Power Architectures for the Next Generation of Solid-State Lighting

David Cox: March 2015
Power Architectures for the Next Generation of Solid-State Lighting

Agenda
- Intro
- Understanding the “Load”
- Application First
  - High Power High Voltage High Reliability
  - Low Voltage Commercial Lighting
    - Emerge
    - POE
  - Replacement lamps
  - Automotive Exterior LED Lighting
Why LED Lighting? It Saves Money & Energy

• Potential to reduce U.S. lighting electricity use by nearly one half
• Equivalent to $30 billion in savings in 2030

Source: U.S. DOE www.ssl.energy.gov/tech_reports.html

Styling/Branding/MPG

Diagram of a car with arrows indicating High/Low Beam, Turn, Position, and Fog lights.
Understanding the “Load”
So Many Lamps…
Light Sources (Technical Characteristics)

- **LED**
  - **Advantages**
    - High light output
    - High efficacy
    - Long life
    - Turn on Time 10nS
    - Easy to Control
    - Easy to focus Light
    - No IR
    - No UV
    - No Mercury
    - Low Heat
  - **Disadvantages**
    - Turn on Time 10nS
State-of-the-art Blue Chip Performance

- Radiant Flux (mW)
  - 82%
  - 79%

- Power Efficiency (%)
  - 90

- Current (mA)
  - 447 nm, Tj ≈ 25 C
  - 782 mW
  - 350 mA

447 nm, Tj ≈ 25 C
Breaking Barriers for High Power White LEDs

- **R&D Result**
  - 303 LPW: 2014
  - 276 LPW: 2013
  - 254 LPW: 2012
  - 231 LPW: 2011
  - 208 LPW: 2010
  - 186 LPW: 2009
  - 160 LPW: 2008
  - 131 LPW: 2006
  - 100 LPW
  - 90 LPW

- **High Volume**
  - 2012: 3.45mmx3.4mm package

- **$ Optimized**
  - 2014
XP Performance over time (cool white up to Lumens) 3.45mm X 3.45 mm pkg

Lumens

XP Performance over time

- XP-E
- XP-G
- XT-E
- XP-G2
- XP-L

Time

© 2015 Cree, Inc. All rights reserved.
The Next Battlefield: Costs at the System Level

Need to focus on these elements

Relative Cost

2014

LED
Thermal
Driver
Optics & Other

2014

© 2015 Cree, Inc. All rights reserved.
The Next Battlefield: Costs at the System Level

Need to focus on these elements

To achieve this kind of system-level savings

LED will only be a PART of the savings going forward
Real LED Levels of Performance (Current)

Just like traditional lamps, LEDs have losses beyond the boiler plate data sheet specs...

...but the source of losses are somewhat different:

- Thermal (also a source of Lumen Depreciation)
- Optical (lenses, etc.)
- Driver (electrical losses in power conversion and dimming)

<table>
<thead>
<tr>
<th></th>
<th>6000K</th>
<th>4100K</th>
<th>3500K</th>
<th>2700K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Sheet LPW</td>
<td>200</td>
<td>180</td>
<td>160</td>
<td>140</td>
</tr>
<tr>
<td>Typical* Thermal Loss</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Typical* Optical Loss</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Typical* Driver Loss</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Achievable* LPW</td>
<td>138</td>
<td>124</td>
<td>110</td>
<td>96</td>
</tr>
<tr>
<td>CRI</td>
<td>~75</td>
<td>~80</td>
<td>~82</td>
<td>~83</td>
</tr>
</tbody>
</table>

* Typical with average/good design practices
Projected LED Levels of Performance (2017)

Up 25% over next 3 years

<table>
<thead>
<tr>
<th></th>
<th>6000K</th>
<th>4100K</th>
<th>3500K</th>
<th>2700K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Sheet LPW</td>
<td>250</td>
<td>225</td>
<td>200</td>
<td>175</td>
</tr>
<tr>
<td>Typical Thermal Loss</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Typical Optical Loss</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Typical Driver Loss</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Achievable LPW</td>
<td>208</td>
<td>187</td>
<td>166</td>
<td>145</td>
</tr>
<tr>
<td>CRI</td>
<td>~75</td>
<td>~80</td>
<td>~82</td>
<td>~83</td>
</tr>
</tbody>
</table>

* State-of-the-art

- LEDs will be the most efficient mainstream light source available
  - >185 delivered LPW roadway light possible (4100K)
  - Indoor fixtures >145 LPW (wall-plug)
Application First
Application First
Lighting Design Philosophy: Power Architecture or Applications First?

