New Considerations for SSL System Reliability – Recent Test Results

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OUTLINE

- Improvements in LED luminous flux maintenance
- Organic light-emitting diode (OLED) lighting performance
- Multi-channel driver reliability
- Conclusions
- Acknowledgements

Acknowledgement and Disclaimer

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Key Questions to be Addressed

- Organic light-emitting diode (OLED) lighting technologies offer potential advantages such as diffuse sources and reduced glare. How do their reliability performance compare to inorganic LED products?

- Solid-state lighting (SSL) technologies are relatively new to the lighting industry but have made significant market gains in the past decade. Have there been corresponding gains in the luminous flux maintenance of LED packages and array (sources)?

- Drivers are a potential failure point in the lighting system, especially for multi-channel lighting systems with tunable lighting. What are some of the key issues with driver robustness and reliability?

Luminous flux maintenance improvements in LEDs

- IES LM-80-08 was first adopted in 2008 as a method to take data on the luminous flux maintenance of LED light sources. When combined with IES TM-21-11, it allows a projection of the rated luminous flux maintenance life using an exponential decay model.

$$\Phi(t) = Be^{-\alpha t}$$

α = decay rate constant

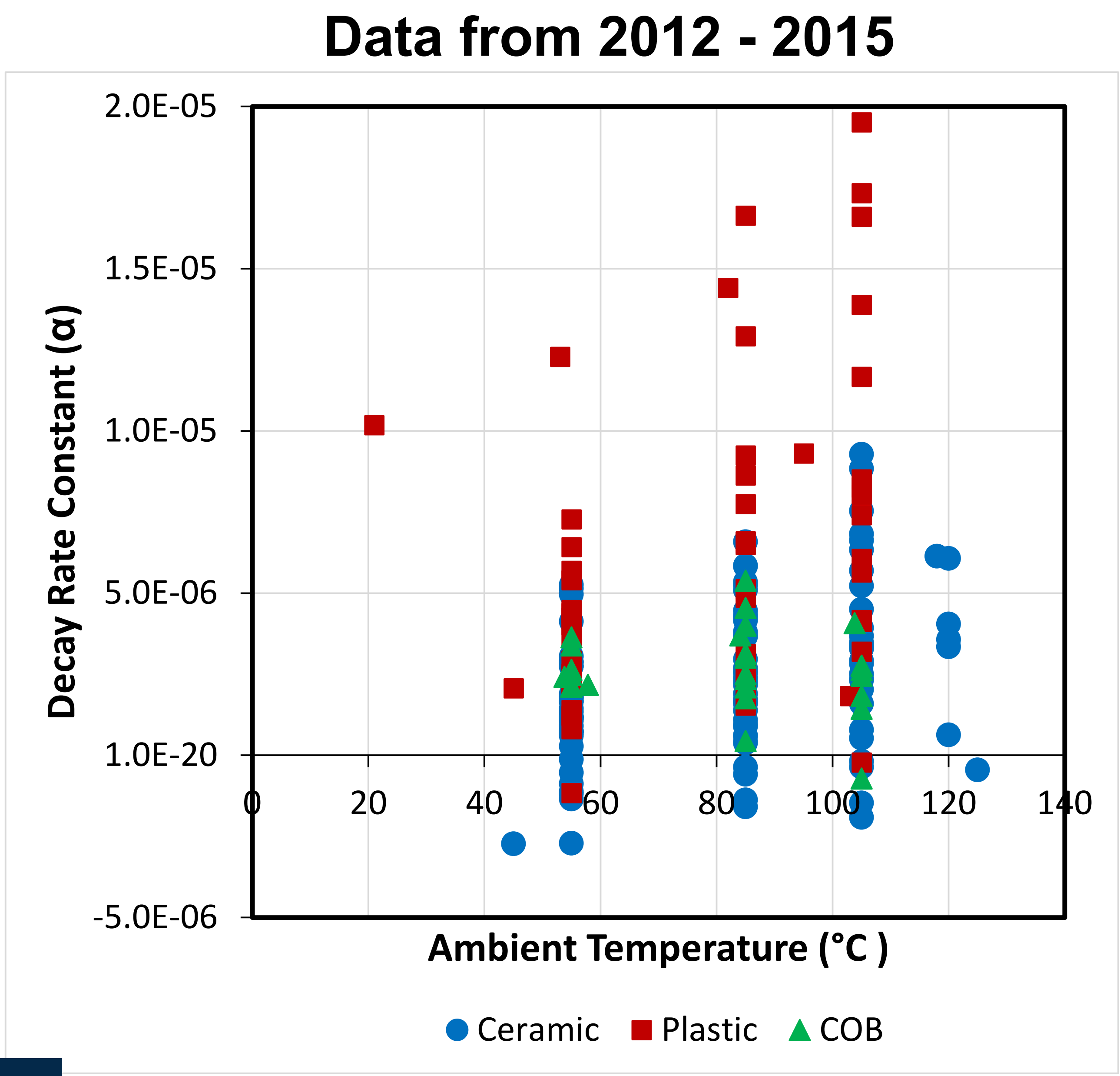
B = normalized initial constant

- Values of α provide a measure of the luminous flux maintenance life (e.g., L_{70}, L_{80}, L_{90}). However, lifetime projections cannot exceed 6-times the test duration (6X rule).

α	Test Duration	L_{70}	L_{80}	L_{90}
2×10^{-6}	10,000	> 60,000	> 60,000	53,000
1×10^{-5}	6,000	36,000	22,000	11,000

- ANSI/IES LM-80-15 is the newest approved method for measuring luminous flux **and** chromaticity maintenance. Requires reporting luminous values and chromaticity coordinates (*u'* and *v'*). Can also be used with IES TM-21-19.

