

Everline Module Application Note: Round LED Module Thermal Management

PURPOSE:

Use of proper thermal management is a critical element of Light Emitting Diode (LED) system design. The LED temperature directly affects device reliability, operation, and compliance with ULT warranty. As temperatures increase beyond reliability temperature specification limits, the device lifetime degrades, and above the maximum operating temperature limits severe damage can occur rendering the LED unusable. The purpose of this application note is to provide system designers with thermal management guidance and tools to implement successful thermal designs.

THERMAL SYSTEM DESIGN MODEL:

Cooling system design is based on use of thermal resistance networks. A thermal resistance network is analogous to an electrical resistor network using parallel and series resistances to represent heat transfer paths. In place of a voltage potential across a resistor, a temperature potential exists, and instead of current flowing through the electrical circuit, heat flows through the thermal network. This is described in the following schematics:

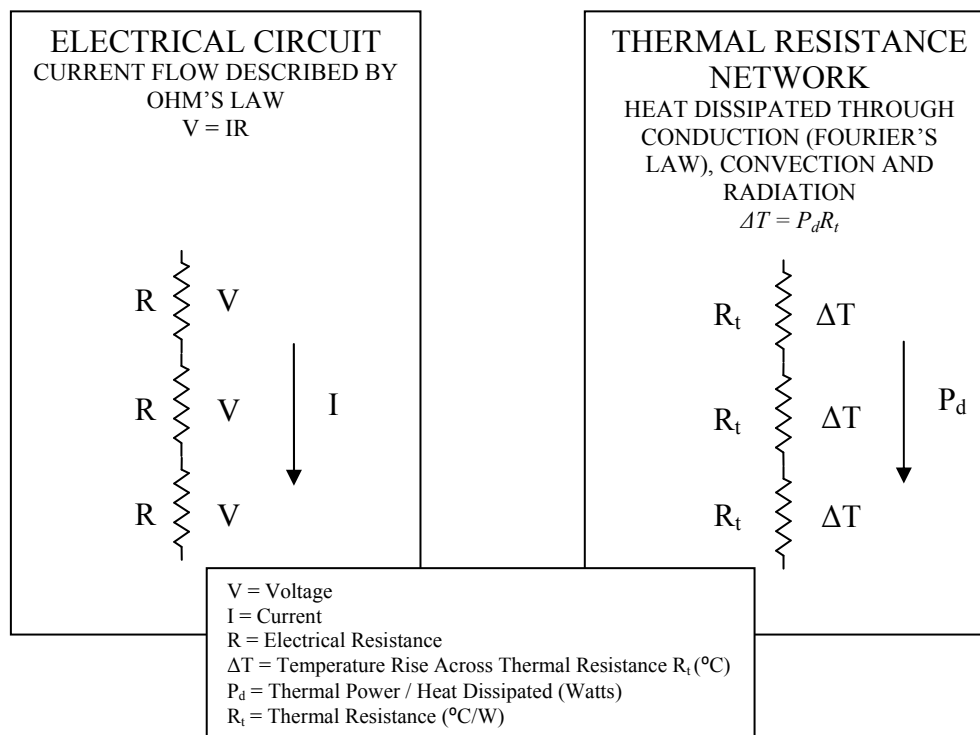
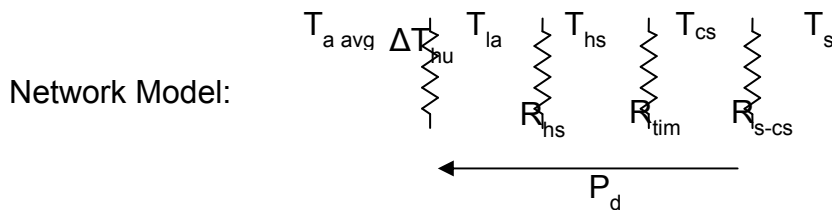


Figure 1: Electrical and Thermal Resistance Network Analogy

Design of Cooling System:

This concept of a thermal resistance network model can be used during the system cooling design phase and during product test after test hardware is available. During the Design Phase, the Everline® Round Module solder temperature can be calculated using the networks and relationships in the following two figures. Employing the appropriate Module with Heat Sink network and equation or the Module without Heat Sink network and equation provides a calculated solder temperature, T_s , based on the application average ambient temperature. The calculated T_s can then be compared to the Maximum Reliability Temperature of 85°C to determine if the cooling system design maintains the solder temperature within this temperature specification limit.

