# ASSIST

# LED System Reliability and Accelerated Life Test Study

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# Background

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- In December 2007, ASSIST Sponsors requested that LRC study and develop a recommendation for LED system reliability definitions and testing methods (beyond lumen depreciation).


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# Introduction

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- An LED system has many components working together.
  - LED
  - Driver
  - Mechanical and thermal management components

- An LED system's reliability depends on the weakest component of the system.

- Therefore, one has to consider possible failure modes for each component.

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# Introduction

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- This is a three-part study. Accelerated testing to predict life of:
  - LED
  - Driver
  - Complete system
- During this past year (2008), the LED and the driver were studied individually.

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# LED Reliability Study

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# Predicting Reliability

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- Reliability prediction is the use of accelerated environmental or operational conditions to predict a system's behavior throughout its life cycle at normal operating conditions.

- Models for predicting reliability at normal operation depend on the acceleration parameters:
  - Temperature
  - Current Density

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# Use-rate (Cycling)

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- Cycled system is switched on-off at a frequency greater than normal while simulating normal wear.[1]
- Cycling variables
  - Current and Temperature
- Presently there is no defined use-rate cycling standard for LEDs
- One or two manufactures have suggestions for cycling test

| Power Cycling Conditions | Stress Duration |
|---|---|
| -40~85°C, 18minutes dwell, 42 minutes transfer (2 hour cycles), 5mins ON/5 mins OFF, If=max. DC | 200 cycles |
| -40~85°C, 18minutes dwell, 42 minutes transfer (2 hour cycles), 5mins ON/5 mins OFF, If=max. DC | 500 cycles |
| -40~120°C, 18minutes dwell, 42 minutes transfer (2 hour cycles), 5mins ON/5 mins OFF, If=max. DC | 500 cycles |

[1] L.A. Escobar and W.Q. Meeker, Statistical Science **21** 4, 552-577 (2006)
[2] I. Somos, D. Piccone, L. Willinger and W. Tobin, IEEE Trans. on Magnetics, **29** 1, 517-522 (1993)
[3] R. Amro, J. Lutz, J. Rudzki, R. Sittig, and M. Thoben, Proc. 18th International Symp. Power Semi. Dev. & IC, Italy, (June 2006)
[4] M. Held, P. Jacob, G. Nicoletti, P. Scacco, and M.-H. Poech, Proc. PEDS 97, 1997, pp. 425-430.
http://www.philipslumileds.com/pdfs/RD25.pdf (accessed on Dec. 5, 2008)

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# Use-rate (Cycling)

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- Power-rule dependence for on:off thermal differential ($\Delta T$) for p-n junctions in Si power thyristors[2]

- Possible power cycling failure mechanisms include[2-4]:
  - Delaminating or cracks due to thermal expansion coefficient mismatch
  - Metal reconstruction from thermomechanical stress in unpassivated metal grains
  - Semiconductor damage due to transient current spikes and thermal stress
  - Encapsulant damage due to transient current spikes and thermal stress

[1] L.A. Escobar and W.Q. Meeker, Statistical Science **21** 4, 552-577 (2006)
[2] I. Somos, D. Piccone, L. Willinger and W. Tobin, IEEE Trans. on Magnetics, **29** 1, 517-522 (1993)
[3] R. Amro, J. Lutz, J. Rudzki, R. Sittig, and M. Thoben, Proc. 18th International Symp. Power Semi. Dev. & IC, Italy, (June 2006)
[4] M. Held, P. Jacob, G. Nicoletti, P. Scacco, and M.-H. Poech, Proc. PEDS 97, 1997, pp. 425-430.

# Pilot Study: LED Power Cycling

**ASSIST**

- For indoor LED luminaires, current and temperature, use rate (cycling) - two possible acceleration parameters.
- Based on literature survey, a pilot study was conducted with two types of high power white LEDs.
  - Same manufacturer/bin
- Control Variables
  - Driver Current
    - 1750 mA
  - On:Off Duty Cycle
    - RMS temperature of the cycle ~75°C
- Independent Variable
  - Cycle Period
    - On:off temperature differential
      - $\Delta T = 70°C$
      - Stressor: thermal fatigue
- Dependent Variable
  - Complete failure of LED
    - Cycles to Failure (CTF)