LED Performance in ~2015 by Package Types

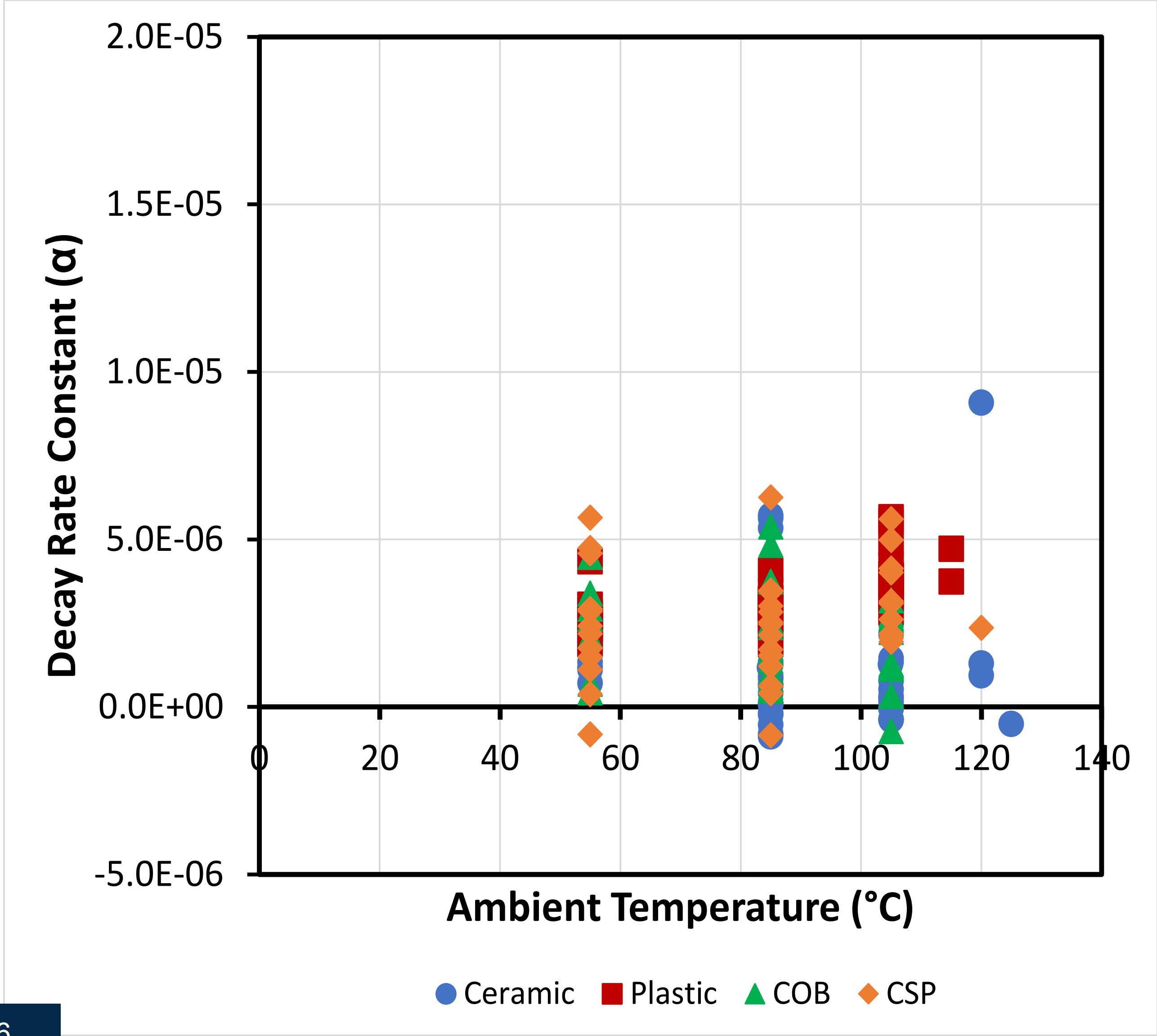


- Ceramic and COB packages provide the best luminous flux maintenance lifetime.
- Luminous flux maintenance lifetime of plastic packages is, on average, lower but there are exceptions due to type of plastic resin in use (e.g., PPA, PCT, EMC, Silicone).
- No information on the impact of chromaticity shift can be gathered from the data.
- Newer packaging formats such as chip-scale packages (CSPs) were just becoming available.

Ref: Final Report on DOE Project DE-EE0005124. doi: 10.2172/1360770. Hansen, 2015 Strategies in Light.

LED Performance Today by Package Types

Most reports issued after Jan. 1, 2018.



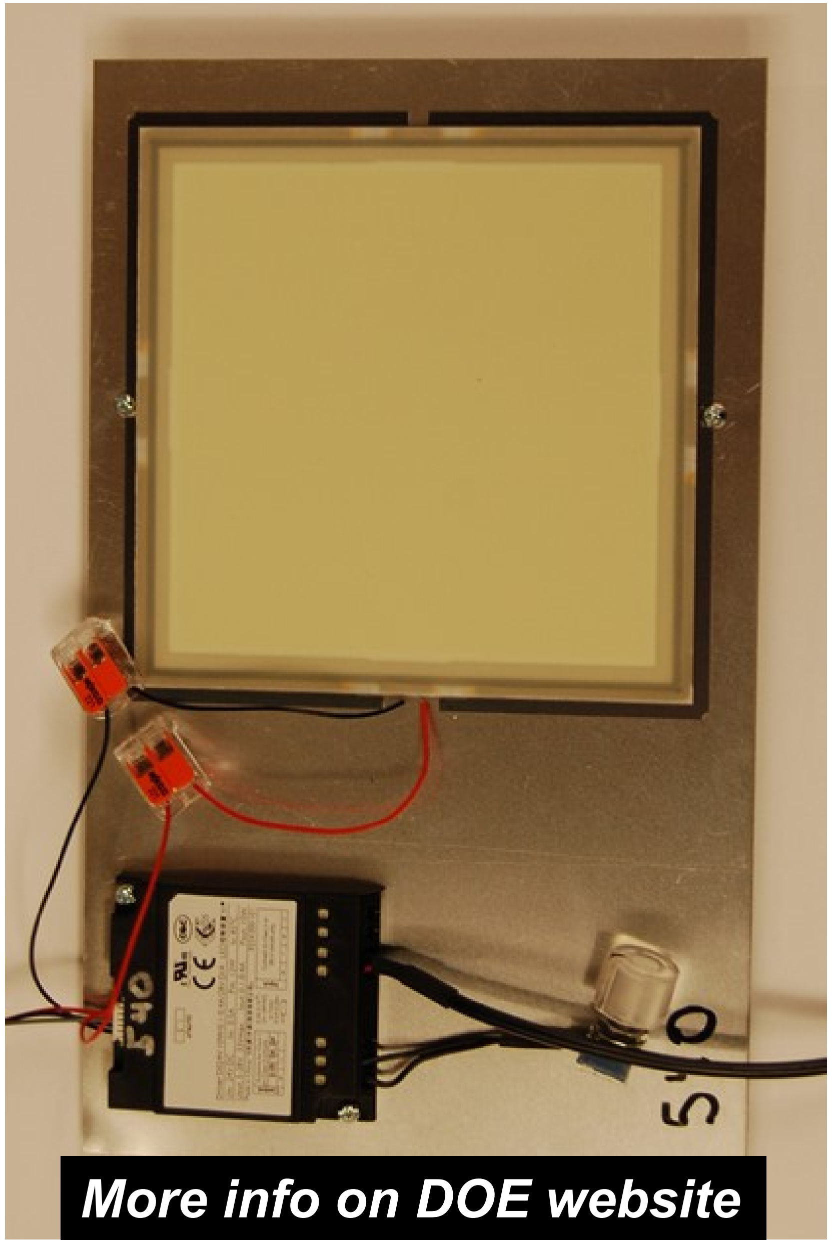
- Ceramic and COB packages continue to improve.
- Performance of plastic packages is more in-line with other package types at most conditions due in part to use of better plastics (e.g., EMC, silicone, ceramics).
- Data on CSPs is becoming more available and performance is in line with other packages.
- ANSI/IES LM-80-15 reports provide information on chromaticity maintenance – the data is being analyzed.

