# A STUDY ON THERMAL PERFORMANCE OF LED SIGNAL HEADS USING INFRARED THERMOGRAPHY

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***Abstract:*** *This article presents results from a study on thermal performance of several LED traffic light heads. Thermal performance of an electronic equipment, especially LED luminaire, is a lifetime determining criteria. In order to simulate real life worst case scenario signal heads are placed in thermal chamber and the internal temperature is set to 60°C. A controller is made to control the LED signal heads with longest time sequences according to statutory requirements. Constant light mode is studied also. Measurements are made with infrared camera and thermocouple for verification. The measured solder point temperatures are used to calculate junction temperatures and estimate dangerous operating conditions.*

**Keywords**: LED THERMAL PERFORMANCE, INFRARED THERMOGRAPHY

## 1. Introduction

Light emitting diodes (LEDs) are used for manufacturing of indoor outdoor luminaires, backlights, traffic and commercial signs, traffic signal heads, headlamps, smart lighting system etc. They are used mainly because of their efficiency and manufacturability. The old traditional lighting sources have lots of drawbacks. Incandescent lamp outputs only 8% of the consumed power as visible light, 19% is conducted as heat, and 73% is radiated as infrared light [1]. The useful lifetime for general purpose lamps is 1000h. The luminous efficency is typically around 14 Lumen per Watt or lm/W. It is better with the halogen lamps with luminous efficiency up to 25 lm/W [2], but still most of the energy is lost on heating. Fluorescent and compact fluorescent lamps (CFLs) are with better efficiency – less than 68 lm/W - but they have limitations in the number of cycles. The efficiency of LEDs is being constantly improved – nowadays white LEDs with efficiency above (80…110) lm/W are easily available and some of the main suppliers announce, that in laboratory conditions they achieved 250 lm/W. However as semiconductor devices, LEDs are sensitive to high temperatures. High working temperatures can reduce the efficiency by reducing luminous flux and can shorten the life of a single LED twice or more. Moreover under normal operating conditions, approximately 50% to 80% [1, 3] (depending on the different LEDs) of the input power of a LED is dissipated through the LED package as heat, while the rest of the input power is converted to light. Therefore thermal management in LED luminaires is highly important for performance and reliability.

Untill recently long life incandescent lamps (8000h) were used in traffic lights, there were as well low voltage long life halogen lamps, but the main problem is high consumption and regular maintenance. Due to the use of reflectors there exists possibility of phantom effect in signal heads. In order to cope with these problems new standards and regulations have been imposing their phase out, leaving space for LED only traffic lights, that are more efficient, durable, most with high class antiphantom rating and long lasting. During hot sunny days in the summer, the ambient temperature between traffic light housing and LED signal head may reach or slightly exceed 60°C. That is why thermal measurement is at high importance when estimating lifetime and appropriate design. During operation junction temperature of LED chip must be below (80…85)°C in order to meet the specified by manufacturer of LED chips lifetime [1, 3, 4] of over than 50000h. High working temperatures negatively affect the momentary light output and as soon as the temperature decreases the light output increases.

## 2. Problem Statement

The thermal generation and distribution in LED luminaire depends on all electrical and mechanical components as in any electronic equipment. Electronic components generate heat which is dissipated, by mechanical components. The model used to describe the thermal path of the heat generated by LEDs to ambient is presented on Fig 1.

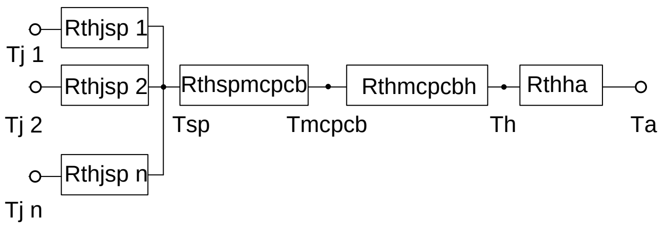


***Fig. 1*** *Thermal resistance model of multiple LED chips on common MCPCB attached to heatsink.*

$T_J$ is the temperature of the junction of each LED. $R_{th}jsp$ is the thermal resistance between junction to solder point of the LED, $T_{SP}$ is the solder point temperature, $R_{th}spmcpcb$ is the thermal resistance between solder points and metal core printed circuit board (MCPCB), *Tmcpcb* is the temperature of the MCPCB, $R_{th}mcpcbh$ is the thermal resistance between MCPCB and heatsink, *Th* is heatsink's temperature, $R_{th}ha$ is thermal resistance between heatsink and ambient and $T_a$ is the temperature of the ambient space. Temperatures are usually measured in °C or absolute temperature scales K, and thermal resistance is measured respectively in °C/W or K/W. For improving thermal conductance thermal interface material is usually applied between MCPCB and heatsink. The total thermal resistance is typically defined as "junction to ambient", or $R_{th}ja$. This indicates the ability of components to transfer thermal power. It is expressed:

