Standard Test Methods for High-Brightness LEDs

Nathalie Renaud, optical design program manager
Marco Michele Sisto, researcher

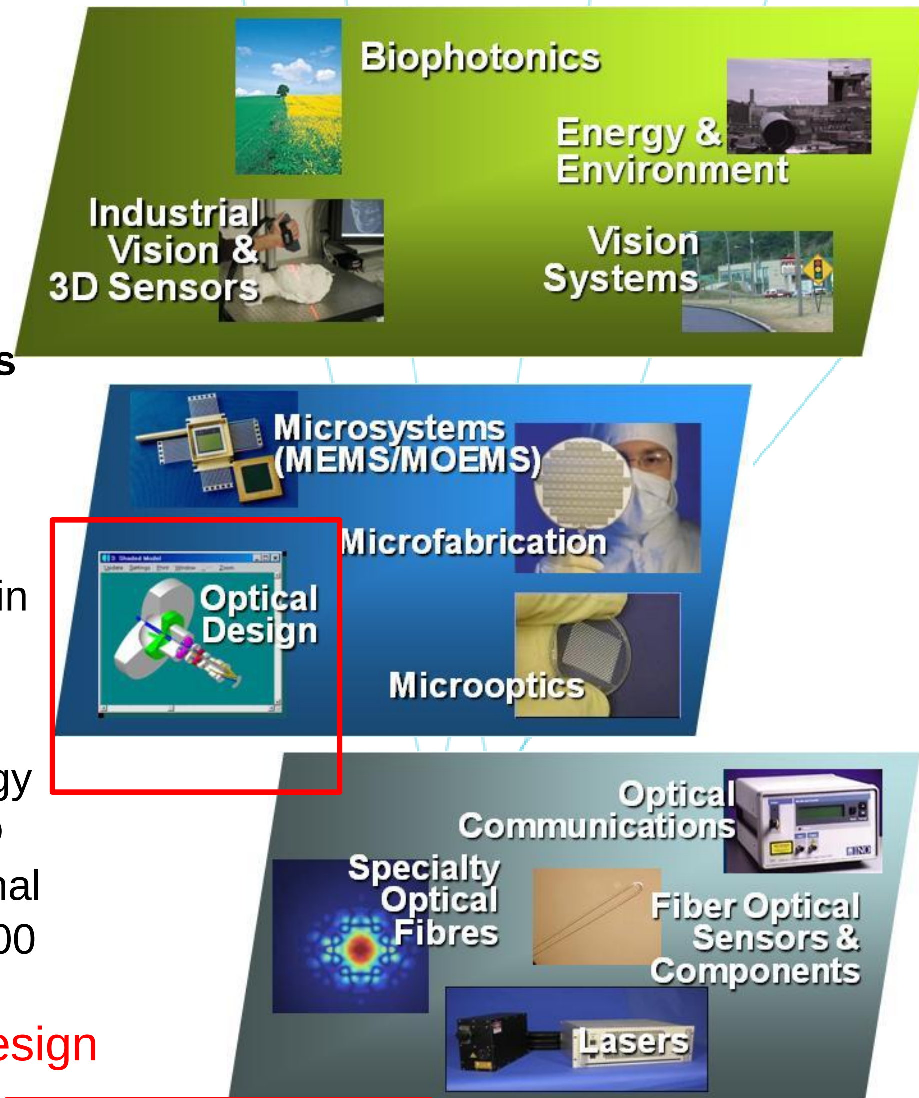
CNC/CIE Workshop 2012
Opportunities and Challenges in Energy-Efficient Lighting
November 30th, 2012

INO – Overview

INO is a technological Design and Development firm for Optic and Photonic solutions for SMEs and large corporations

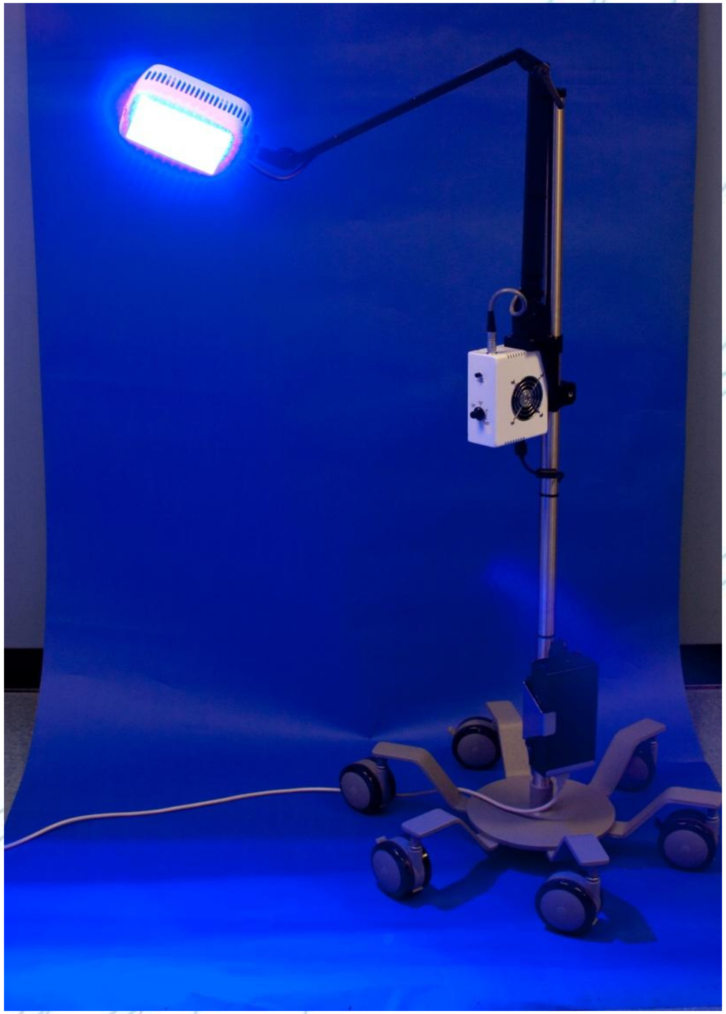
Since1988 INO offers a complete range of integrated services in the fields of optics/photonics to clients of all descriptions in every field of industrial activity