Reliability Testing of OLED Lighting Products

- We have been performing luminous flux and chromaticity maintenance life testing on OLED panels and luminaires for ~4 years.
- Continuous operation at mildly elevated ambient temperatures (25 – 45°C) have been used for testing.
- Several generations of each class of products have been tested. This has provided an opportunity to measure product improvements.
- Luminous flux maintenance data can be modeled using IES LM-84 and IES TM-28-14. These are the luminaire and lamp equivalent of LM-80/TM-21.

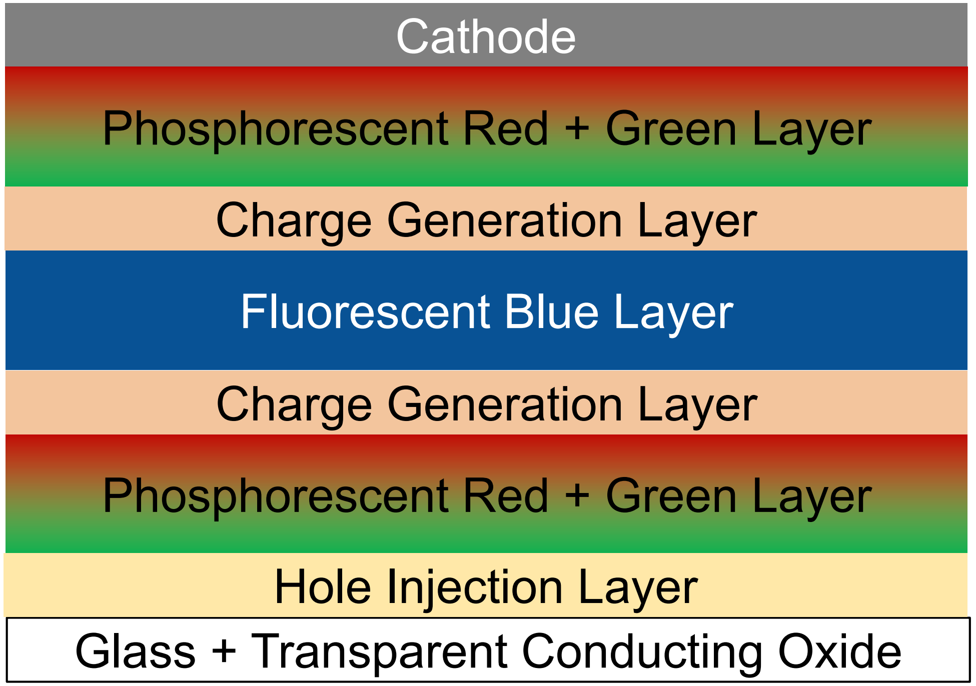
$\Phi(t) = Be^{-\alpha t}$ - Model uses same functional form

IES LM-84 tests usually involve smaller sample sizes than LM-80, so max projection time is 3-6X the test duration.



