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5-FUNCTION STOP LAMP THERMAL ANALYSIS

Can DAŞDEMİR

Master's Thesis

Supervisor

Asst. Prof. Dr. İbrahim KOÇ

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The thesis titled “5-FUNCTION STOP LAMP THERMAL ANALYSIS” prepared by CAN DAŞDEMİR and submitted on 11/05/2022 has been **accepted unanimously** for the degree of Master of Science in Mechanical Engineering.

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DEDICATION

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ÖZET

5-FONKSİYONLU STOP LAMBASI TERMAL ANALİZİ

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Otomotiv aydınlatma sistemlerinde ve birçok alanda kullanılan ışık yayan diyotlar yüksek ısı kaynaklarıdır. Işık yayan diyotlarda oluşan ısı, ışık yayan diyotlara ve sisteme zarar vermeden ortamdan uzaklaştırılmalıdır.

Tez çalışmasında 5 fonksiyonlu bir stop lambasının çalışması sonucunda ışık yayan diyotlarda oluşabilecek ısı ve ışık kayıpları kontrol edilmiştir.

Hesaplmalı akışkanlar dinamiği analizinin doğruluğunu artırmak için baskılı devre kartı parçaları test edildi ve analiz sonucu ile karşılaştırıldı. Analiz sonuçlarına göre ürün parçalarında meydana gelebilecek yüksek sıcaklık değişimleri araştırıldı.

Işık yayan diyotların renklerine göre sıcaklığa bağlı ışık düşümleri incelenmiştir. Baskı devre kartı üzerindeki sıcaklığı azaltmak için, devre yollarının ve yolların yapısının değiştirilmesinin devre kartının sıcaklığı üzerindeki etkileri araştırıldı. Devre yollarının değiştirilmesi sıcaklık düşüşünü sağlar. Bakır devreyi ısı bölgesinden boşluk bırakmadan geçirmek sıcaklığı düşürür.

Anahtar Kelimeler: Stop Lambası, Sis Lambası, Sinyal Lambası, Gündüz Farı, LED Sıcaklığı

ABSTRACT

5-FUNCTION STOP LAMP THERMAL ANALYSIS

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The light-emitting diodes used in automotive lighting systems and many areas are high heat sources. The heat generated in the light-emitting diodes must be removed from the environment without damaging the light-emitting diodes and the system.

In thesis study, the heat and light losses that may occur in the light-emitting diodes as a result of the operation of a stop lamp with 5 functions were controlled.

To increase the accuracy of the computational fluid dynamics analysis, the printed circuit board parts were tested and compared with the analysis result. According to the results of the analysis, high-temperature changes that may occur in the product parts were investigated.

According to the colors of the light-emitting diodes, the temperature-dependent light drops were investigated. To reduce the temperature on the printed circuit board, the effects of changing the structure of the circuit paths and vias on the temperature of the circuit board were investigated. Changing the circuit paths provides the temperature drop. Passing the copper circuit through the heat zone without leaving a gap path lowers the temperature.

Keywords: Taillight, Fog Lamp, Signal Lamp, DRL Lamp, LED Temperature

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ABBREVIATIONS

2D	:	Two dimensional
3D	:	Three dimensional
A	:	Sectional Area
CAD	:	Computer Aided Design
Cam	:	Camera
CFD	:	Computational Fluid Dynamics
CFL	:	Compact Fluorescent Lamp
cm	:	Centimeter
Cp	:	The Specific Heat Capacity
D	:	Downward
DRL	:	Daytime Running Lamp
ECE	:	Economic Comission For Europe
FloEFD	:	Flow environment for development
Fr-1	:	Flame Retardant Kraft
Fr-3	:	Flame Retardant Cellulosic Paper
Fr-4	:	Flame Retardant Glass Fiber
Fr-5	:	Flame Retardant Cellulosic glass fiber reinforcement
H	:	Horizontal direction
hs	:	Heatsink
k	:	Heat transfer coefficient

kW	:	Kilowatt
K	:	Kelvin
Kblaminates	:	King Board Laminates
L	:	Lenght
LA	:	Luminous amber
LED	:	Light Emitting Diode
lm	:	Lumen
LS	:	Luminous super red
Luw	:	Luminous Ultra White
lux	:	Illumination level (lx)
Ly	:	Luminous Yellow
m	:	Meter
MCPCB	:	Metal Core Printed Circuit Board
mms	:	Millisecond
oz	:	Ounce
PC	:	Polycarbonat
PC+ABS	:	Polycarbonat/Akrilonitril Butadien Stiren
PCB	:	Printed Circuit Board
Pel	:	Electric Power
PMMA	:	Polymethyl Methacrylate
Q	:	Thermal energy

R	:	Right direction
R&D	:	Research And Development
T	:	Temperature
Temp	:	Temperature
tim	:	Thermal interface material
Typ.	:	Type
U	:	Up
V	:	Vertical direction
W	:	Watt

LIST OF SYMBOLS

T	:	Temperature ($^{\circ}\text{C}$)
$^{\circ}\text{C}$	:	Celsius degree ($^{\circ}\text{C}$)
K	:	Kelvin ($^{\circ}\text{K}$)
V_f	:	Voltage (v)
I_f	:	Current (A)
Φ_V	:	Luminous Flux (lm)
2θ	:	Viewing Angle ($^{\circ}$)
R_{thJS}	:	Junction Temperature ($^{\circ}\text{C}$)
Φ_e	:	Radiant Power (W)
lm	:	Lumen (cd.sr)
η	:	Light Efficiency (%)

1. INTRODUCTION

Vehicle lighting systems in today's technology are shaped according to customer needs.

With the development of lighting technology, bulbs have started to leave their place to LEDs, which have a faster response time, are more controllable, and constantly developing.

LEDs have a longer life and ease of use than traditional bulbs. Since their dimensions are quite small compared to a light bulb, they paved the way for many developments due to the space advantage in the design.

The high performance of LEDs in luminous efficiency has enabled them to enter the automotive industry quickly. While an ordinary halogen lamp has a lifespan of 2 years, LED lamps can last up to 14-15 years.

A significant cost reduction has been achieved in the sector, as the total price to be spent by automotive manufacturers for lighting during the warranty period is more affordable than halogen lamps. To protect our world, during the transition from fossil fuels to electric vehicles, halogen lamps leave their place for LEDs due to the energy consumed by halogen lamps.

The fact that the LEDs are on the Printed Circuit Board (PCB) as a module due to their structure and can be moved to the desired position in terms of optics has brought a more innovative perspective for the designers and has eliminated the familiar patterns in halogen lamps. Thus, more original designs have emerged.

The biggest problem with LEDs is that they convert 70%-80% of the energy they use into heat. This heat can cause serious damage to the LEDs. Or it can endanger our lives while driving. The heating of the LEDs can cause up to 90% loss in their optical values.

The lighting product may be damaged and melted by this heat. To prevent all these negative situations, it is possible to obtain a safer product by making thermal analyzes during the design phase.

Otherwise, can cause many losses such as plastic injection mold costs, which cost hundreds of thousands of dollars.

The following methods are used to keep the thermal performance of the LEDs stable.

- a. Metal-core printed circuit board
- b. Use of heatsink
- c. Fan use
- d. Use of liquid cooling systems
- e. Peltier use
- f. Use of temperature resistant led
- g. Use of thermal paste
- h. Blinking of LEDs in short 200-300 ms intervals

Figure 1.1 shows the liquid cooling system used for cooling high-performance LEDs. During the active cooling of the LEDs, unwanted fan noises may occur. This may cause a loss of comfort.



Figure 1.1: Liquid cooler [1].

Figure 1.2 shows the thermoelectric peltier used in situations where the sound of the LED cooling system should be low.

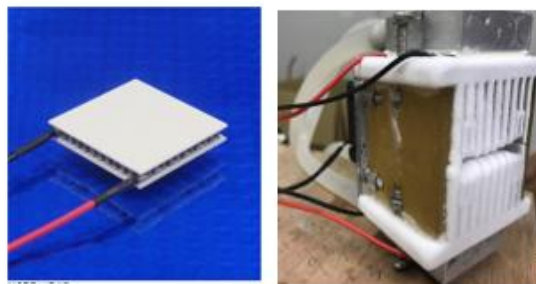


Figure 1.2: Thermoelectric peltier [2].

PCB is designed by R&D. While designing the PCB, the R&D team works together with the optical-mechanical design-electronics and analysis team.

The optical team decides how many lux should be in line with the customer's request. The optical team makes the selection of LEDs and by designing the optical surfaces of these LEDs, it provides light at a suitable value and position. A minor error in the optics causes the system to send the light to the wrong location. For example, when headlights are on, may cause an accident for the driver of the oncoming vehicle due to light deviation.

The mechanical design team designs the part design based on the exterior trim by creating the mounting places according to the location of the vehicle and makes the material selection according to the environment in which the part is used.

The electronics team carries out the desired functions of the LEDs by providing vehicle and PCB transmission and choosing the appropriate electronic equipment.

The analysis team analyzes the information it receives by creating a mesh model in a computer environment and evaluates the results.

The main goal of this study is to provide thermal designs of LEDs and to ensure that the heat-induced deformations of the products at the design stage are usable without changing the functionality and performance characteristics of the product.

1.1 THE THESIS FLOW CHART

The thesis flowchart shown in Figure 1.3 was used for the realization of this thesis.



Figure 1.3: Thesis flowchart used in the realization of this thesis

Figure 1.3 shows the flow chart created for problem solving. After the analysis is verified, the problem points are solved through the analysis, and the final design is reached.

1.2 PROBLEM DEFINITION

LEDs have become a part of our lives in the field of lighting. It is widely used especially in the automotive industry. LEDs are more unstable devices than bulbs. When inserting a bulb into the socket, the amount of heat it generates is certain and can easily measure the heat outside the bulb. Since LEDs are circuit elements, the amount of heat and light that occur in the LED be different depending on the structure of the circuit created. Briefly, the same LED shows different heat and light values in two different circuits.

In thesis is to examine the effect of the air flow on the LED in a system with a total of 72 LEDs and to take precautionary measures against the errors that may occur in the PCB boards. Test conditions were determined to 70 °C to see the worst effect. The PCB boards and LED numbers used are given in Table 1.1.

Table 1.1: The PCB boards and LED numbers.

PCB BOARD NAMES	TOTAL LED
Stop PCB board	8
Reverse PCB board	6
Signal PCB board	10
Fog PCB board	8
Upper parking PCB board	21
Lower PCB board	21

The LEDs on these cards should not operate above 150 °C. If the LEDs work over this maximum temperature, which calls the Junction temperature, for more than a certain hour or in the case of higher temperature, the LED first reduces the amount of light, then the LEDs turn off to protect themselves.

