Design and Characterization of Uniform Spectral Radiance source for test and calibration of radiometers used for KOPMSAT-3

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ABSTRACT

An application-specific uniform calibration source is described. The biggest challenge in developing the system is to achieve 25% higher spectral radiance values than the Earth's spectral radiance, with the lowest wavelength being the hardest to meet. This pre-flight test equipment will be used for characterization and calibration of imaging radiometers which will be used as satellite-borne remote sensors for KOPMSAT-3. The integrating sphere-based system will be used as a spectral radiance standard.

Included are the end user's requirements in regards to spectral radiance levels, radiance stability, radiance uniformity and spectral radiance monitoring. Detailed design challenges, approach and modeling information is discussed. Calibration data and performance results along with uncertainty analysis are presented.

Keywords: KARI, Labsphere, uniform source, integrating sphere, spectral radiance, luminance uniformity, calibration, remote sensing, satellite

1. INTRODUCTION

As a part of the development of KOMPSAT-3 (Korea Multi Purpose Satellite-3) Payload, AEISS (Advanced Earth Imaging Sensor System) performed by Korea Aerospace Research Institute, a Large Uniform Light Source (LULS) System is requested from Labsphere. The source will be used for the electro-optical tests of the payload such as signal to noise ratio, linearity, saturation and uniformity of radiometric response.

The source is used for pre-flight radiometric calibration of the payload and should provide high spatial as well as angular uniformity of better than 98%. The uniform source is required to provide known radiance levels with absolute accuracy traceable to the National Institute of Standards and Technologies (NIST) or equivalent primary standards of radiance scale.

The source is also required to provide known spectral radiance values at a total of 45 wavelengths in the 450 nm-890nm spectral band. The spectral radiance requirements are driven by nominal and saturation earth spectral radiance at sensor aperture. The discussion that follows is based on the 1 m exit aperture source, the most recent uniform source system designed for KARI for calibration of imaging radiometers which will be used for KOPMSAT-3.

2. SYSTEM REQUIREMENTS

KARI requested an integrating sphere based uniform source with 1m exit port diameter. In imaging applications, the source diameter is governed by the object size, aperture, and field of view of the imaging radiometers under test. Whereas, in irradiation applications, the size of the source may be designed based on parameters such as the irradiated area and distance from the source to the target.[1] The size of the integrating sphere is then based on the required size of the exit port. The larger the sphere with respect to the exit port, the greater the uniformity, all other things being equal. However, the power required in the sphere to produce a particular radiance or irradiance increases with sphere size. Thus the source aperture diameter and output radiance determine the optimal sphere diameter and lamp specifications. For practical reasons a 2m diameter integrating sphere was chosen. Labsphere's high reflectance Spectraflect® coating is chosen to achieve high uniformity and output stability.

The uniform source is required to produce two sets of spectral radiance values at sensor aperture; Earth Spectral Radiance (nominal) and Earth Spectral Radiance (saturation). The spectral radiance values are required at 45 key wavelengths in 450 nm-890 nm spectral band (Figure 1)

