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Handbook of LED and SSL Metrology

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Preface

The first edition of the Handbook of LED Metrology was published in 1999 and maintained its popularity over 16 years. We received extremely positive feedback from customers and people interested in the field of LED measurement. The handbook was considered as a helpful introduction to basic terms and definitions and served as a good guideline to test setups and methodology for accurate measurements on LEDs. Although only about 40 pages long, it covered the basic principles of optical characterization of LEDs. The content of this first edition was sufficient at this early stage of the first wave of the Solid-State Lighting (SSL) revolution.

As time moved on, the SSL revolution continued and demanded a more comprehensive view on the subject of SSL and LED measurement. This led to the decision to intensively review and extend the existing manuscript. The outcome is the work at hand entitled Handbook of LED and SSL Metrology. The content is a summary of knowledge gained by Instrument Systems over the last 30 years. A lot of technical advances in the field of SSL measurements made it into scientific papers or were selected as contributions to proceedings of international conferences and symposia. As a matter of fact, numerous people assisted in preparing the scientific content of this handbook.

We want to take the advantage to acknowledge a number of people who contributed in a special way to the preparation of the manuscript and the technical content.

Thomas Nägele was one of the authors of the first edition and left us an excellent basis for this updated second edition.

As an application engineer, Đenan Konjhodžić contributed with measurements and evaluations to numerous chapters. We are very thankful for his contributions.

Thanks also to Matthias Höh who was deeply involved in the preparation of the manuscript for chapter 9 on LED measurements in the production line.

We are further thankful to Thomas Attenberger for technical editing of the entire manuscript. His experience in the field of LED and SSL measurements was greatly acknowledged.

Thanks to Christine Costa, Melanie Maier and Bei-Bei Chuang from the marketing team. They did a fantastic job in preparing the figures and coordinating the layout and print of this handbook.

Last but not least, we are sincerely grateful to Richard Distl. He was not only one of the authors of the first edition, but inspired and launched the preparation of this second edition during his time as president and CEO of Instrument Systems.

The authors

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1 Introduction

Rapid developments in LEDs over the past decade have created a major growth market with completely new applications. Full color displays for large areas only became possible with the introduction of high-intensity blue LEDs, while High Power white LEDs are now widely used in general lighting and the automotive industry. These applications have placed increasingly stringent demands on the optical characterization of LEDs, and Solid-State Lighting (SSL) lamps, modules and luminaires, which serves as the benchmark for product quality.

Specific expertise is needed in order to achieve precise and reproducible results. This handbook discusses the special characteristics of LEDs and emerging OLEDs. It provides an overview of state-of-the-art measurement equipment and gives recommendations for obtaining accurate measurement results. The main goal of this handbook is to give readers who are new to this subject an introduction into LED metrology. However, it also provides a useful reference work for more experienced readers.

As an introduction, basic terms and definitions used in photometry, radiometry and colorimetry are described. This develops into definitions of quantities and details such as the physical properties specific to LEDs and SSL products. Later sections describe the test setups and methodology required for accurate measurements. Possible sources of error arising from interactions between LEDs and measuring instruments are also discussed. The handbook concludes with a section devoted to the unique requirements of LED testing in a production environment.

Readers who are short of time can selectively read individual sections. However, it is recommended to read the entire handbook to obtain an in-depth understanding of this discipline.

2 Terms and Definitions in Photometry, Radiometry and Colorimetry

2.1 Photometric and Radiometric Quantities

This section provides a brief overview of important terms and definitions that are essential for an in-depth understanding and therefore correct use of measuring instruments. A distinction is drawn between radiometric quantities describing physical optical radiation properties, photometric quantities describing the perception of optical radiation by the human eye and colorimetry relating to the visual perception of color by human beings.

The relevant quantities reflect different conditions that are important to people in their everyday lives. For example, a distant traffic light will appear to get brighter as you approach it, until you see it as a circular disc rather than a point source. Then as you start to get closer it still seems to be getting bigger but not brighter. While the traffic light appears to be like a point source, luminous intensity is the relevant quantity, but at a shorter distance the luminance of the source is more appropriate. Other quantities of interest are illuminance (e.g. light falling onto the skin or illuminating an object) and total luminous flux (the entire light emitted in all directions).

Table 1: Important radiometric and photometric quantities.

Radiometry	Symbol	Unit
Radiant power	Φ_e	W
Radiant intensity	I_e	W sr^{-1}
Irradiance	E_e	W m^{-2}
Radiance	L_e	W m^{-2} sr^{-1}
Photometry	**Symbol**	**Unit**
Luminous flux	Φ_v	lumen (lm)
Luminous intensity	I_v	lm sr^{-1} = candela (cd)
Illuminance	E_v	lm m^{-2} = lux (lx)
Luminance	L_v	cd m^{-2}

Table 1 shows similarities between the units of radiometric quantities and photopic quantities (see the “W” in radiometric quantities and “lm” in photometric quantities). Each photometric quantity has its corresponding radiometric quantity, where the suffix “e” in the symbols represents the radiometric quantity and “v” the photometric equivalent.

One watt of light at 555 nm corresponds to 683 lumens, fixing the relationship between the quantities radiant power and luminous flux. This factor varies with wavelength and the variation is defined by the Commission Internationale de l´Éclairage (CIE), also referred to by the translation

“International Commission on Illumination”, as the $V(\lambda)$ function (see Figure 1). The $V(\lambda)$ curve describes the spectral response function of the human eye in the wavelength range from 360 nm to 830 nm[1] normalized to 1. This curve is used to weight the radiometric quantity that is a function of wavelength λ in order to obtain its corresponding photometric quantity. If $Q_e(\lambda)$ is a spectral radiant quantity, the value of the corresponding photometric quantity Q_v is derived by integration of $Q_e(\lambda)$ as follows:

$$Q_v = K_m \int_{360nm}^{830nm} Q_e(\lambda) \cdot V(\lambda) \cdot d\lambda$$

The constant K_m = 683 lm W^{-1} refers to the (physical) radiometric unit of the watt and the (physiological) photometric unit of the lumen.

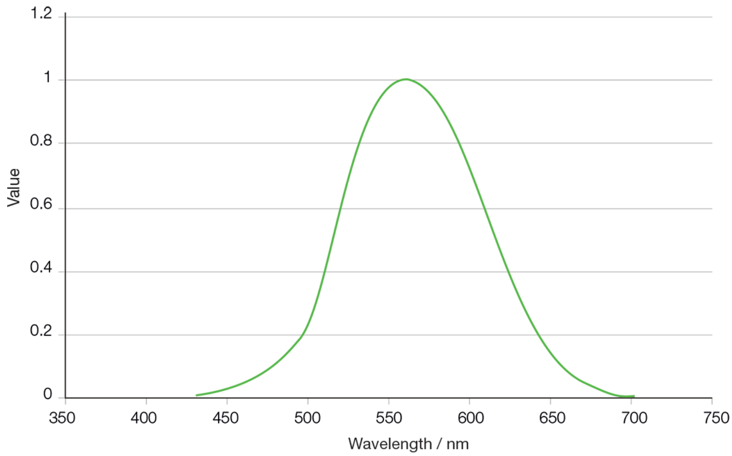

Figure 1: Diagram showing the $V(\lambda)$ curve (human eye response function).

There are four basic radiometric and photometric quantities which are described in the following sub-chapters.

[1] The full range is 360 nm to 830 nm but values are very small at the extremes and it is often limited for practical purposes to the useful range of 380 nm to 780 nm.