The heat generated during the operation of the LEDs can cause damage to the surrounding parts. Especially for plastic parts, the softening temperature is extremely important in order not to damage the part. A plastic part holding the PCB board cannot show a high resistance feature over the softening temperature and may distort the position of the LEDs during movement or due to vibration, or cause a fire in the vehicle by contacting the LEDs with a combustible part. Therefore, the raw material of the plastic material to be used should be selected by foreseeing the temperature to be formed.

LEDs are vital during vehicle driving. It protects us against accidents by giving a visual warning to the drivers in front of us when the brake is pressed during right and left turns or at the moment of stopping.

During the operation of the LEDs, a high rate of heat is generated depending on the amount of current and volts use. With the effect of this heat, there is a serious decrease in the light value of the LED. As this situation that occurs while driving prevents us from warning other drivers, it endangers the lives of us and other drivers. With the analysis and tests to be made before these problems occur, can prevent the errors that may occur by testing the system under the worst conditions. Rear lighting system parts for passenger cars are shown in Figure 1.4.

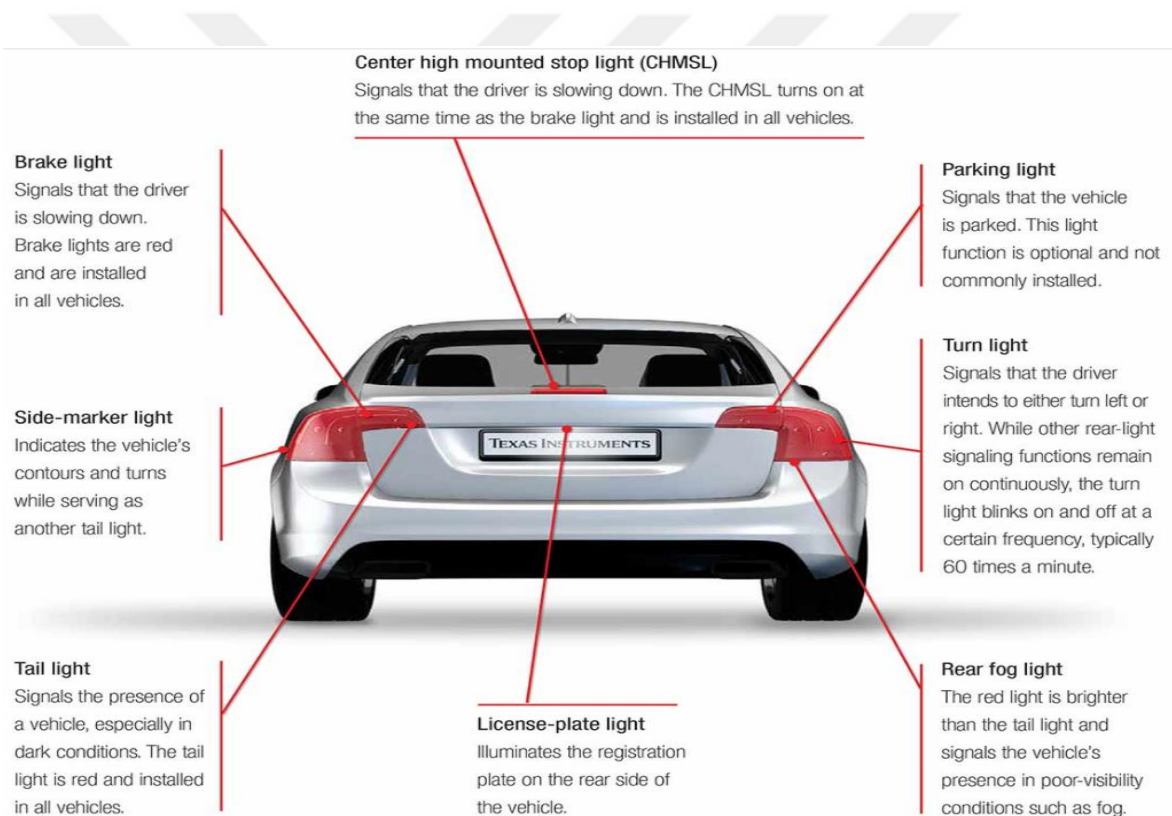


Figure 1.4: Signal lamps [3].

1.2.1 PCB Card Locations

PCB positions are shown in Figure 1.5. There are 6 cards in total in the system.

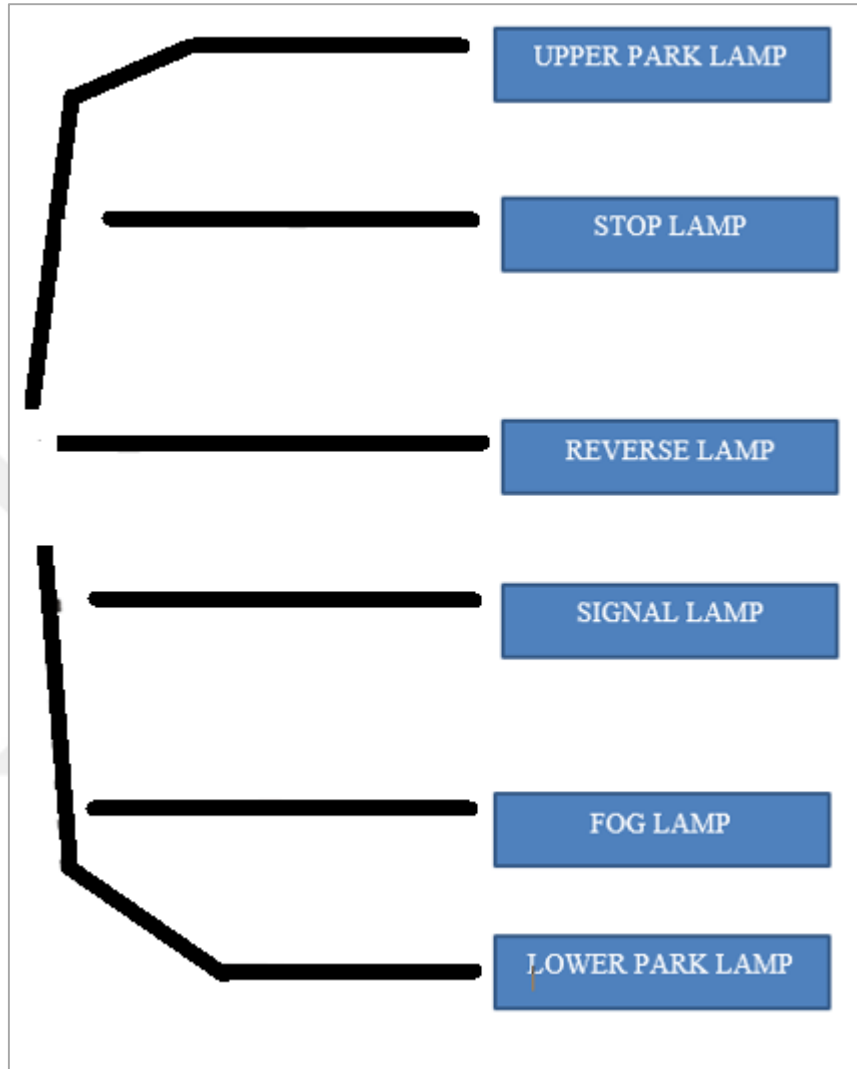


Figure 1.5: PCB card locations.

The order of the PCB circuit is determined according to the customer's request. To minimize the temperature distributions on the model, the parking LEDs, which are in the open position, are distributed over a wide area and the heat effect created is minimized. The LEDs with a wide-angle provide more illumination with less power.

1.2.2 Schematic View of the Problem in Park and Stop Positions

Step 1 all parking PCBs and stop lamp are on and other PCBs are off. The heated air passes through the plastic channels and collects at the top. Since there is no outward air flow in the

upper part, the parking PCB system starts to heat up. The hot air accumulated in the upper part combines with the stop lamp and tries to melt the existing plastic. Figure 1.6 shows the situation when the stop lamp and the DRL lamp are on.

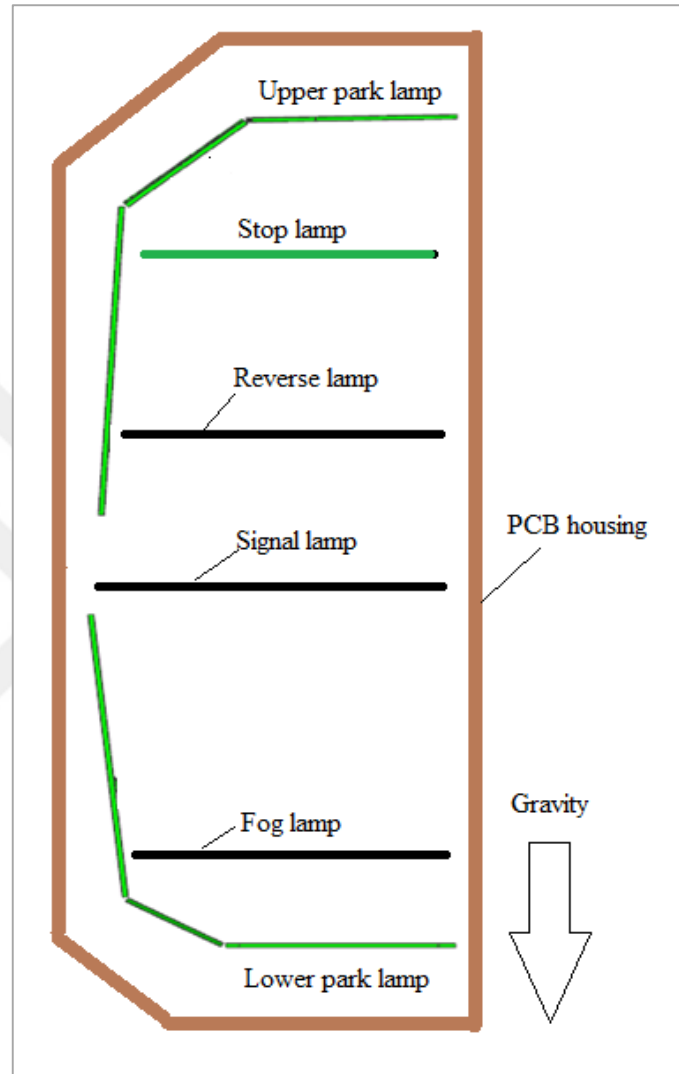


Figure 1.6: Schematic view of the problem in park and stop positions.

The green lines show the PCB circuit in the open state. The black lines show the PCB board in a closed state. The brown lines show the housing where the PCB circuit is attached. The hot air rises from the open PCB circuits in the opposite direction to the gravity direction.

1.2.3 Schematic View of the Problem in Park and Reverse Positions

Step 2 all parking PCBs and reverse lights are on and other PCBs are off. Since the air heated by the reverse lamp is blocked by the stop lamp, the heated air comes back on the reverse. Figure 1.7 shows the situation when the reverse lamp and the DRL lamp are on.