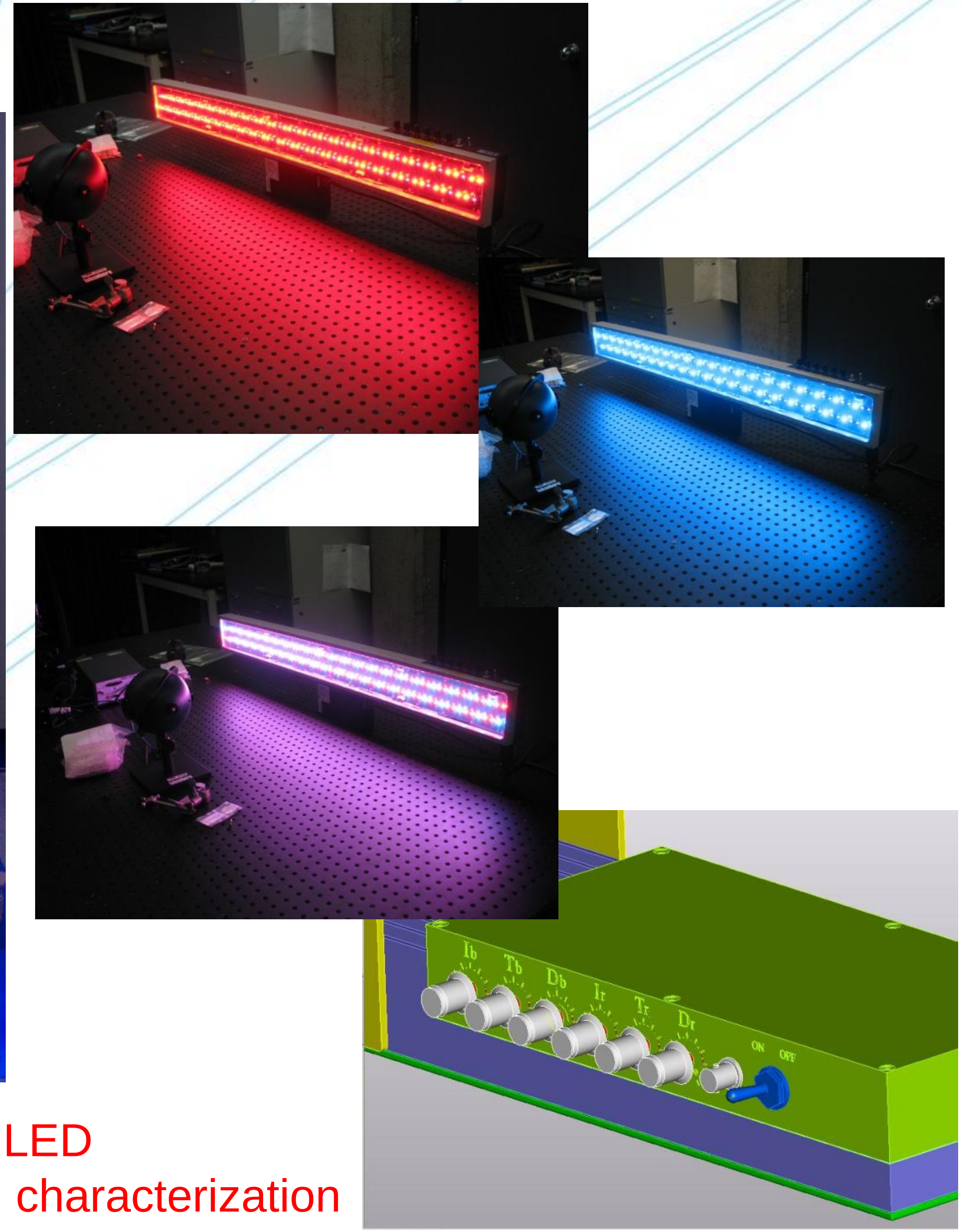
> 200 employees, 38M$ budget , 40 technology transfers, 26 spinoffs companies, 5,000 R&D contracts, 23 agreements with the international scientific community, 107 patents granted, 100 other are pending



LED source design

Led sources





High power
Controlled performance

LED
characterization

FOR-320-149
Version 01

Characterizing LEDs: what should be tested?

In order to support the design of high quality SSL (solid state lighting) products, the engineer should know the following LED parameters:

_Performance characteristics

- _ Photometric quantities: luminous flux, light intensity distribution, luminance
- _Chromatic quantities: chromaticity, CCT, CRI, CQS, color angular/spatial uniformity
- _Source luminous efficacy (lm/W)
- _Thermal behavior: variations of photometric and chromatic quantities with temperature
- _Reliability and lifetime, lumen maintenance, color stability

This data is useful, for example, to ensure that a SSL product using the LED meets performance requirements

We are interested in performance measurements of high power LEDs

High power LEDs: characterization issues

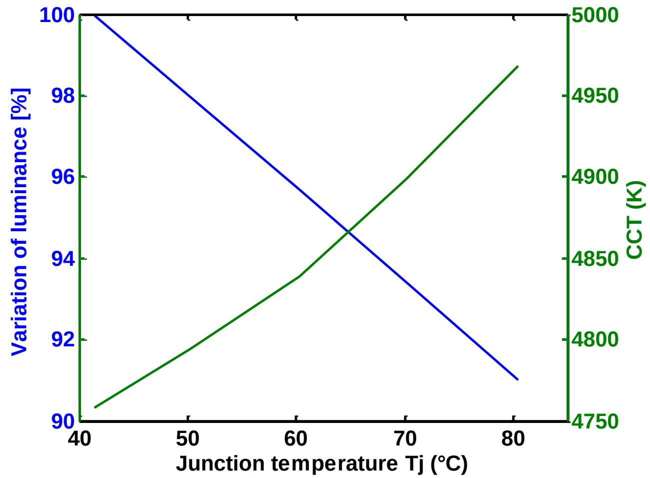
_LEDs manufacturers typically specify devices performance at room temperature and for a typical operating current.

however

_High power LEDs in luminaires operats at much higher temperaturse depending on the SSL heat sink efficiency, operating current and ambient temperature.

_Many performance parameters vary with temperature

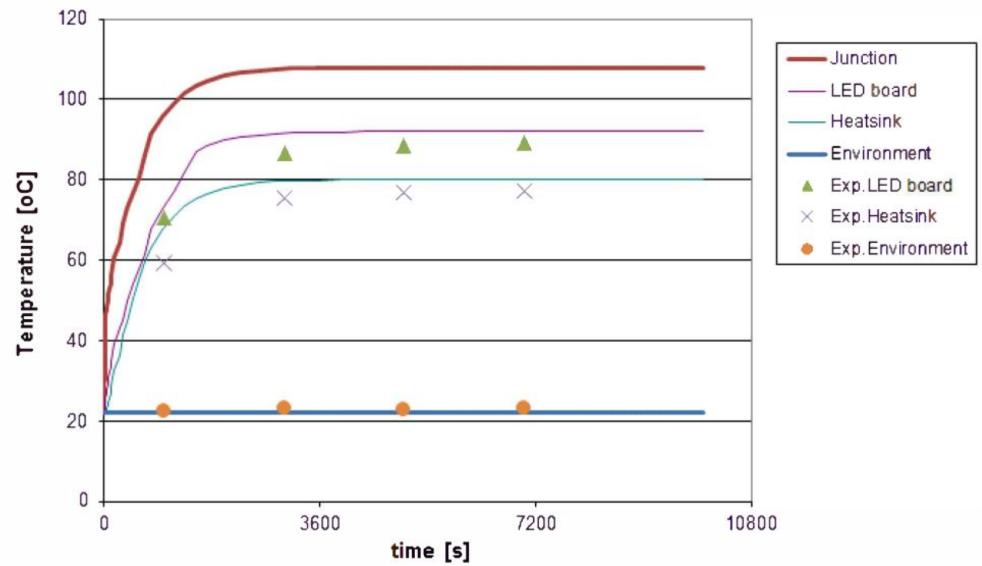
- _Emitted spectrum
- _Chromaticity, CCT, CRI
- _Luminous flux and radiant flux
- _Wall plug and luminous efficacies



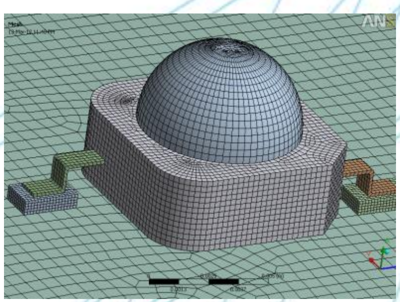
ACULed White emitter in a RGBW LED, 700mA

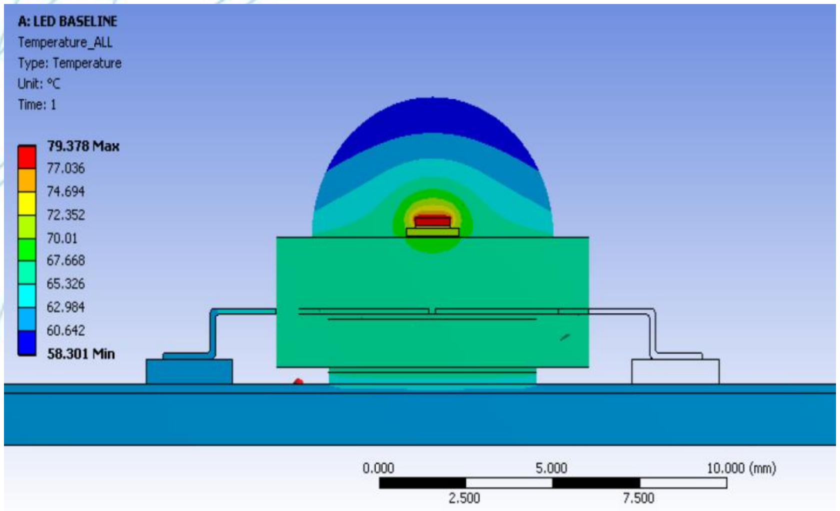
Performance of LEDs extracted from datasheet
≠
Performance in of SSL products

