CONTINUOUS VERSUS DISCRETE CALIBRATION SOURCES: CONSIDERATIONS FOR USE

A White Paper by
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1.0 INTRODUCTION

Radiometric and photometric calibrations have relied on lamp-based sources of radiant flux for decades. Lamps that produce a broad continuum of radiation serve as spectral calibration sources for systems measuring a myriad of radiometric or photometric quantities, while spectral line lamps that have intrinsically sharp spectral features can be used as a wavelength calibration source. Since the mid-20th century, lamp-based calibration standards have proven themselves as dependable tools for calibrating light sensors, imaging cameras, solar cell or detector characterization, and more.

Recently, rapid advancements in the field of solid-state lighting have presented opportunities for the use of LED-based systems for calibrations typically performed with lamp-based sources. Their highly efficient and long-lived performance, rapid power up to stable output, and compact size have made LED-based sources an attractive alternative for lamp-based calibration systems. However, replicating the smooth and broadband emission of lamps poses a challenge for LED-based calibration systems.

The purpose of this information sheet is to explore the feasibility of using LED-based sources of radiant flux for calibrations that have been ubiquitously performed by lamp-based standards. A comparison of the two methods will be discussed, as well as the recent offerings by Optronic Laboratories, LLC utilizing LEDs in lieu of lamp-based systems.

2.0 LAMP-BASED CALIBRATION SYSTEMS

The light that is emitted from incandescent lamps (such as tungsten-halogen lamps) is produced when the thermal energy of a substance at a temperature above absolutely zero is released in the form of photons. While this means that everything is constantly emitting light, that light only falls into the visible region of the electromagnetic spectrum when materials reach hundreds of degree centigrade. This emission process is very well understood, and the emission from these lamps is considered to be absolute.

In applications involving full radiometric or photometric system calibration, lamp-based components are often bundled together to obtain the performance and versatility required. An example would be using a tungsten-halogen lamp that is powered by a precision current source to produce a broad spectral profile whose absolute intensities are known to within a couple percent. Fig.1 shows the relative output achieved for the OL 455 quartz tungsten-halogen based calibration standard. Bundling an atomic emission lamp such as Hg, Kr, Ar, etc. with it allows calibration of the wavelength scale, as well as a spectral response calibration of the system as a whole. Furthermore, including optical filters, gratings, or other optical components allow spectral shaping or spectral selection within the emitted spectrum.

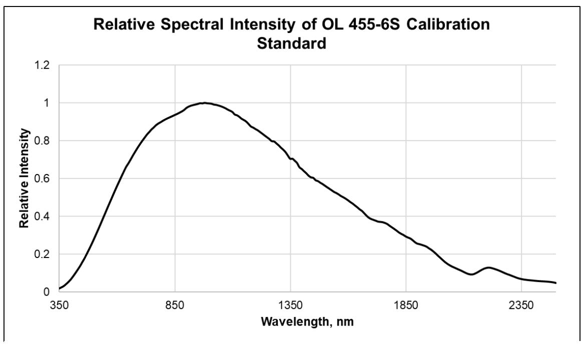
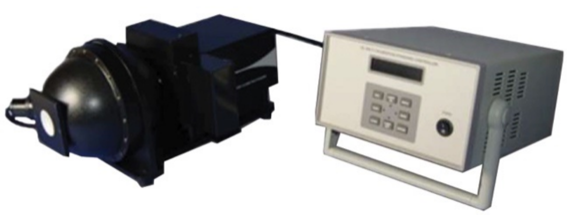


Figure 1: Relative optical output of OL 455-6S Calibration Standard



OL 455-S Integrating Sphere Calibration Standard

The use of lamps for calibration offers several advantages. The broad spectral output of a tungsten-halogen lamps facilitates the calibration of a spectral system starting as low as 300nm in the UV all the way out into the MWIR region. Adjusting the operating current and/or the use of spectral filters allows a range of color temperatures to be achieved.

The upfront cost of a lamp-based calibration standard can vary greatly from the low thousands up to the low tens of thousands of dollars, depending on the performance required; however, replacement lamps are relatively inexpensive and available from a large supply base. In addition, there exists a large number of suppliers fluent in the installation, calibration, and service of lamp-based calibration standards.