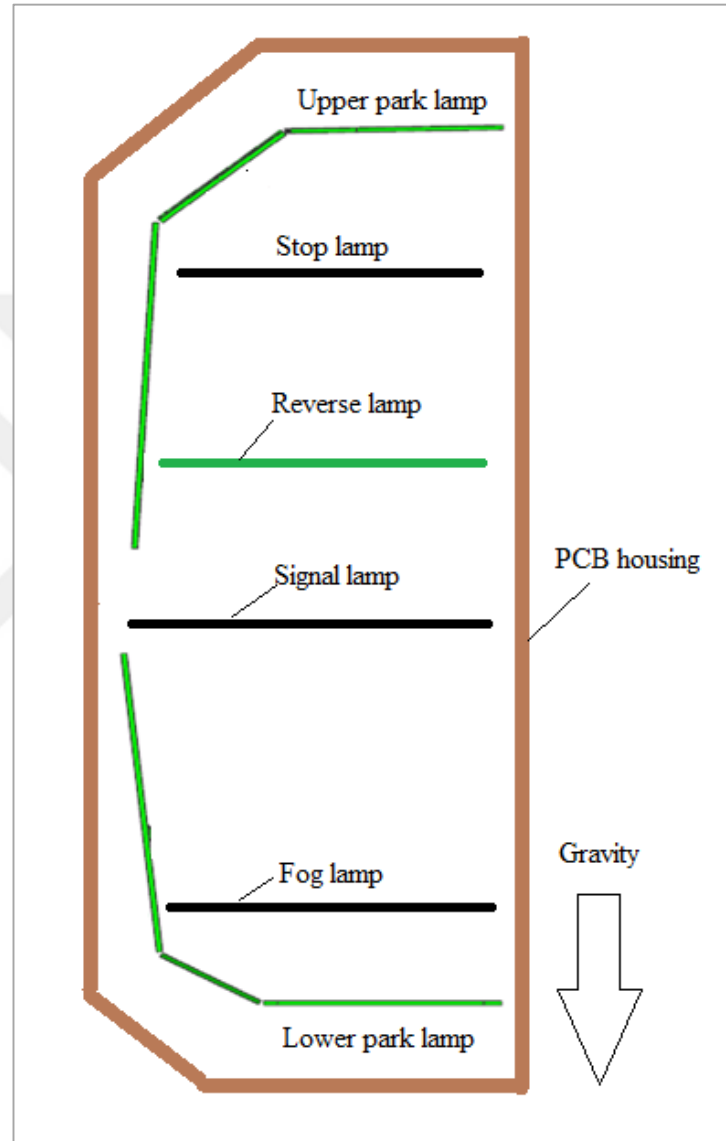


Figure 1.7: Schematic view of the problem in park and reverse positions.

The green lines show the PCB circuit in the open state. The black lines show the PCB board in a closed state. The brown lines show the housing where the PCB circuit is attached.

1.2.4 Schematic View of the Problem in Park and Signal Positions

Step 3 all parking PCBs and signal lamps are on and other PCBs are off. Since the air heated by the signal lamp is blocked by the reverse lamp, the heated air comes back on the reverse. Figure 1.8 shows the situation when the turn signal lamp and the DRL lamp are on.

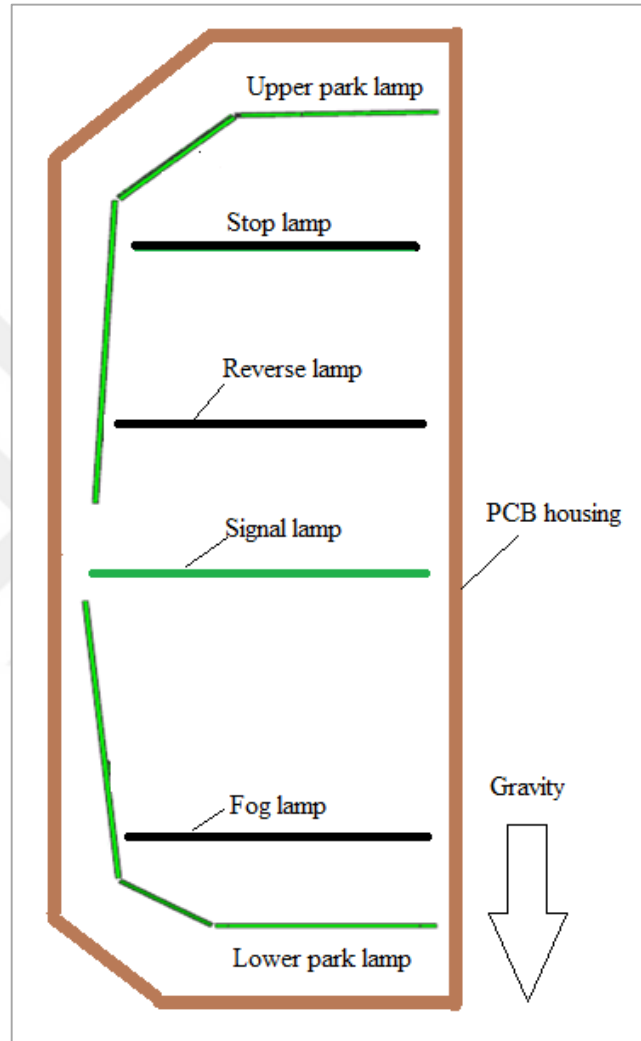


Figure 1.8: Schematic view of the problem in park and signal positions.

The green lines show the PCB circuit in the open state. The black lines show the PCB board in the closed state. The brown lines show the housing where the PCB circuit is attached.

1.2.5 Schematic View of the Problem in Park and Fog Positions

Step 4, all parking PCBs and fog lamp are on and other PCBs are off. Since the air heated by the fog lamp is blocked by the signal lamp, the heated air come over the fog lamp again.

Park PCB heats the fog lamp more because it is in the lower position. Figure 1.9 shows the situation when the fog lamp and the DRL lamp are on.

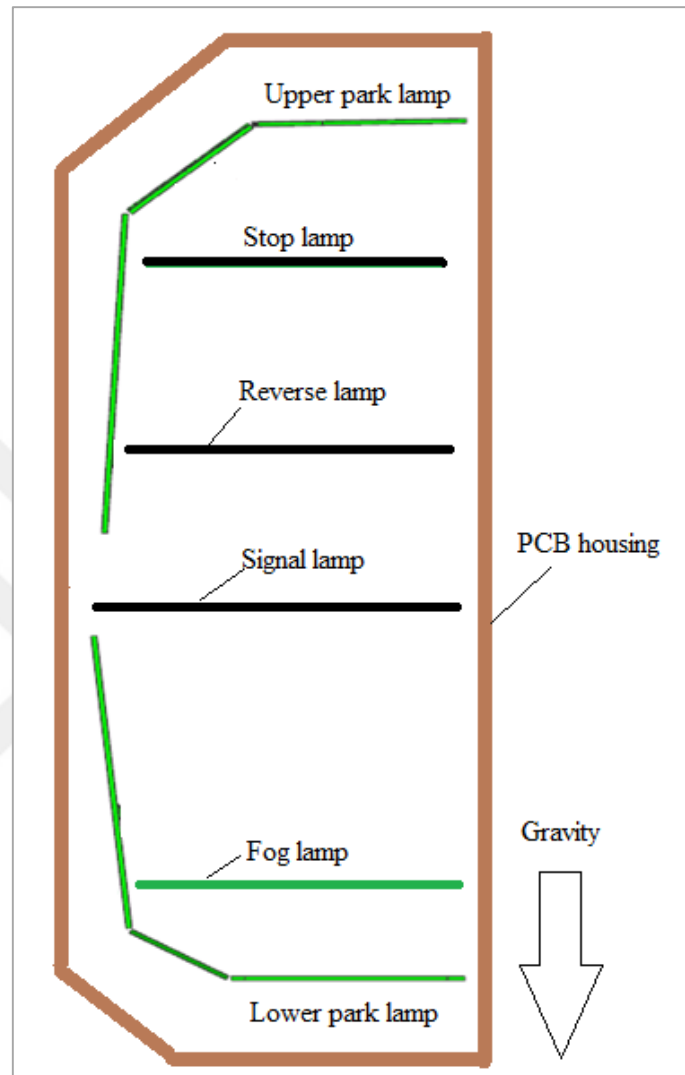


Figure 1.9: Schematic view of the problem in park and fog positions.

The green lines show the PCB circuit in the open state. The black lines show the PCB board in the closed state. The brown lines show the housing where the PCB circuit is attached.

1.3 LITERATURE RESEARCH

With the introduction of LEDs into human life, it has become more used in a number of concepts such as lux and lumen to explain LED properties. A lumen is the amount of light that a light source transmits perpendicularly to a 1 m² surface located 1 meter from the center. The illumination created by this light source in a unit area is defined as lux. As can be seen

in Figure 1.10 while the lumen value in the lighting device is constant, the lux value changes as the light source move away from the environment or get closer.

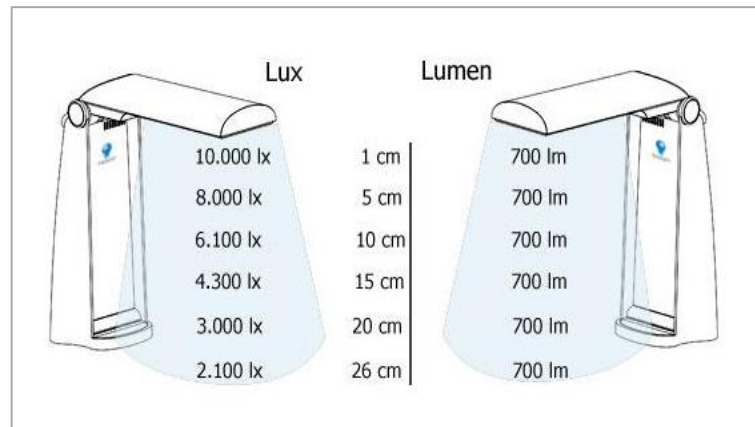


Figure 1.10: Lux and lumen comparison [4].

As seen in Figure 1.11, Lux is defined as the luminous flux per unit area (1 m^2) "It is the luminous intensity of a light source of 1-candela intensity, located at the center of a sphere with a radius of 1 meter, on the surface of a sphere of 1 square meter." [4].

