LED Lamp Thermal Properties

Application Brief A04

Introduction

In the vast majority of customer applications, LED lamps are soldered directly on a printed circuit board. Lamp data sheets provide a conservative power or current derating based on maximum ambient temperature. In virtually any application, an understanding of the thermal properties of LED lamps is useful for several reasons:

1. Avoid over-stressing the LED, which lowers its reliability.
2. Allow the LED to be operated at the highest drive current (and highest light output) possible.
3. In some cases, allow the LED to be driven at conditions beyond the maximum ratings.

LED lamps are usually constructed by encapsulating an LED chip in an epoxy package. The LED chip is attached to a metal pin with electrically conductive epoxy. The top of the LED chip is connected to another pin with a gold wire. Because of different rates of thermal expansion, the gold wire is deformed slightly when the lamp is subjected to large temperature extremes. Even though gold is a very ductile metal, the gold wire can break after large number of temperature cycles, causing the LED to fail as an open circuit. Agilent LED lamps are capable of withstanding thousands of temperature cycles over the temperature range of -55/100°C, non operating.

Above 100°C, each temperature cycle puts more stress on the gold wire causing the wire bond to break sooner. A recent study at Agilent showed that over the range of 100 to 115°C, each increase in maximum temperature excursion by 5°C (non operating), lowered the mean number of temperature cycles to failure by a factor of five. Thus, an LED lamp will fail with 100 times fewer temperature cycles over the range of -40/115°C than the range of -40/100°C.

In an LED lamp, some heat is generated when the lamp is turned on. This heat is generated within the LED chip. The primary thermal path from the LED chip is through the die attach pad into the metal lead. Then the heat flows down the lead into the printed circuit board conductor trace. For Agilent LEDs, all LEDs (except for AlGaAs) have the die attach pad connected to the cathode pin. Minimal heat is conducted down the gold wire and conducted through the anode pin. Thus, for these LEDs, the cathode lead should be connected to a heavy metal printed circuit trace. (For Agilent AlGaAs, the die attach pad is connected to the anode pin. Therefore, the anode lead should be connected to a heavy metal printed circuit trace.)

A thermal model for an LED lamp mounted on a printed circuit board is shown in Equation 1.

Note: Pin temperature is defined as the temperature of the solder joint on the cathode lead (except AlGaAs) on the underside of a 0.062" (1.6 mm) printed circuit when the lamp is mounted at the nominal seating plane.

$$T_J = T_A + P_D (\theta_{J\text{-}P} + \theta_{P\text{-}A}) = T_A + P_D (\theta_{J\text{-}A}) \quad \text{(Equation 1)}$$

Where:
- T_J = LED junction temperature
- T_A = Ambient temperature
- P_D = Power dissipation, i.e. I_F times V_F
- $\theta_{J\text{-}P}$ = Thermal resistance, junction to cathode pin
- $\theta_{P\text{-}A}$ = Thermal resistance, pin to air

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The thermal resistances for a number of Agilent lamp packages are summarized in Table 1.

The basic thermal resistance equation, Equation 1, can be modified to account for lamps mounted above the nominal seating plane. In this application, the heat must flow through a longer path. However, measurements of this thermal resistance indicate a lower thermal resistance than expected because the lead transmits some of the heat directly to air via convection. The additional thermal resistance due to elevating the lamp above the printed circuit board can be estimated from Table 2.

As a last step, the thermal resistance, pin to air, can be estimated by measuring the thermal resistance of different sized copper pads on the printed circuit board. For all Agilent LEDs (except AlGaAs), this copper pad should be connected to the cathode pin. The thermal resistance, pin to air, as a function of cathode pad area is shown in Figure 1.

Thus, the thermal resistance for a lamp mounted to a printed circuit can be modeled with the following equation:

$$\theta_{J\text{-}A} = \theta_{J\text{-}P} + (\theta_S)(h) + \theta_{P\text{-}A} \quad \text{(Equation 2)}$$

Where:
$\theta_{J\text{-}P}$ = Thermal resistance, from Table 1
θ_S = Standoff thermal resistance, from Table 2
h = Height above nominal seating plane in inches
$\theta_{P\text{-}A}$ = Thermal resistance, from Figure 1

Example: What is the junction temperature at 85°C ambient for a T1 lamp driven at 20 mA mounted with a standoff height of 0.5 inch (12.7 mm) on a cathode pad 0.3 inches (7.62 mm) square?

Cathode pad area = $(0.3)^2 = 0.09$ inch^2

$\theta_{J\text{-}A}$ = 290°C/W + (380°C/W)(0.5) + 108°C/W
$\theta_{J\text{-}A}$ = 588°C/W

P_D = (0.020 A)(2.1 V) = 0.042 W

T_J = 85°C + (0.042 W)(588°C/W) = 85°C + 25°C = 110°C

The thermal resistance model, Equation 2, can be used to estimate the lamp junction temperature based on worst case ambient temperature and lamp power dissipation. However, it is only a model and can give a misleading result if external heat sources are mounted near the LED. In applications where the lamp will be driven at conditions close to the maximum ratings, the lamp junction and pin temperatures can be measured directly. The junction temperature can be measured by measuring the change in forward voltage of the LED. Based on previous experiments, the forward voltage of the LED changes by about –2 mV/°C. The pin temperature can be measured using a small thermocouple attached to the cathode printed circuit trace.

Table 1. Agilent Lamp Thermal Resistance

Package	$\theta_{J\text{-}P}$
T1 lamp	290°C/W
T1-3/4 lamp, 18 mil leadframe	260°C/W
T1-3/4 lamp, 25 mil leadframe	210°C/W
Subminiature lamp	170°C/W

Table 2. Thermal Resistance Due to Standoff Height

Package	θ_S
T1 lamp	380°C/W, per inch (25.4 mm)
T1-3/4 lamp, 18 mil leadframe	280°C/W, per inch (25.4 mm)
T1-3/4 lamp, 25 mil leadframe	160°C/W, per inch (25.4 mm)

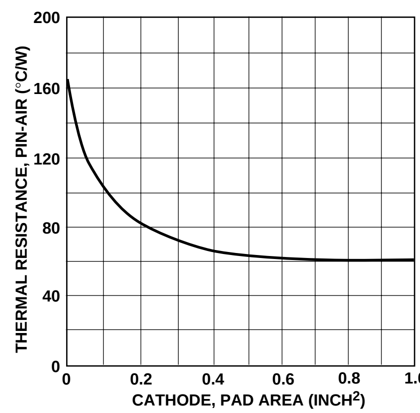

Figure 1. Printed Circuit Thermal Resistance ($\theta_{P\text{-}A}$)

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Data subject to change.

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