LED Module with Heat Sink:



Model Equation: $T_{s \text{ rel design, hs}} = T_{a \text{ avg}} + \Delta T_{hu} + P_d \cdot (R_{hs} + R_{tim} + R_{s-cs})$

Figure 2: System Design Phase - Network and Equation for Module with Heat Sink

where:

- $T_{s \text{ rel design, hs}}$ is the design with heat sink solder temperature for reliability conditions (°C)
- $T_{a \text{ avg}}$ is the average system ambient temperature (°C)
- ΔT_{hu} is the air heat up within the system between $T_{a \text{ avg}}$ and T_{la} (°C)
- T_{la} is the temperature of the air near the heat sink (°C)
- T_{hs} is the heat sink base temperature adjacent to the TIM (°C)
- T_{cs} is the temperature of the LED module adjacent to the TIM (°C)
- T_s is the solder measurement point temperature (°C)
- P_d is the heat dissipated (W)
- R_{hs} is the heat sink thermal resistance (°C/W)
- R_{tim} is the TIM thermal resistance between heat sink and module (°C/W)
- R_{s-cs} is the thermal resistance from the solder measurement point to the module case adjacent to the TIM (°C/W)

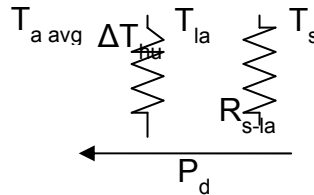
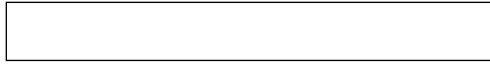


Figure 3: System Design Phase - Network and Equation for Module without Heat Sink

$T_{a\ avg}$ in the reliability calculation is the average ambient temperature of the LED environment to which the LED heat is ultimately dissipated. For example, if the LED module is assembled within a housing, the ambient temperature is that which is external to the housing. This average system ambient temperature rather than the maximum ambient temperature affects LED lifetime.

Both networks include a variable that provides for the air temperature heat up (ΔT_{hu}). Air heat up can be caused by power supplies, other LED's, or any other heat dissipating devices that affect the air temperature near the module of interest and cause a temperature rise from the system ambient air temperature to the module local ambient air temperature. In some cases where no other devices are present to affect the air temperature this variable contributes 0°C to increase in the solder temperature.

The T_{la} is the temperature of the air near the heat sink at a position that is not affected by heat convecting from the LED or from cooling hardware.

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The location of the solder temperature measurement point, T_s , is illustrated in the following figure.

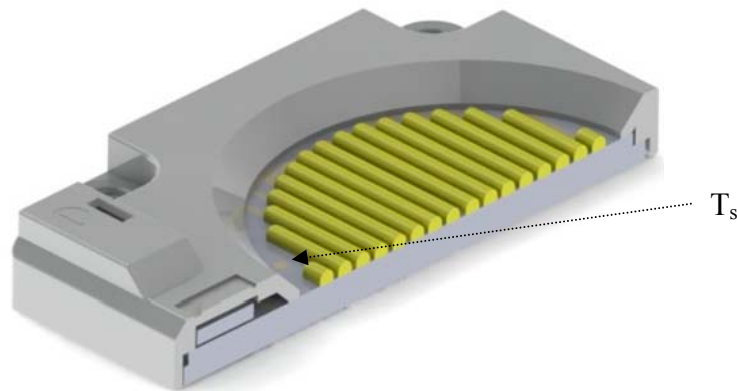


Figure 4: Location of T_s

The heat dissipated by the LED, P_d , is dependent on the efficiency of the LED. For design purposes, the LED converts 20% of the input power to light energy and 80% to heat energy. Consequently, the heat that is dissipated by the cooling system is:

$$P_d = 0.80 \cdot P_{\text{input}} = 0.80 \cdot I_f \cdot V_f$$

where:

P_d is the heat to be dissipated by the system cooling design (W)

P_{input} is the total input power to the LED (W)

I_f is the forward current through the LED (A)

V_f is the forward voltage across the LED (V)

Heat Sink Selection:

From the above modeling equations, it can be determined if a heat sink is needed to provide adequate cooling for the LED module and what heat sink thermal resistance is required. A variety of passive and active heat sinks are commercially available from several suppliers.

