LED 101

LED System Design

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Welcome to this presentation on LED System Design, part of OSRAM Opto Semiconductors LED 101 series.

LED System Topics

LED Optics

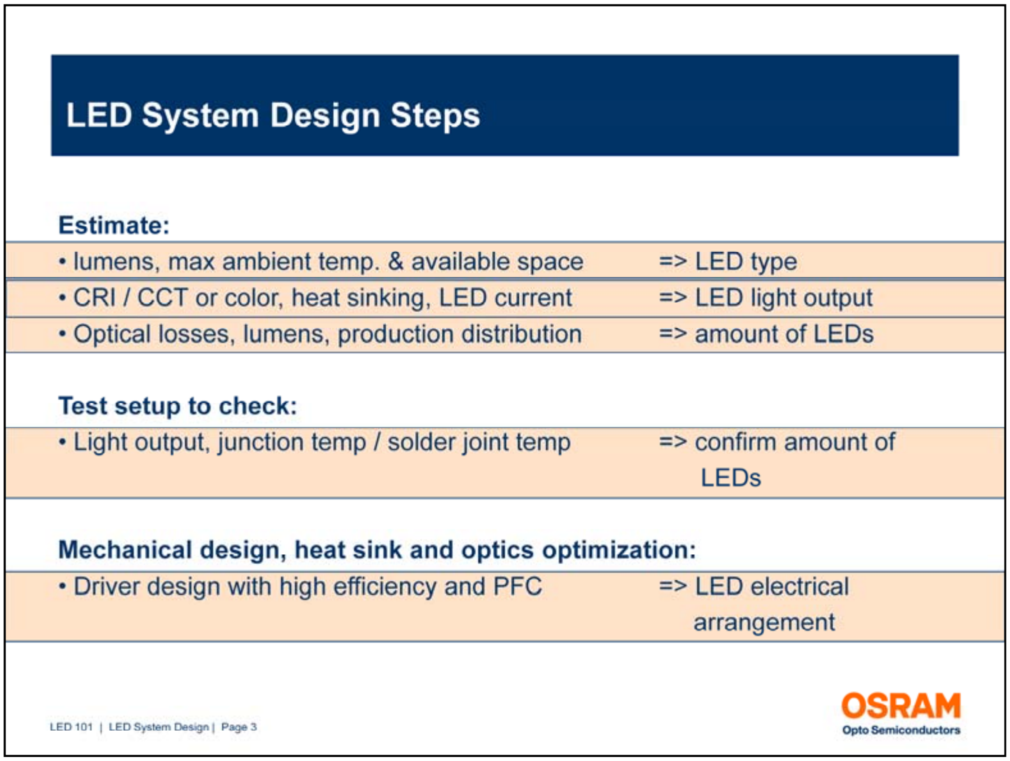
LED

Thermal System

Driver Electronics

To discuss the design challenges of LED systems we look at the individual system components.

A basic LED system consists of an LED, potentially an LED optic, a thermal system, and an LED driver.



LED System Design Steps

Estimate:

• lumens, max ambient temp. & available space	=> LED type
• CRI / CCT or color, heat sinking, LED current	=> LED light output
• Optical losses, lumens, production distribution	=> amount of LEDs

Test setup to check:

• Light output, junction temp / solder joint temp	=> confirm amount of LEDs

Mechanical design, heat sink and optics optimization:

• Driver design with high efficiency and PFC	=> LED electrical arrangement

There are many LEDs to choose from. This page shows how a decision about LED type and number of LEDs per system can be approached.

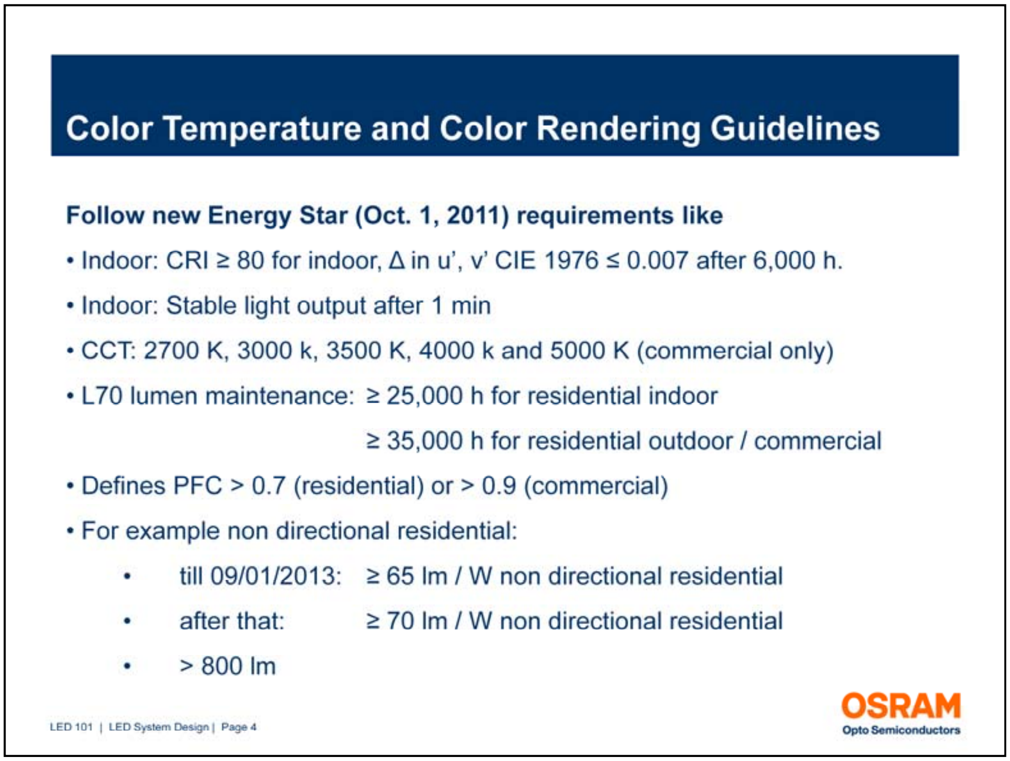
In this example we decide on the LED type by knowing the over-all lumens, the maximum ambient temperature and the available package space.

Looking at the light characteristics, the required system life, and space available for a heat sink, we can define the current per LED. The light output per LED can then be estimated.

Accounting for optical losses, required lumens and production distribution of the LEDs, the necessary amount of LEDs can be determined.

A crucial step during the design is to build some hardware, like a sub system to verify the estimates and to check on the temperature behaviour of the system.

Finally the driver design and the LED arrangement (LEDs in series and/or in parallel) can be optimized.



Color Temperature and Color Rendering Guidelines

Follow new Energy Star (Oct. 1, 2011) requirements like

- Indoor: CRI ≥ 80 for indoor, Δ in u', v' CIE 1976 ≤ 0.007 after 6,000 h.
- Indoor: Stable light output after 1 min
- CCT: 2700 K, 3000 k, 3500 K, 4000 k and 5000 K (commercial only)
- L70 lumen maintenance: ≥ 25,000 h for residential indoor
  ≥ 35,000 h for residential outdoor / commercial
- Defines PFC > 0.7 (residential) or > 0.9 (commercial)
- For example non directional residential:
  - till 09/01/2013: ≥ 65 lm / W non directional residential
  - after that: ≥ 70 lm / W non directional residential
  - > 800 lm