(1) $R_{thja} = R_{thjsp} + R_{thspmcpcb} + R_{thmcpcbh} + R_{thha}$

Usually temperature of LED's solder point is measured and corresponding junction temperature of each LED can be calculated with:

(2) $T_j = T_{sp} + R_{thjsp} * P_{LED}$,

where $P_{LED}$ is the LED chip's power and Rthjsp is taken from the LED's data sheet.

As mentioned in introduction part, the power consumed by LED is spent on lighting and heating. The electrical power consumed by LED is a sum of the heat loses $P_{heat}$ and light output or optical power $P_{opt}$ [1, 5].

(3) $P_{el} = P_{heat} + P_{opt}$

In thermal management Pheat is used, conservatively it is assumed to be 75% of the LEDs input power [6]. This value varies with different LEDs regarding current density, brightness, etc, but is a good estimate for thermal design. The following equation shows how to calculate the thermal power:

(4) $P_{heat} = 0.75 * I_F * U_F$

In LED modules separate LEDs are soldered to a common board – either MCPCB aluminum base layer covered with ceramic dielectric and copper soldering layer, or traditional FR4 PCB with multiple copper vias under and around LED chips to improve heat conduction between upper and lower copper layers. Among the tested LED heads there were both types of boards.

In order to acquire correct values of temperatures of each led several techniques may be applied – with thermocouple probes, with infrared thermography or with using the p-n junction of the LEDs as sensors. The last method is pretty time consuming because for each LED or module the specific forward voltage – temperature relation must be obtained experimentally, but provides accurate "in situ" measurements as previously investigated [7]. And for a LED module with known relation, the procedure requires only forward voltage measurements for obtaining junction temperature.

Thermocouple probes are most common method used for measurements, and are recommended by LED manufacturers for precise measurements. [8, 9, 10]. However this method for solder point's temperature measurements has considerable disadvantages. Practically the temperature can be measured in a few points only. It is impossible to estimate temperature distribution on all LEDs in the light equipment and to verify the correctness of results, obtained by modeling and by thermal management's calculations. The assumption about $P_{heat}$ or the LED (equation (4) ) also introduces some degree of inaccuracy.

Thermal (infrared) camera measurements are convenient for quick visual representation of the heat spreading through LED system. However, using an IR camera for absolute temperature measurements can be very complex and may lead to inaccurate results. Knowing the exact emissivity of the material is crucial for accurate results, but often it is not precisely known. One way to overcome this is to take a measurement with a thermocouple and then adjust the emissivity setting on the IR camera to match these results.

## 3. Materials and methods

In order to simulate the real life operation of traffic signal heads a sequence controller based on MCU is designed. The duration of each signal is programmed according to the statutory requirements for maximum red or green signal which are 81s maximum green with 39s off time and 109s maximum red with 11s off time, where the allowable cycle is 120s.

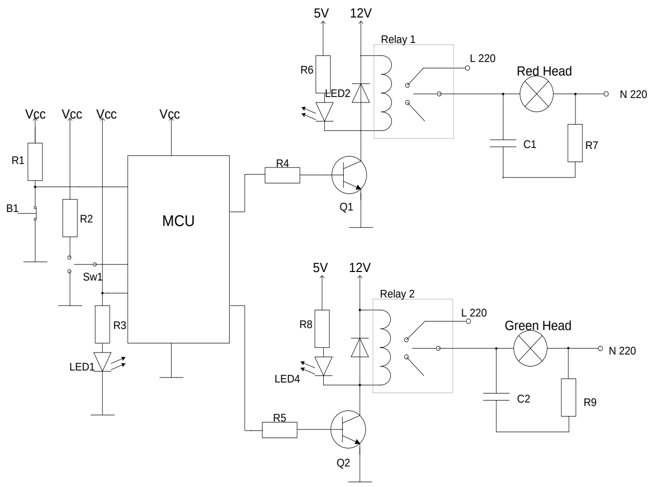


*Fig. 2 Controller for simulating traffic light sequences.*

The digital signal from the MCU is amplified by bipolar transistor and drives relays. Because it is a prototype intended to work in laboratory conditions, relays instead of triacs are used. Each relay contact is protected against sparking with RC snubber. The relays supply phase to traffic signal heads. The circuit of the controller is presented on Fig. 2. The yellow signal is not outputted because its duration is very short and practically does not generate enough heat to enter dangerous operation conditions.

