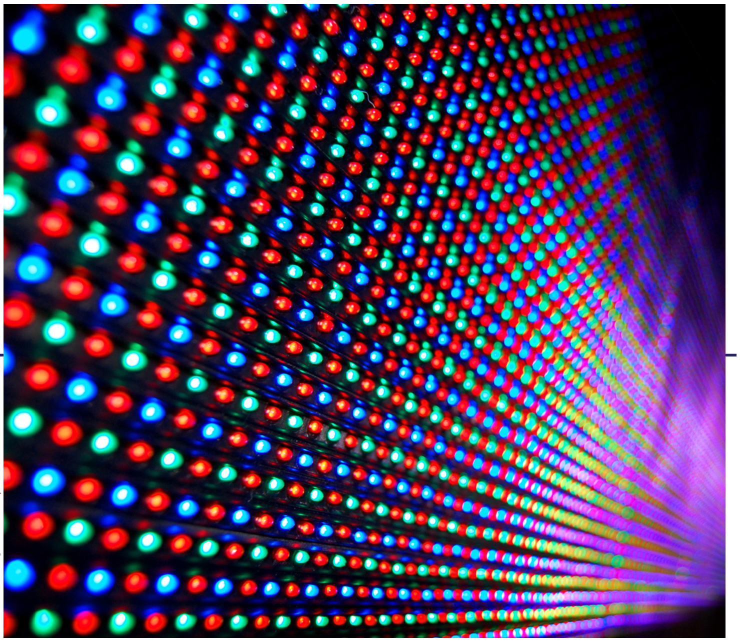
APPLICATION NOTE:
LED SPECTRORADIOMETRY

Techniques

- Spectroradiometry

Keywords

- Radiometry
- LED Lighting
- Clean Energy
- Spectroradiometry



LED Display

Introduction

The lighting industry has gone through a rapid transition over the past ten years with the commercial success of LED lighting. This boom in LED lighting has been fueled by a trifecta of clean energy legislation, increased luminous flux, and decreased costs. The data in figure 1 shows that LED illumination has finally reached the point where it is both as bright and as cost-effective as traditional incandescent sources. As of 2019, the global LED light market was valued at 54 billion USD, according to Grand View Research, with a projected compound annual growth rate of 13.4% [1]. .

As LEDs rapidly replace traditional lighting and displays, in residential, commercial, and industrial applications, the demand for high-quality repeatable test and measurement systems has also increased. In this application note, we will explore the fundamentals of LED lighting technology and discuss best practices for spectroradiometric testing, including luminosity and colorimetry. Since we have already published previous application notes on the “The “Fundamentals of Colorimetry” and “Radiometry,” we will not be reviewing either of these topics in detail.

White Light LEDs

The term “white LED” can be a bit confusing since there is no such thing as a broadband LED. Naturally, all LEDs emit relatively monochromatic light, with typical bandwidths between 20 and 50 nanometers. Currently, two different methodologies for creating white light sources with LEDs have achieved commercial success, multi-chip, and phosphor-coated LEDs. Multi-chip LEDs, also known as RGB LEDs, integrated a red, green, and blue LED onto a single sub-mount with three anodes and a common cathode. As a result, all three LEDs can be driven simultaneously, mixing to provide the appearance of white light. These devices are also commonly used for commercial light displays since they can also produce a wide variety of other colors by varying the intensity of the current applied to each of the anodes. The primary downside of this approach is that it requires rather complicated drive electronics and, as a result, is typically not used for modern household or industrial lighting.