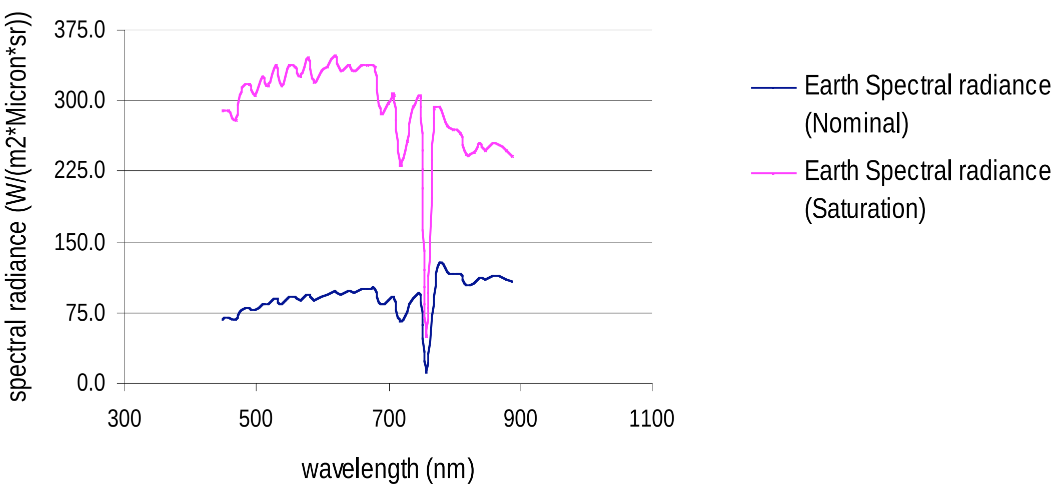

Figure 1. Required spectral radiance at the exit port

Labsphere proposed a system that can not only achieve the nominal and saturation earth spectral radiance values but can also achieve at least 25% higher spectral radiance output than the saturation values at all 45 wavelengths.

One of the challenging system requirements is its class 10,000 clean room compatibility. All the materials and components used in the system follow the clean room compatibility criteria. Other requirements include radiance stability with tungsten halogen lamps to be < 0.05% and the luminance adjustability resolution for 50% ~ 100% of maximum luminance to be 0.1%.

The radiance monitoring unit in the system is required to have a thermo-electrically controlled spectrometer based spectral radiance monitor. The system also includes a feedback loop for the user to set the spectral radiance value from min to max at the selected wavelength via software control. A calibrated Photopic detector is also required to independently monitor the Luminance at the exit port in units of cd/m^2 and fL. Additionally computer controlled temperature sensors for monitoring the internal temperature of the sphere is requested. Electrical requirements include dedicated power supplies for each lamp used in the system and ability to remotely turn all the lamps ON and OFF. The software is required to control the system and includes features such as user defined spectral radiance value at the exit port, controlling lamps, light attenuators, spectral plots, storage and labeling of data files and more. Mechanical requirements include exit aperture cover for interior protection when not in use, height between ground and center of exit port to be 1.5m, manual height adjustability of ± 50mm, and a sturdy frame with Locking Castors; either without lubricant or with 10,000 class clean room compatible lubricant.

3. SYSTEM DESIGN

3.1 Integrating sphere based uniform source system

The class 10,000 clean room compatible, integrating sphere based uniform source system includes 2m Spectraflect coated integrating sphere with 1m exit port. The sphere has multiple external and internal lamps to meet spectral radiance requirements, TE cooled CCD based spectrometer for spectral radiance monitoring, an independent Photopic detector with radiometer for luminance monitoring, a temperature monitoring unit mounted on the sphere wall, and multiple automated variable attenuators mounted in front of external light sources to achieve radiance variability (Figure 2).

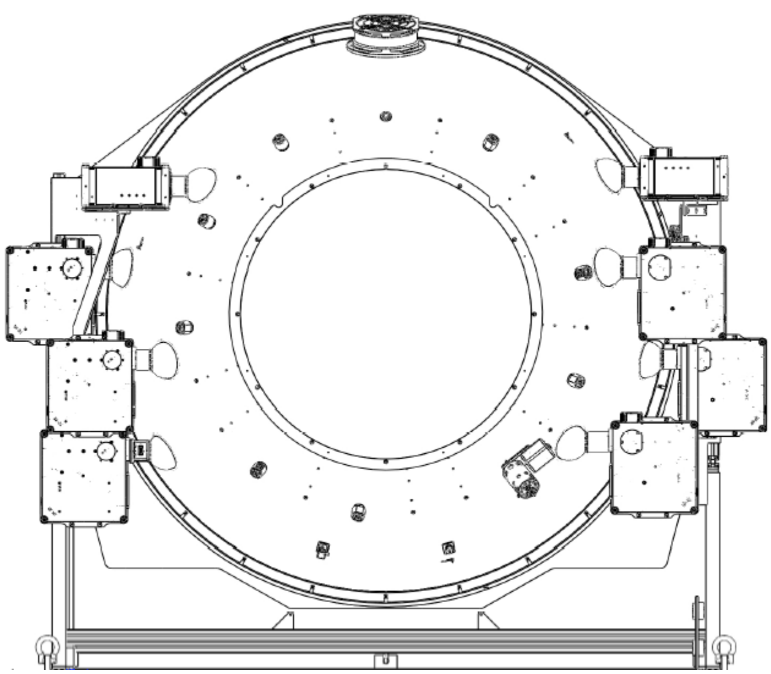

Figure 2. Integrating sphere layout

The system design is driven by the maximum spectral radiance values required by KARI; the maximum spectral radiance values being at least 25% higher than Earth Spectral Radiance (saturation) values at all 45 wavelengths. The spectral radiance values achieved at sphere exit port were modeled using equation (1)[2].

