FluxGage – The calibration traceability chain of a photometric LED test system

Whitepaper

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The new photometric system called ‘FluxGage’ measures the light properties of LED luminaires. A diffuser and a black pinhole array placed over a solar panel form a detection surface which is also a black absorber. The FluxGage, which has a cuboid shape, has this detection surface on five of its six faces, which enables capturing all the light from forward emitting luminaires. Insensitive to reflections, thanks to the black detection surfaces, the system can be at the same size as the DUT (Device Under Test), as opposed to an integrating sphere which should be at least three times larger than the DUT in order to mitigate the effect of self-absorption. The FluxGage contains three sensors: a spectrometer for spectrum and color measurements, black detection surfaces for total flux measurement, and a fast photodiode sensor for flicker measurement. All measurements are controlled using easy-to-operate software.

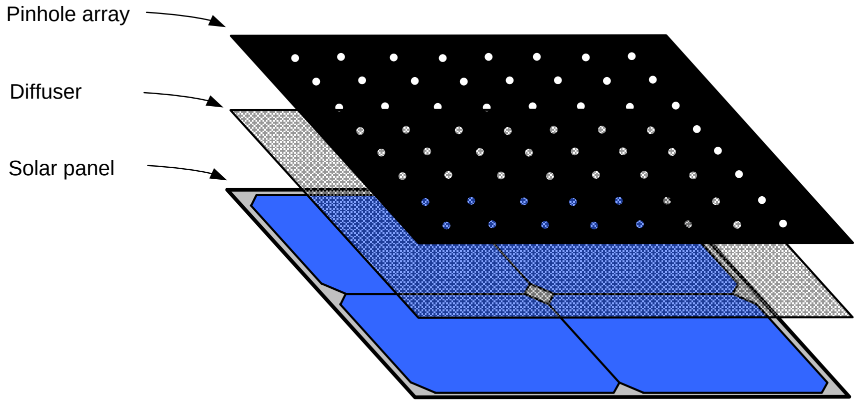

Figure 1. Black detection surface

FluxGage Calibration

The FluxGage system is calibrated using the FGC100 calibration source. The FGC100, developed by Ophir, is a current and temperature stabilized LED source. The FGC100 uses a white LED with a 410nm violet LED as the excitation source for the phosphor. This provides a broadband emission in the visible light range (390-800 nm).

Figure 2. FGC100 FluxGage calibration source

The calibration chain and uncertainties are shown in the next figure.

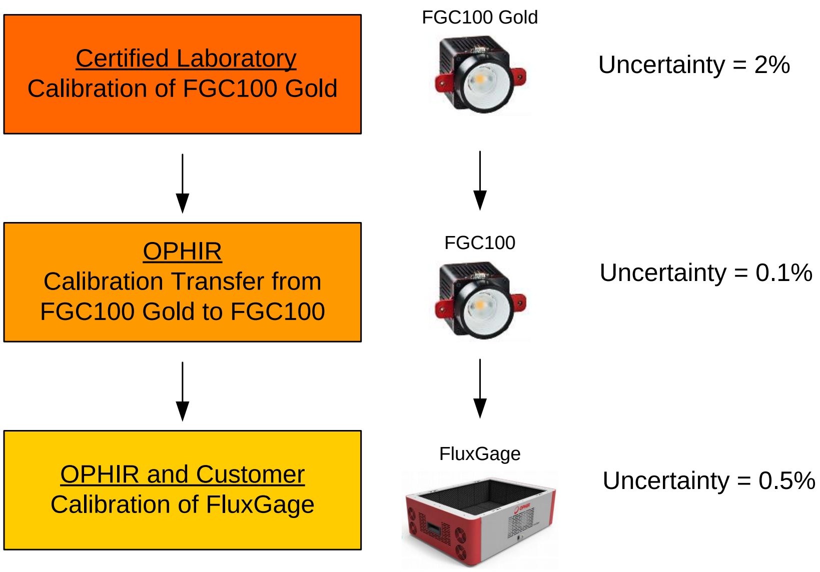

Figure 3. FluxGage calibration chain

An FGC100 unit designated as 'FGC100 Gold' was calibrated at ITL laboratory in Boulder, Colorado (USA). ITL is an NVLAP accredited and NIST traceable laboratory. ITL calibrated the FGC100 Gold with an uncertainty (K=2 expanded uncertainty) of 2.0%.

At Ophir, the FGC100 Gold is used to calibrate commercial FGC100 units. Since the FGC100 Gold and the FGC100 units are ideally identical, the calibration transfer uncertainty is very small.

FluxGage systems built at Ophir and operated in the field are calibrated using an FGC100 unit. The FluxGage has a special mount on the top cover for attaching the FGC100 for calibration. This ensures repeatable calibration of the FluxGage. Once calibrated with an FGC100 unit, the FluxGage system calibration uncertainty is 2.1% (rms sum of the contributors), relative to NIST.

There are several advantages to using an LED calibration source over a tungsten one:

- Tungsten lamps emit a lot of infrared radiation which manifests as stray light inside the spectrometer, causing a calibration error at short wavelengths.
- Tungsten lamps emit a small amount of blue light which increases the measurement error in short wavelengths.
- Better spectral match between the calibration source and DUT.
- Higher flux and better stability over time.

Calibration Uncertainty

The calibration uncertainty is summarized in the following table.