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# Experiment Setup

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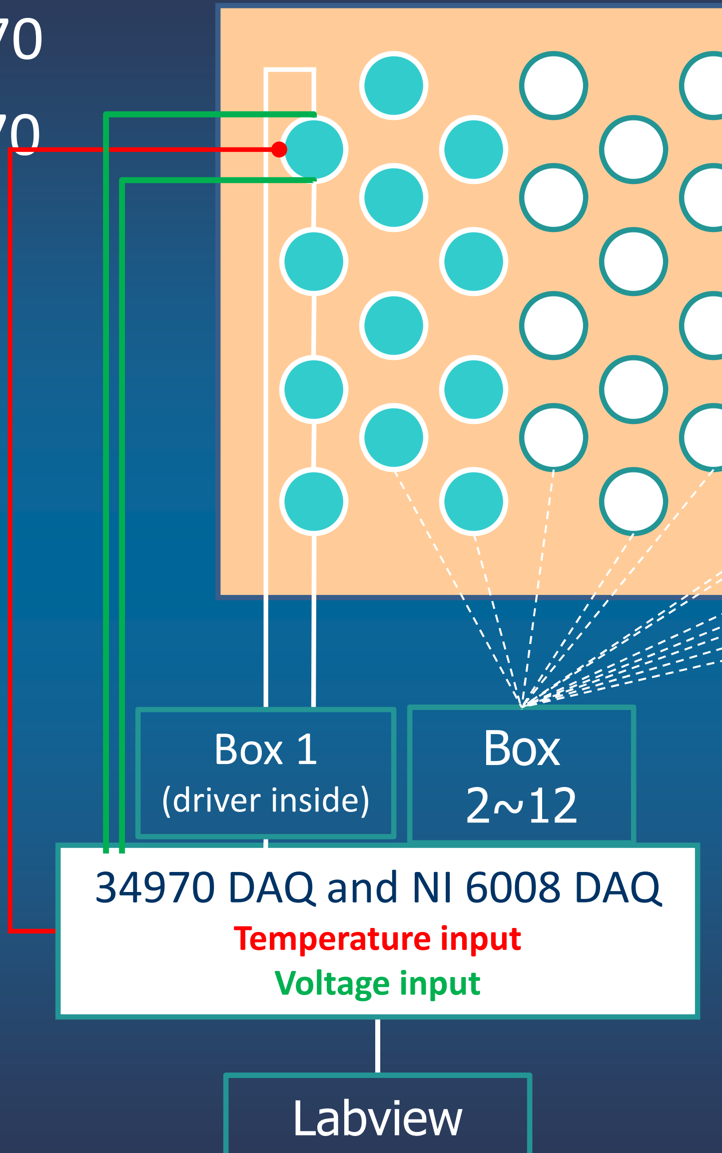
Model A ΔT=70