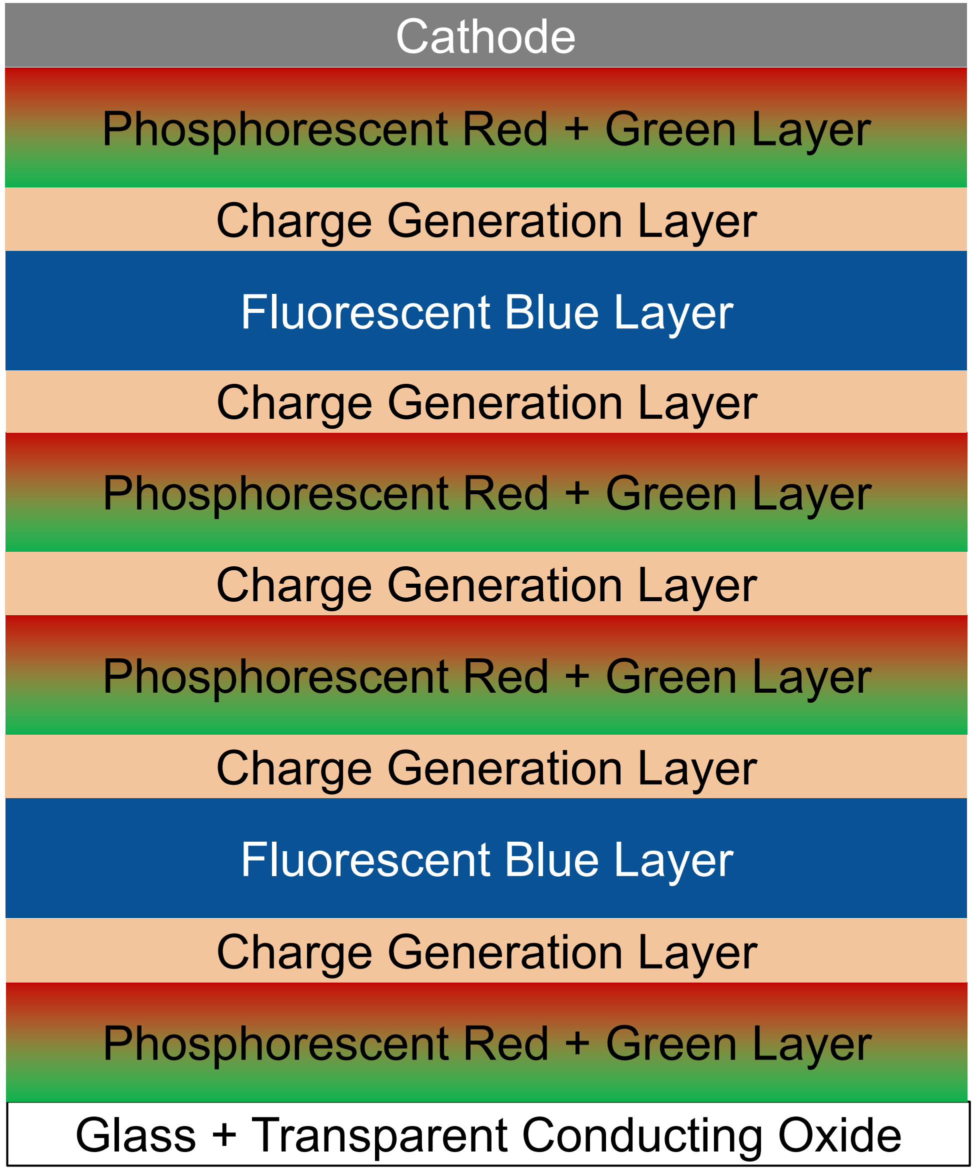
Commercial OLED Sample Description

3-Stack Structure

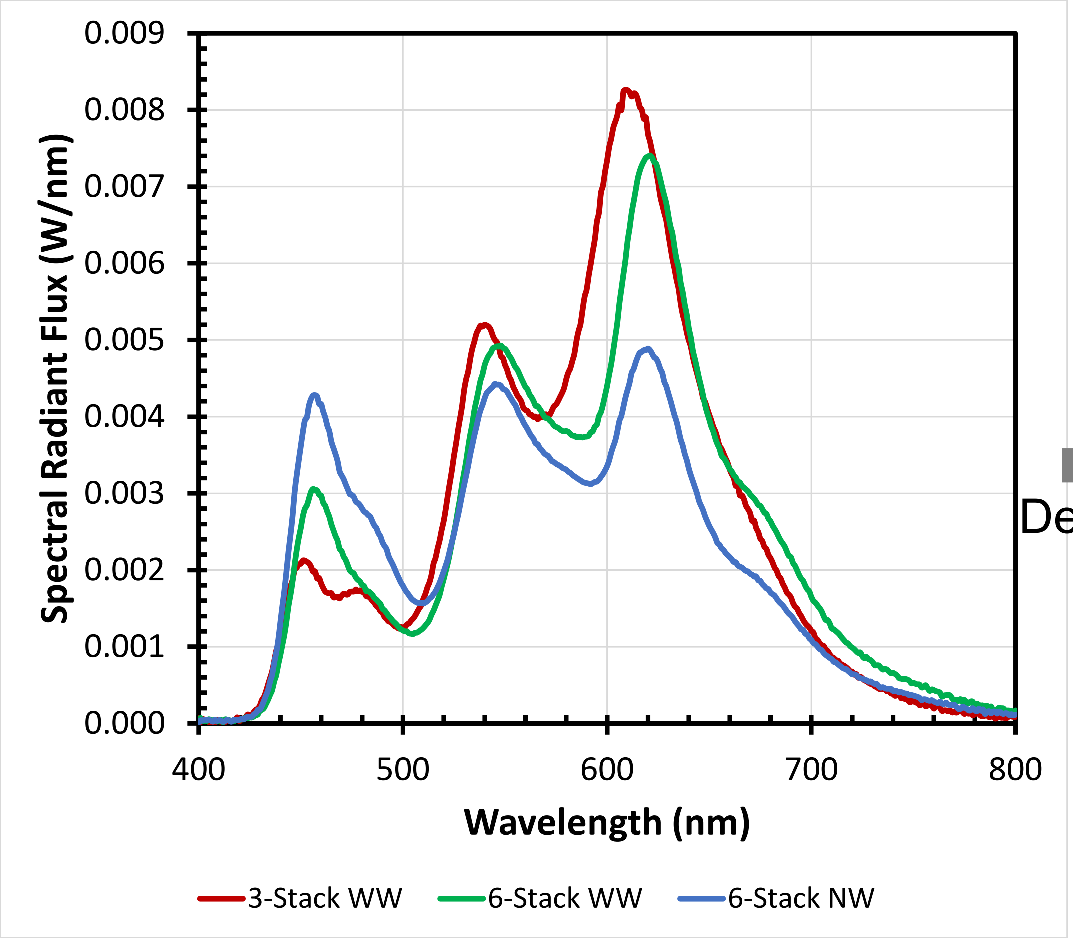


- 3-Tandem stacks. Testing was performed on luminaires from 3 different generations.
- 6-Tandem stacks. Testing was performed on panels from 2 different generations at two different CCT values for each generations.
- Manufacturer supplied drivers included in test.