Single Stage: QRC Flyback

- Single Stage: QRC Flyback
- Single Stage: Flyback

- Buck
- Boost
- PFC
- LLC
- CCM
- DCM
- BCM

Buck-Boost

© 2015 Cree, Inc. All rights reserved.
Copyright © 2015, Cree Inc.
# Application First: High Power High Voltage High Reliability

- **Power**: 200W-2000W
- **Voltage**: 230V-480V
- **Reliability**: In top 5 concern
- **Meet Lighting requirement**: Top Concern

**LED Stadium Lighting**
Application First: High Power High Voltage High Reliability

Typical topologies used in LED drivers today

- Two-Stage
- Buck
- Boost
- PFC
- Quasi-Resonant
- Sepic
- Flyback
- CCM
- DCM
- BCM
- LLC

Output Power, Watts

Converter Type
Two Stage vs. Single Stage Topology

Two Stage: PFC + LCC
- Advantages
  - Good topology for 650V Si devices
  - Low THD and high PF
  - High efficiency

Single Stage: QRC Flyback
- Advantages
  - Low THD and high PF
  - High efficiency

Single stage topologies reduce complexity and part count
- SIC FET enables
  - 15-20% cost reduction
  - 40-50% volume reduction
  - 65-75% weight reduction
Tradeoff with LED Driver Approaches

- **Single-stage approaches** are best suited for **cost-driven solutions**

- **Two-stage approaches** are best suited for **performance-driven solutions**

- The clear division on the most cost-effective way of implementing LED drivers is set, a good part, by the performance of the FET

- **SIC MOSFET**, with its superior performance, allows for the implementation of a **simple and cost-effective** single-stage topology that delivers the performance of a two-stage topology
Application First: High Power High Voltage High Reliability

<table>
<thead>
<tr>
<th>Power</th>
<th>200W-2000W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>In top 5 concern</td>
</tr>
<tr>
<td>Flicker Free</td>
<td>In top 5 Concern</td>
</tr>
<tr>
<td>Meet Lighting requirement</td>
<td>Top Concern</td>
</tr>
</tbody>
</table>

LED Stadium Lighting
Application First: High Power High Voltage High Reliability
Application First: High Power High Voltage High Reliability

Challenge

- Single stage topologies, such as flyback, have a hard time passing surge testing

SiC MOSFET Solution

- The superior voltage (1200V) and avalanche capability of the SiC MOSFET simplifies the design of overvoltage protection circuits

Reference design pass 6kV testing using standard surge pack
LED Driver Reliability

- Failure rates of LED drivers are dominated by the semiconductor devices which includes the main MOSFETs, diodes, control ICs, and opto-coupler.
- The electrolytic capacitors contribute only a small portion of the driver failure rate.
- The failure rates of semiconductor devices are largely dependent on the operating temperature.
- Typically the failure rate of an LED driver is increased by 25-40% for every 10°C increase in the case temperature (and internal components).
Application First: High Power High Voltage High Reliability

Top 5 LED Component Field Failures

- EOS: 50%
- Chemical incompatibility: 10%
- Heat damage: 20%
- Customer handling: 10%
- Sulfur contamination: 5%

© 2015 Cree, Inc. All rights reserved.
What about safety agency approvals
• Working Collaboratively with UL using HBSE (Hazard Based Safety Engineering) as a way to allow new and alternate design features in SSL lighting that are not entirely or effectively address by legacy lighting standards such as UL1598.

• Goal is to eliminate requirements based on the application. Thus eliminate testing where possible and UL pilot started in a project called Street LiTE, with LiTE = Limited Test Evaluations.