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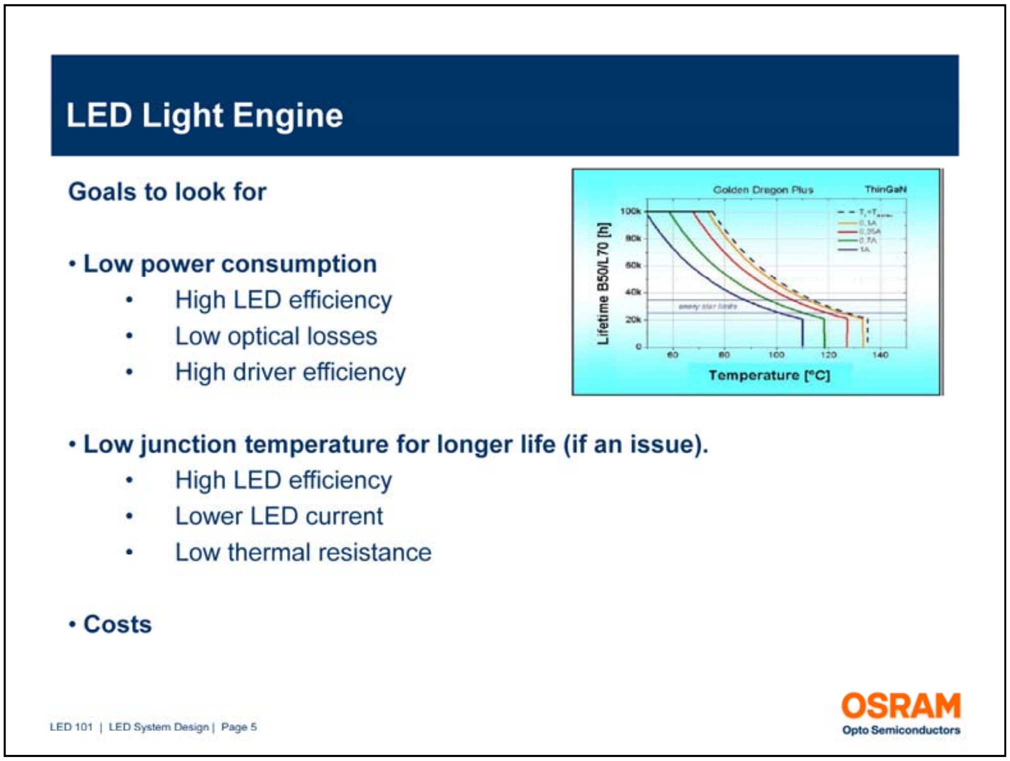
Color temperature and color rendering are also important considerations when selecting an LED. Besides customer input, the latest Energy Star requirements can provide guidance. The information listed here is from the Energy Star requirements which will become effective on Oct. 1, 2011.



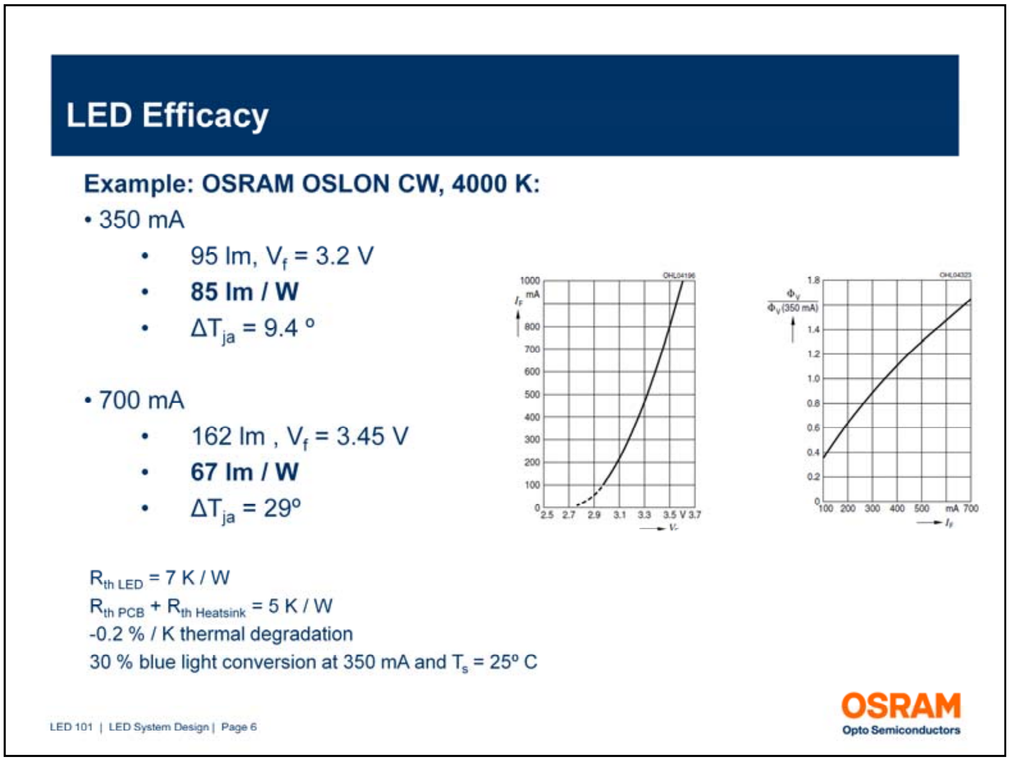
LED Light Engine

Goals to look for

- **Low power consumption**
  - High LED efficiency
  - Low optical losses
  - High driver efficiency
- **Low junction temperature for longer life (if an issue).**
  - High LED efficiency
  - Lower LED current
  - Low thermal resistance
- **Costs**

After satisfying the light quality requirements, the emphasis lays on wall plug efficiency, light engine life, and cost.

Providing a more efficient heat sink or running the LED at a lower current, reduces the LED junction temperature and thus increases the life of the LED, a valuable design option if life time is an issue.



LED Efficacy

Example: OSRAM OSLON CW, 4000 K:

- 350 mA
  - 95 lm, V_f = 3.2 V
  - **85 lm / W**
  - $\Delta T_{ja} = 9.4\,°$
- 700 mA
  - 162 lm , V_f = 3.45 V
  - **67 lm / W**
  - $\Delta T_{ja} = 29°$

$R_{th\ LED}$ = 7 K / W
$R_{th\ PCB} + R_{th\ Heatsink}$ = 5 K / W
-0.2 % / K thermal degradation
30 % blue light conversion at 350 mA and T_s = 25° C

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Doubling the LED current often gives you less than twice the LED light output.

A higher LED current also requires a larger forward voltage.

The effect is a reduction in efficacy, or lumens per Watt. We show here an OSRAM OSLON 4000 K white LED as an example. The efficacy in this example of 85 lm/W @ 350 mA goes down to 67 lm/W @ 700 mA.

Using more LEDs increases the costs, but reduces the electric bill.

LED Optics

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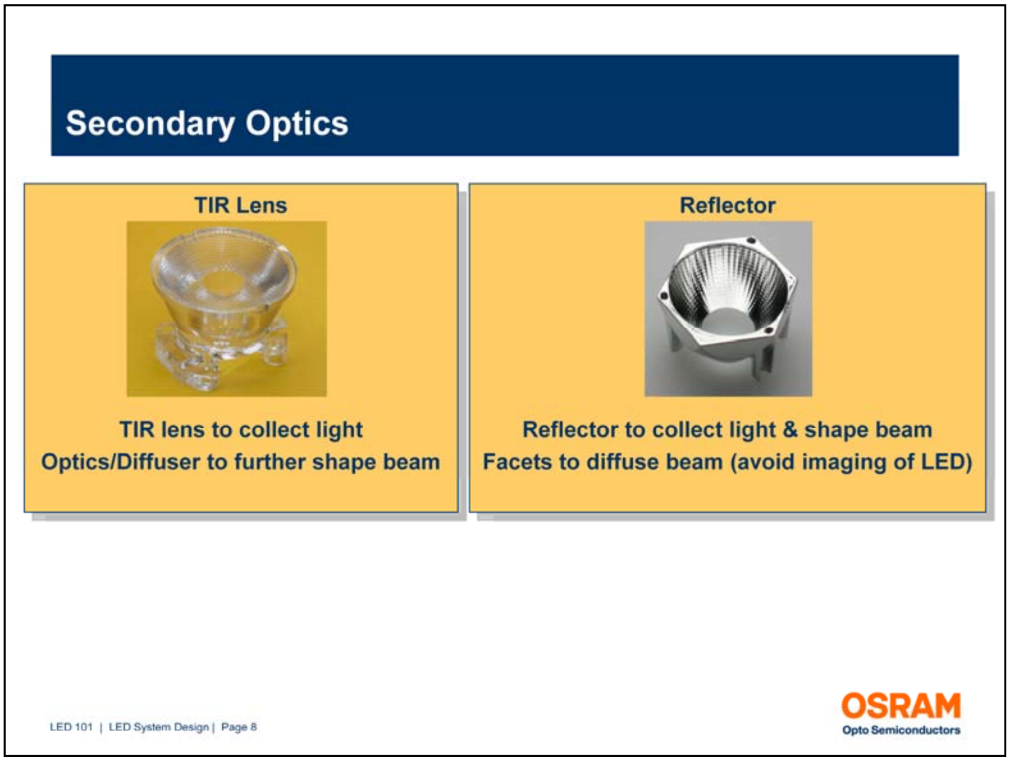
LED optics are used to shape the beam to fulfill system requirements.