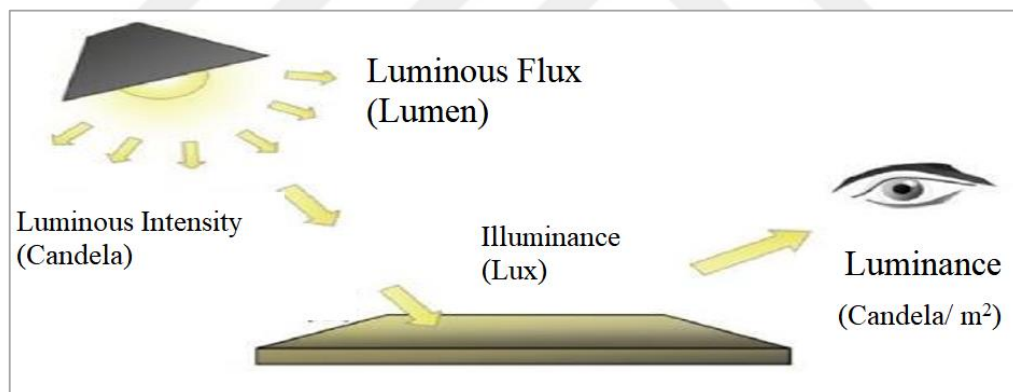


Figure 1.11: Illuminance and luminance comparison [5].

In Figure 1.12, the energy efficiency of lighting products changing over the years can be seen. Today, the efficiency of lighting products; Incandescent lamps perform at around 16 lm/W, fluorescent lamps over 70 lm/W, and LEDs over 120 lm/W [6].

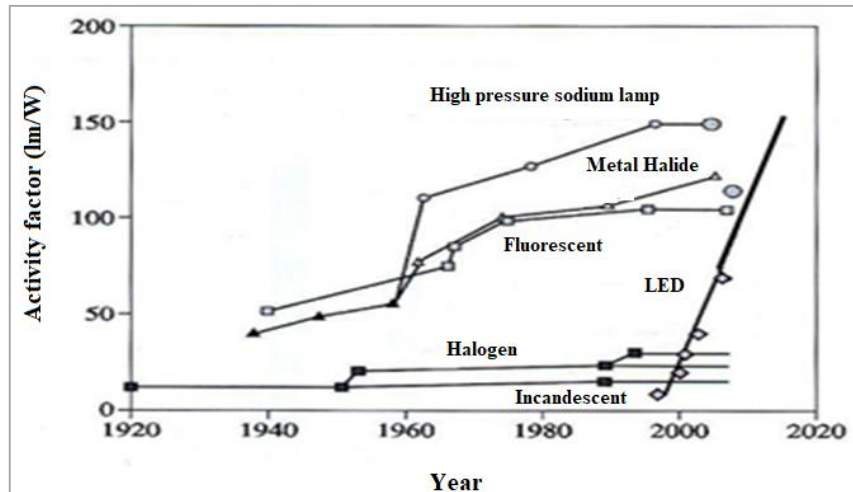


Figure 1.12: Efficiency of lighting products [6].

Figure 1.13 shows the lighting effect of increasing lux value.

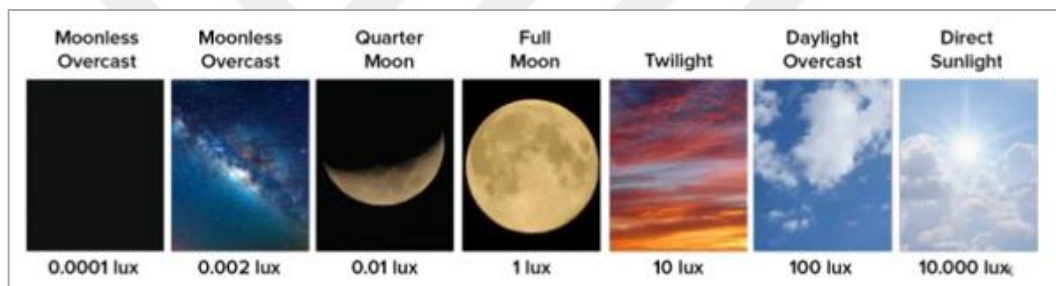


Figure 1.13: The lighting effect of increasing lux value [7].

The human eye has the highest sensitivity to green light (the ideal monochromatic 555 nm source) at 555 nm. The photopic curve peaks at 555 nm, i.e., green. Using one Watt of power at this wavelength, a maximum of 683 lumens of light can be produced at one hundred percent efficiency [7].

Figure 1.14 shows the illuminance effect of increasing lumen value.

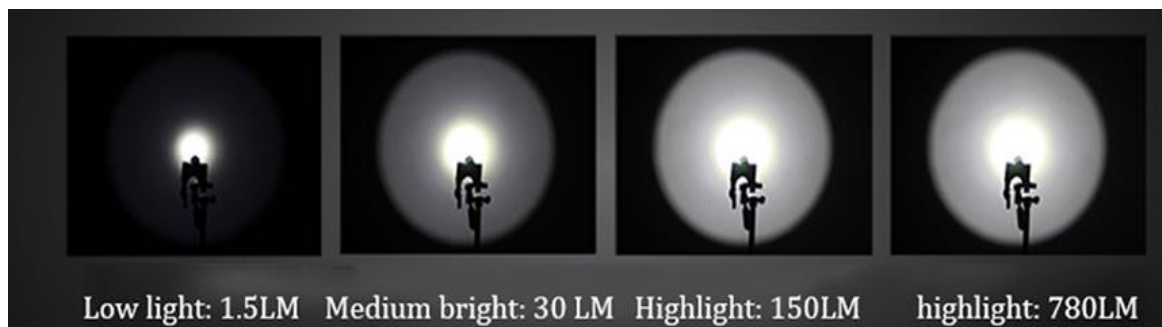


Figure 1.14: The illuminance effect of increasing lumen value [8].

The theoretical limit for the lumen/watt ratio is 683 lumens. If it is desired to achieve the same brightness in white, more power is needed. Increasing the power value too much can reduce the luminous efficiency. A theoretical limit of 400 lm/W is acceptable for white LEDs. The efficiency of a luminaire; It is the ratio of the amount of light coming out of the luminaire to the electrical power consumed by the luminaire. This is called the efficiency factor and its unit is lm/W [9]. Figure 1.15 shows the changes in the light efficiency according to the developing technology.

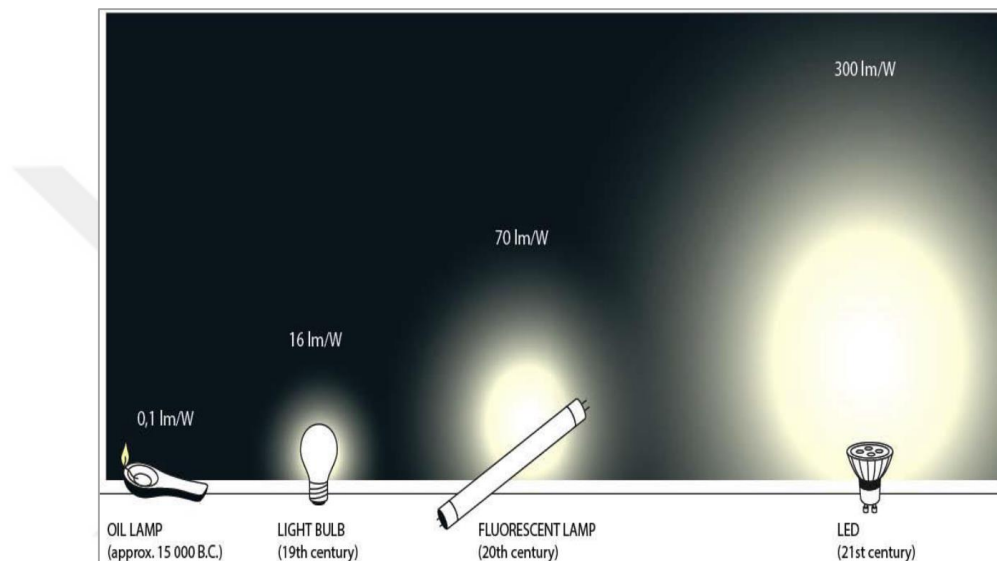


Figure 1.15: The changes in the light efficiency according to the developing technology [10].

The parts that make up the vehicle lighting group consist of parts such as the main body, outer lens, reflector, PCB, and glass. Each of these products has a different light absorption rate. This affects to use of all the light get from the LED. In figure 1.16, the main body, PCB, reflector and outer lens are seen from the parts used in the lighting system.

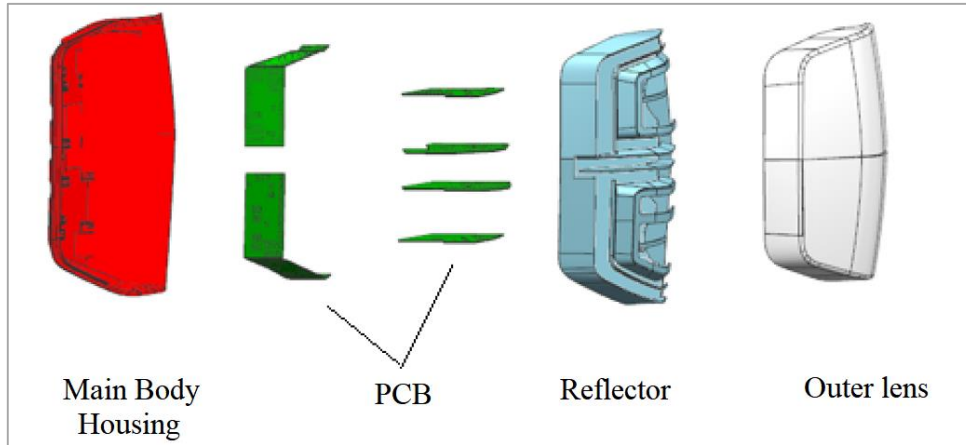


Figure 1.16: The parts used in the lighting system.

The light emitted from the LED is reflected from the reflector. The reflector ensures that the scattered light is collected and reflected towards the focal point. As the light passes through the lens, some of the light is absorbed by the lens. Also, there are losses in these absorption and reflection values due to the production of plastic parts. This loss rate is calculated as 30% in order not to cause any errors while making LED lighting calculations. Parts produced in plastic injection molds such as lenses cannot fully provide the values given by the raw material manufacturers depending on the part geometry, based on 30% more than the required lux value in order not to be affected by this situation [8]. Figure 1.17 shows that the light reflected from the reflector passes through the lens.

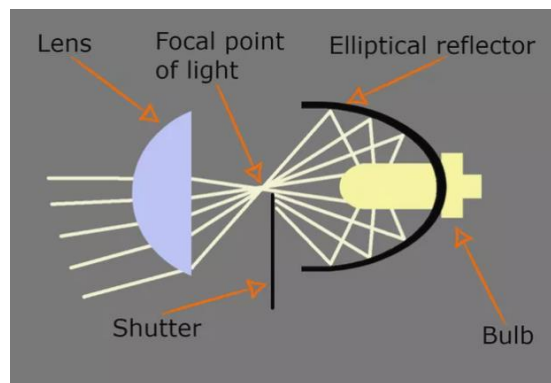


Figure 1.17: Light reflection [11].

