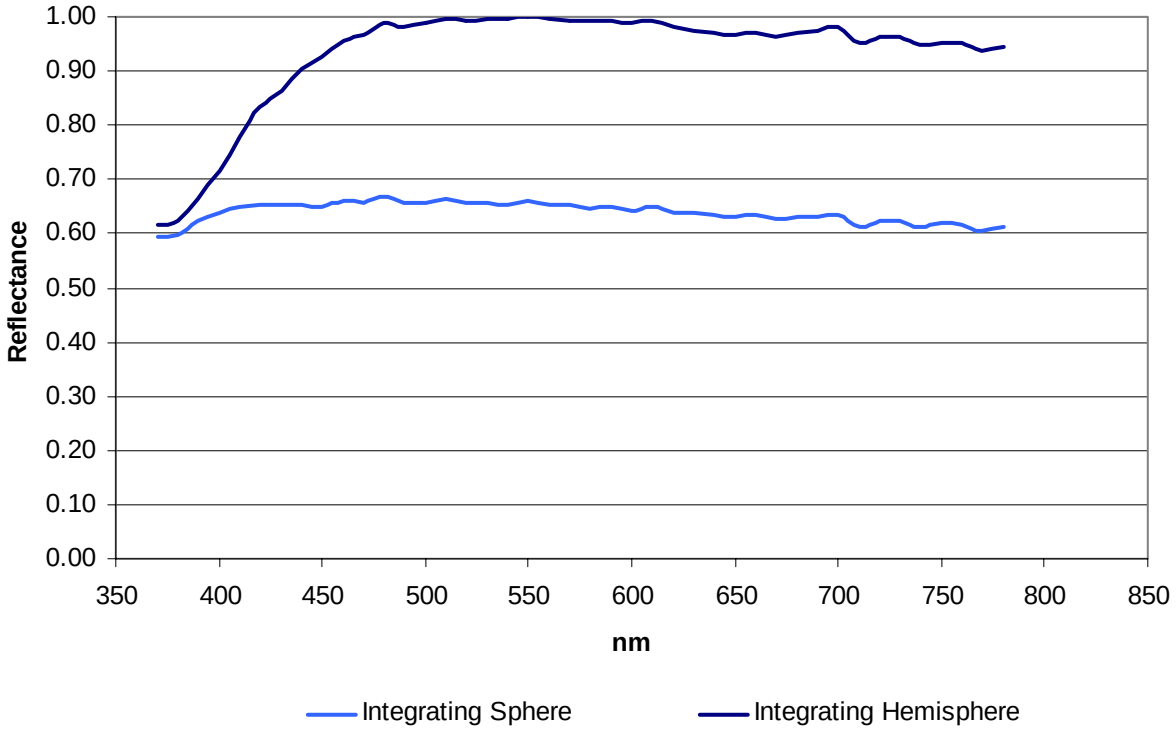
if $\rho_m \cong 1$

$$L \cong \frac{2\phi}{A_S\pi}\frac{\rho}{1-\rho(1-2f)}$$

Interior Coatings



Relative Efficiency Comparison

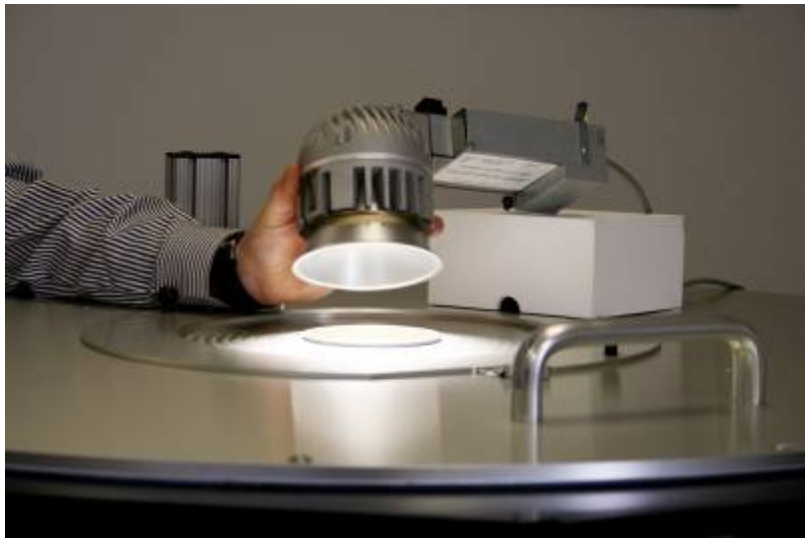


Measurement Comparisons

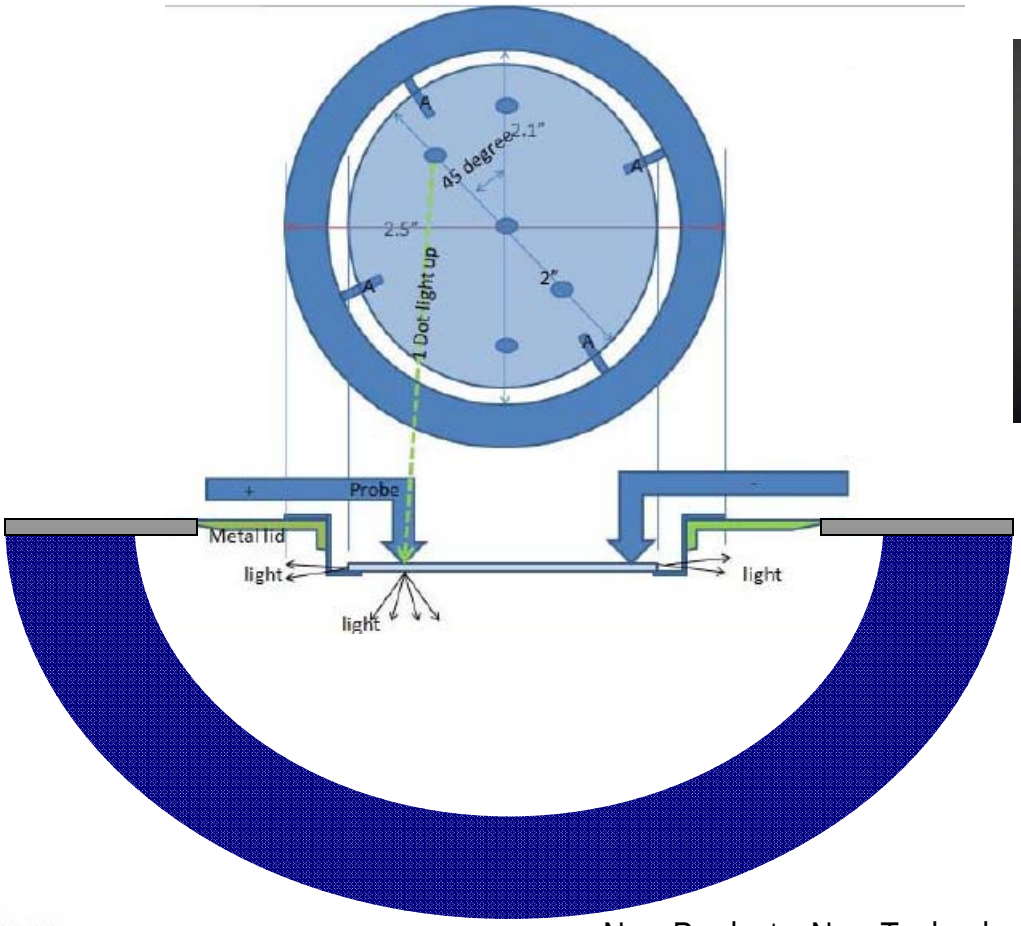
Sample		Exp	Φ	Φv	Chromaticity coordinates		CCT			
		sec	mW	lm	x	y	K	Ra	Dom W	Lamp Type
Krypton Lamp	IS	0.3	283	44.1	0.4500	0.4080	2825	100	-	Clear lamp
	IH	0.2	284	44.3	0.4500	0.4080	2823	100	-	
White LED	IS	8.0	5.46	1.58	0.3170	0.3140	6359	85	-	5mm Clear
	IH	5.0	5.52	1.59	0.3160	0.3120	6475	85	-	
White LED	IS	6.0	7.14	1.99	0.3060	0.3090	7167	85	-	5mm Diffuse
	IH	4.0	7.15	1.99	0.3050	0.3080	7217	85	-	
Blue LED	IS	1.8	0.24	0.152	-	-	-	-	475.5	5mm Clear
	IH	1.9	0.25	0.151	-	-	-	-	475.4	
Green LED	IS	5.8	2.72	0.162	-	-	-	-	524.6	5mm Clear
	IH	5.9	2.76	0.161	-	-	-	-	524.5	
Red LED	IS	2.9	0.54	0.698	-	-	-	-	623.7	5mm Clear
	IH	2.9	0.53	0.698	-	-	-	-	623.8	
Before correction	IS	1.1	39.5	11.5	0.3150	0.3150	6490	84	-	Diffuse BackLight
	IH	0.6	41.2	12.0	0.3130	0.3130	6628	84	-	
After correction	IS	1.1	42.1	12.2	0.3140	0.3140	6560	84	-	
	IH	0.6	41.7	12.1	0.3130	0.3120	6641	84	-	