Optics can be primary lenses mounted directly on the LED or secondary optics placed above the LED package.



Secondary Optics

TIR Lens

TIR lens to collect light
Optics/Diffuser to further shape beam

Reflector

Reflector to collect light & shape beam
Facets to diffuse beam (avoid imaging of LED)

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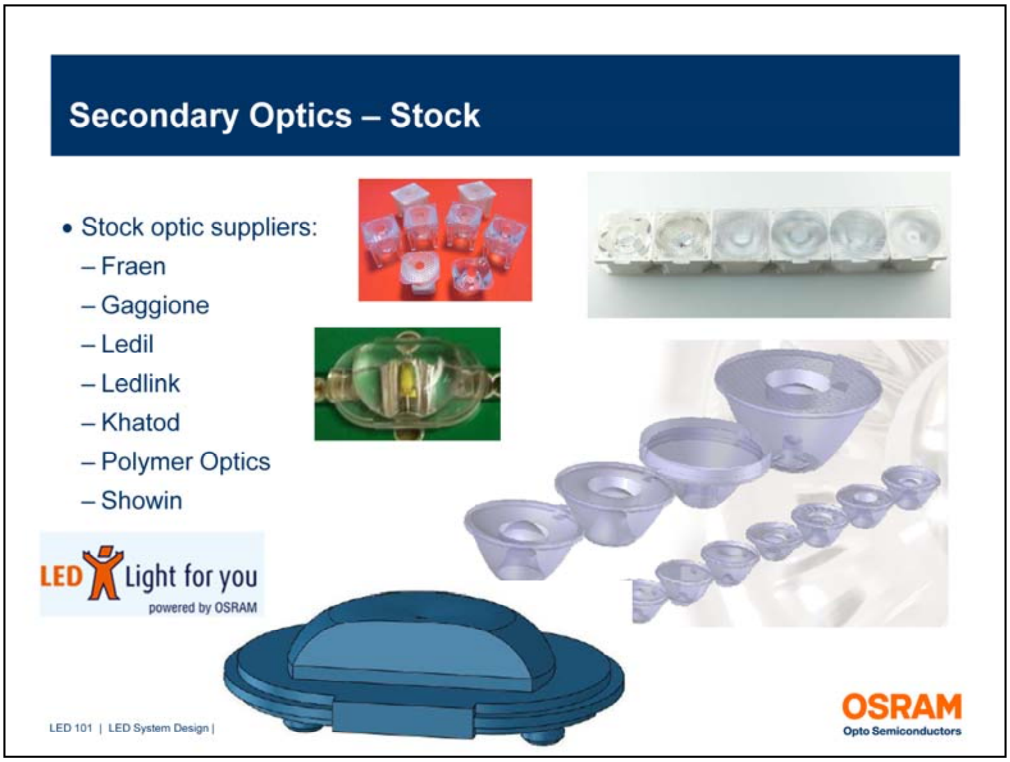
Reflectors and total internal reflection (TIR) optics are popular choices for beam shaping due to their high efficiencies, often around 85%. The choice between reflectors and TIR optics depends upon the application goals.



Secondary Optics – Stock

- Stock optic suppliers:
  - Fraen
  - Gaggione
  - Ledil
  - Ledlink
  - Khatod
  - Polymer Optics
  - Showin

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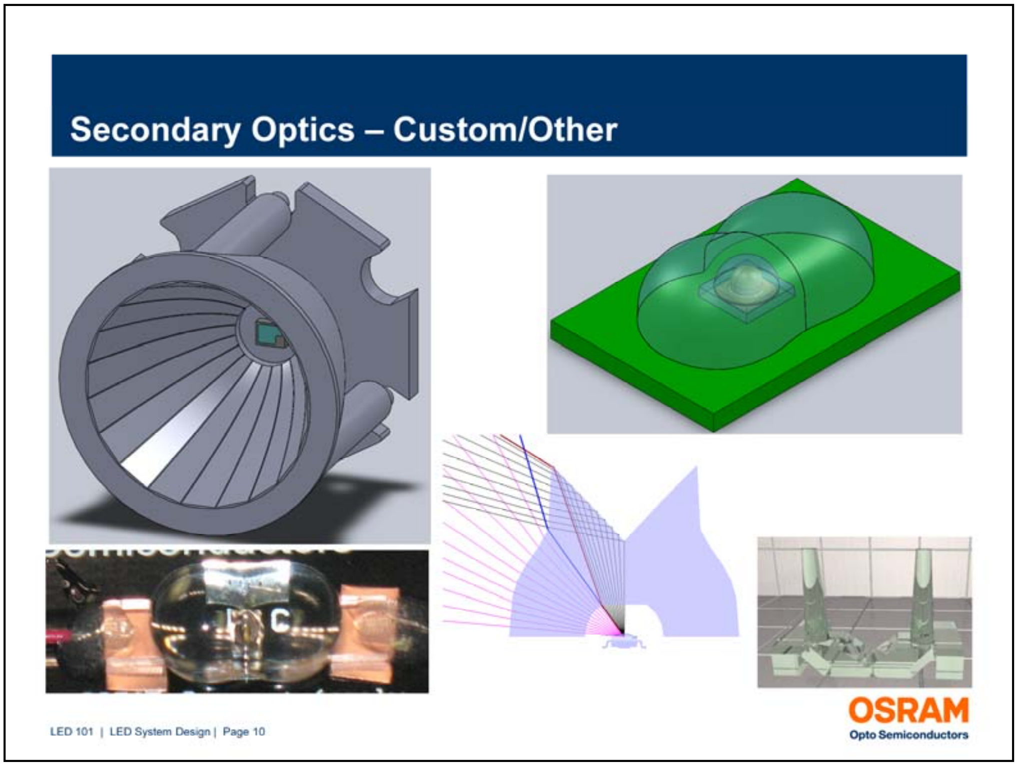
A large number of secondary optics are available as stock items from various optics manufacturers.

Historically, these optics typically create circular beam patterns of differing half angles; however, the latest offerings include optics for such specialized applications as equal-illuminance areas and streetlight beam patterns.

OSRAM Opto's "LED Light for You" partners stock many optics for high power SSL LEDs. They can also design and manufacture custom optics.



Secondary Optics – Custom/Other

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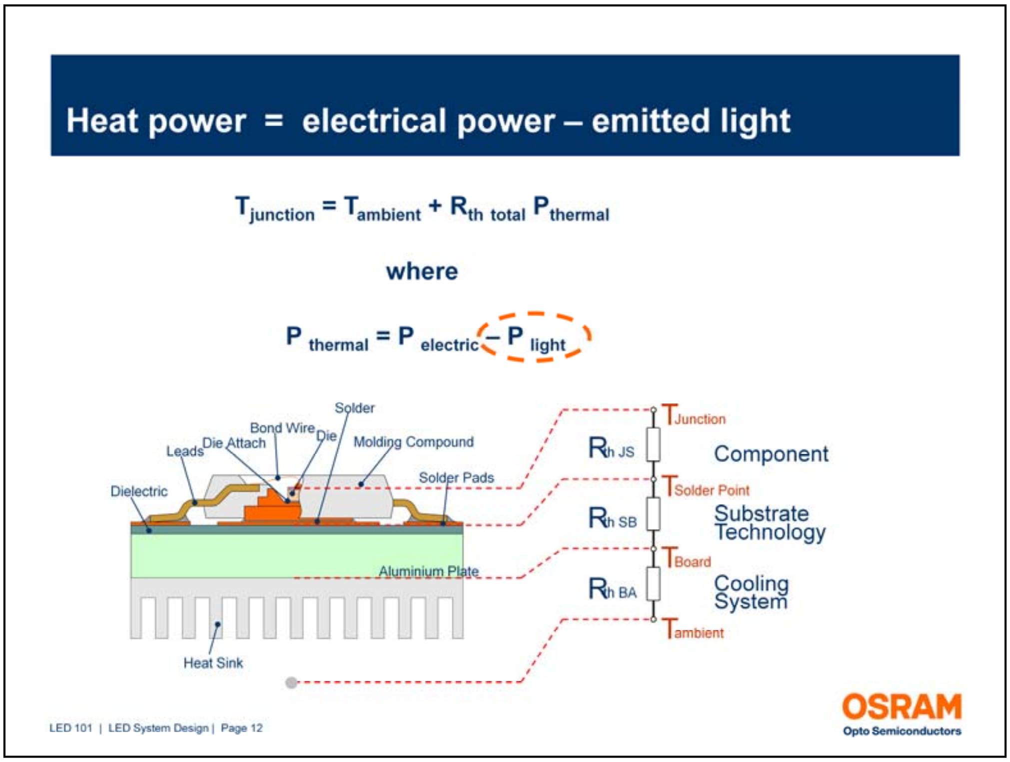
When a non-standard or specialized light distribution is required, a custom optic may be the only choice.