The greatest drawback of most lamp-based calibration systems is the short lifetime of the lamps themselves. Supply and calibration companies typically express these operating lifetimes on the order of tens of hours and is highly dependent on the current used to drive the lamps. And while the spectral output and stability of these lamps are well known, minute changes in these operating conditions result in large deviations in the spectral output. These operating conditions extend beyond the operating current to the environmental conditions in which the lamp is being used. As previously mentioned, the spectral performance of a lamp at a given set of operating conditions are only valid for a finite period of time, after which it can no longer be guaranteed.

Another disadvantage of lamp-based systems is the relatively long warm-up times required to achieve the prescribed optical performance. Most lamps operate at relatively high temperatures, and therefore require a substantial warm-up period (typically at least 15 minutes) to achieve thermal equilibrium with the environment. After this initial cold start-up time, it is often required to change the calibration system by adding/ removing optical filters or switching to a different driving current, either of which require the system to reestablish thermal equilibrium prior to use. Furthermore, if switching from one lamp-based standard to another is needed, additional components may be required that introduce more points for the system as a whole to deviate from the prescribed behavior or even fail altogether.

Lamp-based systems are also sensitive to mechanical shock. The physical positioning of the lamp and the alignment of any associated optical components are highly critical to the optical performance. A change to either results in substantial deviations to the optical performance and, as a result, require extreme caution when handling, moving, and operating lamp-based systems.

While it has been discussed that lamp-based systems are widely established and understood, there is little work being done to further develop lamp-based systems. The resources that are required to produce these lamps are also limited, meaning that obsolescence is inevitable.

3.0 LED-BASED CALIBRATION SYSTEMS

Light-emitting diodes (LEDs) are comprised of a p-n junction diode that emits light when a current is applied. At this p-n junction, electrons recombine with electron-deficient areas referred to as ‘holes’ and release energy in the form of photons. The spectral emission from diodes is a function of the electronic structure of the materials making up the diode as well as the dopant levels present.

Unlike lamp-based systems whose technology are destined for obsolescence, solid-state technology has rapidly evolved. According to Haitz’s Law, the optical output of LEDs has doubled every 36 months since the mid-20th century and will continue to do so. The result will be increased performance and affordability for many years to come.

The spectral output of LEDs is particularly narrow, such that UV or blue LEDs can be used to excite phosphors, which in turn emit a broad continuum similar to that of lamp-based systems, albeit over a much more limited spectral range. Figure 2. shows the spectral output of the OL 458 Calibration Standard that utilizes blue LEDs to excite a phosphor that emits a broad continuum over the visible spectrum.

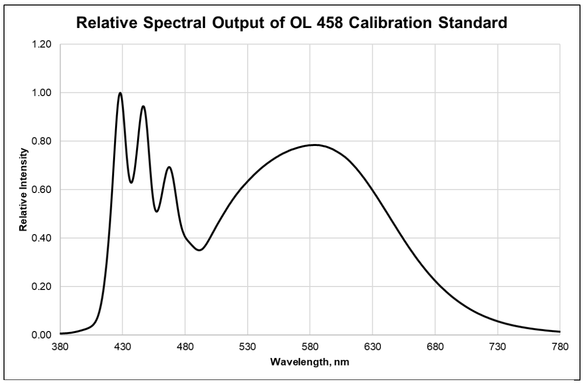
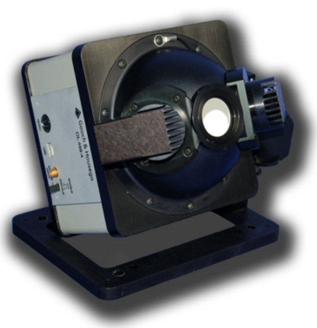