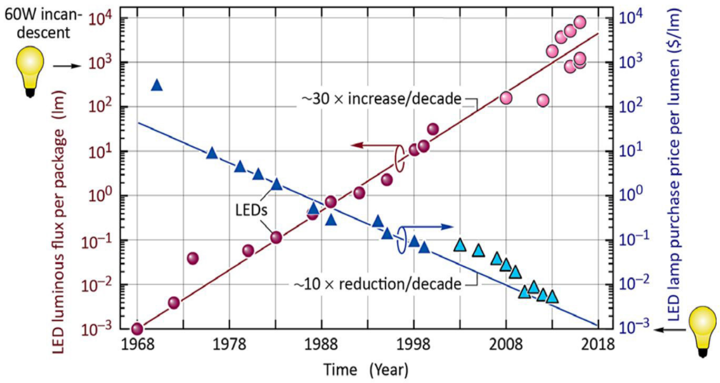


Figure 1: LED luminous flux (red) and LED lamp purchase price per lumen (blue) from 1968 to 2018 compared to a 60W incandescent light bulb. [2]

Phosphor coated LEDs, on the other hand, make use of a single emitter, which is upconverted into visible light through fluorescence. This process is remarkably similar to that of a more traditional fluorescent light bulb, which uses UV emissions from low-pressure mercury-vapor to excite fluorescence in the white phosphor coated tube. The earliest attempts at producing phosphor-coated white light LEDs used the exact approach with UV LEDs and white phosphors, but this was found to be too inefficient. Today's phosphor-coated LEDs instead use blue LEDs coated in "yellow" phosphor, which fluoresces in the green and red. Since not all of the blue excitation light is absorbed, these LEDs result in the emission of apparently white light.

As a result, no matter which approach is being used multi-chip or phosphor-coated, white light LEDs do not produce a continuous white light spectrum. The discontinuous spectral output of these light sources makes the characterization far more complicated than traditional incandescent light bulbs. Figures 2 and 3 show examples of the differences between the spectrum of sunlight and a phosphor-coated white LED. The spectral irradiance of LED-backlit displays can be even more discontinuous due to the filtering of the Bayer pattern in the LCD, and figure 4 shows an example spectrum of a white LCD with an LED backlight. All three of these spectra were measured using an irradiance calibrated AvaSpec-ULS2048CL-EVO spectrometer from Avantes.

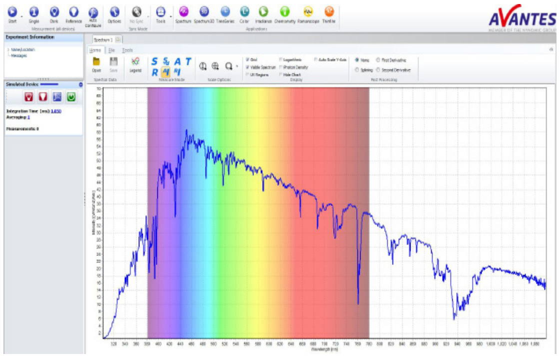


Figure 2: Spectral irradiance of the Sun measured with an irradiance calibrated AvaSpec-ULS2048CL-EVO from Avantes

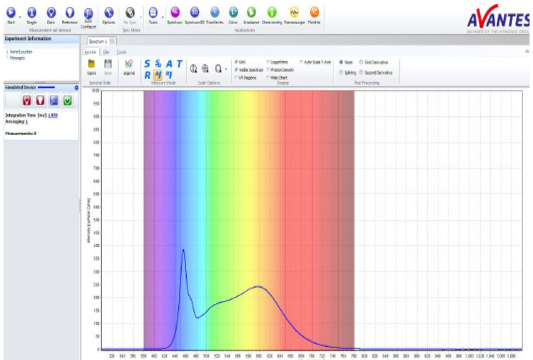


Figure 3: Spectral irradiance of phosphor-coated white LED, measured with an irradiance calibrated AvaSpec-ULS2048CL-EVO from Avantes

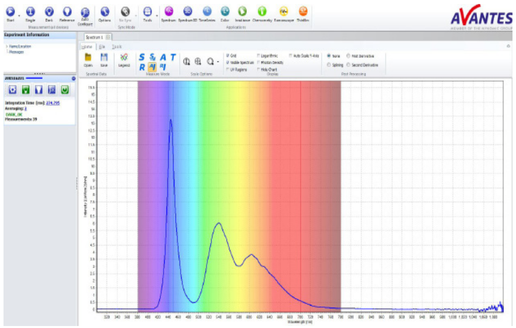


Figure 4: Spectral irradiance of phosphor-coated white LED-backlit LCD white display, measured with an irradiance calibrated AvaSpec-ULS2048CL-EVO from Avantes