(1)

Where *L* is the sphere wall spectral radiance,   is the sphere wall reflectance, A_s is the sphere surface area and a *f* is the port fractional area of the integrating sphere. Thus it can be seen that the spectral radiance integrating sphere from the spectral flux input is dependent on the sphere diameter, number of apertures in the sphere or coined aperture fraction area, and the spectral reflectance of the interior coating.

The most challenging spectral radiance level is that at the shortest wavelength, 450nm, where the system must achieve a spectral radiance of 360.9 W/(m^2*Micron*sr). The required spectral radiance values also indicate significantly higher output in the blue region of spectrum. A ~ 3000K tungsten halogen light source has fairly high output beyond green region of spectrum, peaking at ~ 900 nm, but the output in the blue region of spectrum is quite low. Due to mechanical and thermal considerations, it is practically impossible to meet the spectral radiance requirements at shorter wavelengths with tungsten halogen lamps only. To achieve high output in the blue region of spectrum, xenon lamps are used in addition to tungsten halogen sources. Xenon sources with high output in blue region of spectrum when combined with tungsten halogen lamps provided sufficient output in 450 nm to 890 nm spectral band (Figure 3)

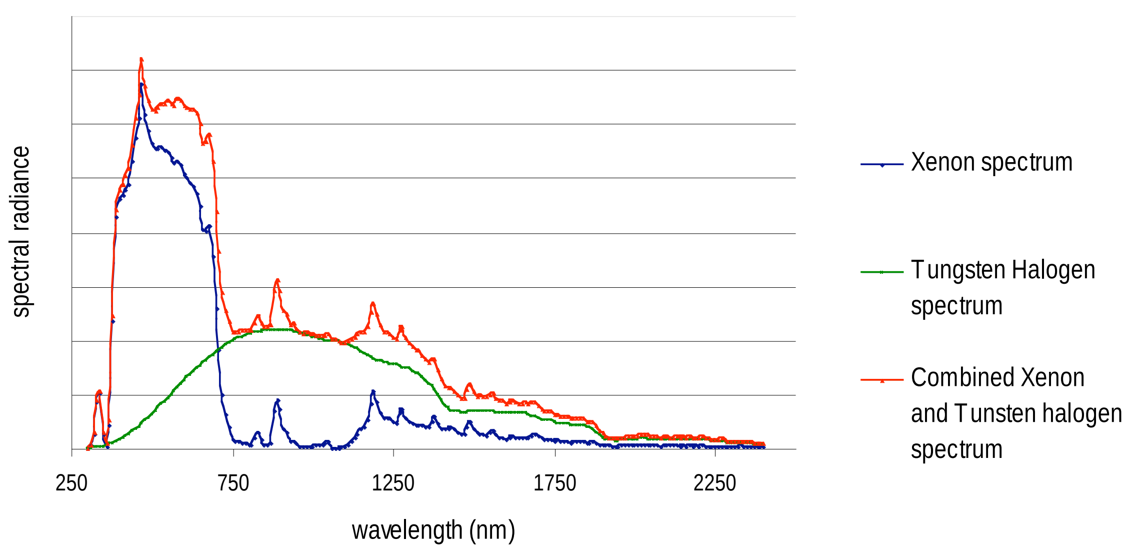

Figure 3. Relative spectral radiance plot for xenon and tungsten halogen sources

Due to mechanical design constraint the number of 300W external xenon sources is limited to 8, which is practically the highest number to fit on a 76" sphere. A hot mirror made on a fused silica substrate is included for each xenon source in the design to get rid of the NIR peaks in the xenon spectrum while preserving the high Blue/UV as well as visible light. Rejecting infrared radiations from xenon source improves overall short term and long term radiance stability of the uniform source system. A hot mirror due to its transmittance properties also lowers the output at 450nm to 80% of full output. With 8 xenon sources we achieved about 185 W/(m^2*Micron*sr) at 450nm. The difference is made up with TH lamps. This requires about 6100W of 3000K TH lamps to reach the 360.9 W/m2 sr um spectral radiance level.