Figure 1.18 shows the changes in the life of the white LEDs in response to a temperature increase of about 10 °C.

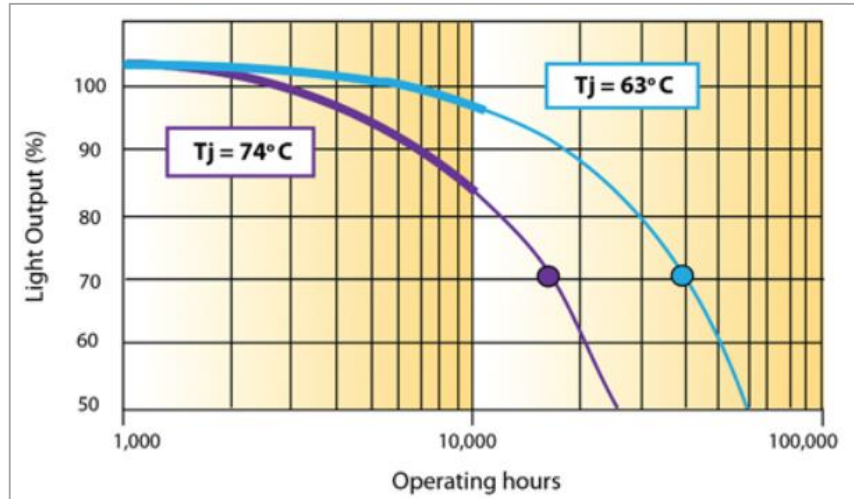


Figure 1.18: The changes in the life of the white LEDs in response to a temperature increase of about 10°C . [12].

A life expectancy increase of more than 20 000 hours occurred with the decrease in temperature in the graph. The point to be noted here is that this ratio varies according to the brand and model. For a 150°C temperature resistant LED, this temperature increase is not very important, while for a 100°C temperature resistant product, a 10°C temperature increase is of vital importance [12]. In automotive applications, analysis and tests are performed by assuming the ambient temperature of 80°C . That's why need to use LEDs with a temperature of at least 125°C as the junction temperature.

Babus'Haq and friends stated that a decrease of 10°C in LED temperatures affects the lifetime of the LED in half [13]. However, this value may vary depending on the type of LED and the maximum junction temperature, considering today's applications. In short, it is not possible today.

When the bulb's lifetime is over, the product continues to be used by simply changing the bulb. Since the LEDs are usually soldered on the PCB, the mainboard should be replaced in case the LED fails. This can be considered a serious waste of money. While designing LEDs, studies are being carried out to minimize the temperature of the LED and maximize the light efficiency.

The temperature increase of the led connection causes a significant decrease in the LED light flux. Of the light source colors used, blue is one of the colors that are least affected by the temperature increase. For the blue color, 8-12% light loss occurs in the temperature range of

-40 °C and 150 °C. Red and its tones are affected by the temperature increase up to 80-90%. After a certain temperature increase, the LEDs turn off by protecting themselves. The effect of LED colors by temperature can be visibly controlled. This issue is extremely important as it is used in red color stop lamps in automotive applications [14].

Figure 1.19 shows the temperature-dependent light drop in the LED colors.

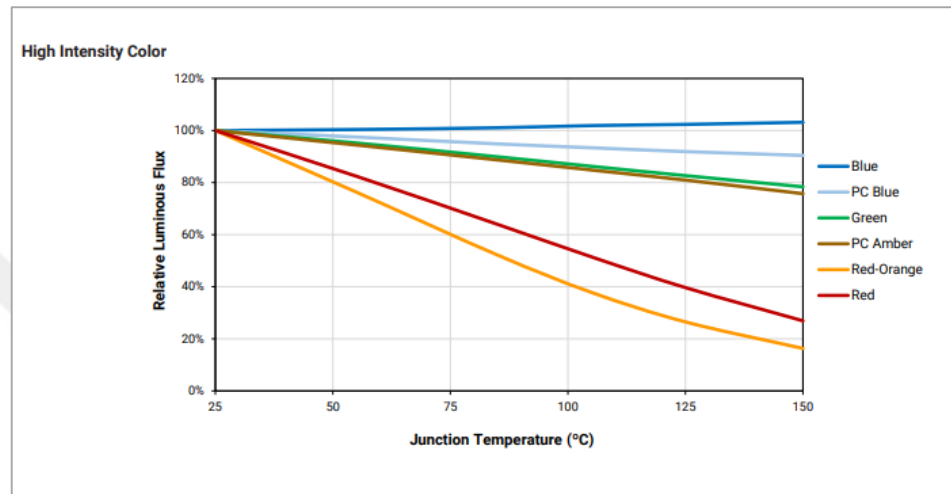


Figure 1.19: The temperature-dependent light drop in the LED colors [14].

Orange and red LEDs are the LED colors that are frequently used in automotive. The color most affected by temperature is orange [14].

The important parameter for LEDs is the junction temperature. The value of the junction temperature directly affects the life, lighting power, and photometric value of the LED [15].

Adrian Plesca investigated the effects of the position and number of PCB vias on thermal resistance. Within the scope of the study, the positions of the vias did not change the led junction temperature, while the increase in the number of vias decreased the junction temperature. However, when the Via positions come to the lower part of the Led part, the decrease in the temperature of the system can be measured in terms of thermal [16].

Huber made studies to examine the effect on the thermal resistance of the system by using different materials between Led and PCB. As a result of the studies with MCPCB and Fr4, it has been seen that the aluminum-based MCPCB circuit improves the temperature of the system by 30% compared to the Fr4 circuit [17]. By adding fins to the PCB, he tested the

performance of the system according to the fin positions and reported that the thermal resistance of the system is lower for the fins with vertical air flow.

Cheng and friends with CFD analysis, it has succeeded in reducing the thermal effects of the LEDs on each other by changing the positions of the led circuits in their location. The regions that the LEDs heat through the copper areas increase the junction temperature of the other LEDs. They optimized the temperature distributions in the computer by trying various variations. The temperature of the system can be lowered by separating the zones under the influence of heat [18].

Filipuzzi and friends examined the air flow paths in the automotive lighting group by performing CFD analysis on the sheds and directed the air by making design changes at the points where the hot air came. In this way, the design could be changed without interfering with the mold during the design phase [19].

İrfan Kamaş et al. in the study of taillights with light curtains has made efforts to increase the optical and thermal efficiency of the system by using the least number of LEDs to reduce energy efficiency and cost. By making design improvements in the position where the LEDs are placed optically, air channels were opened and the heated air was tried to be evacuated from the system [20].

İbrahim Ozdil analyzed the number of via holes and the hole diameters in his studies on the led circuit board and made the optimization of the copper roads. Optimization of copper paths significantly affects the heat conduction mechanism to the bottom plate [21].

Mehmet Aktaş examined the effects of light drop and temperature increase on other plastic parts in the cooled and uncooled designs of automotive headlight groups. While 510 lumens of light can be obtained on the uncooled circuit board, it has been seen that the light values increase at the level of 562 Lumens by cooling the LEDs. Thanks to low junction temperatures, an increase in the life of the LED occurs [22].

Bilge Yanık Bekar shaped the design of the air flow trajectories he saw in the optical-mechanical analyzes in his headlight system design for military vehicles. She reduced the thermal effects of the LEDs with optical and thermal analyzes based on homologation tests [23].

Efecan DUZYER has made thermal and air flow analyses for DRL and fog lights according to their position in the vehicle. Condensate hole has been added to the design according to the flow trajectory of the air [24].

Schäfer R investigated the voltage drops of red and white LEDs against temperature. While it is around $-2 \text{ mV}/^{\circ}\text{C}$ for Al-In-Ga-P based LEDs producing red/orange color light, it is around $-3 \text{ mV}/^{\circ}\text{C}$ for In-Ga-N based blue/white color light producing LEDs [25].

Min Seok tried to reduce the thermal effect that may occur on the led by using a Fr4 and MCPCB. He tried to reduce the thermal effect created by a single led with multiple LEDs [26].

1.4 LED ENERGY EFFICIENCY

The heat transfer rates in light sources have also changed with the developing technology from traditional light sources to the present day. Figure 1.20 shows the comparison of energy efficiency and lumen values of traditional lamps and today's LED technology.

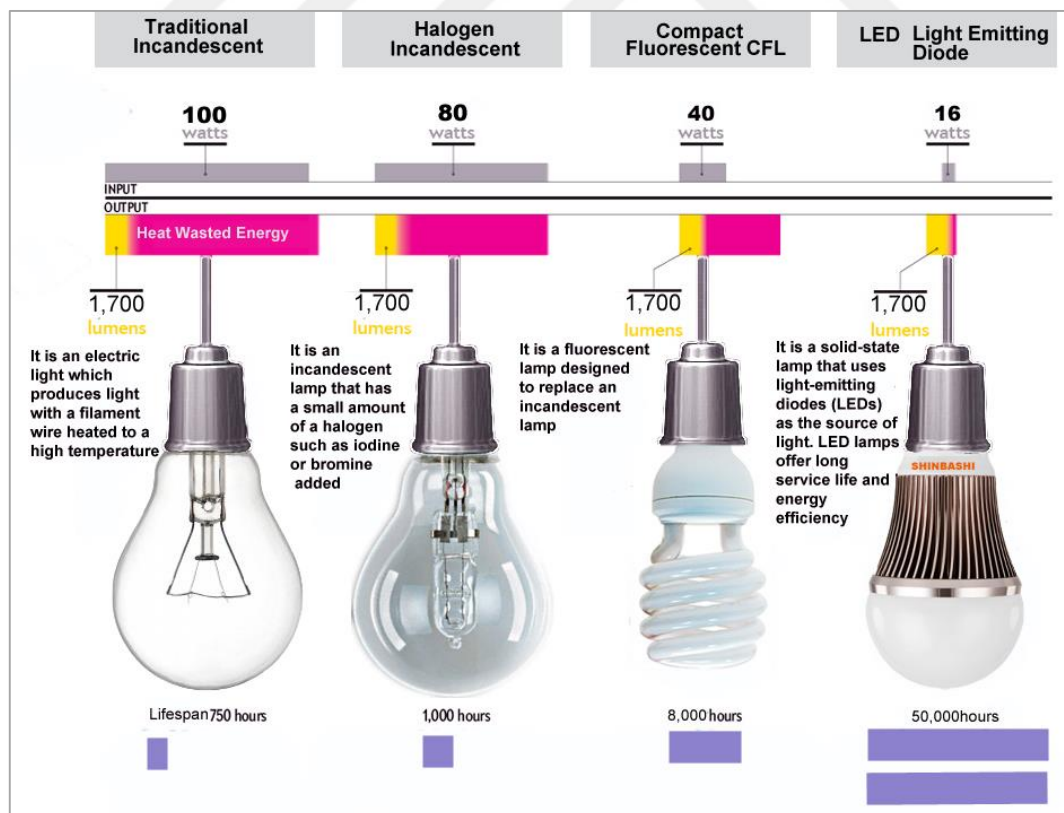


Figure 1.20: Led energy efficiency and usage time [27].