When performing thermal measurements, the system under examination must be tested at worst real life conditions expected during operation. In our case the maximum ambient temperature for the LED head is measured to be 60$^{o}$C. This is the temperature inside traffic light housing during sunny summer days. To achieve this, the traffic signal heads are placed inside thermal chamber with precisely controlled and measured temperature. The experimental set up is presented on Fig. 3.

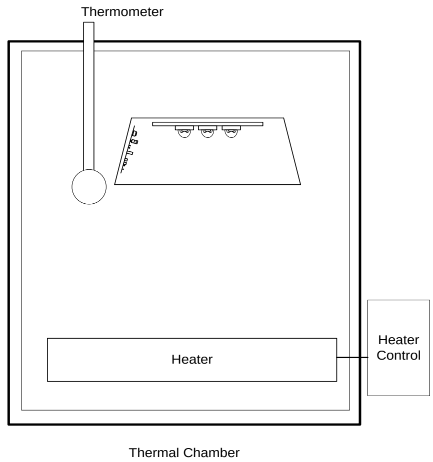


***Fig 3*** *Tested signal head in thermal chamber.*

## 4. Results

Each LED signal head is cyclically switched on and off by the sequence controller, in the chamber and left until thermal equilibrium is reached. For each one, the temperature rise for each cycle, from the time being switched on to the time being switched off is recorded. The results are presented on Fig. 4.

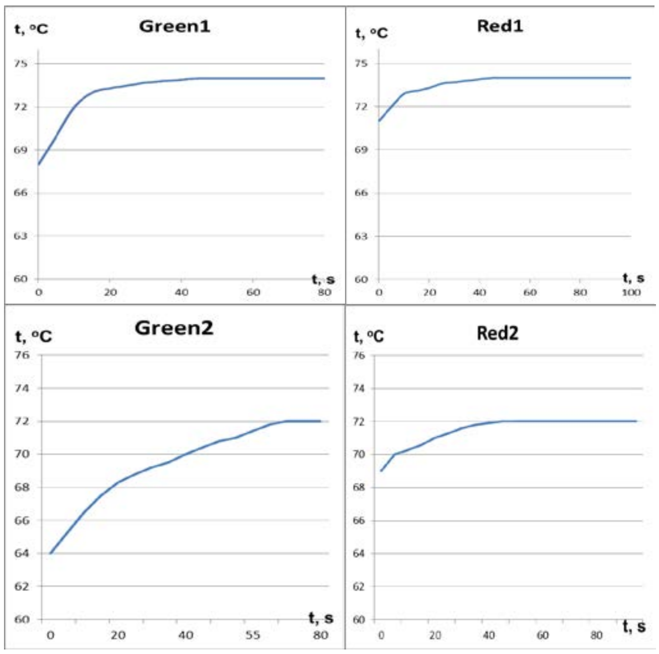


***Fig. 4*** *The rise of temperature over time for each of the examined LED heads*

Obviously the temperature reaches its maximum and stays constant for several seconds. During that time Theramal images are made using IR camera Therma Cam E300 – FLIR Systems. The thermal settings are calibrated with thermocouple sensor attached to the MCPCB with LEDs. The processed thermal images are shown on figures 5 to 12.