To achieve variability and resolution requested by KARI as well as attain symmetric illumination within the sphere for the best uniformity, a total of 7810W of tungsten halogen power was coupled in the sphere. The overall lamp configuration used for the uniform source system is summarized in table 1.

Tungsten Halogen lamp configuration:

Quantity	Model	Location	Wattage (W)	Voltage (V)	Current (A)
13	Direct Mount 500	Internal	500	120	4.17

To produce the equivalent of a variable 500W lamp:

Quantity	Model	Location	Wattage (W)	Voltage (V)	Current (A)
5	IHLS-100-100	Internal	100	12	8.33
1	IHLS-100-50	Internal	50	12	4.17
1	IHLS-100-20	Internal	20	6	3.33
1	IHLS-100-10	Internal	10	6	1.67
1	EHLS-100-100R	External	100	12	8.33

Total Tungsten Halogen power = 7180W

Xenon lamp configuration

Quantity	Location	Wattage (W)
8	External	300

Total Xenon power = 2400W

Table 1.Uniform source system lamp configuration

3.2 Spectral radiance and Luminance monitor

The uniform source system includes a TE cooled back thinned CCD array based spectrometer for real time spectral radiance monitoring. The spectral range for spectrometer is from
350 nm–1050 nm and has better than 0.5 nm spectral resolution. The control software not only enables users to monitor spectral radiance in real time, but also provides a feedback loop that sets the lamp configuration and variable attenuator position to achieve the spectral radiance set by the user. The software has options for two working modes. The first one shown in Figure 4 is the main window and the normal operating mode of the program. This is also known as "automatic" mode. The operator can select one of the 45 wavelengths; enter the desired spectral radiance for that wavelength, then click the Set Spectral Radiance button. The program takes it from there. After turning the necessary lamps on or off, as well as setting the required opening size for the two variable attenuators, a reading is taken and the spectral radiance table is filled in as well as shown graphically

and the luminance is also displayed. At all times the three thermocouples are monitored once a second and are updated whenever a temperature change has occurred from the last reading. The software also provides a number of options on the graph, including zooming in on the view and printing the graph.