While the lumen value required to emerge when the light in the first light sources, which is formed by heating the tungsten wire in halogen lamps, is created by irradiating with radiation, this rate has increased to 120 lm/W thanks to the led technology. While heat transfer by conduction has the least effect in light sources such as incandescent and halogen lamps, heat transfer by conduction is extremely important in led and CFL technology. Only 2% of the heat energy produced by the LEDs is lost by radiation, while the remaining part is approximately lost. They lose 75% through heat. They use about 23% of energy to illuminate the environment, but since this energy is distributed from a small point to a large area, calculations are usually neglected in the calculations. This causes them to have a different cooling system [27].

Figure 1.21 shows the effect of temperature change between two different walls.

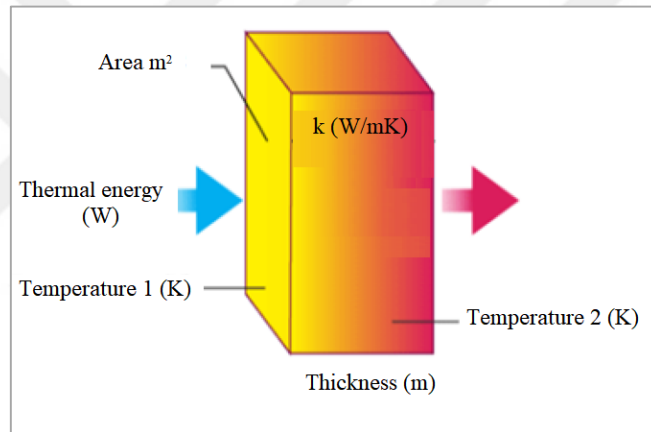


Figure 1.21: Schematic view of conduction heat transfer [28].

Keeping the LED temperature below a certain level increases the LED efficiency and LED life. To control the LED temperature, the LED and cooling system should be selected according to the environment to be used. Heat conduction equations can be used to determine the temperature of the LEDs. Eq. (1.1) is known as the heat conduction equation

$$Q = k \cdot A \cdot \frac{(T_2 - T_1)}{L} \quad (1.1)$$

Since there is heat transfer in the LEDs by conduction, the points to be considered in the calculations are the amount of heat energy transmitted per unit time in the unit area Q (W), the temperature differences of the faces in the unit area $(T_2 - T_1)$ It is directly proportional to

the surface area A (m^2), and the heat conductivity coefficient of the material k (W/mK), while it is inversely proportional to the distance $L(m)$.

In short, need to keep the material thickness to a minimum and increase the surface area so that can remove the heat from the environment in the fastest way.

1.5 LED THERMAL RESISTANCE

Figure 1.22 shows the thermal resistances occurring in the PCB circuit.

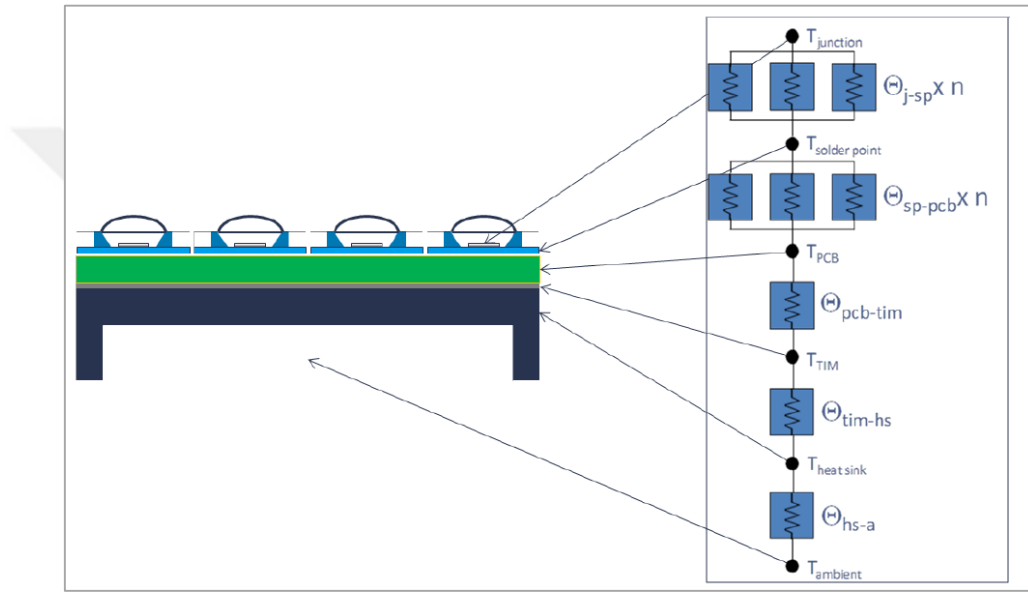


Figure 1.22: Schematic view of the thermal resistances occurring in the PCB circuit [29].

The thermal model of an LED system can be calculated by analogy to the series and parallel resistor model used in the electrical circuit. To show the thermal path that the heat creates; the heat is transmitted to the junction point starting from the led case point. Then it is transmitted from the led solder point to the PCB surface and then to the cooling element with the thermal interface material.

In Figure 1.22, T is the temperature($^{\circ}C$) at location, Θ_{a-b} is the thermal resistance ($^{\circ}C/W$), n is the number of LED components on a single PCB, T_a is the temperature ($^{\circ}C$) at point “a”, T_b is the temperature ($^{\circ}C$) at point “b”. Eq. (1.2) is known as electrical power

$$P_t = 0.75 \cdot V_f \cdot I_f \quad (1.2)$$

Where V_f is LED voltage(V), I_f is LED current (A)

The temperatures that the LEDs can reach can be calculated by creating a model such as a series-connected resistor model.

Table 1.2 shows thermal resistance values between Junction point and solder point on different colored LEDs.

Table 1.2: LED color and junction to solder point thermal resistance [30].

Characteristics	Thermal resistance (°C/W)
Junction to solder point • High Density white	6
Junction to solder point • High intensity white	7
Junction to solder point • Royal blue	4
Junction to solder point • Blue, PC blue	6
Junction to solder point • Green, PC amber	7
Junction to solder point • Red-Orange, red, HE photo red	5

Thermal resistance can be defined as the ratio of the amount of heat transferred between two surfaces to the transferred energy. While this rate was 120 °C/W in the first LEDs produced, this ratio has been reduced to 4-5 °C/W in today's technology. The easier it is to lower the temperature on it [30].

1.6 USE OF LEDS IN AUTOMOTIVE

The use of LEDs in the automotive industry has led to many changes in vehicle aesthetics.

Since LEDs are smaller circuit elements than halogen bulbs, they provide dimensional freedom to designers in style work.

Since halogen bulbs are elements that give 360° light, optically directing and controlling the light is more difficult than LEDs. The angle of light exposure of LEDs is approximately 120°. The light can be spread evenly through optical surfaces by avoiding unnecessary light losses. Response times of LEDs are much shorter than halogen bulbs. While the LEDs can be controlled at the level of 5 ms, this rate is around 300 ms in halogen bulbs [31]. These extraordinary response times of the LEDs can quickly warn the vehicle behind us in sudden brakes. The time to emit light with full efficiency in halogen bulbs is quite high compared to LEDs. Therefore, LEDs are faster in vital parts such as stop lamps and are preferred

because of their efficient response times. Figure 1.23 shows the allowable maximum pulse range of different LA G6SP 0.1 code LEDs. where I_t indicates the current value of LED and D indicates the ratio of the on-off time.

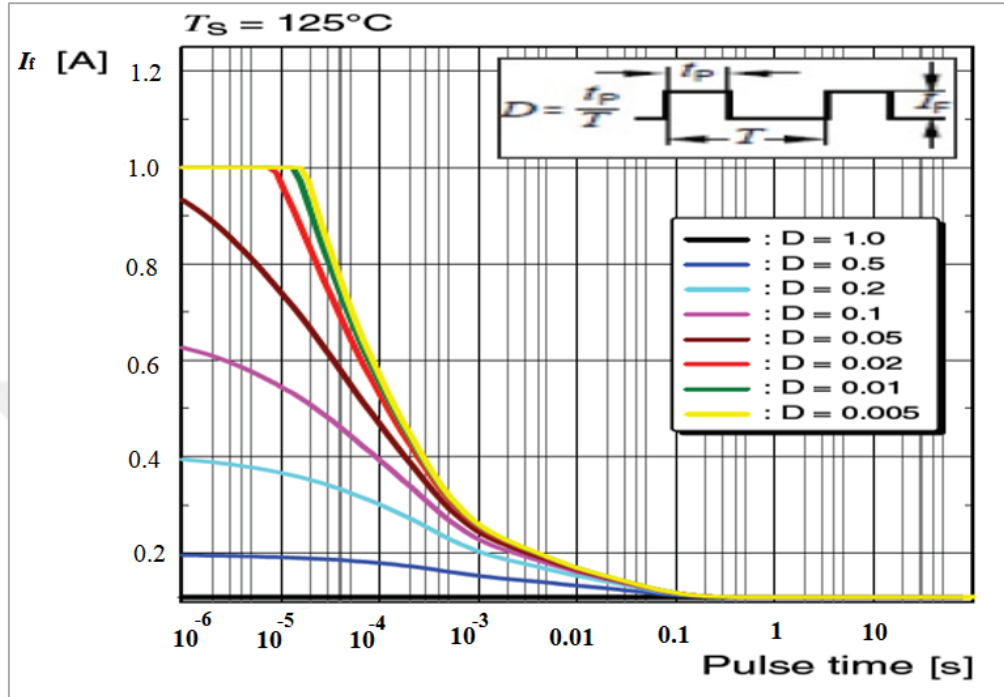


Figure 1.23: The allowable maximum pulse range of different LA G6SP.01 [31].

When the LEDs are driven with Pulse, on-off is done. This reduces the LED temperature.

1.7 LED COLORS AND THERMAL EFFECT

The light-emitting part of the LEDs consists of semiconductor material pairs (Al-In-Ga-P or n-Ga-N.) that call the case. It creates a heat transfer at the junction point in the lower region. In the constant current condition, the temperature increase at the led case point of the high-energy electrons passing from the case region to the junction region causes the potential difference on the chip to decrease by 0.2-0.3 volt according to the characteristics of the semiconductor material of the led.