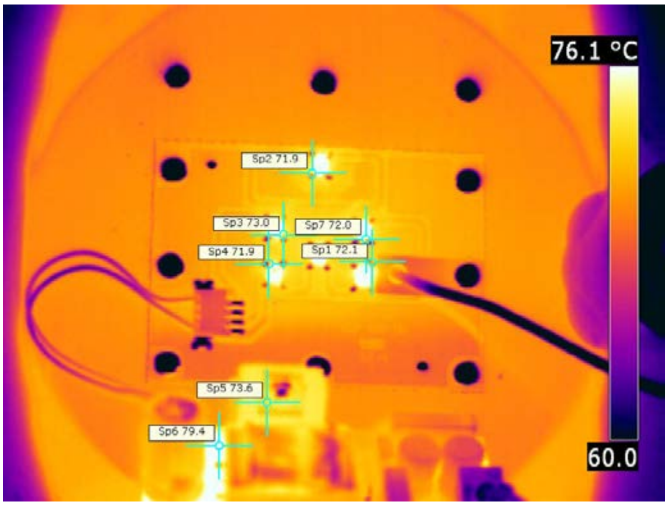


***Fig. 5**. First Green LED head at 81s on time 39s off*

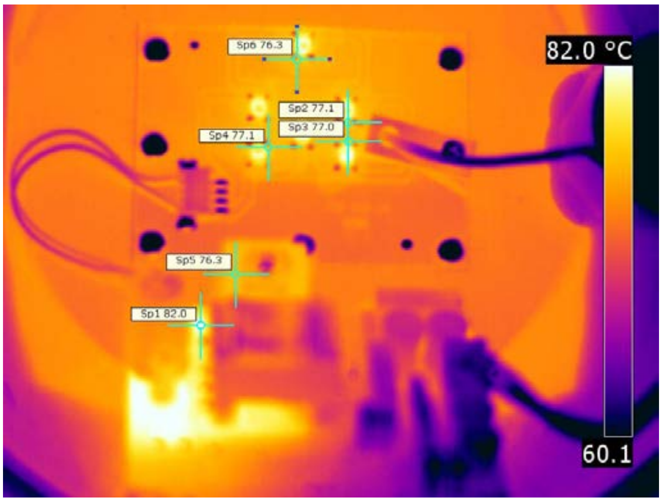


***Fig. 6.** First Green LED head at constant on mode*

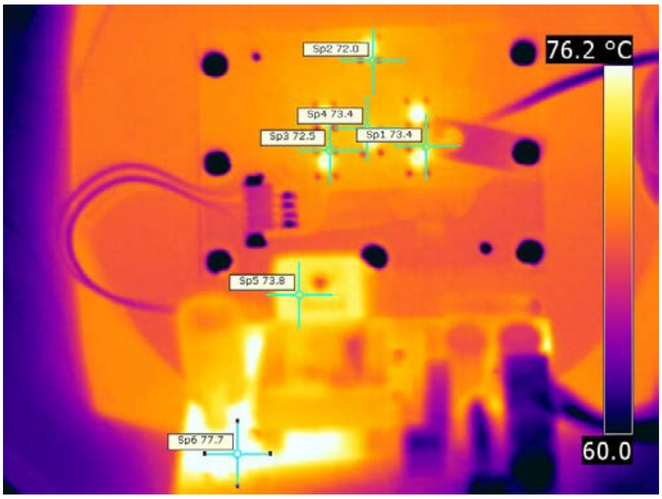


***Fig.7.** First Red head at 109s on 11s off time*

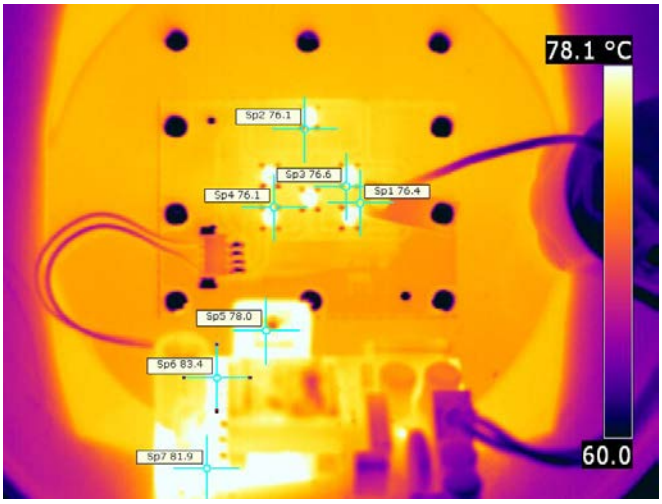


***Fig. 8.** First Red head at constant on mode*

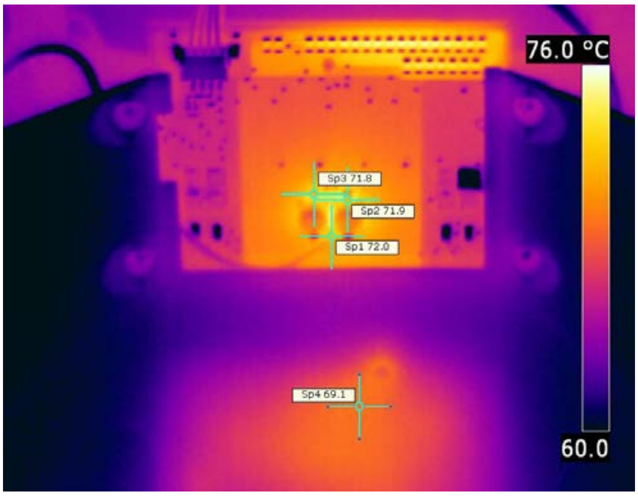


***Fig. 9.** Second Green head at 81s on 39s off time*


***Fig. 10.** Second Green head at constant on mode*

As mentioned, thermal imaging has lots of advantages during measurement, the pictures of the first group of LED signal heads (figures 5 to 8) present information about thermal load, not only for single led chips, but for some exposed driver components. It is visible that the main switching transistor does not exceed 78$^{o}$C, on its thermal dissipation plate even at constant mode (Fig 6 and Fig 8), which means less than 90$^{o}$C junction temperature which is inside safe operation limits for this transistor, specified by its manufacturer. Capacitor temperatures also stay below their limits for safe operation.