Common passive heat sinks types used in free or natural convection cooling configurations are: Extruded, Bonded, Cast, Folded Fin, Forged, Skived, and Stamped. Heat sink performance is a function of heat sink material thermal conductivity, fin surface area, and fin spacing supporting air flow between fins. Proper orientation of fins parallel to gravity optimizes flow of air through the heat sink driven by heated air buoyancy with respect to surrounding cooler air.

Active heat sink types used in forced convection are: Fan Sinks, Thermoelectric (Peltier) Devices, Liquid Cooling Systems, Radial Fan Sinks, and Heat Pipes Coupled with Any of these Heat Sinks.

Additional considerations in selecting either a passive or active heat sink are base thickness affecting heat spreading that is important to quickly removing heat from the high power density LED's and base surface flatness and surface roughness needed in conjunction with the TIM used to avoid air pockets and enhance microscopic contact between heat sink and TIM.

Heat sink supplier performance data can be analyzed to optimize thermal performance for either heat sink type. Then the thermal performance, cost, weight, size, and reliability (especially for active heat sinks) will need to be evaluated to determine the best solution for the application.

Thermal Interface Material (TIM) Selection:

Again using the above modeling equations, the required thermal performance of a TIM between the heat sink and LED module can be determined. This may require parametric analysis varying the heat sink and TIM thermal resistance values to establish the required performance within an achievable range for each.

Several types of TIM are available: Pads, Grease, Gels, Epoxy, Tapes, and Phase Change Materials. Thermal conduction resistance through TIM is the mode of heat transfer. Consequently, the thickness, thermal conductivity, and coverage area of the TIM controls thermal performance. A variety of trade-offs are needed to complete the TIM selection and optimum characteristics can be in conflict between 2 or more of the following. Each needs to be considered in the selection process:

- High thermal conductivity enhances heat flux
- Minimal thickness reduces thermal resistance
- Maximum area coverage optimizes heat flow
- Conformability to both the LED and heat sink surfaces improves conduction of heat
- Increasing heat sink mounting pressure on the TIM generally reduces thermal resistance
- Durability and reworkability if heat sink disassembly and reassembly is required
- Operating temperature range
- Manufacturability/ease of assembly
- Bond line thickness control for liquid TIM's
- Cost

COOLING SYSTEM TEST:

ULT has characterized the thermal behavior of the round LED module and defined a location for standardization of the temperature measurement. This measurement location is located near the center of the module as shown in Figure 4 and is defined as T_s . The temperature of the module at this location must be maintained at or below the value outlined in the specification sheet, 85°C. This requirement has been established to ensure safe operation and stated lifetimes are achieved.

To determine from measured data if the LED is within the temperature specification, the following relationship can be used to compare the measured thermal performance with the reliability temperature limit either with or without a heat sink installed. This relationship applies an adjustment to the measured T_s to compensate for the difference between the average ambient temperature that is expected for the system and the measured ambient temperature:

$$T_{s \text{ rel test}} = T_{s \text{ meas}} + T_{a \text{ avg spec}} - T_{a \text{ meas}}$$

where:

$T_{s \text{ rel test}}$ is the ambient adjusted LED module solder temperature for reliability conditions (°C)

$T_{s \text{ meas}}$ is the measured LED temperature at the location in Figure 4 (°C)

$T_{a \text{ avg spec}}$ is the expected average system ambient temperature (°C)

$T_{a \text{ meas}}$ is the measured system ambient temperature (°C)

The testing environment of the LED module and cooling system should simulate the application environment as closely as possible. Air movement, power input, ambient temperature, mechanical orientation, and other heat sources affecting the thermal performance of the LED module need to be realistic.

The thermal environment for the typical application of linear LED modules does not have guaranteed air movement in natural convection. Consequently, it is not recommended that testing be performed in a thermal chamber or oven that uses forced convection or has any significant air movement within it. Also, natural convection requires significant space to avoid restriction of natural air movement. The module and cooling system location within the test environment must have open area surrounding it and quiescent air.

Test multiple LED's and ensure that the LED with the expected highest temperature is measured.

Test until the measured temperatures stabilize at maximum values reaching steady state temperatures.

Test with the thermal probe installed at the T_s location specified in Figure 4 with direct contact to the module and secured with thermal epoxy or the equivalent.

Measure T_{ambient} to determine any difference between it and the specified ambient temperature upper limit.

Use the above test relationship and the measured data from realistic test conditions to determine if the LED module temperature in the system application is within the specified upper temperature limit.