• “The HBSE approach allows us to better focus in on the critical luminaire design elements that establish compliance with the safety and regulatory requirements of the standards and codes. This in turn allows us to put fewer controls on other design features, providing the manufacturer with more freedom to update the product over time in response to their desire to swap out components, make aesthetic improvements, or any number of other issues that don’t have a significant impact on critical safety performance. Our product description reports (the FUS procedure) are more brief and thus grant manufacturers greater flexibility by NOT controlling features we previously controlled. This brevity will also make the FUS inspection quicker and less time intrusive.”

• * Thanks goes out to Shari Hunter & Mike Shuman with UL
Low Voltage Commercial Lighting: Emerge & POE
## Low Voltage Commercial Lighting: Emerge & POE

<table>
<thead>
<tr>
<th>Power</th>
<th>Down light 9W; Troffer 22W-50W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Emerge 24V</td>
</tr>
<tr>
<td></td>
<td>POE 37V–57V</td>
</tr>
<tr>
<td>Class II</td>
<td>No special Voltage by country</td>
</tr>
<tr>
<td>Minimum requirement</td>
<td>DLC</td>
</tr>
<tr>
<td>Control &amp; power</td>
<td>IoT enabled</td>
</tr>
</tbody>
</table>
Low Voltage Commercial Lighting: Emerge & POE
Standardized IT Power

Power over Ethernet (PoE) Delivers DC power and data over a standard copper Ethernet Cable (CAT5e or CAT6 with RJ45 terminations)

IEEE 802.3af/at Industry Standard PSE/PoE+ – two twisted pairs

Under IEEE 802.3 Committee Review 802.3bt – four twisted pairs
Estimated release – End of 2015

Example block diagram

LED Driver Block Diagram

Rules of Engagement

<table>
<thead>
<tr>
<th>PSE Voltage</th>
<th>PD Requested Power (Max)</th>
<th>PSE Allowed Power (Max)</th>
<th>Pairs Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>PoE 802.3af</td>
<td>36V-57VDC</td>
<td>12.95W</td>
<td>15.4W</td>
</tr>
<tr>
<td>PoE+ 802.3bt</td>
<td>42V-57VDC</td>
<td>25.5W</td>
<td>30W</td>
</tr>
<tr>
<td>4-Pair PoE 803bt</td>
<td>42V-57VDC</td>
<td>51W</td>
<td>60W+</td>
</tr>
</tbody>
</table>

Thanks to Cisco and NuLEDs
Replacement Lamps
## Replacement Lamps

<table>
<thead>
<tr>
<th>Power</th>
<th>A19: 6W-18W; PAR: up to 36W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>120V (country specific)</td>
</tr>
<tr>
<td>Price (first cost)</td>
<td>Top concern</td>
</tr>
<tr>
<td>Minimum requirement</td>
<td>Energy Star Version 1.1</td>
</tr>
<tr>
<td>Top challenges</td>
<td>Thermals/price/Performance</td>
</tr>
</tbody>
</table>

Copyright © 2015, Cree Inc.
Tradeoff with LED Driver Approaches

- **Single-stage approaches** are best suited for **cost-driven solutions**
  - Non Isolated designs are now mainstream – High LED String voltage optimizes efficiency

- **Two-stage approaches** are best suited for **performance-driven solutions**
- What about IoT?? Do we provision separate power?
Automotive Exterior LED Lighting
# Automotive Exterior LED Lighting

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.5W – 24W</td>
</tr>
<tr>
<td>Voltage</td>
<td>7.2V-14.5V</td>
</tr>
<tr>
<td>Styling</td>
<td>Top concern</td>
</tr>
<tr>
<td>Top challenges</td>
<td>New Start Stop feature</td>
</tr>
<tr>
<td></td>
<td>Adaptive Head Lighting</td>
</tr>
<tr>
<td></td>
<td>Styling trumps everything</td>
</tr>
</tbody>
</table>

- **Resistor**
  - Lighting was easy

- **Power**
  - LDO
  - Sepic
  - Boost
  - Buck
  - Buck-Boost
Automotive Exterior LED Lighting

• Adaptive head light -

Adaptive High Beam
• Camera based input
  – Behind rearview mirror

Thanks Texas Instruments