OSRAM Opto can support concept development, while our LED Light For You partners can design and manufacture the final optics.

Thermal System

Thermal System
- LED
- PCB
- Interface Material
- Heat sink

The thermal system consists of some or all of the following: the LED mounted on a printed circuit board, a thermal interface layer, and a heat sink.



Heat power = electrical power – emitted light

$$T_{junction} = T_{ambient} + R_{th\ total}\, P_{thermal}$$

where

$$P_{thermal} = P_{electric} - P_{light}$$

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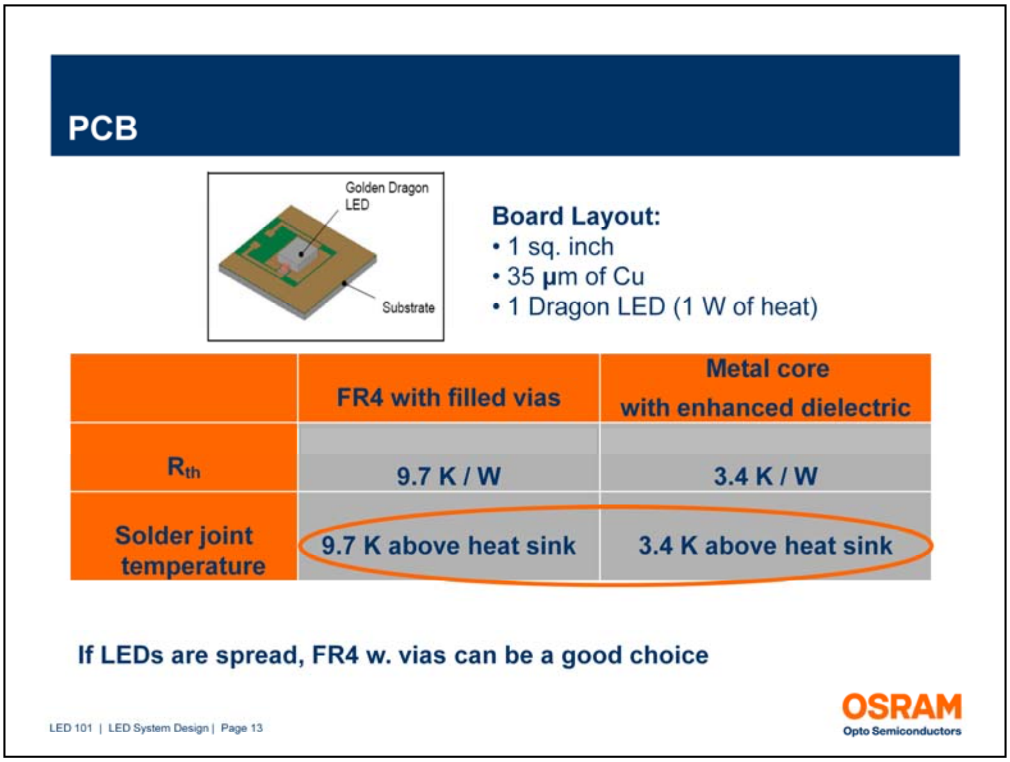
A thermal system can be compared to an electric circuit where the heat flux corresponds to the electric current, the thermal resistance corresponds to the electrical resistance, and the temperature above ambient to the electric voltage. The thermal resistance of the system is then simply obtained by adding the individual values.

The LED junction temperature above ambient is calculated by multiplying the total thermal resistance with the produced heat power. With today’s highly efficient LEDs, the heat power is not simply the electrical power applied to the LED, but the electrical power minus the generated light flux.



PCB

Board Layout:

- 1 sq. inch
- 35 µm of Cu
- 1 Dragon LED (1 W of heat)

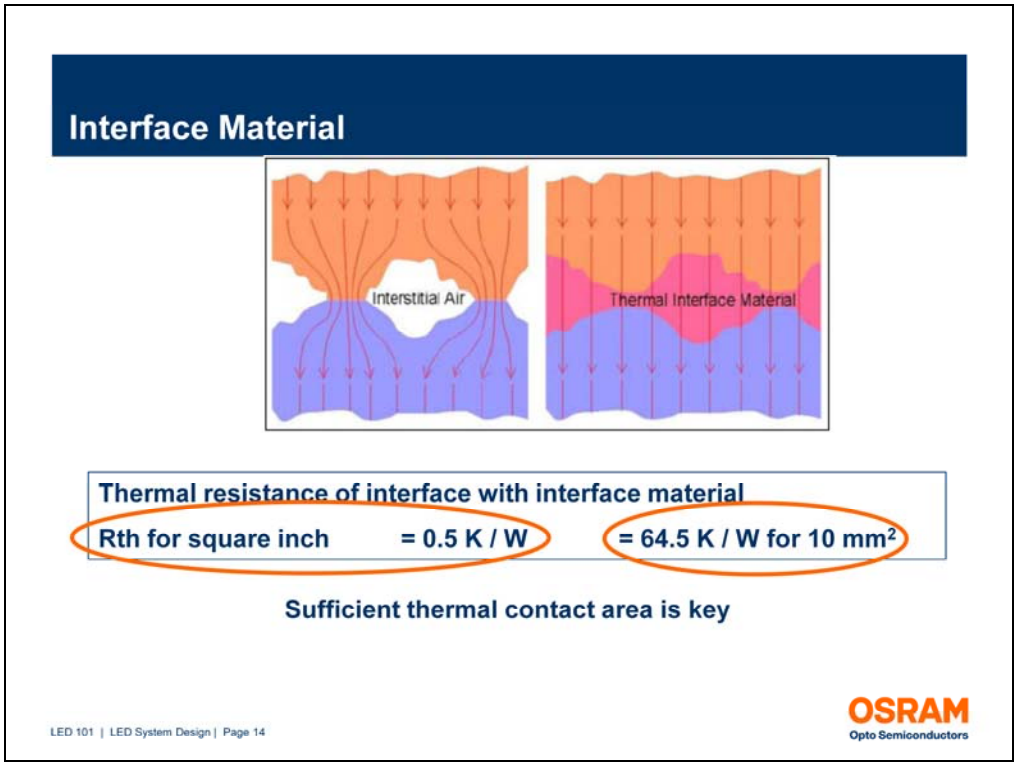
	FR4 with filled vias	Metal core with enhanced dielectric
R_{th}	9.7 K / W	3.4 K / W
Solder joint temperature	9.7 K above heat sink	3.4 K above heat sink

If LEDs are spread, FR4 w. vias can be a good choice

There are various choices of PCB materials which differ in their thermal performance and price.

Here we compare a 1 square inch board carrying an LED producing 1 W of heat. Though the thermal resistance of the metal core board is lower, the 10º Celsius temperature increase for an inexpensive FR4 with filled vias might be acceptable in many designs.

For lamp applications where LEDs are placed close together and a life time of 50,000 hours or more is expected, a metal core board is the better choice.