Examples of SSL thermal analysis



From: Dynamic thermal simulation of high brightness LEDs with unsteady driver power output, H. Ye, EuroSimE 2012





Power (W)	1	2	3
Tj (°C)	79.3	129.2	175.8

Tambient = 25°C
δT= 150 °C with 3W dissipated power

From: A Parametric Study of a Typical High Power LED Package to Enhance Overall Thermal Performance, A. Vipradas, 13th IEEE ITHERM Conference, 2012

Standardization effort

CIE and IESNA are defining new standards for measurement of high-power LEDs

TC 2-63: Optical Measurement of High-Power LEDs

To develop a CIE recommendation on methods for the operation of high-power LEDs in DC and in pulse mode, at specified junction temperatures, for optical measurements. Chair: Yuqin Zong (US)

IESNA LM-85: Approved Method for Electrical and Photometric Measurement of High Power LEDs (non official description)

Address the measurements for high-power LEDs that require heat sink for their normal operation, and include white LEDs as well as single color LEDs.

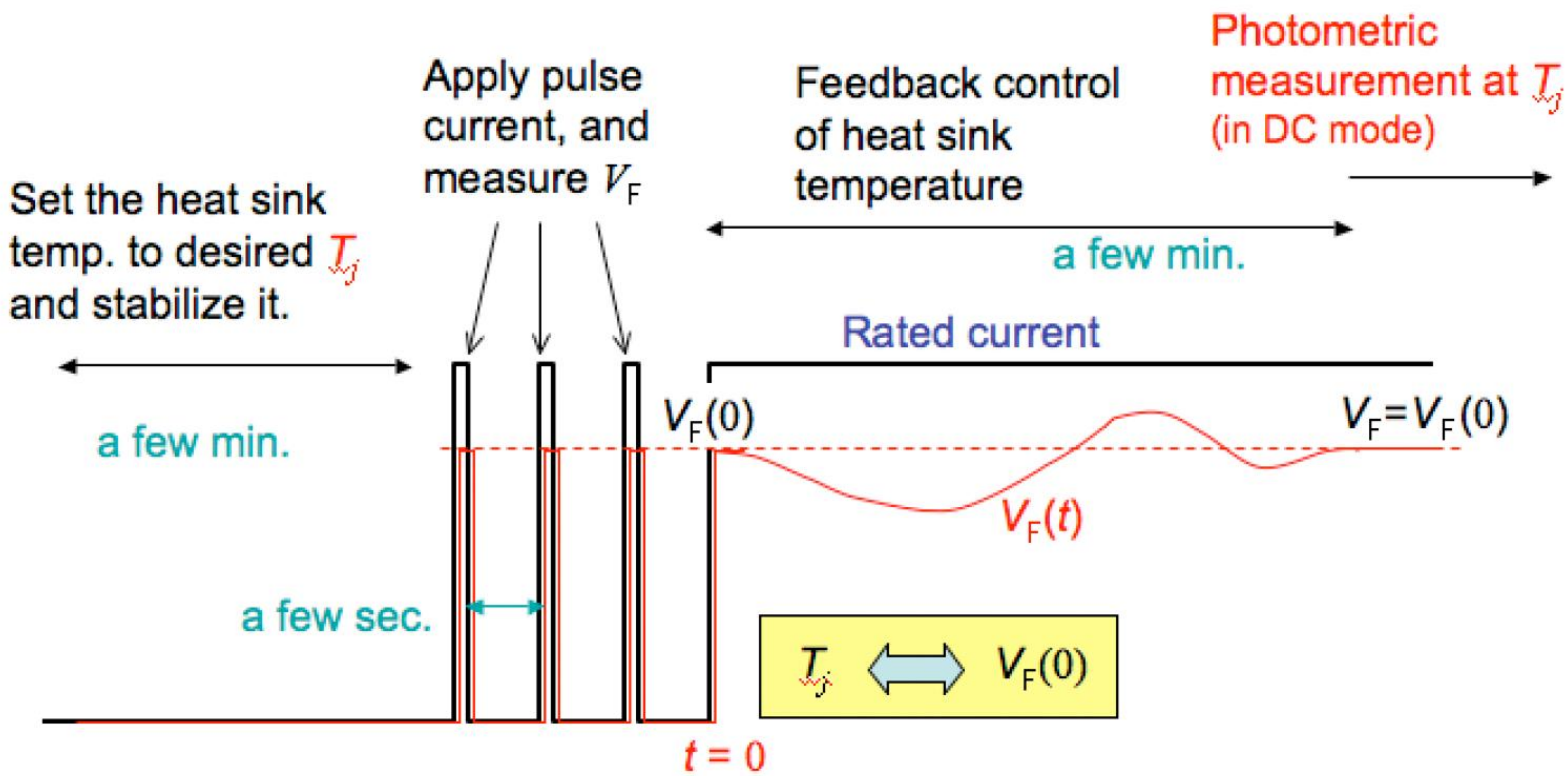
_Measure total luminous flux, total radiant flux (optical power), electrical power, luminous efficacy, and color characteristics of high-power LEDs

_Measure under pulse operation as well as steady DC operation of LEDs, and in all cases, the thermal condition of LEDs refers to their junction temperature

_Does not cover measurement of ultraviolet LEDs, IR emitters, and AC-LEDs.

Setting the junction temperature T_j

_One proposed method. From “NEW PRACTICAL METHOD FOR MEASUREMENT OF HIGH-POWER LEDS”, Yuqin Zong and Yoshi Ohno (NIST), CIE Expert Symposium 2008 on Advances in Photometry and Colorimetry

