Solid-State Light Sources for DLP® based Display Products

A combination of 147 Christie Roadster S+20K DLP® and Christie CP2000-ZX DLP Cinemas® projectors were selected to project dynamic visuals for the opening ceremony at the 2008 Beijing Summer Games held on August 8th inside the newly-built Beijing National Stadium. Christie projectors will also be used for the closing ceremony on August 24th as well as the Beijing 2008 Paralympics Opening and Closing Ceremonies on September 6th and 17th respectively.
Agenda

1. What is the right LED or RGB LED combination for a certain DLP chip?
2. What are the major differences between Laser and LED based systems?
3. How a typical LED based DLP system works?
4. Choice of DLP Chip
5. Systems Challenges that need to be addressed
DLP Chipsets and their applications
(a few examples only)

- DC4K
  - Digital Cinema
  - Lamp Based

- .55" XGA
  - Front Projection
  - Lamp Based

- .3" WVGA
  - Pico Projectors
  - LED Based

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Why solid-state and DLP® technologies Together?

Two technologies famous for their Durability, DLP® & solid-state light sources, combine for the ultimate in Performance!

- **Not polarized**
  - No extra losses as in 3LCD
- **Reliability**
  - >100,000 hrs and counting
- **No lamp replacements**
  - Total Cost of Ownership
- **Fast response times**
  - Instant On/Off, no motion blur
  - unlike 3LCD, both technologies (DLP® and LEDs/LDs) have microsecond response times
- **Color saturation**
  - unmatched Image Quality, and wide color gamut
- **Perceived Brightness Boost**
  - Helmholtz-Kohlrausch effect (in some cases)
How a typical LED based DLP system works...

Output Color

<table>
<thead>
<tr>
<th>Color</th>
<th>17%</th>
<th>10%</th>
<th>23%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>16%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>11%</td>
<td>50%</td>
<td>55%</td>
</tr>
</tbody>
</table>

LED On time

Color overlap

CIE 1931 (2 deg)

Rec. 709 (xy)

LED Model

How a typical LED based DLP system works...

LED Model

Color overlap

CIE 1931 (2 deg)

Rec. 709 (xy)

LED Model
LED Illumination Approaches

Conventional 3 Channel Approach

Benefits:
• In-line system
• Different channels have different efficiency
• Non 45 degree incidence allowed
• Simpler cooling solution
• 1 channel has higher efficiency

Drawbacks:
• Larger form factor
• 2 channels have lower efficiency than the 3rd channel

Dichroic Cross Approach

Benefits:
• Compact system form factor
• All channels have almost the same efficiency

Drawbacks:
• Difficult cooling solution
• Non 45 degree incidence NOT allowed
Spectral overlap

**Notes:**
- Choice of color filter is critical for max efficiency
- Energy in cyan band is lost due to dichroic filter slope
- Choice of green LED is important to minimize this spectral overlap region
- Different vendors have different center wavelength for Green

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A word on LED color gamut

- Meets Rec 709 gamut standard
- Yellows are good looking
- Rec 709 gamut is clipped here.
- Yellows are not very good looking

Note:
- These are only two example LEDs
- Different LEDs from different vendors behave differently
- Thermal solution also impacts color gamut
Collector Optics for LED

- A two lens element collimator optic collects light from the LED
- Collimators collect up to 160 degree of emitted LED light
- Each color is recombined using dichroic beamsplitter plates (X dichroic shown)
- A single condenser lens creates an image of the LED surface at the light tunnel input

Coupling efficiency is a function of LED area and collimator collection angle
Etendue matching

DLP Chip etendue:

\[
\pi n d^2 \left( \sin \theta_{\text{tilt}} \right)^2 \cos \left( 2 \theta_{\text{tilt}} \right) \left( H \times V \right)
\]

LED etendue:

\[
\pi n w \times h \left( \sin \theta_{\text{collimator}} \right)^2
\]

For maximum light coupling efficiency:

\[
\text{LED etendue} = \text{DLP Chip etendue}
\]

Where \( n \) is refractive index of an optical material, \( d \) is micromirror pitch, and \( H \) and \( V \) are the number of pixels in a row and a column for a certain resolution display (e.g.: 640 X 480 for VGA resolution).
How to select an LED for a DLP Chip...

- LED die area needed for a certain application depends upon DLP-chip chosen, and optical design (F/# of optics)
- In general, the bigger the DLP-chip, the more the LED die area needed to optimize brightness
Thermal Challenges

**Droop:**
- Rate of return is dynamic
- It depends upon:
  - Forward current, If
  - Thermal solution, Rth
- A more linear Lm response is desired

**LED Thermal Resistance (Rth):**
- LED packaging is very important
- Lower thermal resistance package allows for driving the LEDs harder
  - more lumens out
  - Lower Tj

**System Thermal Resistance (Rth):**
- Tj linearly depends upon system Rth.
- System Rth determines peak allowed If

\[ T_j = R_{Th} \times V_F \times I_F + T_{Heatsink} \]
Solid-State Illumination Update
Array LED solution

- **Achieved performance:**
  - Brightness: 1800 lm (1000lm in 2009)
  - Power: 360 W (full ON white screen)  
    Avg. power <250W (depends upon image content)
  - Color: Wider than Rec.709 (better than flat LCDs)

- **Issues in work:**
  - LED reliability: Spec is 6 amps @ 50% DC – Demo 7 amps 82% DC – testing is ongoing
  - Size reduction activities. Once new boards performance quantified, will accordingly pursue new paper designs, if needed.
# Technology Comparison

<table>
<thead>
<tr>
<th></th>
<th>Lamp</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brightness</strong></td>
<td>2200 lm</td>
<td>1800 lm</td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>250W</td>
<td>360W</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>8.8 lm/W</td>
<td>5 lm/W</td>
</tr>
<tr>
<td><strong>Light source Lifetime</strong></td>
<td>2-5k hrs</td>
<td>~20k hrs</td>
</tr>
<tr>
<td><strong>Light source type</strong></td>
<td>Gas/Plasma</td>
<td>Solid-state</td>
</tr>
<tr>
<td><strong>Reliability issues</strong></td>
<td>Lamp bulb and color wheel</td>
<td>None</td>
</tr>
<tr>
<td><strong>Eco-friendly</strong></td>
<td>Mercury</td>
<td>Green</td>
</tr>
<tr>
<td><strong>Instant On/Off</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Total Cost of ownership</strong></td>
<td>2x</td>
<td>1x</td>
</tr>
</tbody>
</table>

: Good / Better  : Need improvement
Thank You

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It’s amazing. It’s the mirrors.™

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Backup
LED-based DLP Display Block Diagram

Goals are to:
- Minimize cost
- Increase efficiency
- Increase brightness
- Minimize # of components
- Minimize system size (volume)

Light Sources

Converting multiple light beams into one collinear beam

Color Combining (Dichroic Filters)

Illumination Uniformity (Integrator Rod/Tunnel, Fly's Eye Lenslet arrays)

Making sure that the light beam has uniform intensity on the screen

Making digital image to be displayed on screen

Magnifying the image present on the DLP chip onto the screen

Projection Lens

Screen

Viewing surface

Goals are to:
- Minimize cost
- Increase efficiency
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Desirable LED Characteristics for projection

- More lumens, AND fewer Watts (High lm/W)
- More lumens in a smaller Area (High lm/mm²)
- Low thermal resistance LED package
- Higher Junction Temp limit
- Higher extraction efficiency