Interface Material

Thermal resistance of interface with interface material

Rth for square inch = 0.5 K / W **= 64.5 K / W for 10 mm²**

Sufficient thermal contact area is key

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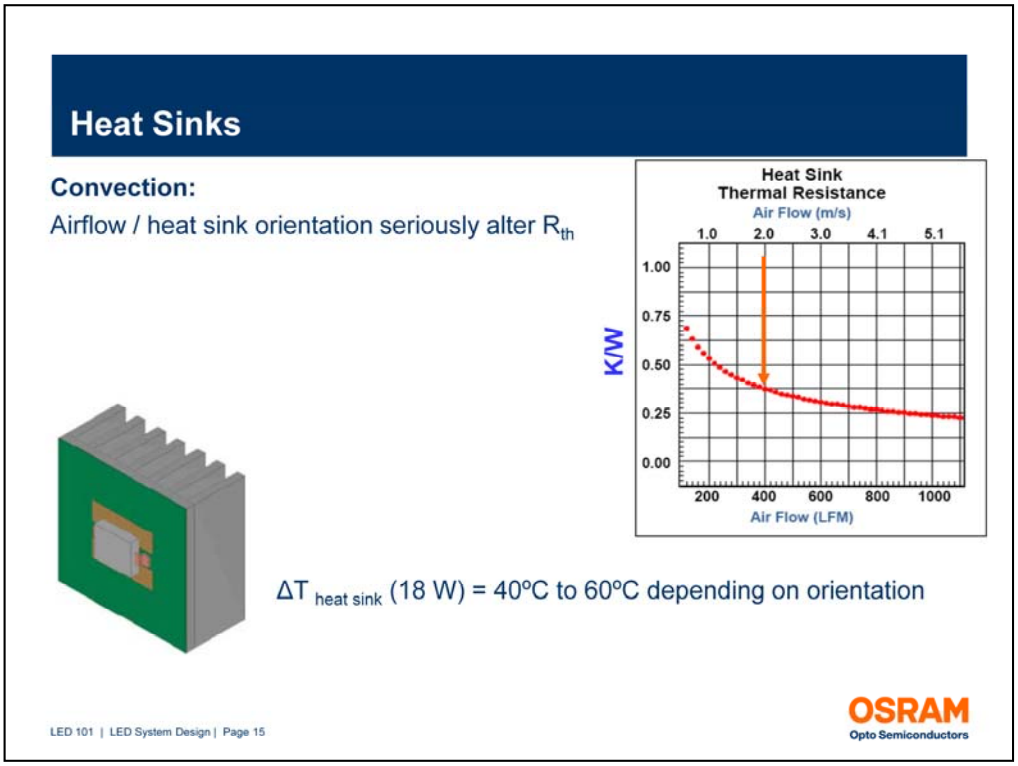
The mechanical surfaces of the PCB and the heat sink are not polished, which results in many air pockets between the surfaces.

As air is a bad heat conductor, the air pockets increase the thermal resistance of the interface.

Interface materials like thermal grease or tape are commonly used to fill the pockets.

However, for a small thermal contact area the thermal resistance can become quite large even with these interface materials are used.



Heat Sinks

Convection:

Airflow / heat sink orientation seriously alter R_{th}

$\Delta T_{\text{heat sink}}$ (18 W) = 40ºC to 60ºC depending on orientation

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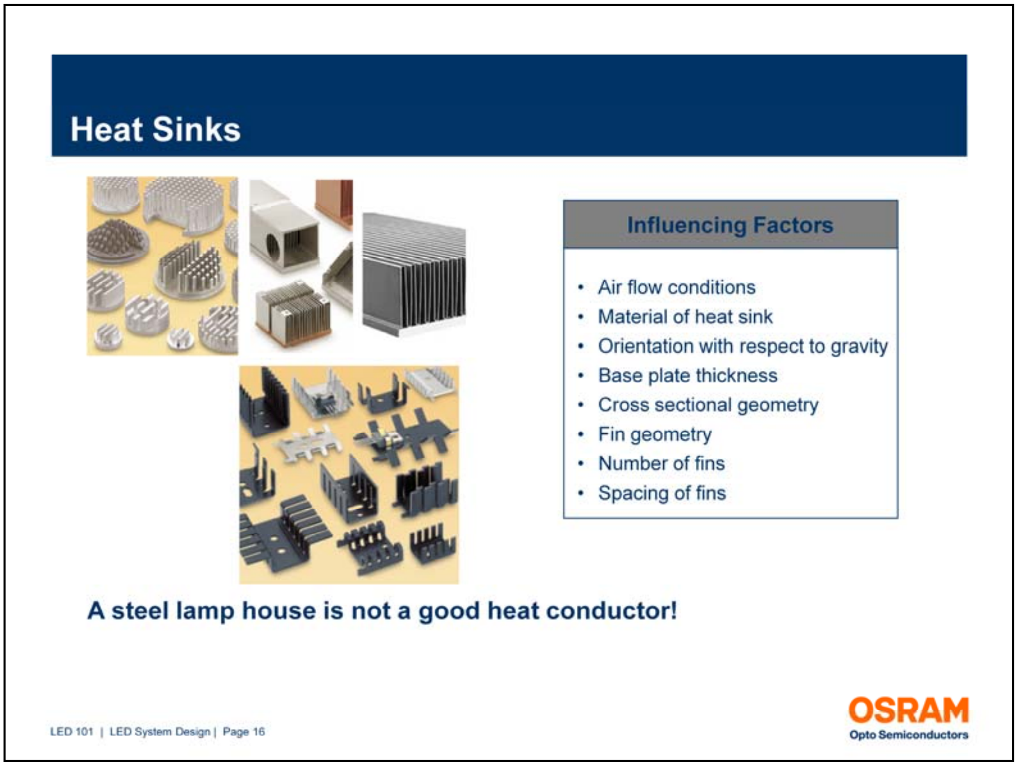
The heat sink disipates heat to an outside medium like air. This convection process significantly influences the thermal performance of a heat sink. Convection increases with the temperature difference. Thus, the thermal resistance of a heat sink goes down for a higher heat flux.

The heat exchange also increases with the speed of the air flow. Air flow could be provided by the environment, a fan, or simply by the local heating of the air around the heat sink fins.

That makes the performance of heat sinks orientation dependent.

As shown in the example the heat sink surface temperature at the PCB can be 20º Celsius higher when it’s positioned LED down compared to the shown orientation.



Heat Sinks

Influencing Factors

- Air flow conditions
- Material of heat sink
- Orientation with respect to gravity
- Base plate thickness
- Cross sectional geometry
- Fin geometry
- Number of fins
- Spacing of fins

A steel lamp house is not a good heat conductor!

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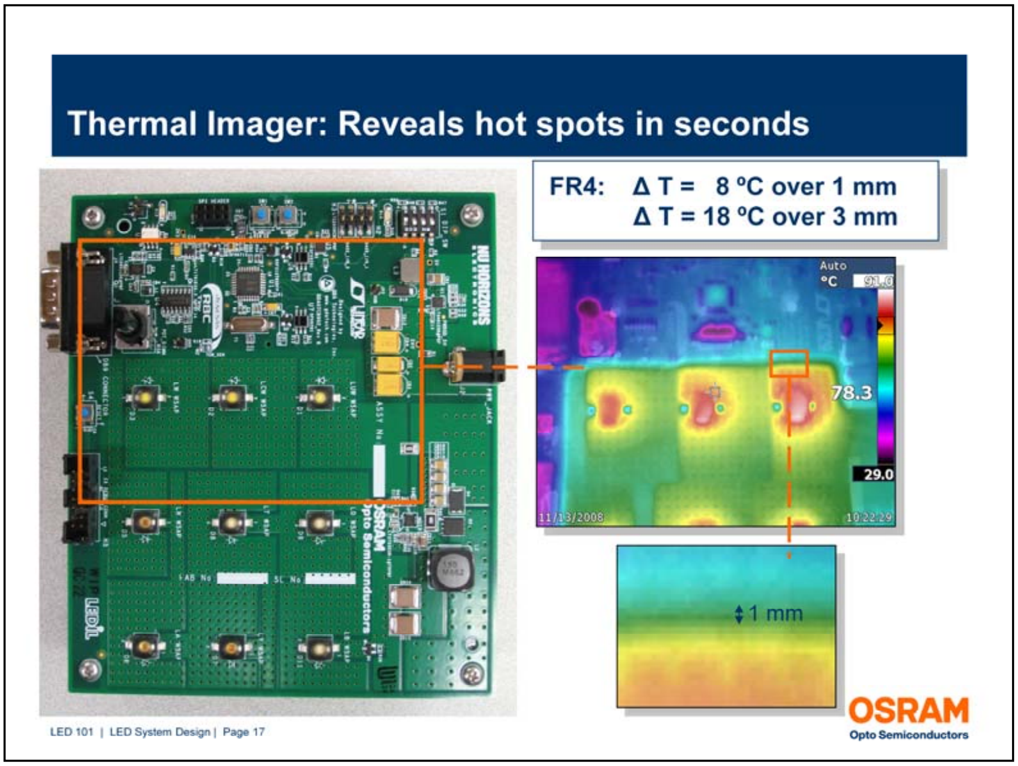
Heat sinks come in various shapes and dimensions. Some important heat sink parameters are listed here. Web pages of heat sink suppliers offer tools to optimize the heat sink for an application.