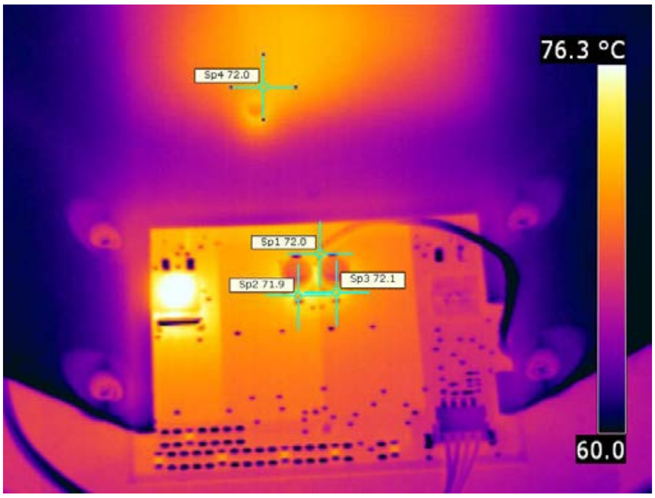


***Fig. 11.*** *Second Red head at 109s on 11s off time*

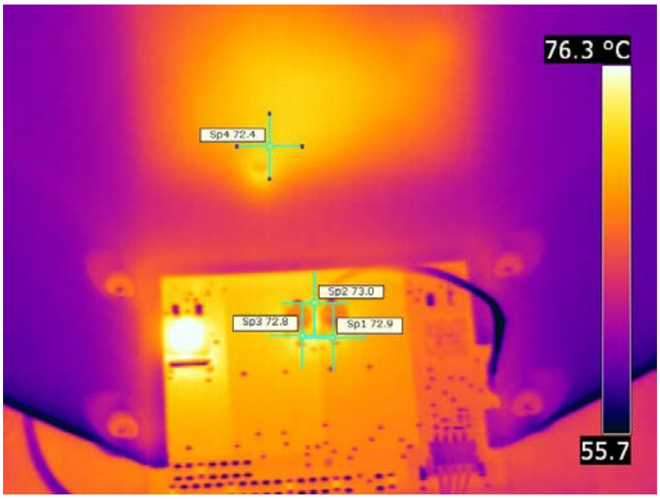


***Fig. 12.*** *Second Red head at constant on mode*

Each LED's solder point temperature $T_{SP}$ may be found from these images, something difficult to achieve with thermocouple sensors only. From solder point temperatures, the junction temperatures $T_J$ of the LEDs may be calculated using formulas (2) and (4). The results for most stressed LEDs on each signal head are presented in table 1:

***Table 1:*** *Measured solder point temperatures, and calculated junction temperatures, for the LEDs in the examined traffic signal heads.*

| LED head | Green 1 | Green 1 | Red 1 | Red 1 |
|---|---|---|---|---|
| time on, s | cycle 81 | const | cycle 109 | const |
| $T_{SP}$ °C | 72.1 | 77.1 | 73.4 | 76.6 |
| $T_j$ °C | 78.85 | 83.85 | 77.66 | 80.86 |
| LED head | Green 2 | Green 2 | Red 2 | Red 2 |
| time on, s | cycle 81 | const | cycle 109 | const |
| $T_{SP}$ °C | 71.9 | 73.5 | 72.1 | 72.9 |
| $T_j$ °C | 83.6 | 85.2 | 80.63125 | 81.43125 |

It is visible that junction temperatures do not exceed 85°C, which means those modules are expected to live at least 50000h. Only LED Green head 2 at constant operational mode slightly exceeds 85°C, but having in mind that such extreme ambient conditions of temperatures close 60°C inside traffic light housing are only present in hot summer days, the overall lifetime is not expected to be significantly affected.

## *5. Conclusion*

Thermal performance measurements with infrared thermography of 4 traffic signal heads from two manufacturers are performed. The results are good and show, that at worst ambient conditions, during cyclic operation junction temperatures of the LEDs stay below 85°C. Even at constant mode, junction temperatures are close to the safe operation zone ensuring long life service.

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