Uncertainty contributor	Uncertainty
FGC100 Gold	2.0%
FGC100 Gold to FGC100 field unit calibration transfer	0.2%
FGC100 field unit to FluxGage calibration transfer	0.5%
Total uncertainty (k=2)	**2.1%**

Table 1. FluxGage Calibration Uncertainty Budget

Uncertainty over working conditions

In this section we evaluate the measurement uncertainty over various working conditions beyond the calibration conditions.

Luminaire size and angle

The effect of luminaire size and beam angle is shown in the next figure.

Figure 4. Effect of luminaire size and beam angle

The illustration on the left shows a small and relatively collimated luminaire. Light rays from this luminaire will hit the bottom of the FluxGage at a nearly perpendicular angle. The illustration on the right shows a large, wide angle luminaire. A small portion of the light from this luminaire will hit the bottom and side panels at steep angles. Because the response of the FluxGage solar panels decreases when the incidence angle, this will cause an error in measurement. This effect was modeled using ray tracing simulation. The magnitude of this effect is ±2.6% depending on the luminaire size and beam, and is corrected by entering the luminaire length, width, and beam angle in the FluxGage software application.

Reflection from the luminaire

This effect is depicted in the next figure. In the left illustration there is a black luminaire. The small amount of light reflected from the FluxGage panels is absorbed by the luminaire and is not reflected again. In the right illustration, the luminaire is white and therefore reflective. Light reflected from the solar panels bounces from the luminaire back towards the panels. This effect was evaluated experimentally to be 1.4% in the extreme case of a luminaire that totally covers the FluxGage (64x48 cm). This is in contrast to measurements done with an integrating sphere, where self-absorption calibration must be performed in order to account for the effect of the DUT on the measurement.

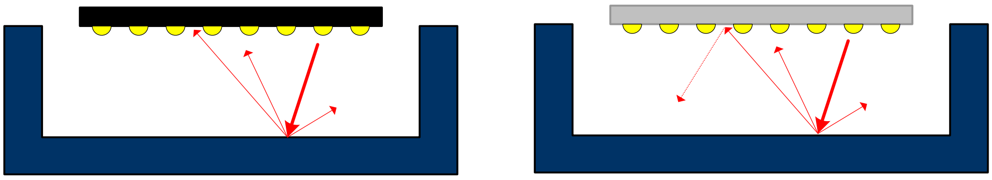

Figure 5. Secondary reflection from the luminaire

Experimental Verification

Two FluxGage units were tested using four white LED sources with the following specifications:

- Total luminous flux 10,000 lumen
- CCT: 3000°K, 4000°K, 5500°K, 6500°K

The verification setup is shown in Figure 3. An integrating sphere system was used as the benchmark, and an FGC100 Gold unit was used to calibrate it. An FGC100 calibration unit and the four white LED sources were measured using the integrating sphere. This FGC100 calibration unit was then used to calibrate the FluxGage, and the four white LED sources were measured again with the FluxGage.

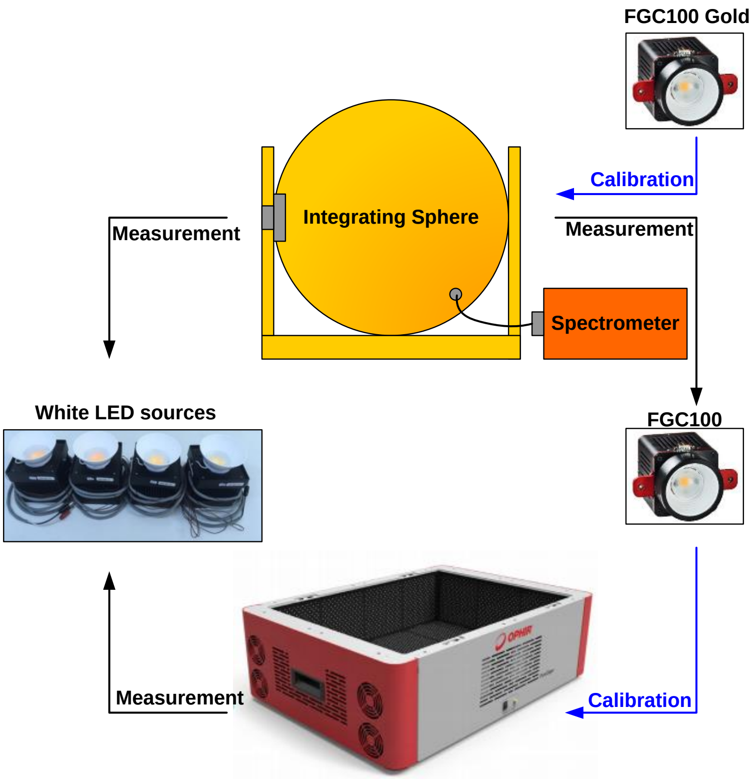

Figure 6. Experimental verification scheme

The results of these measurements were:

- Total luminous flux [Lumen]: Expanded uncertainty [K=2] 0.72%, average agreement with integrating sphere 1.2%.
- CCT [°K]. Expanded uncertainty [K=2] 1.0%, average agreement with integrating sphere 0.77%.

Conclusion

FluxGage is a LED luminaire tester and provides a small and cost-effective solution for testing LED luminaires in 2π geometry. The black measurement surface and the lack of multiple reflections make the system much more predictable and allow using information about the DUT such as size, beam angle and surface reflectivity, to calculate correction factors. FluxGage is based on a novel combination of photometric detectors and the measurements and calculations within this whitepaper proof the reliability of the measurement device. It opens new ways to easily proof the quality of LED luminaires.

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