Though a popular material, steel has a thermal conductivity of only 10% of aluminium or 30% of iron. Thus, steel of more than a few millimeters thickness within the thermal path might add an unnecessary temperature increase to the system.

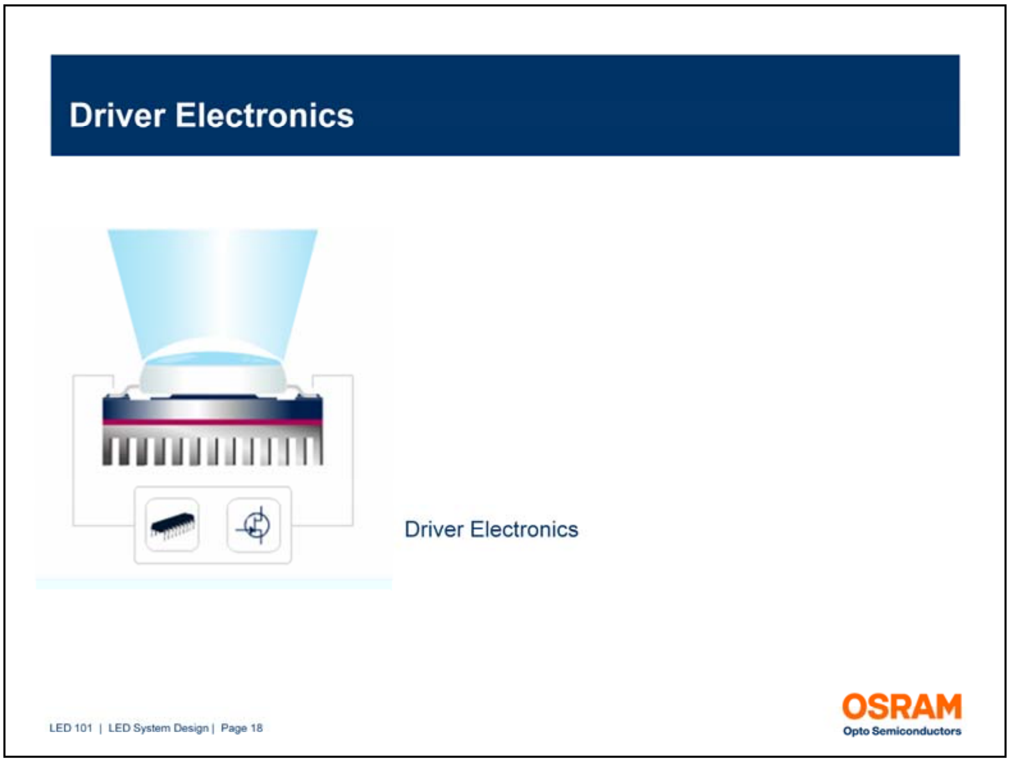


Thermal Imager: Reveals hot spots in seconds

FR4: Δ T = 8 ºC over 1 mm
Δ T = 18 ºC over 3 mm

The complexity of PCBs can lead to extensive thermal simulation. Unknowns in the airflow add to error in the results. A thermal imager can make a quick survey of the real temperatures within seconds. It reveals the temperature of PCB hot spots like LEDs and other components. OSRAM Opto offers thermal imaging as a customer service.

In this picture, the insert to the right shows the steep temperature gradients across the PCB epoxy material. This means that the on-board temperature measuring devices need be placed as close as possible to the heat sources.



Driver Electronics

Driver Electronics

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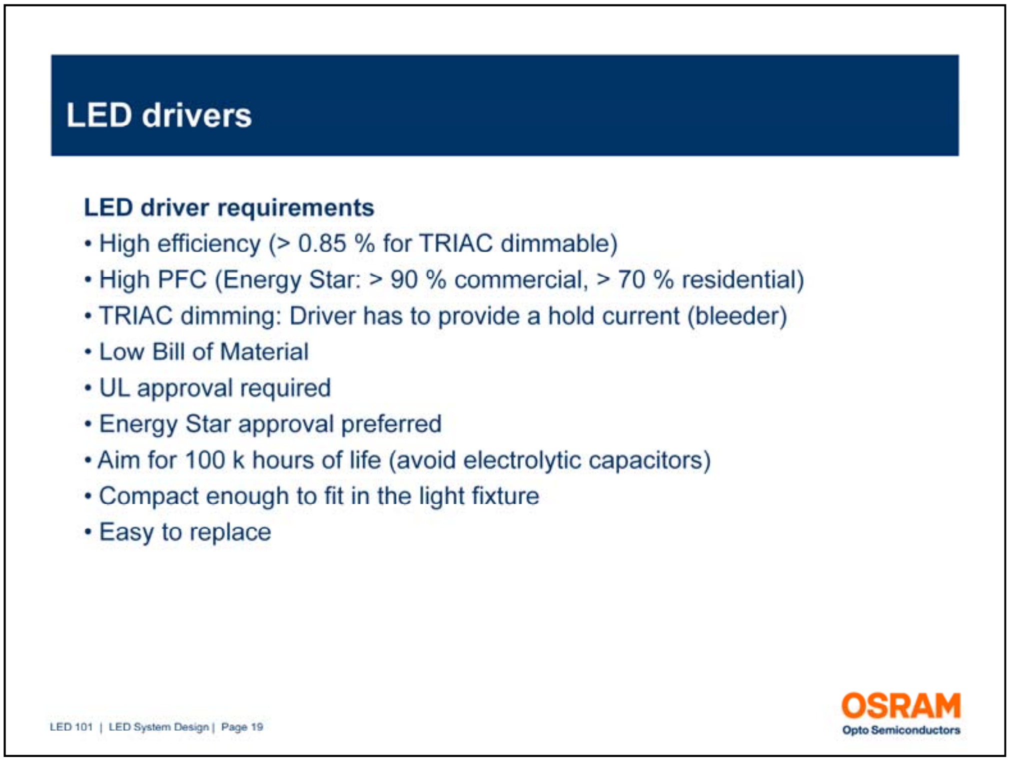
Finally, we will discuss LED drivers.



LED drivers

LED driver requirements

- High efficiency (> 0.85 % for TRIAC dimmable)
- High PFC (Energy Star: > 90 % commercial, > 70 % residential)
- TRIAC dimming: Driver has to provide a hold current (bleeder)
- Low Bill of Material
- UL approval required
- Energy Star approval preferred
- Aim for 100 k hours of life (avoid electrolytic capacitors)
- Compact enough to fit in the light fixture
- Easy to replace