Model B ΔT=70

White LEDs
-Model A, B
Current=1750mA

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# Cycle Analysis

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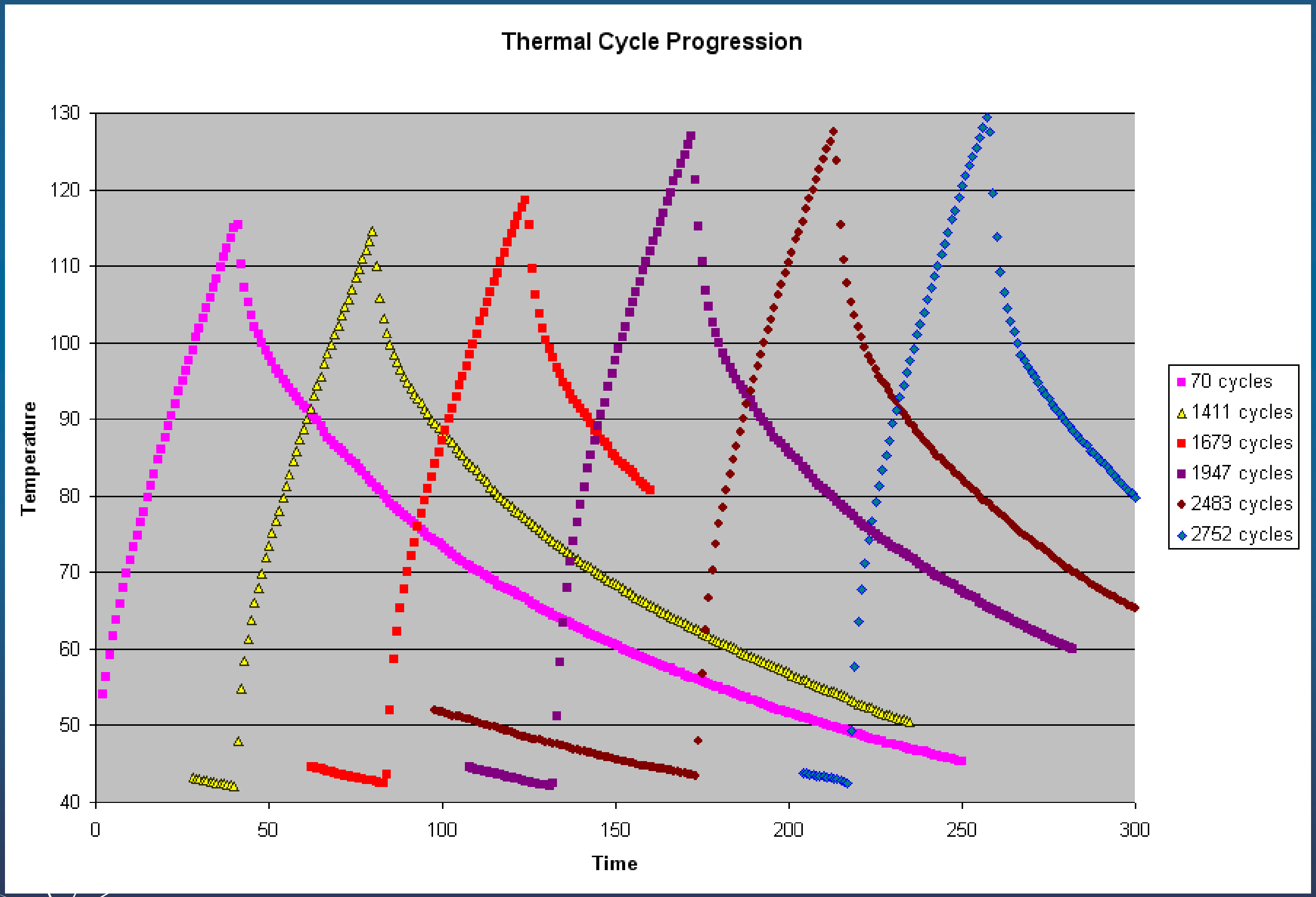
- Significant increase in pin temperature with time
  - Increased resistance over time




[1] R. Amro, J. Lutz, J. Rudzki, R. Sittig, and M. Thoben, Proc. 18th International Symp. Power Semi. Dev. & IC, Italy, (June 2006)

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# ΔT = 70°C Results

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| | BOX 6 Model B | BOX 5 Model B | BOX 4 Model B | BOX 3 Model A | BOX 2 Model A | BOX 1 Model A |
|---|---|---|---|---|---|---|
| No.1 | Short 5448 cycles | Short 3939 cycles | Short 6260 cycles | Short 2593 cycles | OK | Short 1516 cycles |
| No.2 | Short 3912 cycles | Short 3339 cycles | Short 3411 cycles | Open 2662 cycles | Open 4839 cycles | Open 3056 cycles |
| No.3 | Short 3452 cycles | Short 5841 cycles | Short 2062 cycles | OK | OK | Open 5330 cycles |
| No.4 | Short 3284 cycles | Short 2117 cycles | Short 3280 cycles | Short 4069 cycles | OK | Open 3086 cycles |

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# ΔT = 70°C Reliability Analysis