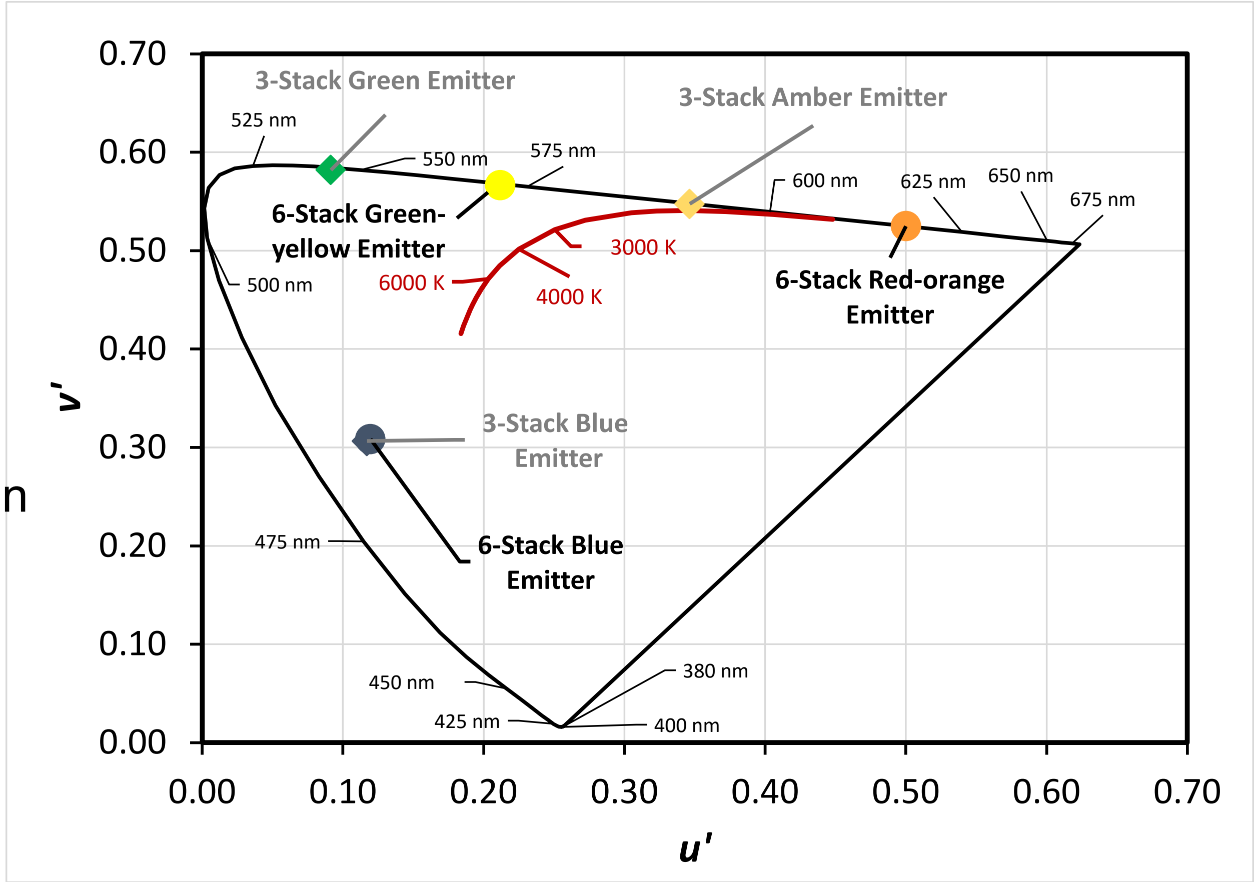
6-Stack Structure



Chromaticity of 3-Stack and 6-Stack OLED Panels



Spectral Deconvolution



- Blue is a fluorescent emitter (lower efficiency but very stable)
- Red + Green are phosphorescent emitters (higher efficiency)
- Luminous flux maintenance = stability of all emitters V(λ) weighting.
- Chromaticity maintenance = relative stability of the emitters.

OLED Luminous Flux Maintenance Life Data

Product	Test Duration	α Value	Rated L_{70}
3-Stack, Gen-2A WW	19k hrs @ 25°C	1.7×10^{-5}	21,000 hrs
3-Stack, Gen-3A, WW	12k hrs @ 45°C	3.9×10^{-5}	9,100 hrs
3-Stack, Gen-1A, WW	15k hrs @ 45°C	5.4×10^{-5}	6,600 hrs

** Value limited by 3X rule in IES LM-28-14.*

- First generation of OLED luminaires and panels exhibited α values of > 3×10^{-5} at 45°C.

OLED Luminous Flux Maintenance Life Data

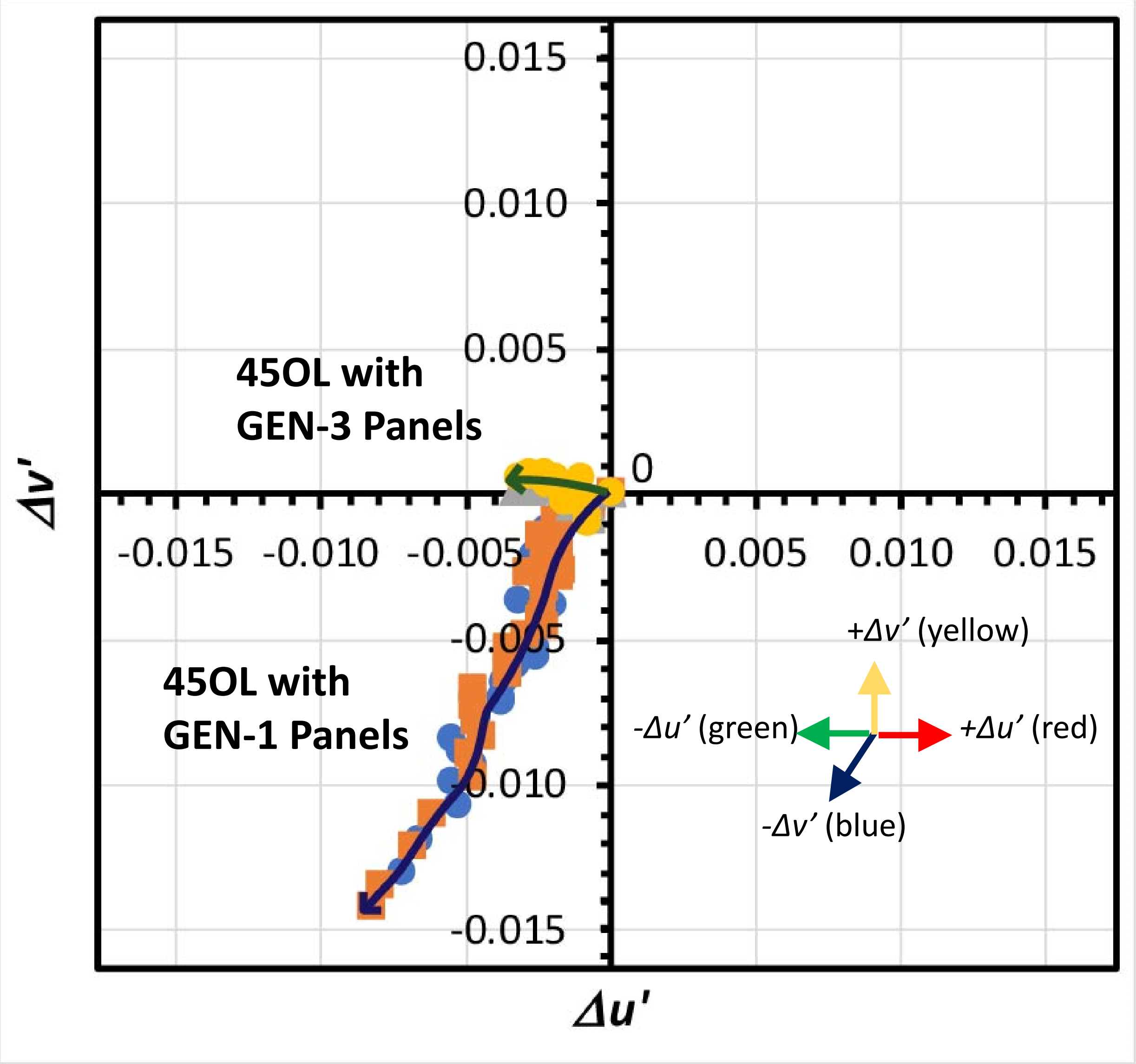
Product	Test Duration	α Value	Rated L_{70}
6-Stack, Gen-2B NW	12k hrs @ 25°C	8.9×10^{-6}	> 36,000 hrs*
6-Stack, Gen-3B NW	7k hrs @ 25°C	7.6×10^{-6}	> 21,000 hrs*
6-Stack, Gen-3B WW	7k hrs @ 25°C	1.8×10^{-5}	18,200 hrs
6-Stack, Gen-2B NW	12k hrs @ 45°C	1.6×10^{-5}	21,000 hrs
6-Stack, Gen-3B NW	7k hrs @ 45°C	1.4×10^{-5}	> 21,000 hrs*
3-Stack, Gen-2A WW	19k hrs @ 25°C	1.7×10^{-5}	21,000 hrs
3-Stack, Gen-3A, WW	12k hrs @ 45°C	3.9×10^{-5}	9,100 hrs
3-Stack, Gen-1A, WW	15k hrs @ 45°C	5.4×10^{-5}	6,600 hrs