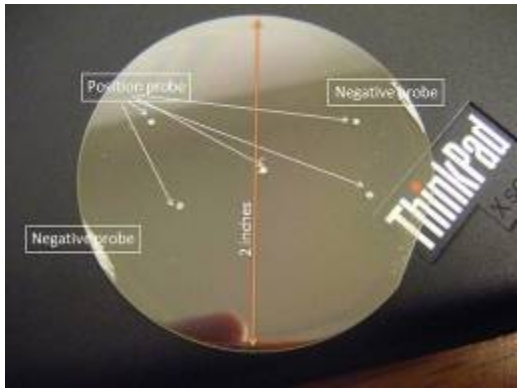
Application: SSL Down Lighting

- Smaller Footprint
- Accurate: Can mount sample in center of hemisphere plane and associated control/cooling electronics outside of measurement area
- Orientation: Test in same orientation it will be used



Application: Wafer Test





Application: Street Light

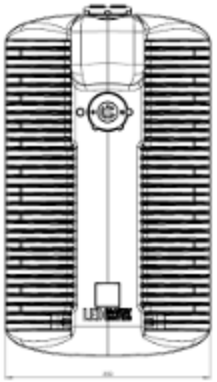


Figure 1 – Luminaire Top

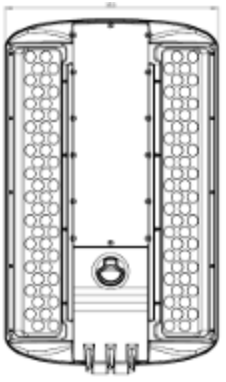


Figure 2 – Luminaire Bottom