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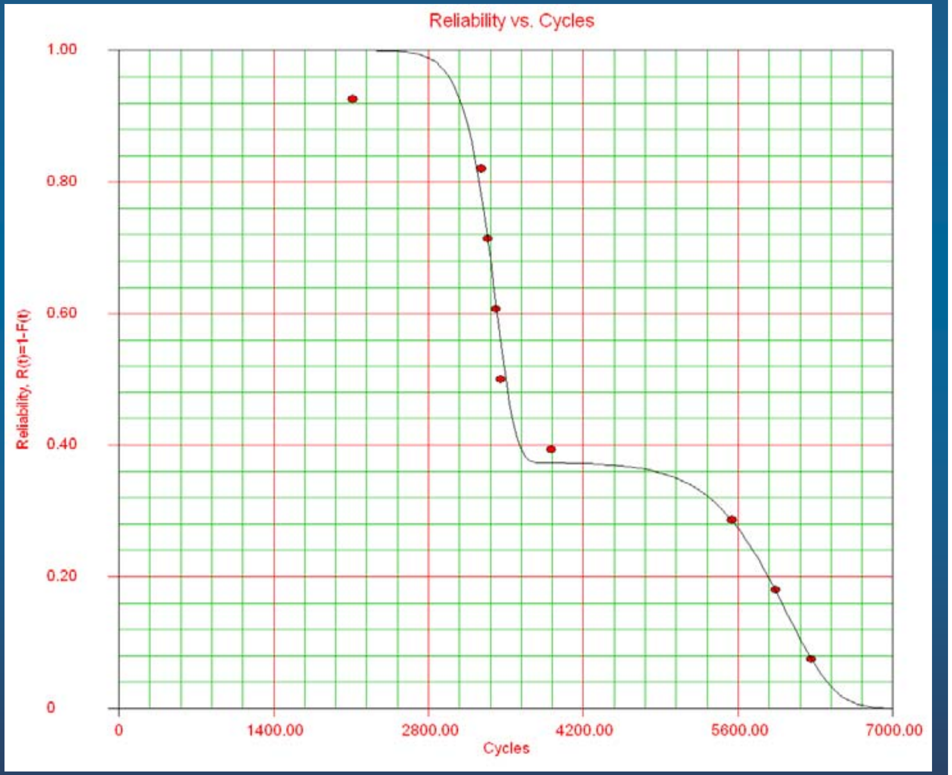
LED Model A


LED Model B

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# Pilot Study Summary

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- Increased thermal stress on internal LED components observed as system aged.
- Failure modes are both open and short circuit.

[1] M. Vazquez, C. Algora, I. Rey-Stolle, and J. R. Gonzalez, Prog. Photovolt. Res. Appl. 2007; **15**:477-491.
[2] M. Ott, Capabilities and Reliability of LEDs and Laser Diodes. What's New in Electronics, **20** 6 (2000).
[3] http://www.philipslumileds.com/pdfs/RD25.pdf (accessed on Dec. 5, 2008)

# Future Experiments

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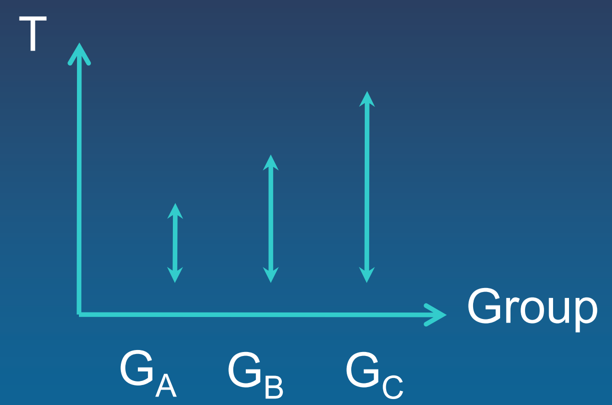
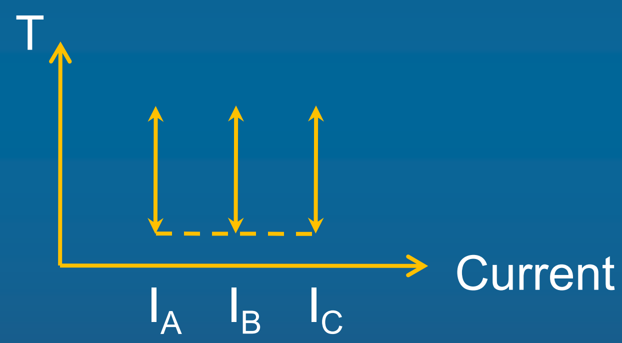
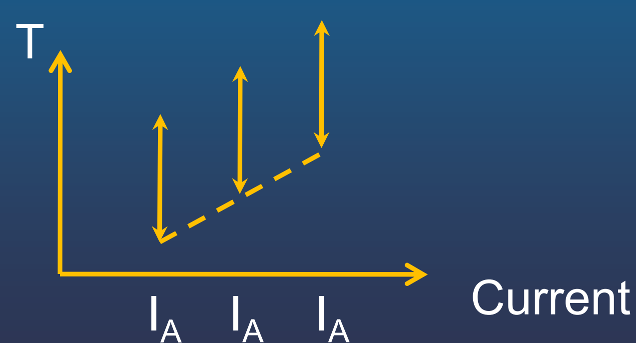
Fixed Current
Different ΔT
Fixed RMS Temp