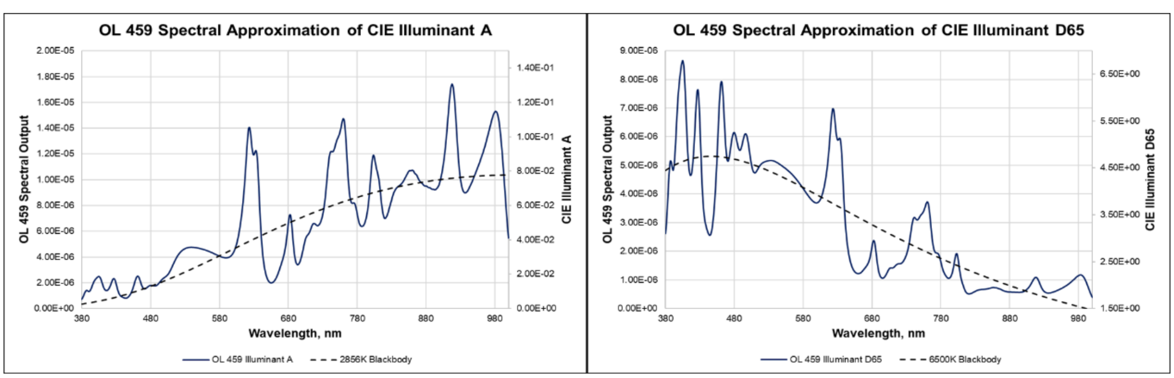
Figure 2: Relative optical output of OL 458 Calibration Standard

The manner in which LEDs are powered offers the possibility of increased versatility over lamp-based systems. Whether controlling individual LEDs or LED channels/groups, spectral shape and control of LED-based systems is achievable without the addition of optical filters, gratings, or changes in driving current required by their lamp-based counterparts. Figs. 3a and 3b show the spectral approximations for CIE illuminants A and D65, respectively, achieved by controlling the 5 independent channels of the OL 459 Tunable LED Standard.



OL 458-4 White LED-Based Calibration Standard

OL 459 Tunable LED Standard



(a) (b)

Figure 3: a.) OL 459 LED calibration standard approximation of CIE Illuminant A. **b)** OL 459 LED calibration standard approximation of CIE Illuminant D65.

One of the most promising advantages of LED-based systems is the significantly increased lifetime of LEDs relative to lamps. Lifetimes of LED (typically measured as the amount of time it takes for half of the devices to drop to 70% output) is on the order of tens of thousands of hours. This alone has major implications on the cost and frequency of maintenance but more importantly on the amount of downtime required for maintenance and calibration. Additionally, the warmup of LEDs is practically immediate upon startup relative to lamps. This means the cold start-up time is usually limited by the thermal equilibration of monitoring detector/photometer of the devices. Furthermore, once thermal stability is achieved, switching from one operating condition to another is virtually instantaneous.

Unlike lamp-based systems, the shock sensitivity of LEDs is vastly superior. LED-based systems are inherently more rugged and less susceptible to costly repairs and recalibrations.

While the narrowband emission of LEDs allows for the excitation of phosphors or wavelength calibration capabilities, it poses a problem when performing broadband system calibration. To achieve broadband coverage, several discrete LEDs at various wavelengths are required. This can very quickly result in a substantial upfront cost. Furthermore, the narrow peaks of LEDs, even if superimposed on a broadband background, can result in noticeable spectral mismatch when performing spectral calibrations of broadband radiometers/photometers.

The optical output of LEDs can also vary significantly with electrical and environmental changes. As such, extra precautionary measures need to be taken to ensure a stable environment for calibration and measurement. LEDs are also highly directional, so when using several discrete LEDs, often an integrating sphere is needed in order to produce a uniform output.

4.0 SUMMARY

Lamp-based calibration systems have been the method used in industry for many decades. For several applications, lamps still pose a cost-effective means of calibration. The mechanical and thermal characteristics of lamp-based systems carry certain hidden costs for repair, maintenance, and calibration over time. In addition to the monetary cost, lamp-based systems can also impose a massive inconvenience in terms of measurement down time as lamps get replaced and systems get recalibrated.

LED-based calibration standards offer noticeable advantages over lamp-based systems when it comes to durability and versatility. And although the upfront cost of an LED-based system can be higher than a lamp-based system, the durability and substantial lifetime of LEDs relative to lamps can offer a significant advantage, particularly when frequent use is required. Continued development and advancements in solid-state lighting technology offer future optimism for the established use of LED-based calibration standards in the field of spectroradiometry.