** Value limited by 3X rule in IES LM-28-14.*

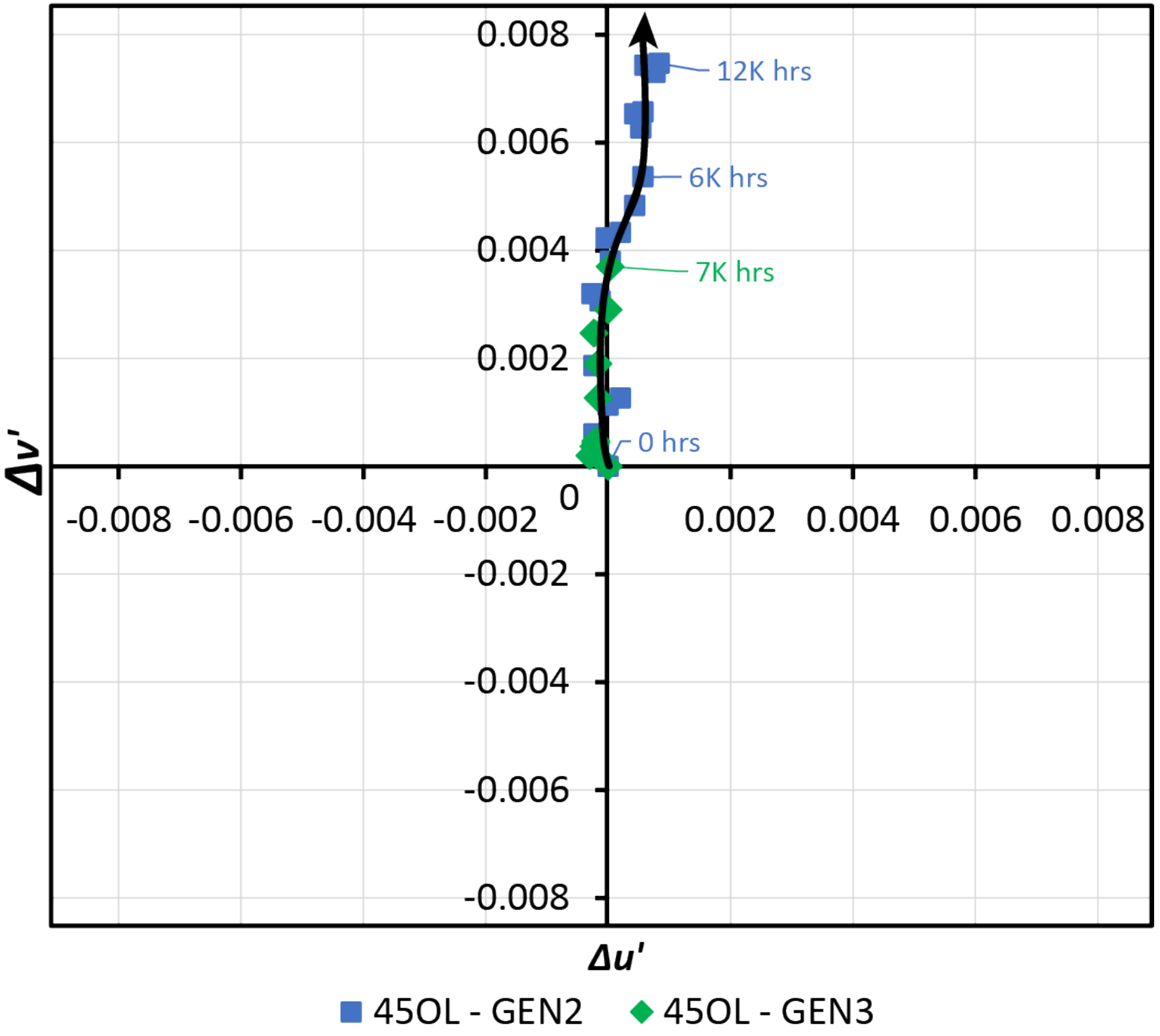
- First generation of OLED luminaires and panels exhibited α values of > 3×10^{-5} at 45°C.
- The latest generation of OLED panels performed significantly better than the 1×10^{-5} threshold in luminous flux maintenance testing at low temperature.
- Neutral white (4,000 K) products performed better than warm white (2,700 K) products.
- Breaking the α < 1×10^{-5} threshold is significant. Overall efficacy still needs to be improved.