Different Current
Fixed ΔT
Fixed RMS Temp




Fixed Current
Fixed ΔT
Different RMS Temp

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# Future Work

ASSIST

- Complete pilot studies
  - Components:
    - LED (define failure, identify acceleration factors)
    - Driver (define failure, identify acceleration factors)
- Begin luminaire study
    - Based on LED and Driver pilot study results, define failure and identify acceleration factors for complete luminaires and conduct pilot studies.

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# LED Driver Reliability Study

(Study Funded by NYSTAR)
Han Lei, Master's Thesis, 2009

# Study Objective

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- To propose a definition for the useful life of an LED driver that is applicable to the majority of LED drivers with different topologies.

- To develop an accelerated test method that can be used for predicting the useful life of an LED driver


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Han Lei, Master's Thesis, 2009





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# Electrolytic Capacitor

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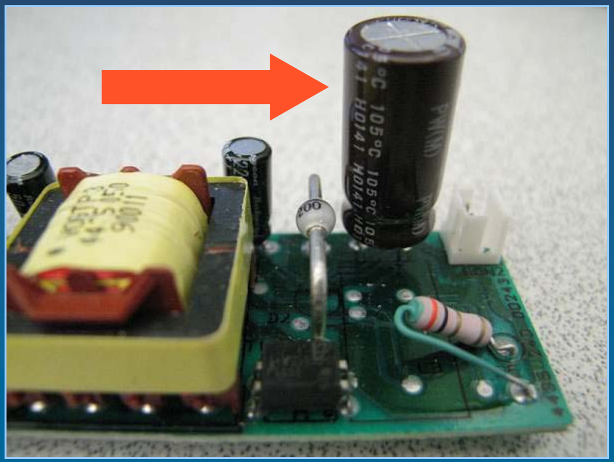
- Majority of LED drivers employ an electrolytic capacitor at the output stage of the electronic circuit.
- From past studies, it is well known that electrolytic capacitors are one of the weakest elements and frequently result in failure, especially at elevated temperatures.



Han Lei, Master's Thesis, 2009

# Electrolytic Capacitor

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- Presently, there is no definition for electrolytic capacitor end-of-life.
- However, manufacturers typically use
  - 10% to 20% decrease in capacitance (measured at 120 Hz) to define end-of-life.

  or
  - 200% increase in Equivalent Series Resistance (ESR) (measured at 120 Hz)
- The useful life of an electrolytic capacitor decreases exponentially as the capacitor body temperature increases.