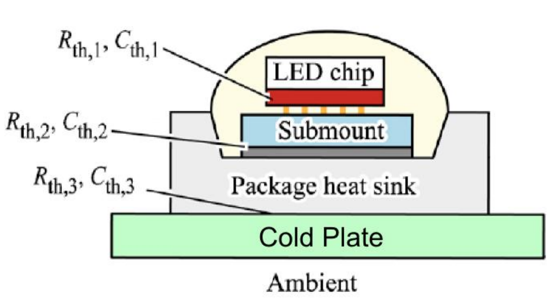


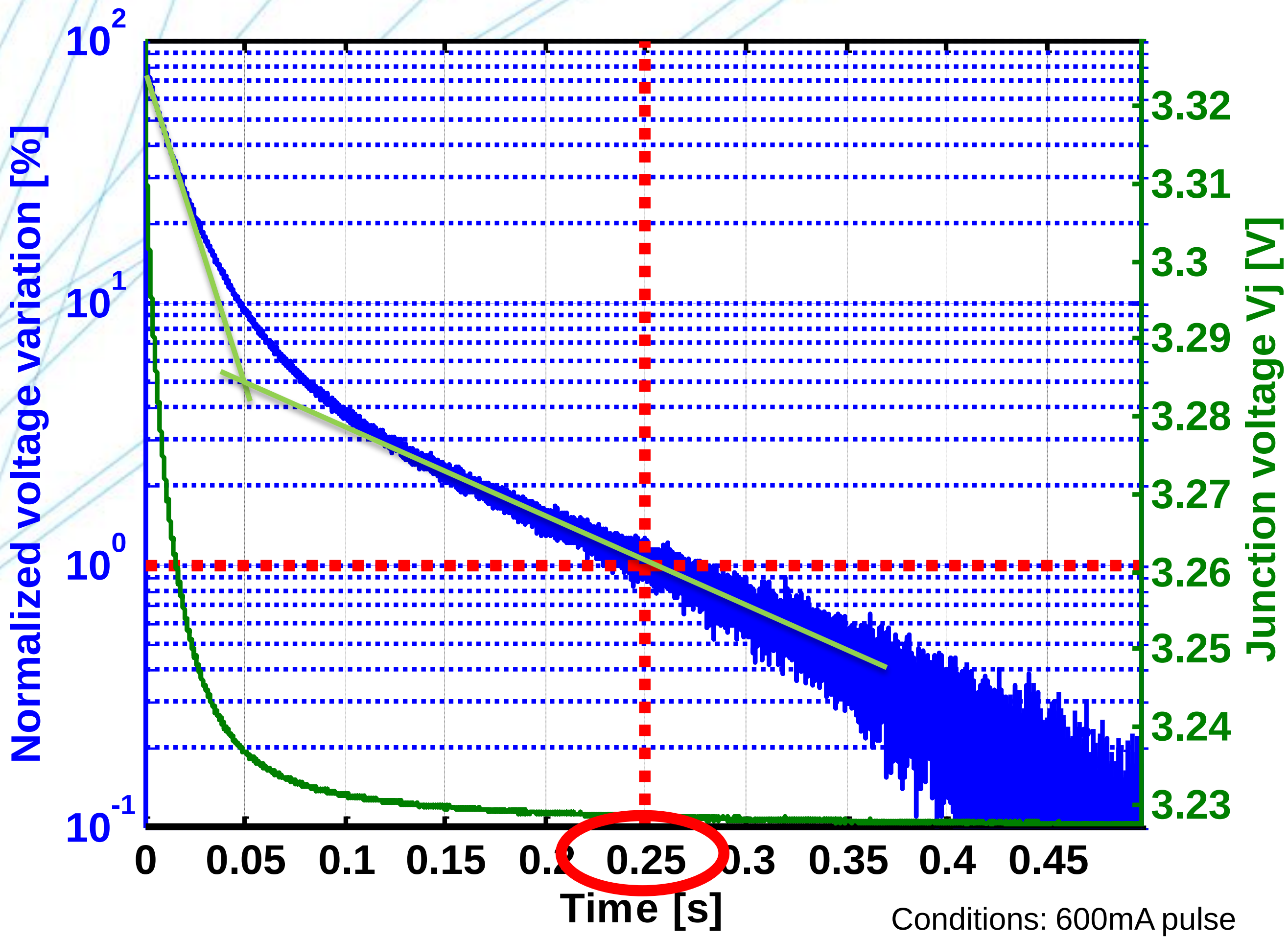
Thermal behavior of the junction

In our system, the junction temperature stabilizes within ¼ sec with respect to a reference heat sink

Stabilization time defined as time required to reach a voltage within 1% of the steady state value

The multiple time-constants behavior is justified by the multilayer thermal path between the junction and the heat sink.





Conditions: 600mA pulse

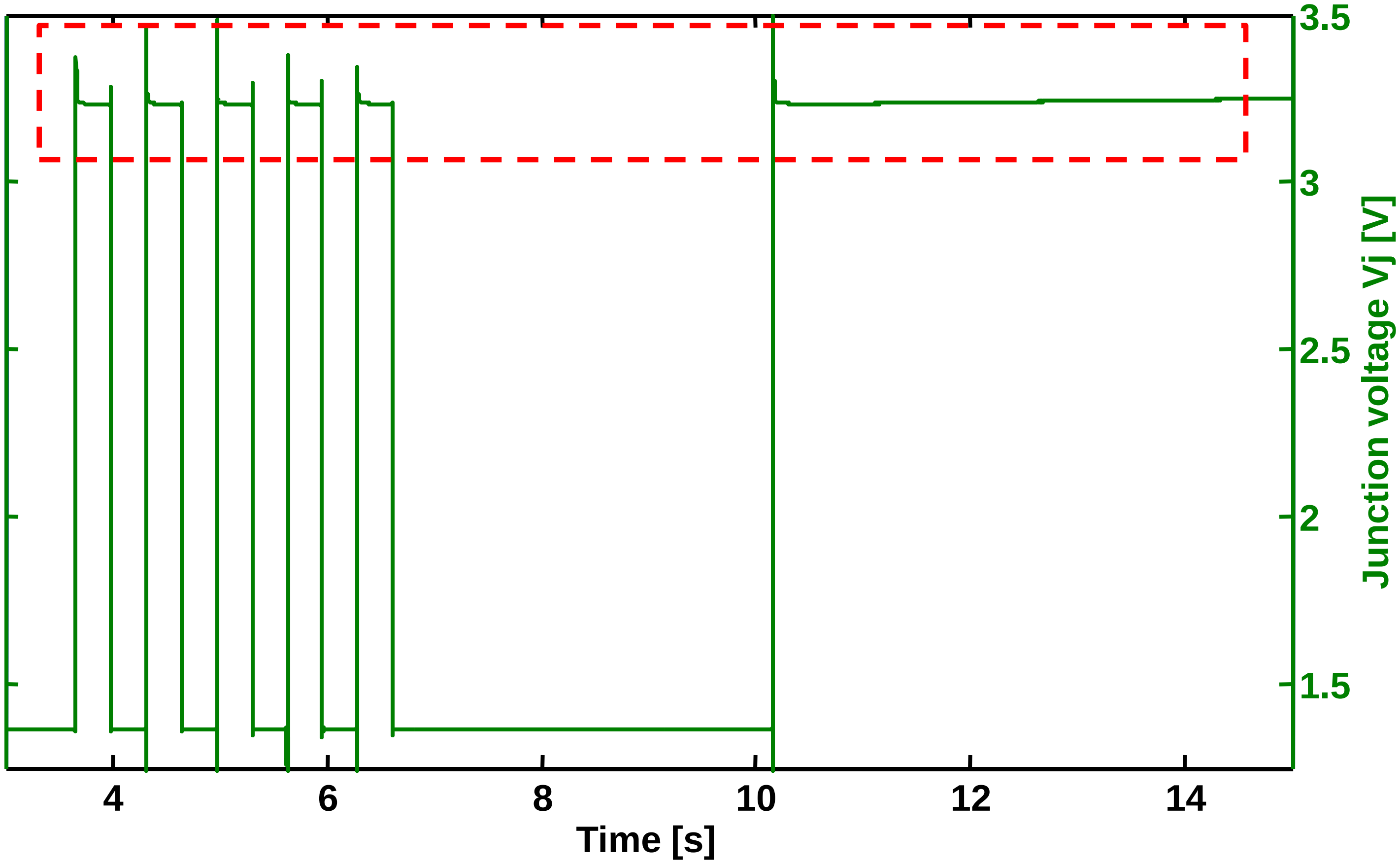
FOR-320-149
Version 01

Implementing the algorithm for setting Tj

Typically, the heat sink temp. feedback response time is much slower than the thermal stabilization time of the junction

- _The heat sink thermal mass is much larger than the junction itself
- _The junction has time to heat up considerably before the heat sink temp. feedback can react effectively