OLED Chromaticity Maintenance Data

3-Stack OLED WW Panels



6-Stack OLED NW Panels

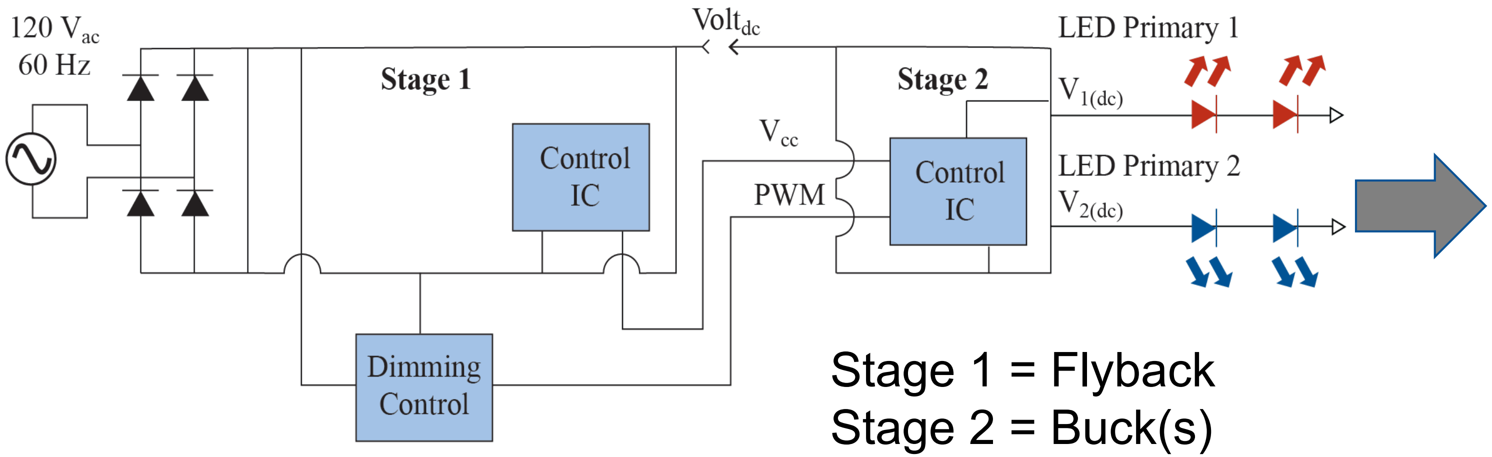


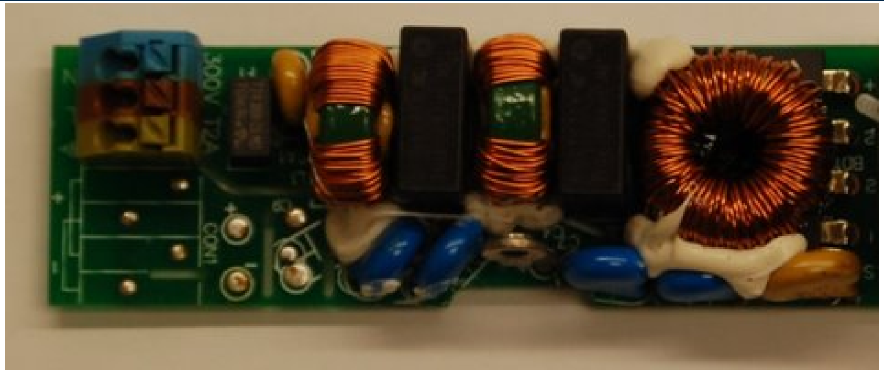
Key OLED Findings

- The luminous flux maintenance of OLED panels and luminaires has improved significantly. Rated luminous flux maintenance lifetimes > 36,000 hrs are possible for room temperature operation for neutral white panels.
  - Indicative of greater stability of organic emitters (weighted by $V(\lambda)$)
  - Rated luminous flux maintenance lifetimes are typically shorter for warm white OLEDs and decrease as temperature increases.
  - Improvements still needed in luminous efficacy and costs.

- The chromaticity maintenance of OLEDs has also improved in the last 5 years and can be less than 0.004 after 12,000 hrs at 45°C.
  - Warm white panels exhibit better chromaticity maintenance than neutral white panels.
  - Findings demonstrate improvements in the relative stability of the different organic emitters.

Multichannel Drivers





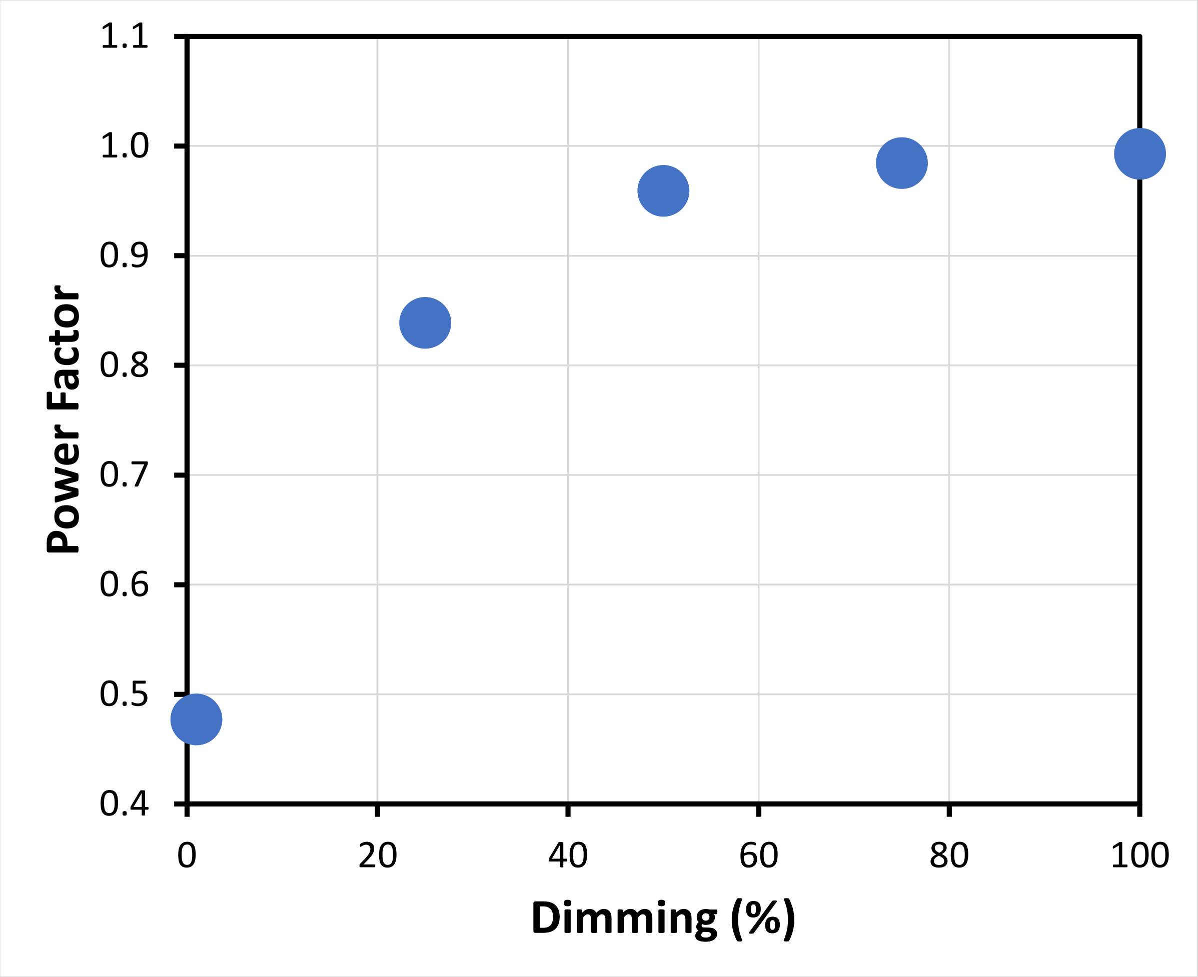
Stage 1 = Flyback
Stage 2 = Buck(s)