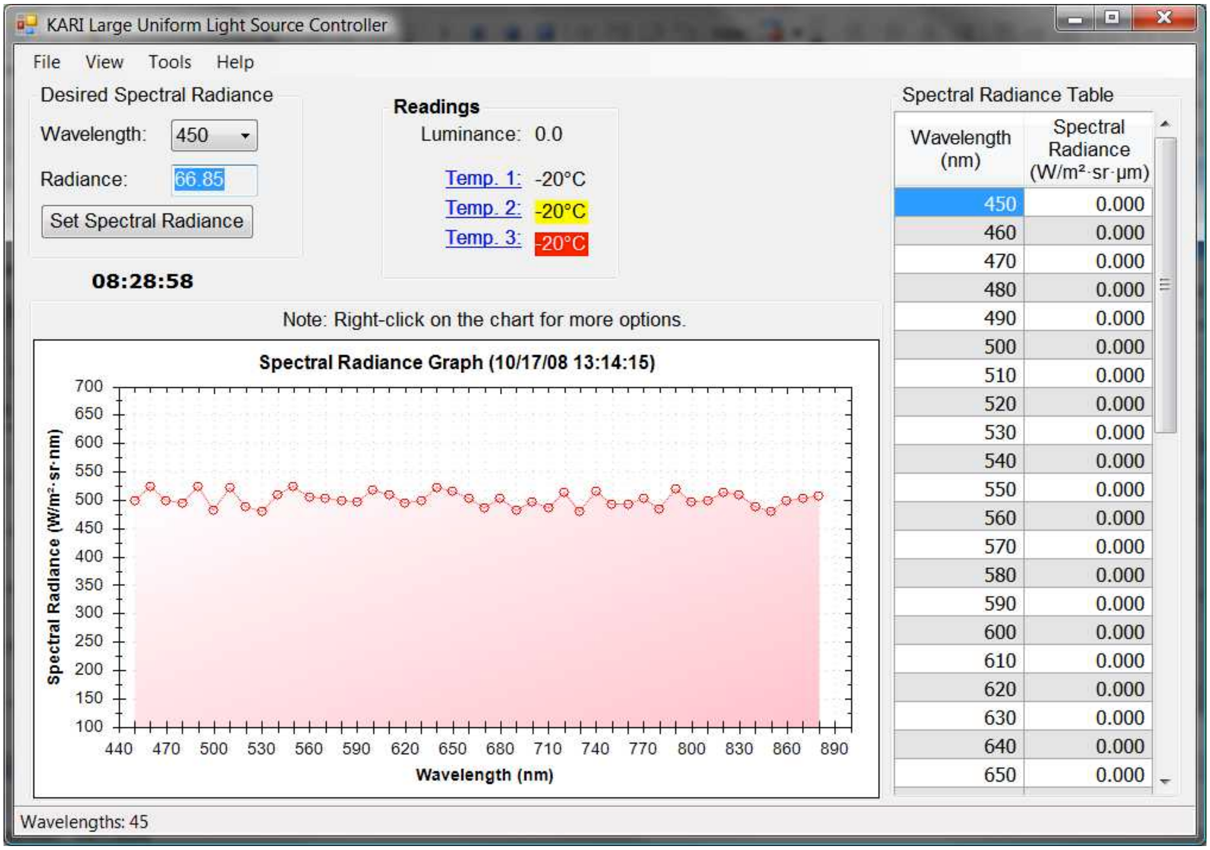

Figure 4. Automatic mode display window for the system control software

The user also has an option of selecting manual control option where the user can choose specific lamp configuration to turn ON or OFF as well as select the variable attenuator position. If the Manual Control is selected, the program goes into manual mode and the screen shown in Figure 5 is displayed.