Best Practices

Historically the lighting industry has relied on tristimulus colorimeters as their primary measurement tool for both luminance and chromaticity. These colorimeters operate by approximating the human eye's response by using a set of three filters designed to match the CIE 1931 standard observer color matching functions and, therefore, directly measuring the tristimulus values. At the same time, inexpensive and highly repeatable filter-based devices suffer from two major drawbacks. The first is limitations on the manufacturing of the filters themselves, making them susceptible to finite errors and deviations from the ideal human-eye response. Secondly, these filters are designed to work broadband light sources and do a poor job of accounting for discontinuities in the spectrum. For example, when spectral peaks do not fall precisely under the bandwidth of the red, green, and blue filters, it may not be accurately accounted for in the chromaticity data. Therefore, these devices are prone to error when measuring discontinuous spectra, such as LED lamps and displays.

On the other hand irradiance calibrated spectrometers, also known as spectroradiometers, measure the full spectral range and mathematically determine the tristimulus values by integrating over the product of the measured spectrum and the standard observer curves. Since these devices no longer depend on physical filters, they do not suffer from the drawback of tristimulus colorimeters. Additionally, since the entire spectrum is recorded, it allows for more analytics to be calculated. Avantes' AvaSoft-IRRAD software module is capable of displaying radiometric values such as intensity μW/cm2/nm, photometric quantities, including color coordinates (Yxy) and correlated color temperature (CCT), and photon statistics. It is also important to point out that when performing spectroradiometery on LED lighting fixtures, one is almost always in an extremely high light level situation. As a result, it is best to use CMOS detectors instead of CCDs because of the larger dynamic range. The AvaSpec-ULS2048CL-EVO, is an ideal choice for these applications, because of its 2048-pixel CMOS linear array detector.

When performing spectroradiometric measurements, it is essential to make sure to use the proper sampling technique. For example, when measuring individual LED light bulbs, it is best practice to use an integrating sphere, such as the AvaSphere-50/80-IRRAD, to collect all of the light emitted from the source. By contrast, if testing the overall performance of a lighting fixture, for example, in a commercial setting, it is best to use cosine corrector, such as the CC-UV/VIS/NIR-8MM, which collects a sample of light from a 180-degree field of view. In these applications, it is often best to take measurements at multiple locations using the cosine corrector to ensure that the lighting fixture is uniformly illuminating the entire area. Lastly, when measuring display, it is often preferable to take spot measurements at different locations across the screen to verify that the display is producing proper colors. These measurements will require the use of a fiber-coupled collimating lens, which will limit the field-of-view of the measurement to roughly 24-degrees , ensuring the measurement area does not pick up interference from other locations on the screen. It is important to note that the spectroradiometer must also be calibrated with the intended sampling accessory attached, and once calibrated, the accessory should never be removed; otherwise, it will invalidate the calibration.

Figure 5: Avaspec-ULS2048CL-EVO

Final Thoughts

As the LED lighting market continues to grow, so too will the demand for high-quality portable spectroradiometers, for both in-house and field testing of light fixtures and displays. While this application note primarily focuses on end-user spectroradiometers, it is vital to note that all of the spectrometers discussed above are also available as OEM modules and can be integrated into turnkey industrial LED testing systems as well. These units can communicate via USB, Ethernet, and the native digital & analog input/output capabilities of the Avantes AS7010 EVO electronics board, which provides for a superior interface with other devices. Additionally, the Avantes AvaSpec DLL software development package, with sample programs in Delphi, Visual Basic, C#, C++, LabView, MatLab, and other programming environments, enables users to develop code for their own applications. Avantes instruments can also be controlled via Linux or MacOS devices with a new library dedicated to these operating systems.

For more information about the full range of laboratory and OEM spectrometer options available from Avantes, please feel free to visit the website at www.avantesusa.com or give us a call at +1 (303)-410-8668 where our knowledgeable applications specialists are standing by to help.

References
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[2] Cho, J., Park, J.H., Kim, J.K. and Schubert, E.F., 2017. White light-emitting diodes: History, progress, and future. Laser & photonics reviews, 11(2), p.1600147.