# Electrolytic Capacitor – Data

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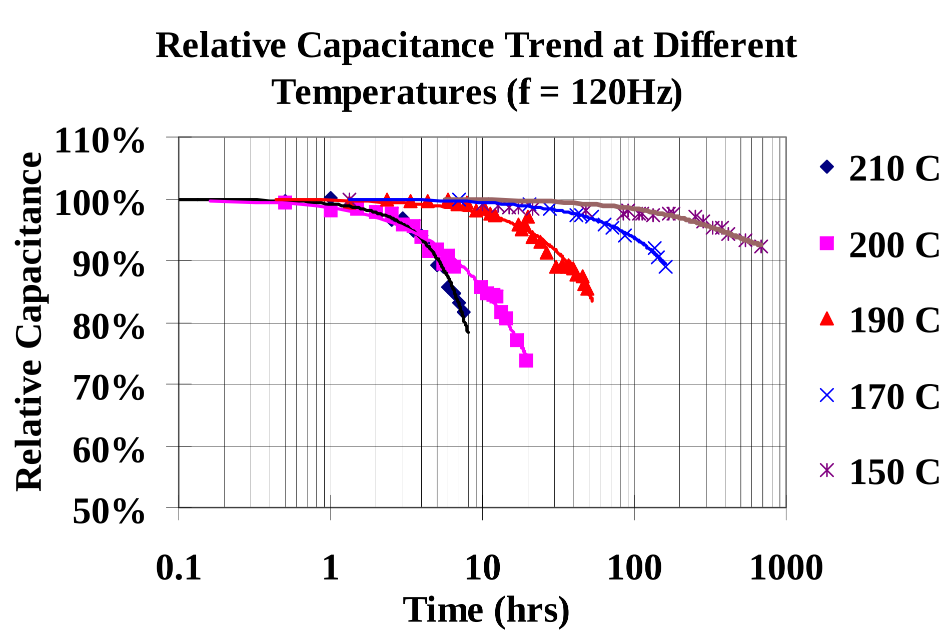
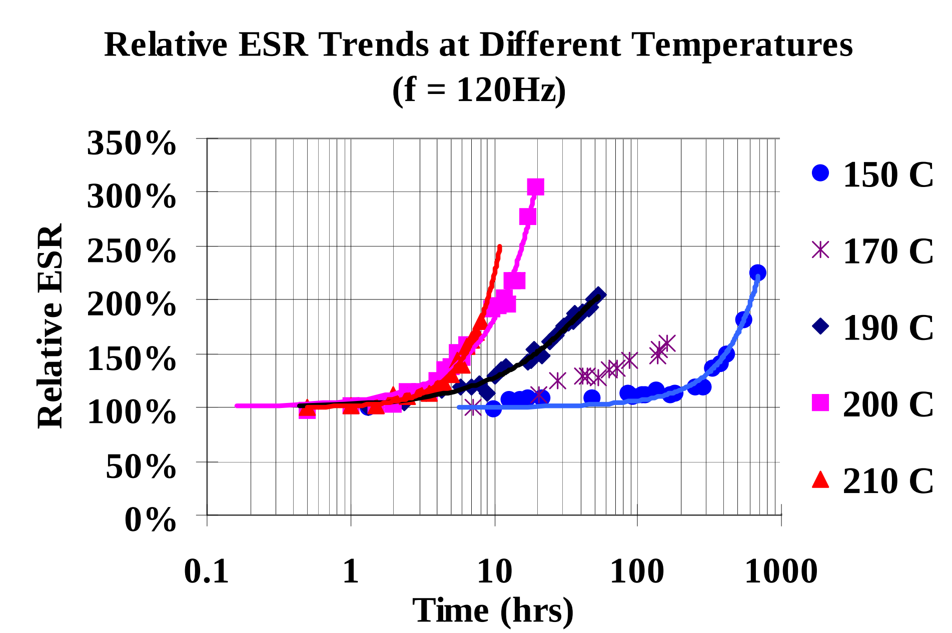
- Pilot study: Capacitance / ESR test
  - 330 μF , Rated 5000 hrs at 105 deg. C; 35 V max
  - Capacitance decreases while ESR increases with time