While Al-In-Ga-P-based LED chips produce red and orange colors, In-Ga-N chip LEDs produce white and blue colored light. In Al-In-Ga-P-based LEDs, the voltage drop is approximately -3 mV/°C. Whereas, there is a voltage drop of -2 mV/°C in In-Ga-N-based chips. In short, chips producing red light are more affected by heat than chips producing white color light [32]. Table 1.3 shows the temperature-dependent voltage drop on the LEDs.

Table 1.3: Al-In-Ga-P and In-Ga-N led chip volt drop [32].

Color	Voltage drop ΔV	Semiconductor material
Red	0.18	GaAlAs
Orange	0.20	GaAsP
Yellow	0.23	GaAsP
Green	0.35	InGaN
Blue	0.36	InGaN
White	0.40	InGaN

Considering the voltage drop that occurs in the case of serial or parallel connection of systems where more than one LED producing red light such as a stop lamp is used, the voltage drop that occurs in the parallel case is negligible, while the voltage drop that occurs on the resistors connected in series may affect the proper operation of the system. It can reduce up to 80%-90% in red-colored LEDs [32]. This event can cause fatal accidents in a vital part such as the stop lamp, causing the drivers from behind to not see the warning given.

Figure 1.24 shows the change in wavelength of light depending on temperature in a red LED.

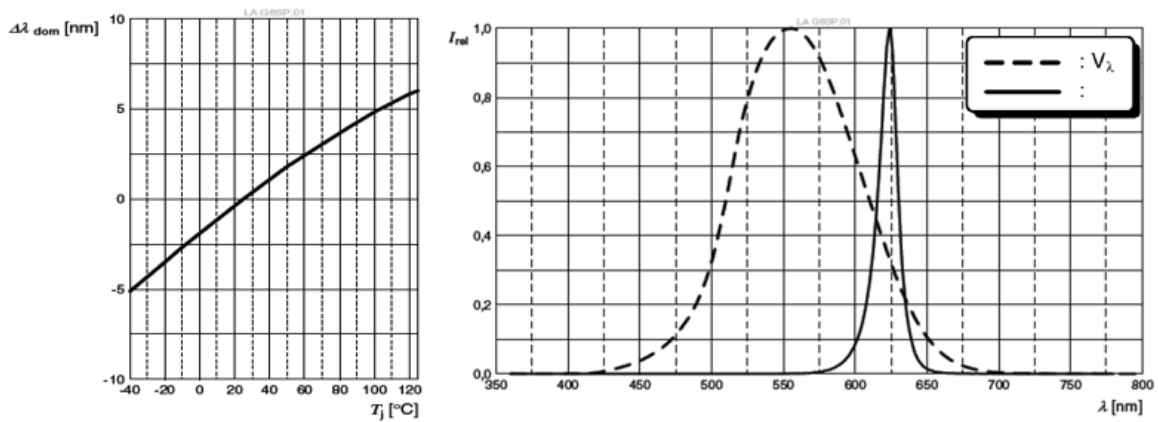


Figure 1.24: Red LED wavelength and temperature change [33].

In most of the LEDs, the heated led chip shows shifts in the light color and lumen values it gives depending on the temperature. When the white-colored LEDs are heated, the yellow color shifts towards the wavelength, while the red color light shifts from 610 nm wavelength to 720-740 nm wavelength. Figure 1.25 shows the voltage drop and the decrease in light intensity depending on the temperature of a red LED. The LED used was tested at 25 °C ambient temperature with a voltage of 2.05 volts, and a current of 140 mA [34].

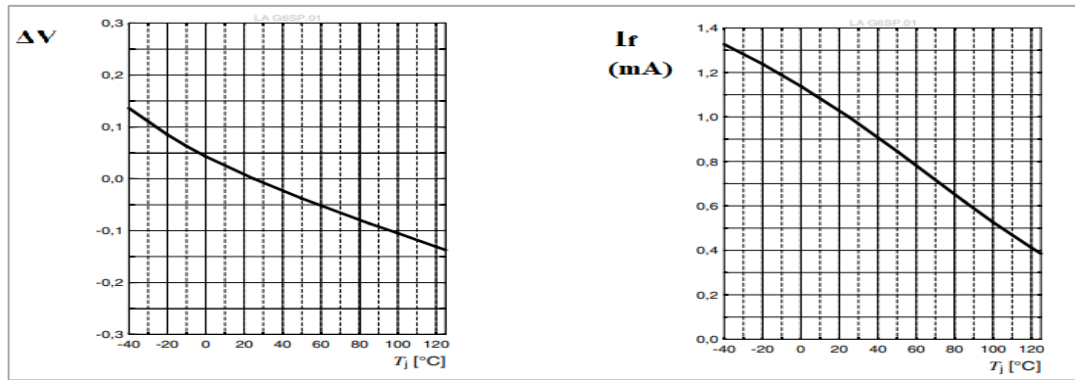


Figure 1.25: Red LED voltage and luminous intensity drop [34].

To prevent the LEDs from being affected by heat and color shift, the design, electronics, thermal, and optics teams have to come together during the design phase. They need to create a design control school by anticipating the events that may occur. Since there are regulations that the equipment used in the automotive industry must comply with, the maximum temperature that the led chip reach should be determined before the product tests and it should be proven by thermal tests that.

1.8 PRODUCT DESCRIPTION AND TECHNICAL SPECIFICATIONS

The project was created with the synchronized operation of 72 led systems by using many lighting products together. In this way, a separate mold is not made for each product, and the following functions can be used together at once.

1. Stop lamp
2. Reverse lamp
3. Signal lamp
4. Fog lamp
5. Daytime running lamp

Since powerful LEDs be used in systems where high optical regulation values are required such as fog lamp-stop lamp, high temperatures occur on the LEDs. This both reduces the life of the LEDs and causes damage to the plastic parts.

Damaged plastic parts distort the optical reflecting surfaces and cause deterioration of our vision.

Figure 1.26 shows a picture of a vehicle with similar features.



Figure 1.26: Similar stop lamp product display [35].

In-vehicle lighting systems, there is an expectation for each unit to be at a certain height from the ground. According to the function of the product, LED selection and optical orientation are done by optical engineers. During the electronic circuit design, the optical engineer determines the position of the desired LED, while the electronics engineers take care of the rest of the circuit. It makes optimization studies on the circuits to make the cooling more balanced and effective. According to the suitability of the system, the LEDs are not operated at a continuous current, but at intervals such as 20-50-100 ms, to prevent further heating.

Figure 1.27 shows the maximum and minimum heights of the lighting devices determined in the homologations.

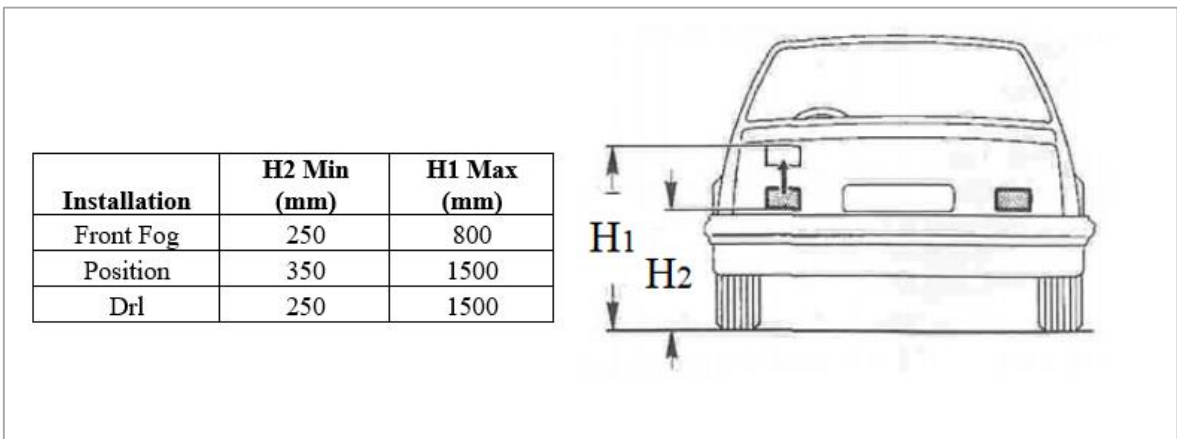


Figure 1.27: Product locations determined by regulations [36].

1.9 PCB SCHEMATIC VIEW

In Figure 1.28 PCBs with different features in the product are seen.

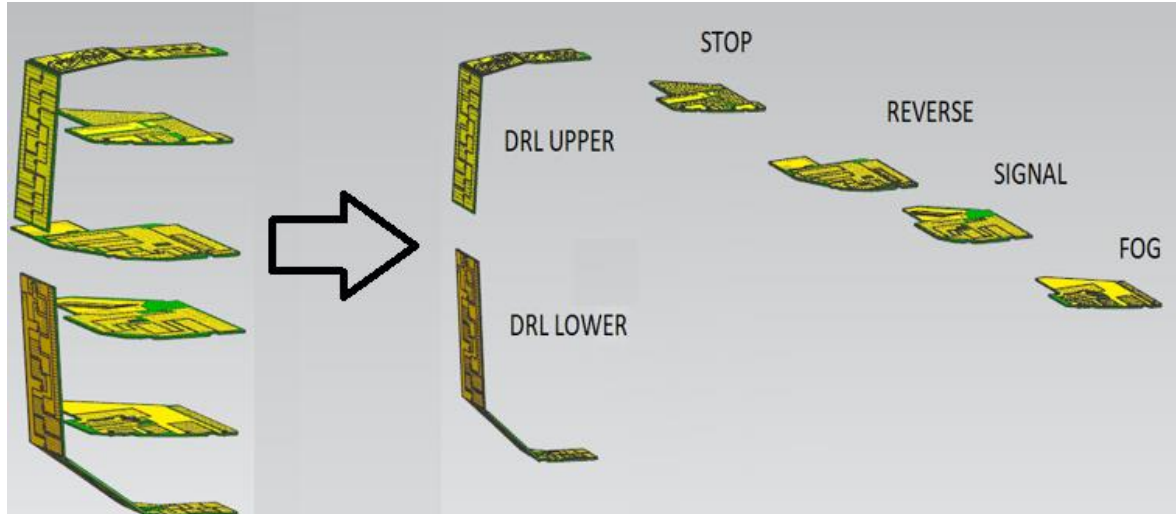


Figure 1.28: Schematic view of product PCB.

The model consists of a system with 5 functions.

- a. Stop lamp
- b. Reverse lamp
- c. Signal lamp
- d. Fog lamp
- e. Daytime running lamp

DRL LEDs are constantly active. When the stop and fog function is activated, a serious increase in the temperature of the product occurs. LEDs and plastic parts should be protected by thermal analysis. In the automotive industry, customer expectations and homologation compliance criteria are sought for all products.

1.10 LED TYPES USED IN THE PRODUCT

The LEDs determined by the optics team are shown in Table 1.4. In homologation, there are the light colors and light intensity values determined for the vehicle, as well as the style and technical specifications expected by the customer.