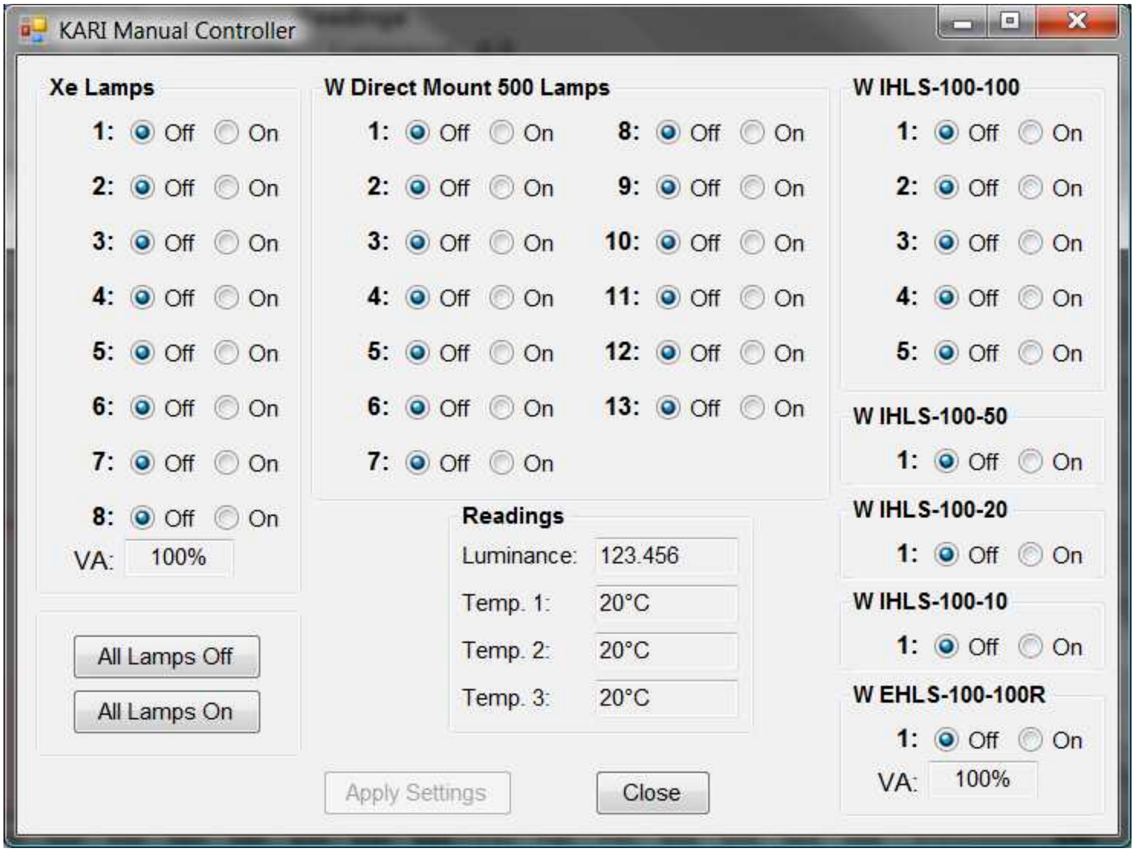

Figure 5. Manual mode display window for the system control software

3.3 Lamp power supplies

To achieve ability to remotely control lamps used in the system, programmable power supplies are required. Each lamp is operated with a dedicated power supply. The power supplies are rack type with clean room compatible casters for mobility. The power supplies used for operating tungsten halogen lamps have a current accuracy of ≥ +/- 0.1%, current stability of ≥ 0.1% and rise time of 20 +/- 5 sec. For xenon sources, PerkinElmer's Cermax® power supplies are used. The power supplies have Remote enable and disable capability as well remote current regulation capability. All the electronics in the system operate at 220V.

4. MODELED SYSTEM PERFORMANCE

The modeled spectral radiance values at the sphere exit port are compared to the required maximum (25% higher than Earth's spectral radiance at saturation) spectral radiance values in Figure 6. It can be seen that the spectral radiance at all wavelengths in 450 nm - 890 nm spectral range are greater than required. Having met the highest spectral radiance requirement at 450 nm all other lower spectral radiance requirements can be met with proper lamp selections and the radiance adjustability feature. The radiance stability values at sphere exit port are expected to be greater than 0.18% with xenon light sources and greater than 0.008% with tungsten halogen lamps. Measurement results are not available at the time of submission of this paper but will be available with Labsphere and KARI in future.

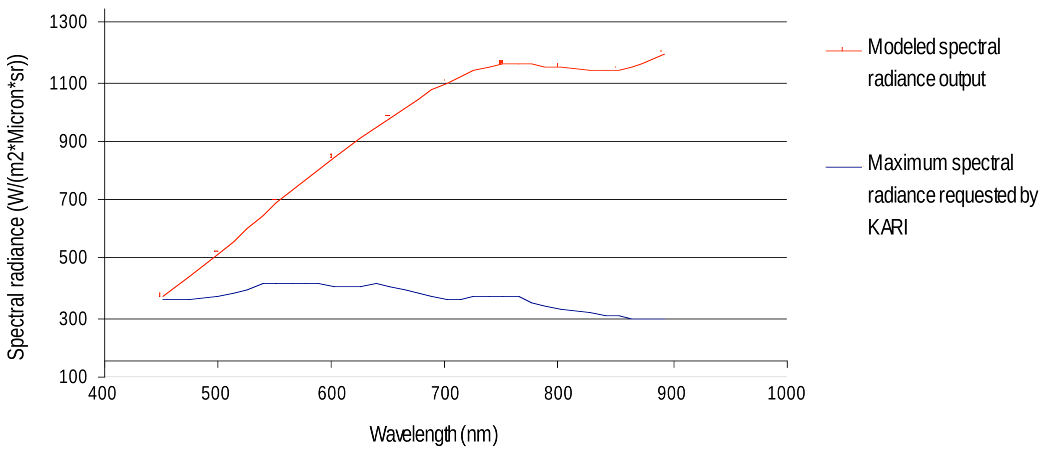

Figure 6. Modeled spectral radiance output

5.0 CONCLUSION

Based on Korea National Space Program, Korea Aerospace Research Institute (KARI) has developed Korea Multi-Purpose Satellite (KOMPSAT-1, KOMPSAT-2 and KOMPSAT-3) which generally accommodates Electro-Optical Camera (EOC), Ocean Scanning Multi-spectral Imager (OSMI), and Space Physics Sensor (SPS). Labsphere's supplied large uniform source is used to calibrate the sensors used on KOMSAT-3 satellite. This paper shows that the uniform source system designed by Labsphere provides exceptionally large output in the blue region of spectrum, required for testing the sensors at saturation, using a combination of tungsten halogen and xenon light sources. Additionally a spectral radiance feedback loop makes the system highly versatile and simple to use.

6.0 ACKNOWLEDGEMENTS

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7.0 REFRENCES

[1] "A Guide to Uniform Source Systems Applications", Labsphere, Inc. TECHGUIDE

[2] "A Guide to Integrating Sphere Radiometry and Photometry" Labsphere, Inc. TECHGUIDE