Conditions: target Tj at 45°C, current 600mA



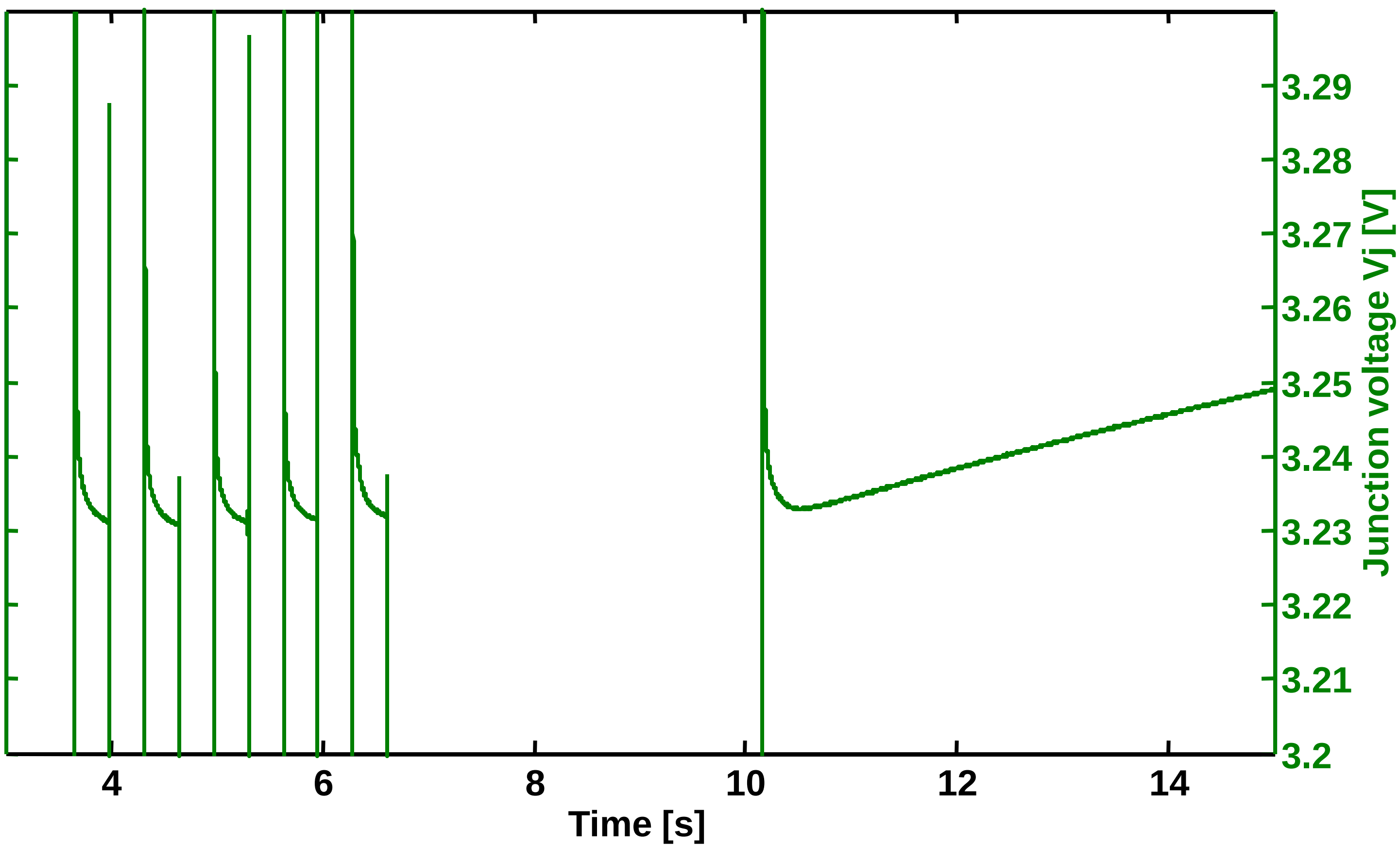
FOR-320-149
Version 01

Implementing the algorithm for setting Tj

Typically, the heat sink temp. feedback response time is much slower than the thermal stabilization time of the junction

- _The heat sink thermal mass is much larger than the junction itself
- _The junction has time to heat up considerably before the heat sink temp. feedback can react effectively

Conditions: target Tj at 45°C, current 600mA

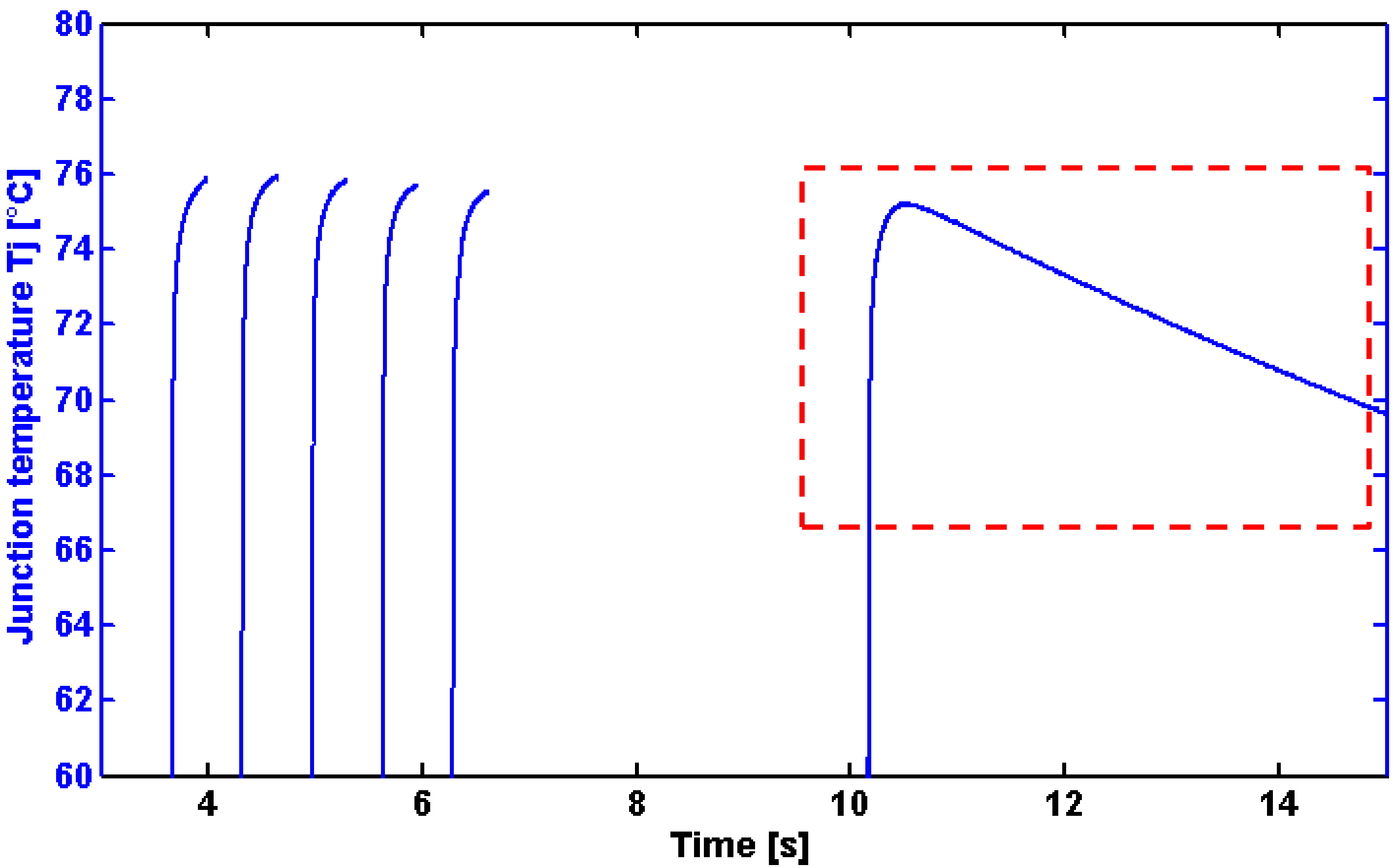


Implementing the algorithm for setting Tj

Typically, the heat sink temp. feedback response time is much slower than the thermal stabilization time of the junction

- _The heat sink thermal mass is much larger than the junction itself
- _The junction has time to heat up considerably before the heat sink temp. feedback can react effectively