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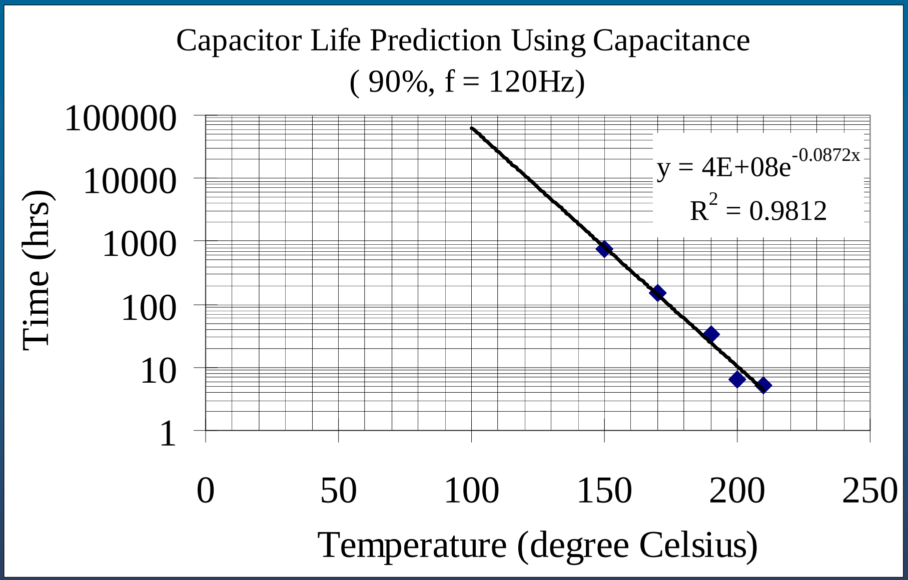
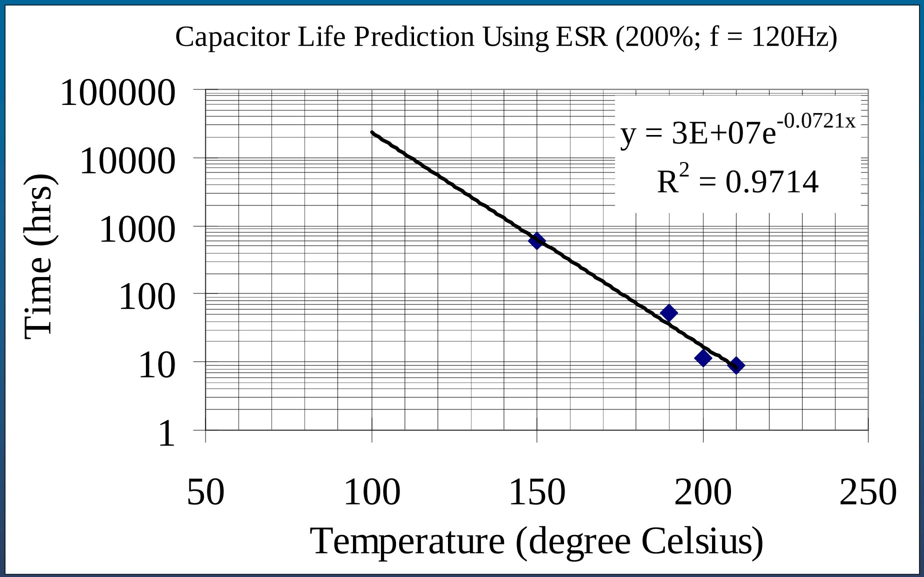
# Electrolytic Capacitor – Data

ASSIST

- Pilot study: Capacitor life test experiment
  - 330 μF , Rated 5000 hrs at 105 deg. C; 35 V max
  - Life prediction based on 90% capacitance and 200% ESR

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# Driver Output

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- The output current peak-to-peak value will increase as the capacitance decreases.
- The output current peak-to-peak value will increase as the Equivalent Series Resistance (ESR) increases.

# Impact of Heat on LED Driver

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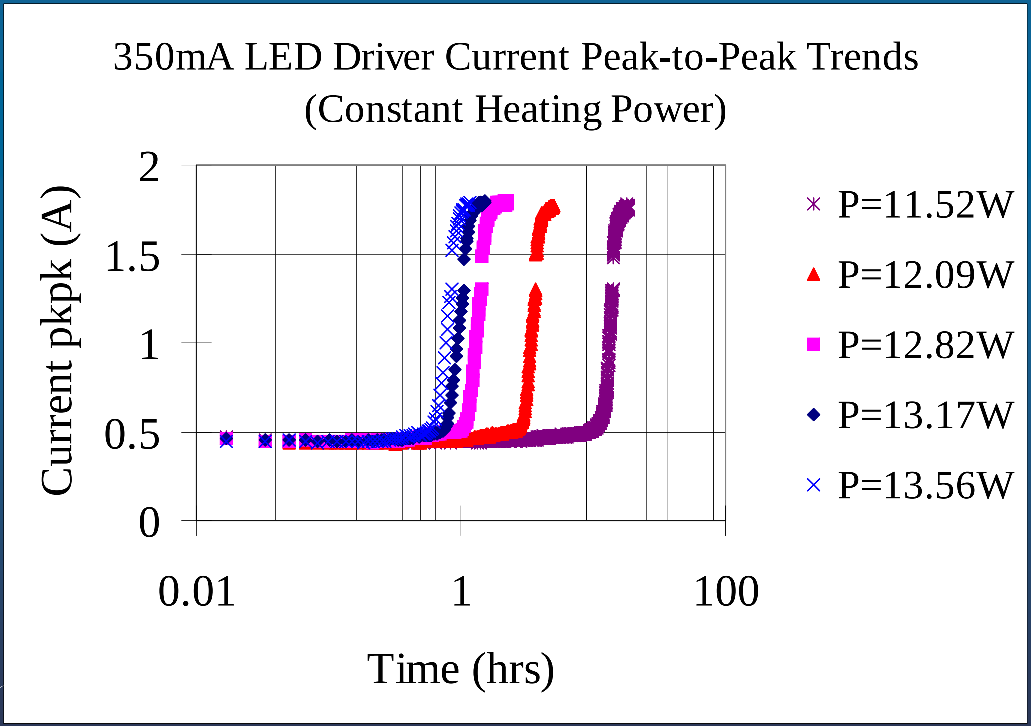
- For an LED driver using electrolytic capacitor
  - The higher the operating temperature is, the faster the output current peak-to-peak value will increase.