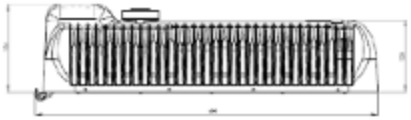
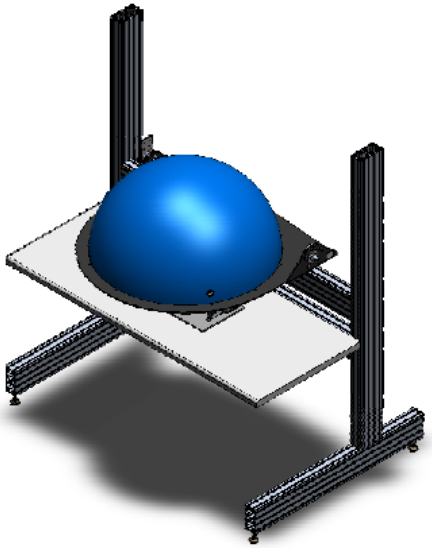
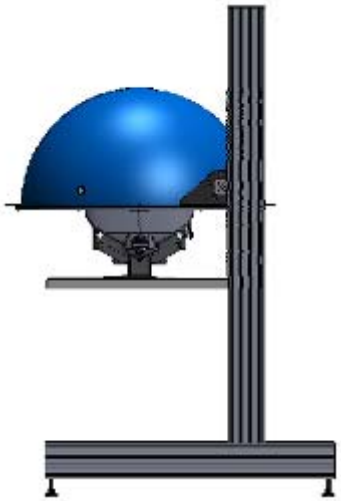
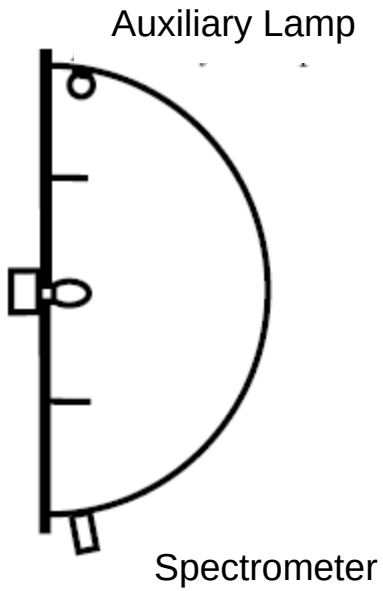


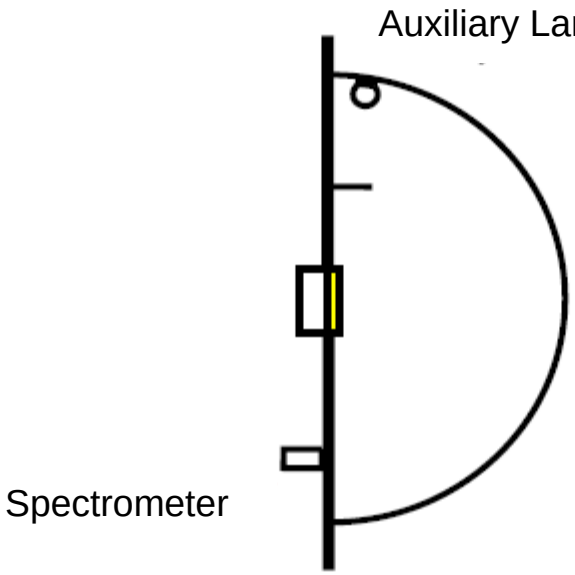
Figure 3 – luminaire Side Profile

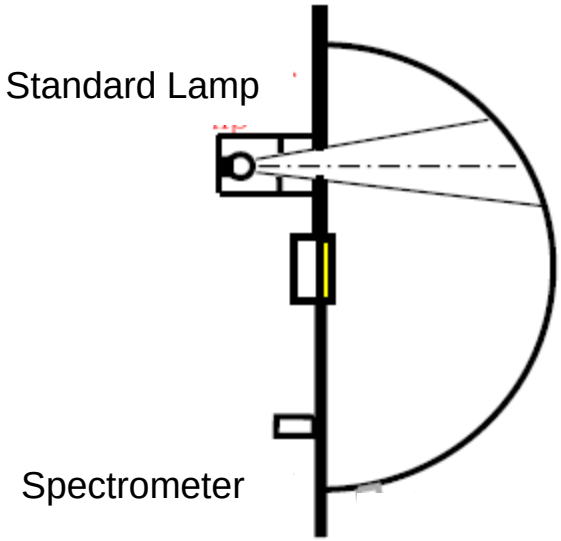




Other Geometry Potentials







Next Steps

- Extended Range UV mirrored components
- Mirrored vs. Diffuse Coated adaptors
- Full Integration of thermal controllers
- Uncertainty budgeting