Circuit functions include ac-dc conversion, power factor correction, and dc-dc conversion

- Rapid switching in Stage 2 produces a light output that can vary widely– from near dc output to high frequency pulse width modulation.
- In multichannel drivers, the timing of this switching depends on dimming level and the contribution of each channel to the final light output. Flicker can come from either Stage.
- An overlooked part of the driver is the metal-oxide varistors (MOVs) and EMI filter networks (i.e., capacitors and inductors) used for surge suppression and EMI filtering.

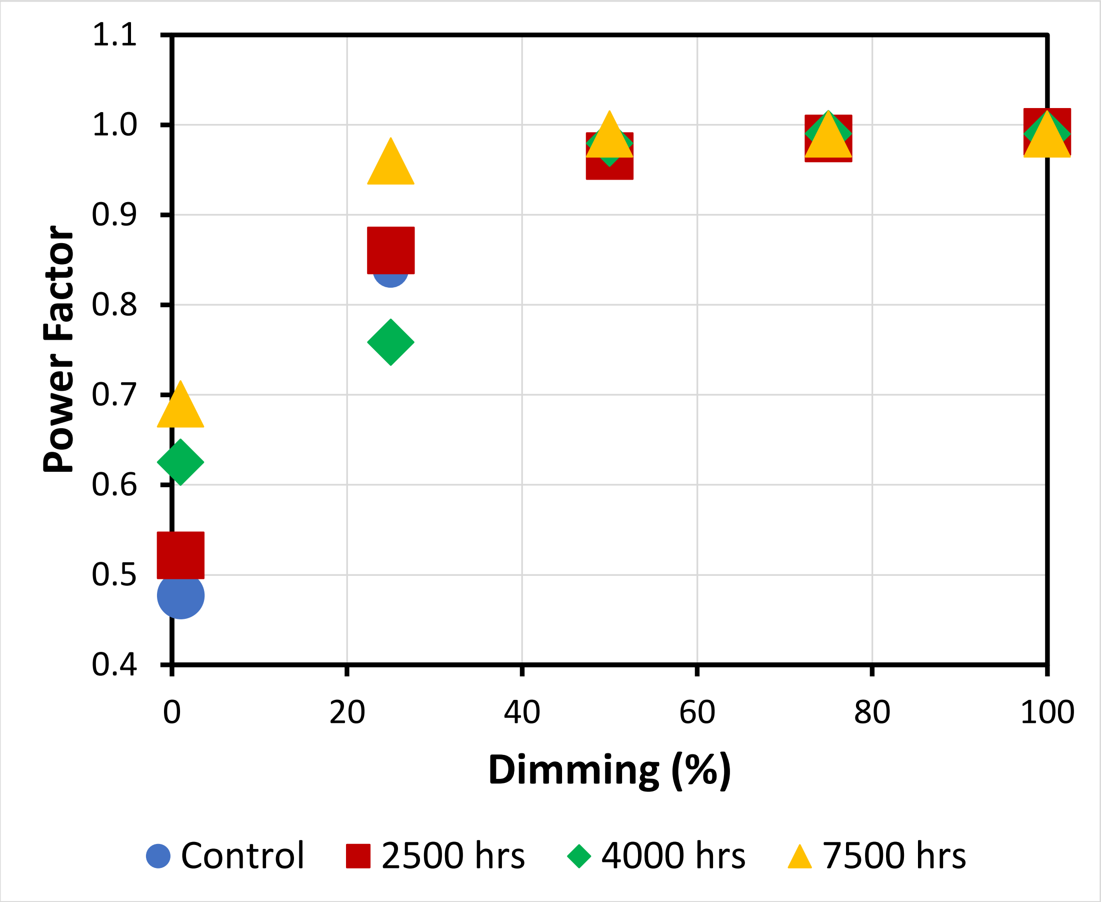
Test Methods & Evaluation – LED Drivers

- Methods
  - Tested at 100% power output in a temperature & humidity (7575) ambient.
    - Power cycling protocol chosen to accelerate component aging.
    - LED modules used as loads in driver testing and CCT was set to 3500 K..
- Evaluation (@ 25°C)
  - Driver electrical properties (voltage, current, power factor, waveform, THD) evaluated at five dimming levels between 100% and 1%.
  - Flicker properties of LED loads at five different dimming levels between 100% and 1%.



Major Findings in Driver Study

- Degradation (but not failure) of the capacitors and inductors in EMI filter networks makes the device appear to be more resistive over time.
  - This degradation can lead to failures throughout the device.
  - Stage 1 components generally see the highest voltage levels – making them more susceptible to aging.
  - Impact is easier to detect at low dimming levels in driver metrics such as power consumption, power factor, in-rush current, and efficiency.
- Degradation of Stage 2 components can also have an observable impact on flicker.
  - Degradation rates are often slower due to lower voltages across components.



See DOE SSL website for more info.

Summary

- The luminous flux maintenance lifetime of LED packages continues to improve. The performance of plastic packages have improved the most, while CSP, COB, and ceramic packages show improvements in luminous flux maintenance lifetime.
- Testing of multiple generations of OLED panels and luminaires have shown consistent improvement in luminous flux maintenance lifetime. The best products are projected to operate for >36,000 hrs at room temperature before decaying to 70% of original luminous flux levels.
- Chromaticity maintenance in OLEDS has also shown consistent improvement and is within industry expectation. Chromaticity shift is also affected by the relative degradation rates of the organic emitters.
- Not to be overlooked is the impact of surge suppression in EMI filtering on driver reliability. Degradation of these circuits will impact driver operation, and monitoring their performance may provide health status indicators.
- More info at https://www.energy.gov/eere/ssl/technical-reports-briefs.