Conditions: target Tj at 45°C, current 600mA

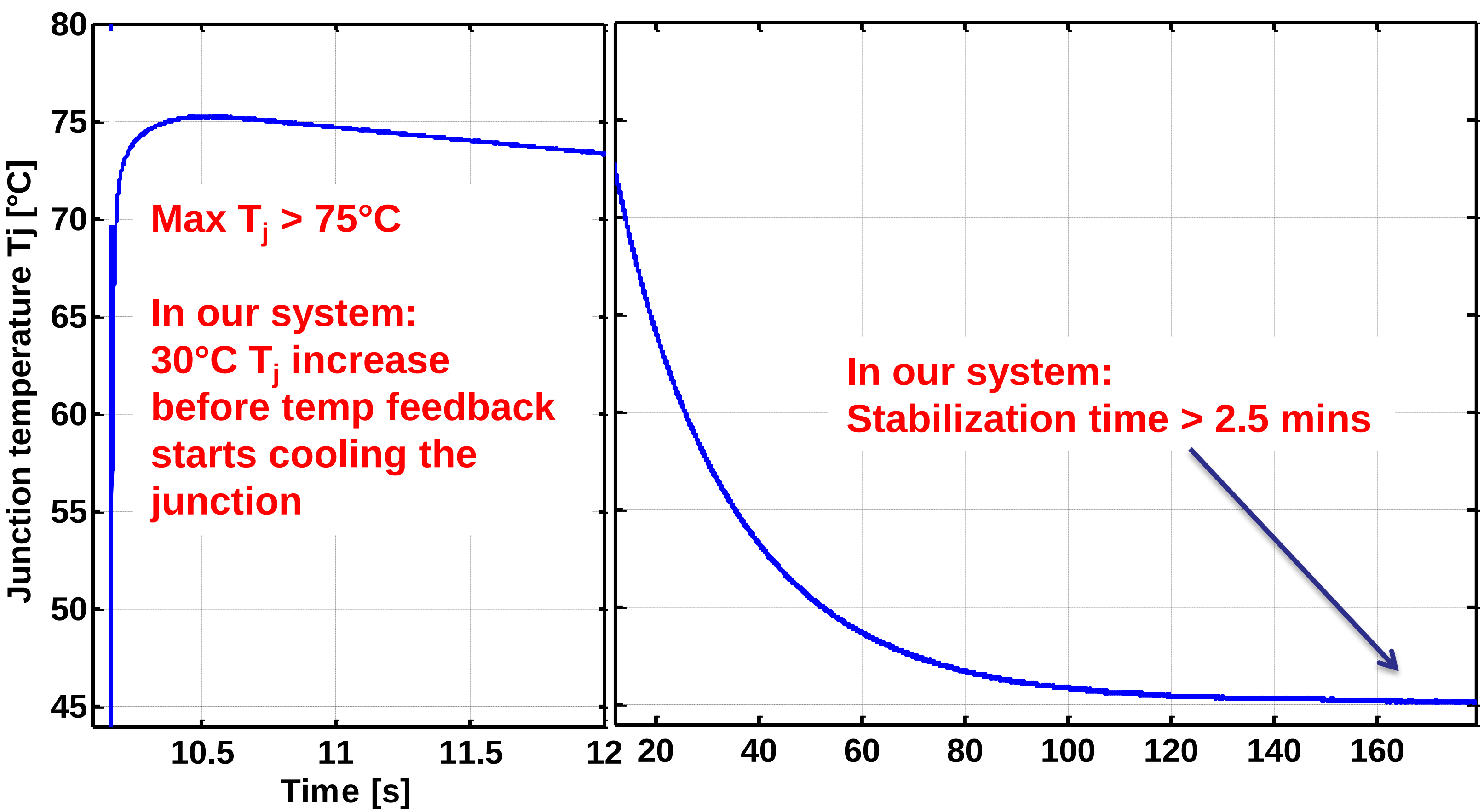


Implementing the algorithm for setting Tj

Typically, the heat sink temp. feedback response time is much slower than the thermal stabilization time of the junction

- The heat sink thermal mass is much larger than the junction itself
- The junction has time to heat up considerably before the heat sink temp. feedback can react effectively

Conditions: target Tj at 45°C, current 600mA



Importance of avoiding T spikes during characterization

From SSL thermal simulation we can predict the steady state T_j for a given dissipated power

In order to properly predict SSL colorimetric/radiometric performance, the LED should be characterized at the expected T_j.

However, the characterization algorithm described before may cause the LED to temporarily overheat.

Junction overheating is known to be the source of LED degradation, reduced lifetime and possibly catastrophic failure.

If the LED is characterized near its maximum allowed T_j and at high current:

_Performance measurements are actually affected by degradation due to heat overstress

_Potential of catastrophic failure , mainly due to thermomechanical stress and associated failure mechanisms [Solid State Lighting Reliability: Components to Systems, van Driel, W.D.; Fan, X.J. (Eds.), ISBN 978-1-4614-3067-4]

A new T_j stabilization algorithm

One can minimize the LED overheating by:

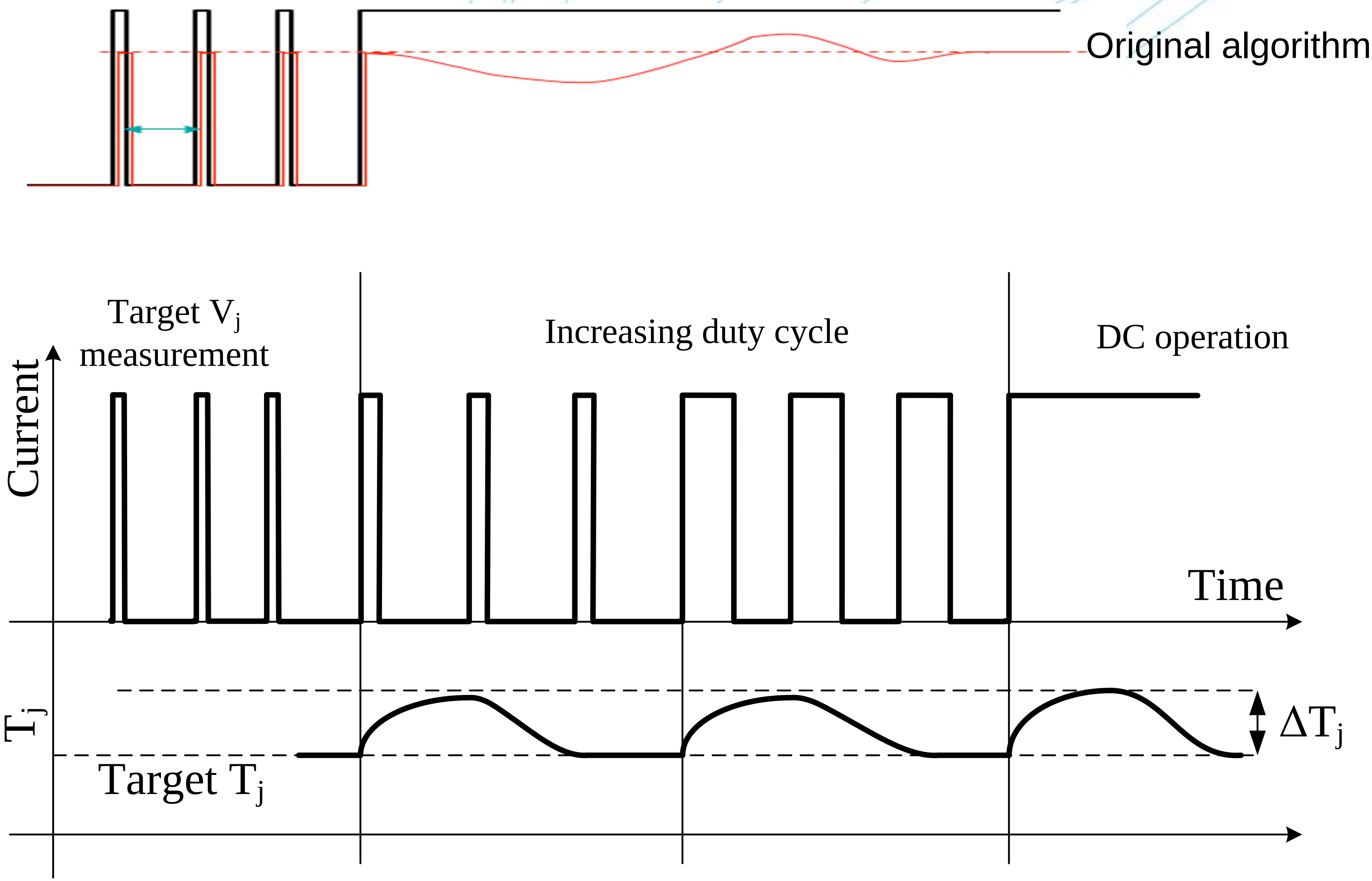
_ Designing a very effective temperature control system. However, this solution has limitations since heat is generated directly within the junction and thermal mass of the heat sink is non negligible.