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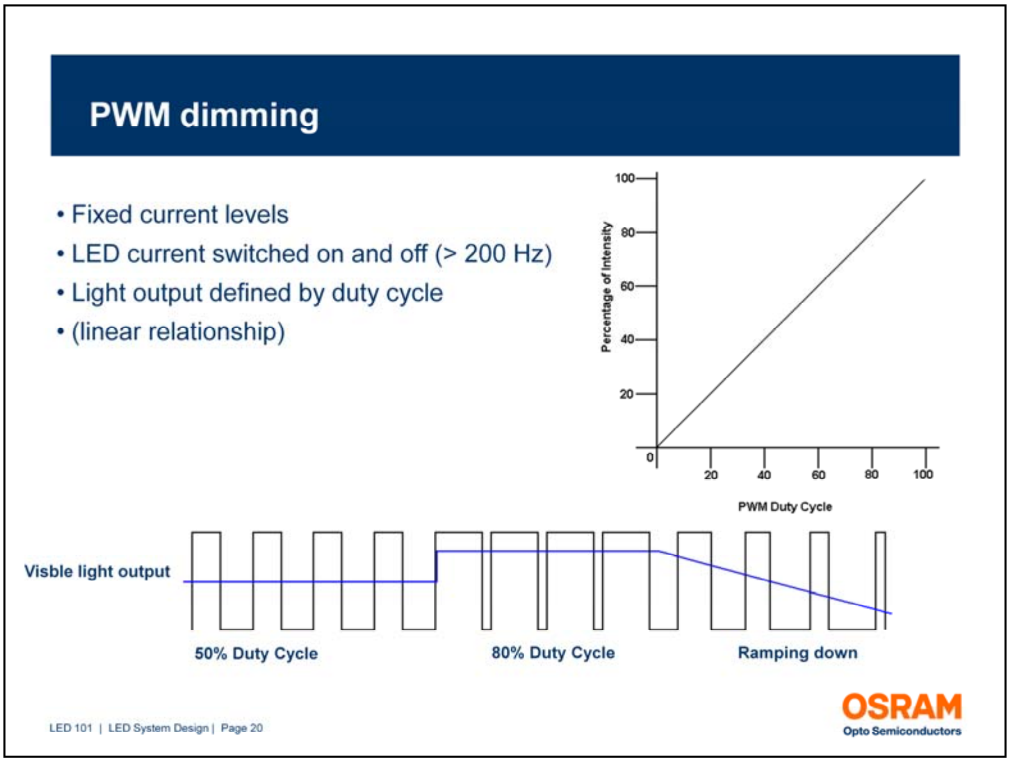
Since LED drivers affect system efficiency, Energy Star defines basic limits like efficiency and power factor correction. LEDs are driven by constant current supplies. Many companies offer solutions on the chip level.

A lamp requires an AC to DC system able to pass UL standards and possibly Energy Star standards. Also, the life of the driver should match the life of the LEDs. These requirements make the driver design challenging and often require working directly with chip suppliers and integrators.



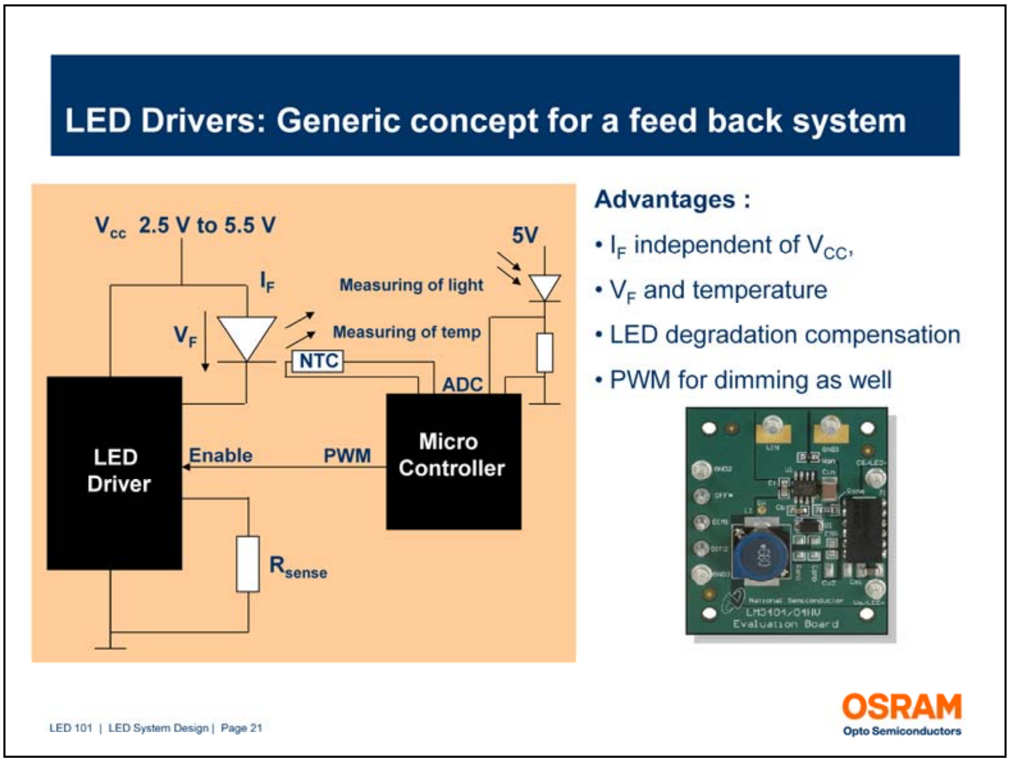
PWM dimming

- Fixed current levels
- LED current switched on and off (> 200 Hz)
- Light output defined by duty cycle
- (linear relationship)

As the LED current to light output relationship might not be linear, and LED control is difficult at low current levels, dimming is best done with Pulse Width Modulation, or PWM.

PWM means that the LED is supplied with a fixed current, but the current is switched off and on.

The duty cycle then defines in a linear way the light output. The PWM frequency has to be at least a few hundred Hertz to avoid noticeable light flicker.



LED Drivers: Generic concept for a feed back system

Advantages :

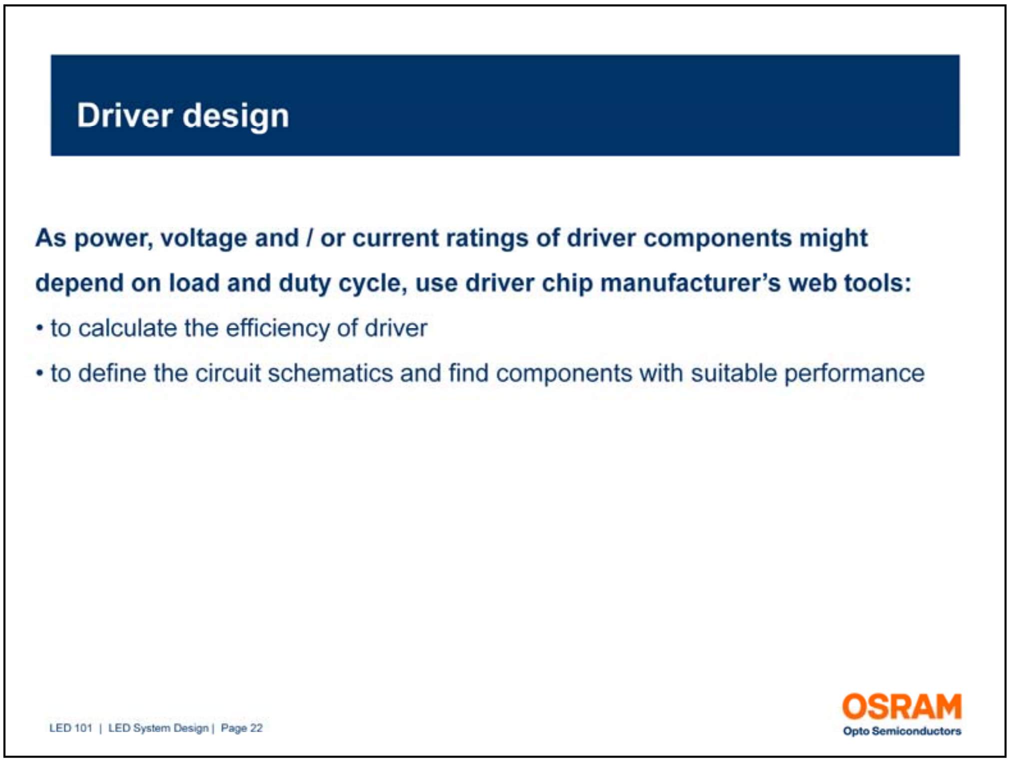
- I_F independent of V_{CC},
- V_F and temperature
- LED degradation compensation
- PWM for dimming as well

The LED light output decreases with temperature and age. A feedback loop can compensate for these changes. The system shown here uses an LED driver whose output current is Pulse Width Modulated according to the micro controller PWM signal.

A photo diode measures a fixed portion of the LED light output, enabling the controller to adjust the PWM duty cycle.

The NTC temperature sensor acts as an over-temperature protection for the LED.

The insert shows a typical LED driver demo board, courtesy of National Semiconductor.