Han Lei, Master's Thesis, 2009

# LED Driver Lifetime

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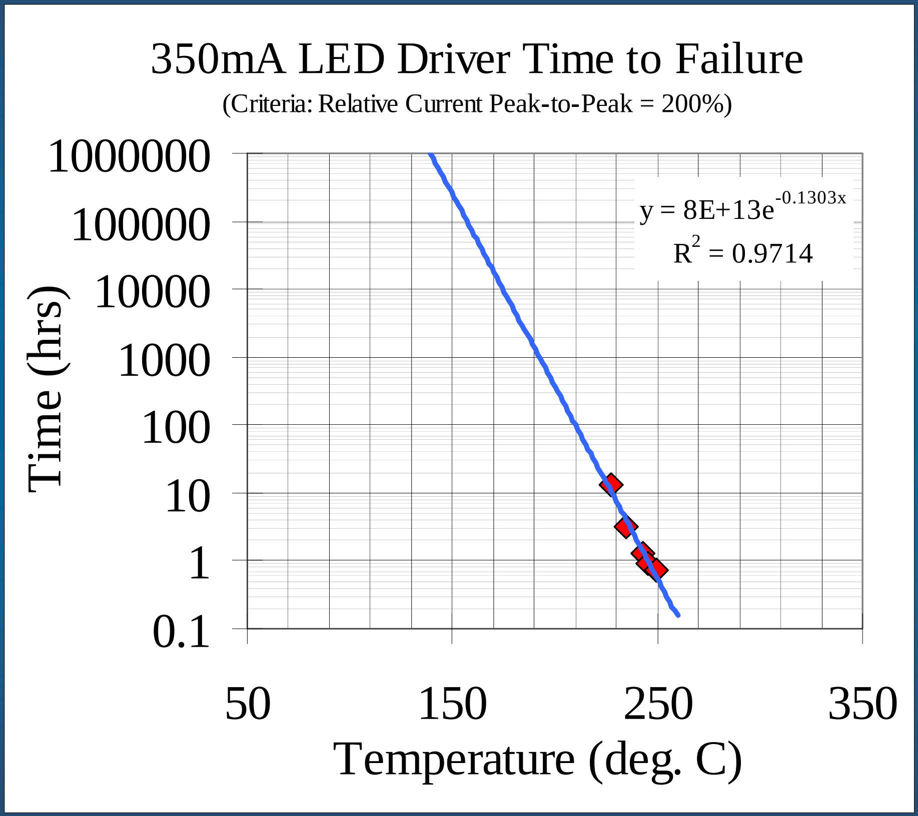
- Assumption: End-of-life of the LED driver is reached when the output current peak-to-peak value reaches 200% of the initial value.

- The useful lifetime of the LED driver is decreased exponentially as the temperature of the electrolytic capacitor increases.




Han Lei, Master's Thesis, 2009

# Summary

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- Absolute maximum value of output current can be used as the criterion for LED Driver life.
- Accelerated life test using higher temperature heat treatments can lead to predicting LED driver life at normal operating temperatures.

# Schedule & Budget

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- Ongoing
  - Pilot study – LED (Complete by March 2009)
    - funded by ASSIST, ongoing $50K
  - Pilot study – Driver (Complete by March 2009)
    - funded by Energy CAT, ongoing $100K
- Future funds
  - Pilot study – Luminaire (6 months, $50K)
  - Final study – Luminaire (1-yr, $50K)
- Balance request – $100k over 2 years

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