_ Increasing gradually LED drive current from 0 to the desired value. This allows the temperature feedback system to maintain the T_j temperature over time even if increasing power is dissipated in the junction. However, this requires an analogic control over the current values, which may be unavailable.

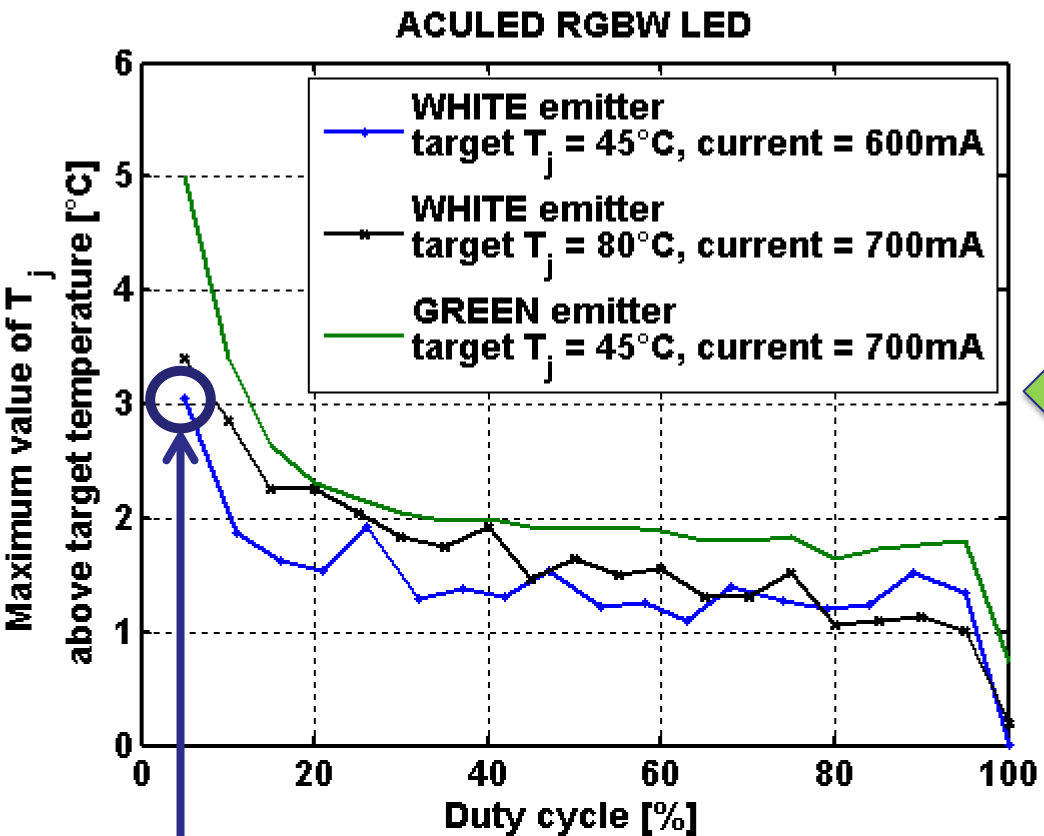
_Alternatively, one can take advantage of the current pulsing capability that is already required to implement the original algorithm.

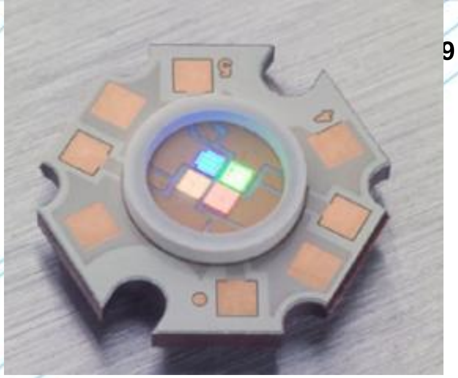
We propose a stabilization algorithm that gradually increases the duty cycle up to full DC operation. For every duty cycle step, the heat sink temperature is adjusted to maintain the T_j near its target value.

Proposed T_j stabilization algorithm



Experimental results



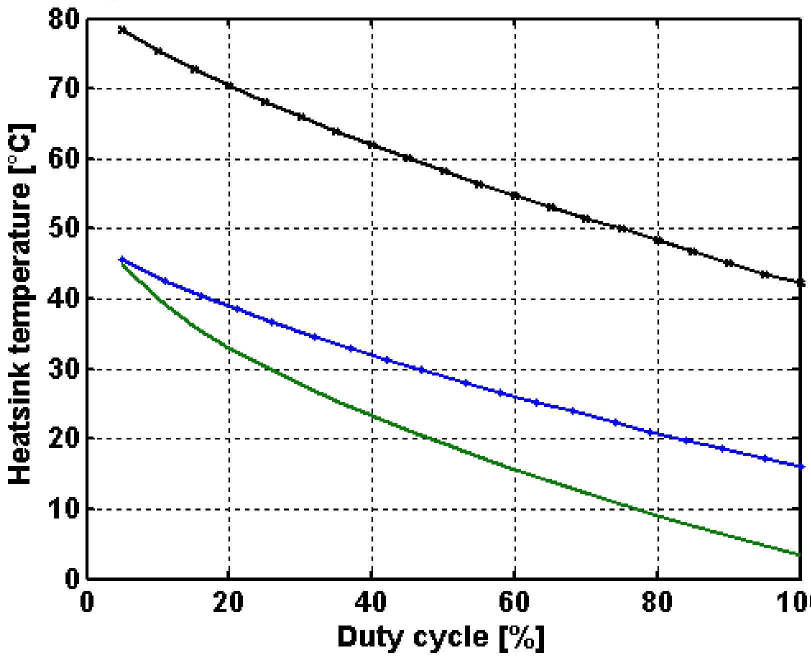


PerkinElmer ACULED

Increase of T_j temperature is kept below 5°C from the target value while Duty Cycle is increased from 5% to 100%

With the original algorithm in these conditions, T_j increases by 30°C. Here the maximum T_j variation is +3°C

Heat sink temperature lowered with increasing duty cycle to maintain T_j near target temperature