Driver design

As power, voltage and / or current ratings of driver components might depend on load and duty cycle, use driver chip manufacturer's web tools:

- to calculate the efficiency of driver
- to define the circuit schematics and find components with suitable performance

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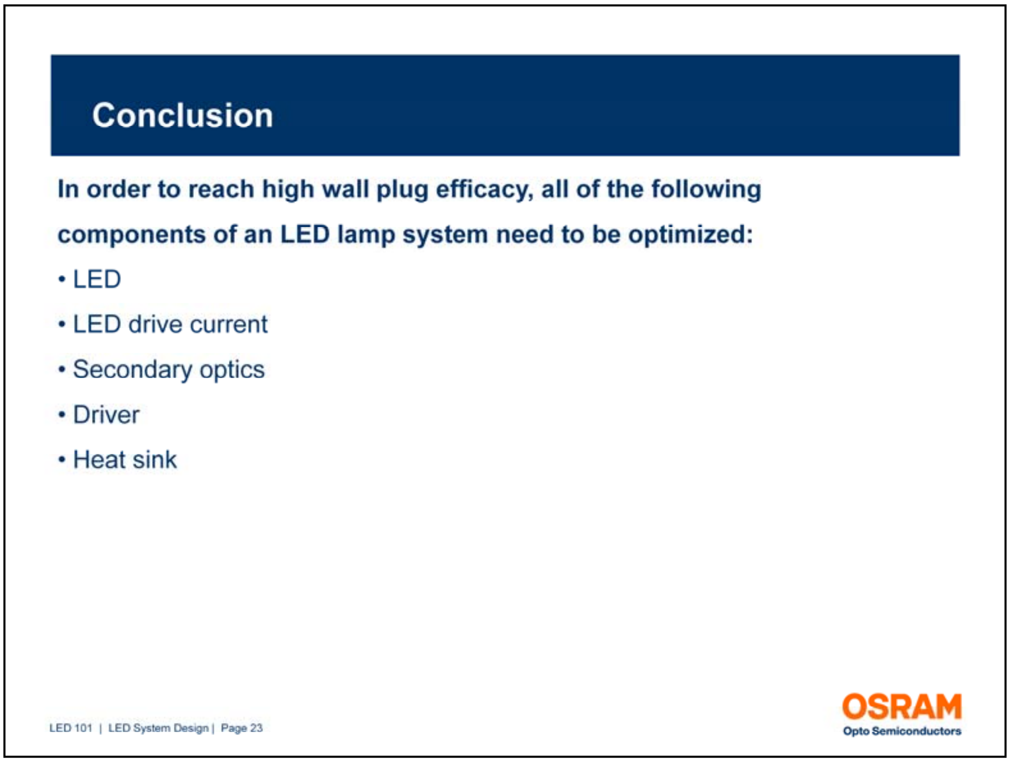
Many constant current sources are switching power supplies. This results in changing loads and duty cycle-dependent loads for circuit components.

Web pages from driver chip suppliers can help to optimize the efficiency of your system and recommend electronic components with suitable spec limits.



Conclusion

In order to reach high wall plug efficacy, all of the following components of an LED lamp system need to be optimized:

- LED
- LED drive current
- Secondary optics
- Driver
- Heat sink

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As we have seen, the efficacy of an LED lamp system depends upon the component efficiencies. Therefore all components need to be optimized: The LEDs themselves, the LED drive current, the secondary optics, the driver design, and the heat sink. Only then are high lumen/Watt values achievable.

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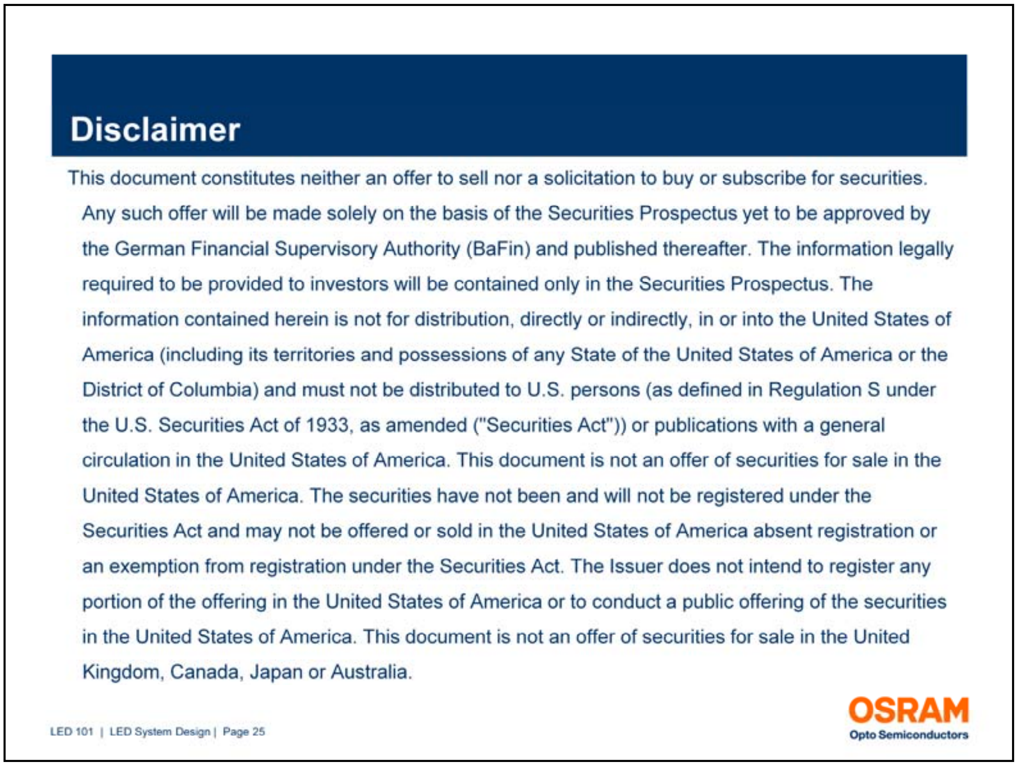

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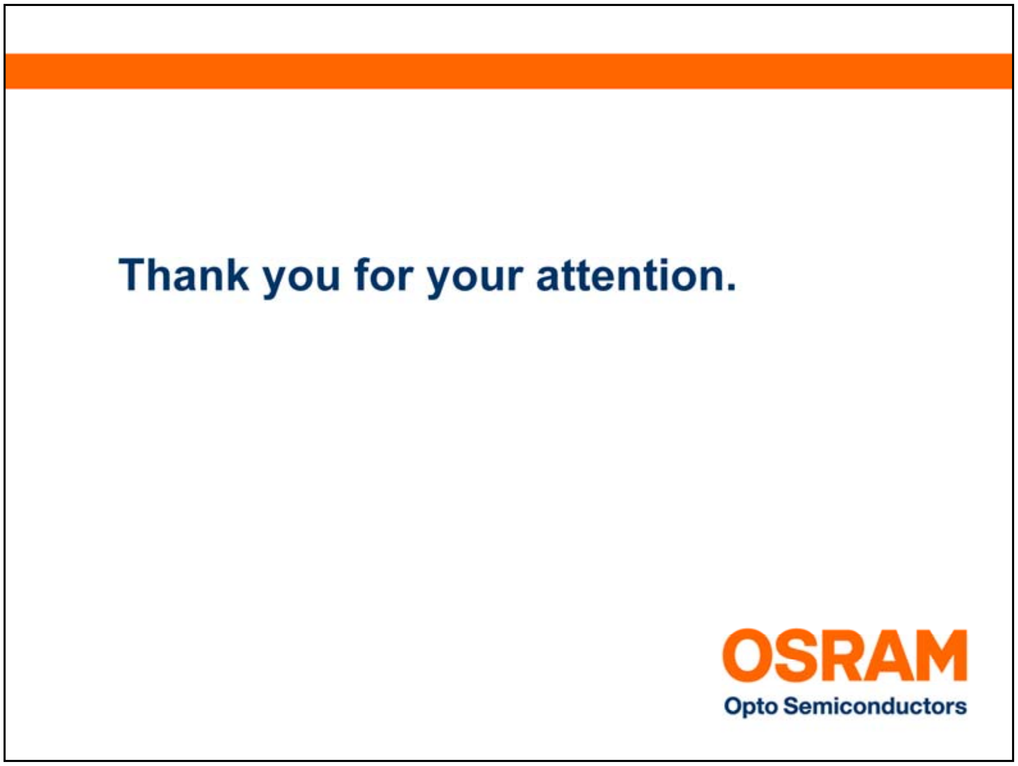

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