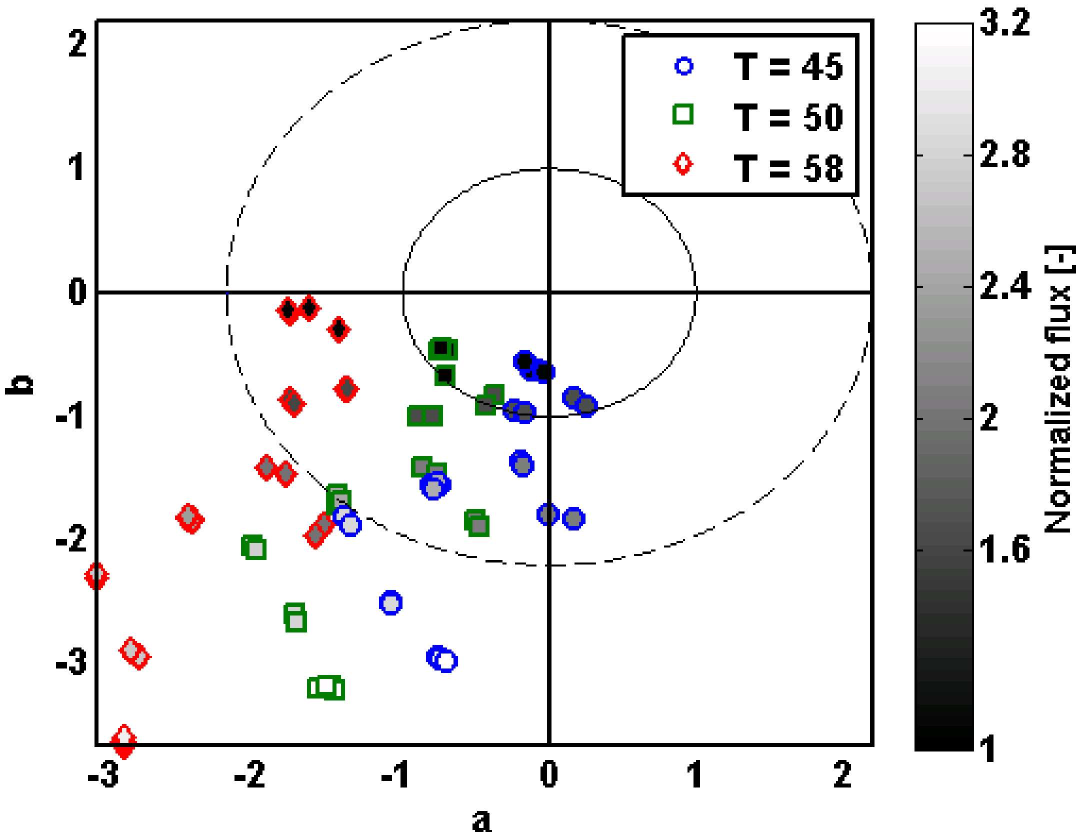
Color control feed forward algorithm based on accurate LED calibration

CIELab plot of color emitted from an ACULED RGBW LED using a feed-forward control algorithm that assumes constant LED junction temperature at T_j=45°C, while ambient temperature vary from 45°C to 58°C.

The internal circle corresponds to CIE76 ΔE^*_{ab}=1 (JND for sources [1])

The external circle corresponds to CIE76 ΔE^*_{ab}=2.3 (JND for surfaces [1])

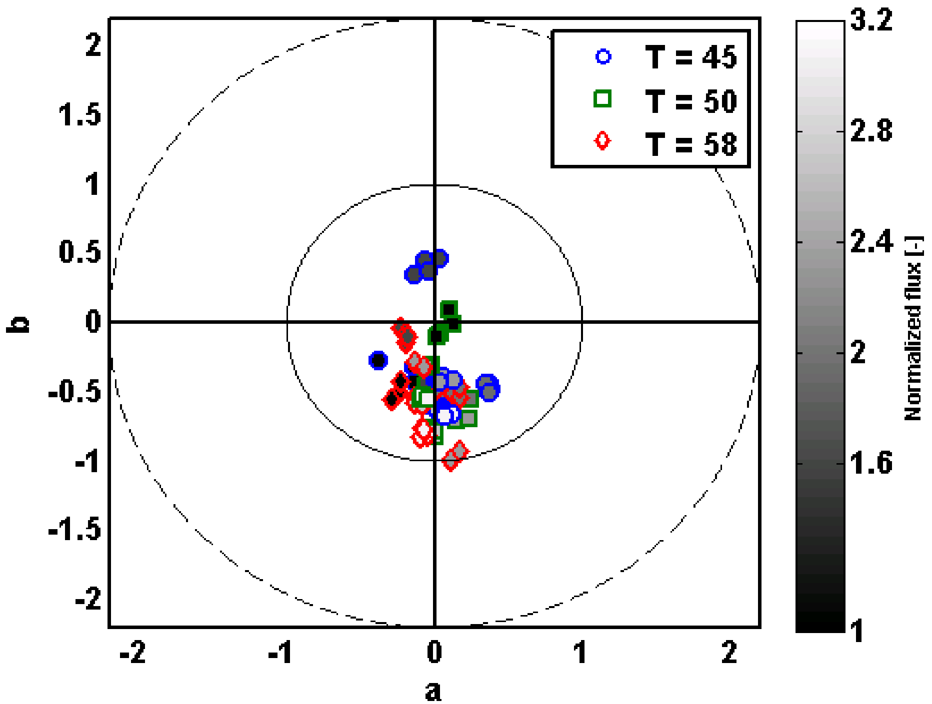
The various color points correspond to 3 ambient temperature values and 6 values of flux from the LED. The flux vary by a factor 3.

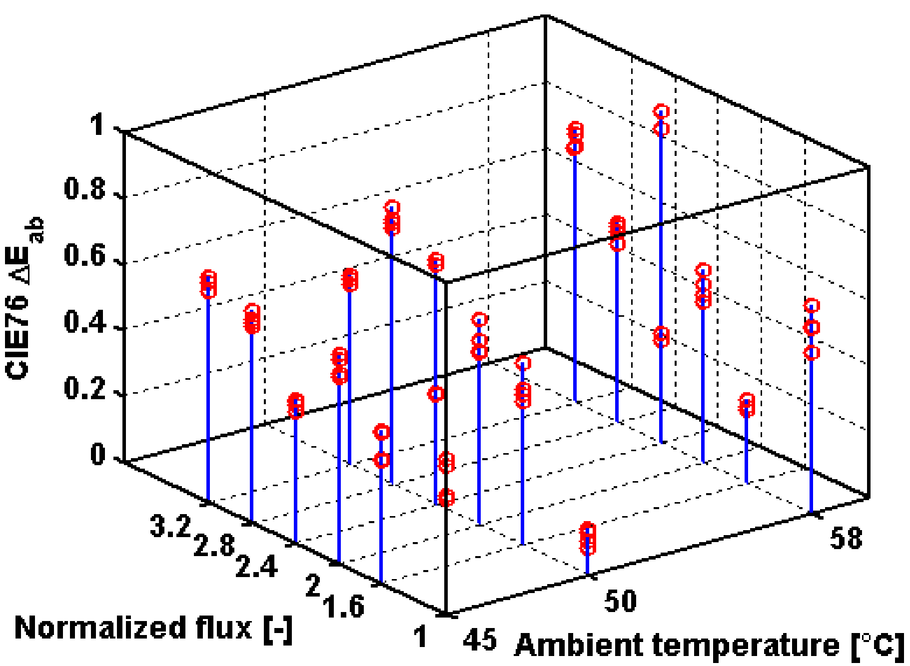


[1] M. Mahy, L. Van Eycken, and A. Oosterlinck,
"Evaluation of uniform color spaces developed after the adoption of CIELAB and CIELUV," Color Res. Appl. 19, 105–121 (1994).

Color control feed forward algorithm based on accurate LED calibration

_The same plot, but using a control algorithm that takes into account real junction temperature. This algorithm is based on an appropriate LED characterization at multiple T_j temperatures. The characterization near maximum operating T_j was only possible with the proposed temperature stabilization algorithm. Otherwise, we experienced several LED failures!





Good temperature characterisation of LEDs is mandatory for SSL design using high brightness LEDs when optical performance has to be controlled

A junction temperature setting algorythm is proposed to allow reliable LED characterisations at high temperatures and currents

For info:

nathalie.renaud@ino.ca