While making the LED selections, it was requested that the LEDs be one of the outdoor lighting groups that can be used in the automotive industry. It is expected that the LEDs have low thermal resistance and high lumen values. The LEDs used in the model are surface mount device (SMD) package types to are suitable for mass production. The reflector surface is epoxy coated so that the LEDs can be resistant to the external environment.

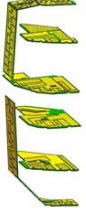
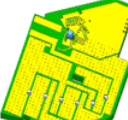
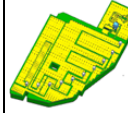
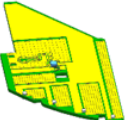
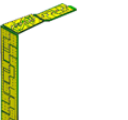
Table 1.4: Led types used in the product [37].

			Stdrc1lx 3030x	Stapc1lx 3030x	Stw0c1lx 3030x
					
Parameter	Symbol	Unit			
Color	-	-	Red	Orange	White
Forward Voltage	V _f	V	2.20	3.1	3.1
Luminous Flux	Φ _v	lm	17	33	62
Dominant Wavelength	W _d	-	632	600	450
Viewing Angle [3]	2θ _{1/2}	[°]	120	120	120
Real thermal resistance	R _{th}	K/W	9.1	5.8	5.2
Forward Current (T _a =25°C)	I _F	mA	350	300	300
Junction Temperature	T _j	°C	150	150	150
Package Size		mm	3.0x3.0x0.6 5	3.0x3.0x0.6 5	3.0x3.0x0.6 5

1.11 PCB CARDS AND LED POWERS

Table 1.5 shows the number and technical features of the LEDs used in the product. The use of LEDs in 3 different colors for 5 different products has been determined by the optics unit. Colors to be used in the system. It was chosen as Red-Orange-White. DRL and Reverse type lighting units are not driven at full power to avoid full heating of the system.

Table 1.5: LEDs in the lighting product and their power.

PCB NAME	STOP LAMP	REVERSE LAMP	SIGNAL LAMP	FOG LAMP	DRL UPPER	DRL LOWER
						
LED DRIVER	0.85W	0.4W	0.6W	0.85W	0.6W	0.6W
MAX POWER	0.44	0.62	0.465	0.44	0.44	0.44
LED (1 PIECE)	0.44W	0.31W	0.465W	0.44W	0.165W	0.165W
LED NAME	STDRC1LX	STW0C1LX	STAPC1LX	STDRC1LX	STDRC1LX	STDRC1LX
						
TOTAL LED	8	6	10	8	21	21
COLOR	RED	WHITE	ORANGE	RED	RED	RED
FLUX (lm) MAX	28	62	33	28	28	28
TOTAL FLUX (lm)	224	372	330	224	588	588
THERMAL RES. K/W	18	10.4	7.9	18	18	18
JUNCTION TEMP.	150 °C	150 °C	150 °C	150 °C	150 °C	150 °C

1.12 LED JUNCTION TEMPERATURE AND LUMINOUS FLUX

In Figure 1.29, the temperature-related light losses of the LEDs in the system are visible. While 33.33% of the light given by the white-colored LED at 150 °C was lost, 85% of the red-colored light disappeared. Orange-colored light has a light loss of 36.36%. The most

important point here is that the red LED's light loss due to temperature is high. Need to keep the Red LEDs at a temperature that does not harm the operation of the system [38].

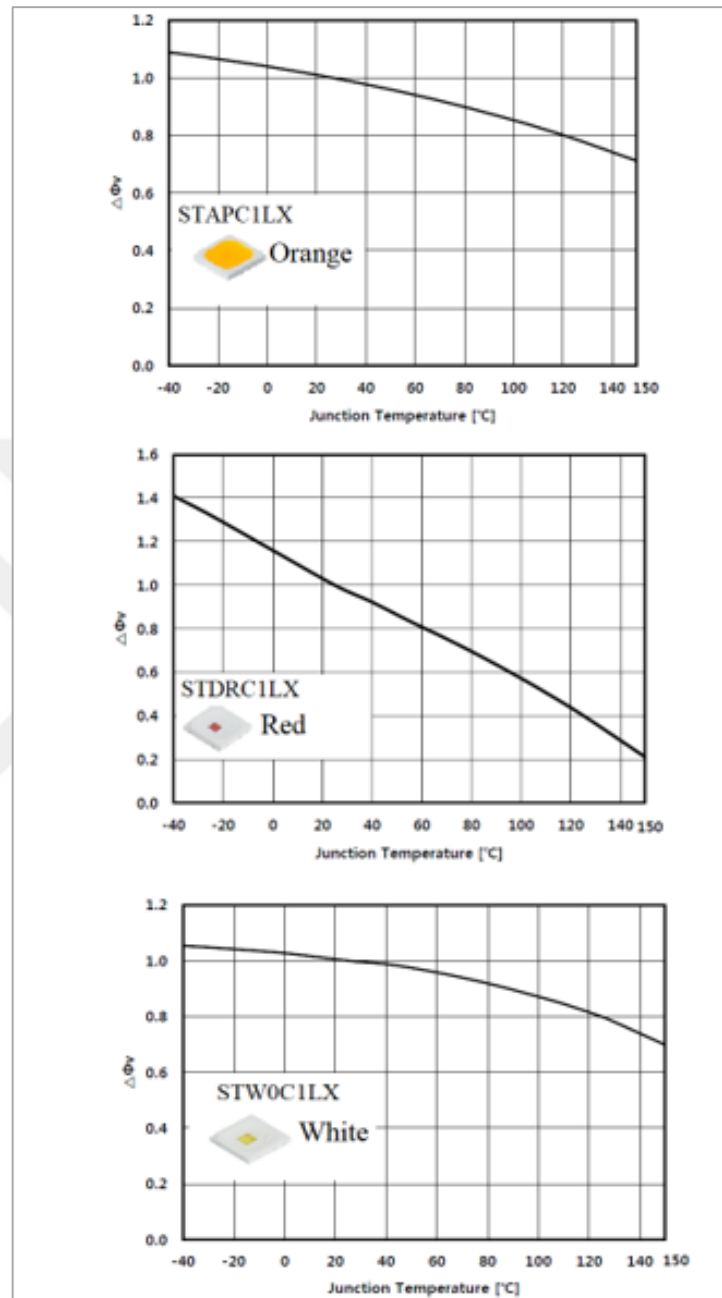


Figure 1.29: Temperature-dependent light drops of LED colors [38].

1.13 OPTICAL REQUIREMENTS

Before the homologation tests, a similar dark room test should be made to test the system. In this way, the required light intensity is tried to be obtained by changing the product voltage values. Optical engineers increase the light intensity by 30% on average during the design

phase and balance the light losses that may occur due to the production and material of the system [37]. It prevents the problems that occur in the production of plastic materials.

The products to be tested are connected to the goniometer with a fixture to simulate the vehicle position. The part is controlled with a goniometer according to the group to which the product is connected. The light intensity at their location is measured with the help of sensors by moving the part with horizontal-vertical angles, which are by the goniometer homologation requirements.

According to the Ece R7 specification, the picture indicating the angular positions of the stop lamp is shown in Figure 1.30.

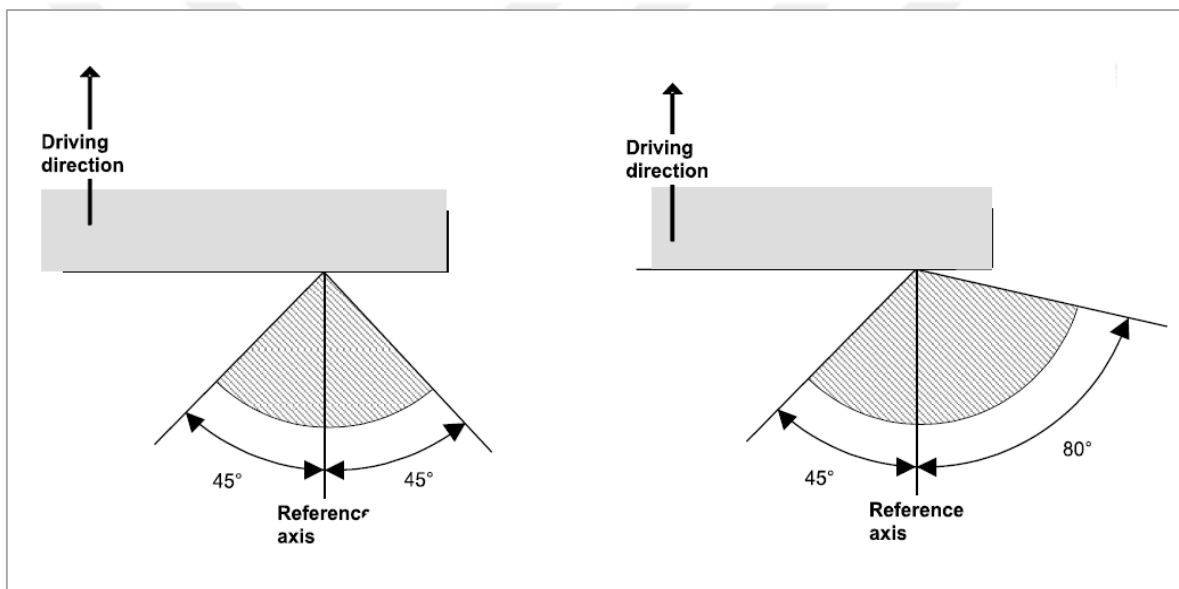


Figure 1.30: Stop lamp and rear lamp angle positions [39].

Since the desired values in the optical regulations for the fog and stop lamps are high, the 28 lumen Seoul STDRC1LX brand Led was chosen.

The abbreviations specified in photometry tests are given in Table 1.6

Table 1.6: The abbreviations specified in photometry tests.

Abbreviation	Meaning
H	Horizontal direction
V	Vertical direction
R	Right direction
L	Left direction
U	Up
D	Downward

The sample values determined in the ECE specification for the stop lamp are shown in the Table 1.7 below.

Table 1.7: Stop lamp ECE specification [40].

Lamp positions	H (°)	V (°)	Light limits (Candela)		
			Minimum	Maximum	
10U / 5L	-5	10	12	365	
10U / 5R	5	10	12	365	
5U / 20R	20	5	6	365	
5U / 10R	10	5	12	365	
5U / V	0	5	42	365	
5U / 10L	-10	5	12	365	
5U / 20L	-20	5	6	365	
H / 10L	-10	0	21	365	
H / 5L	-5	0	54	365	
H / V	0	0	60	365	
H / 5R		5	0	54	365
H / 10R		10	0	21	365
5D / 20R		20	-5	6	365
5D / 10R		10	-5	12	365
5D / V		0	-5	42	365
5D / 10L		-10	-5	12	365

The goniometer sample is shown in Figure 1.31.

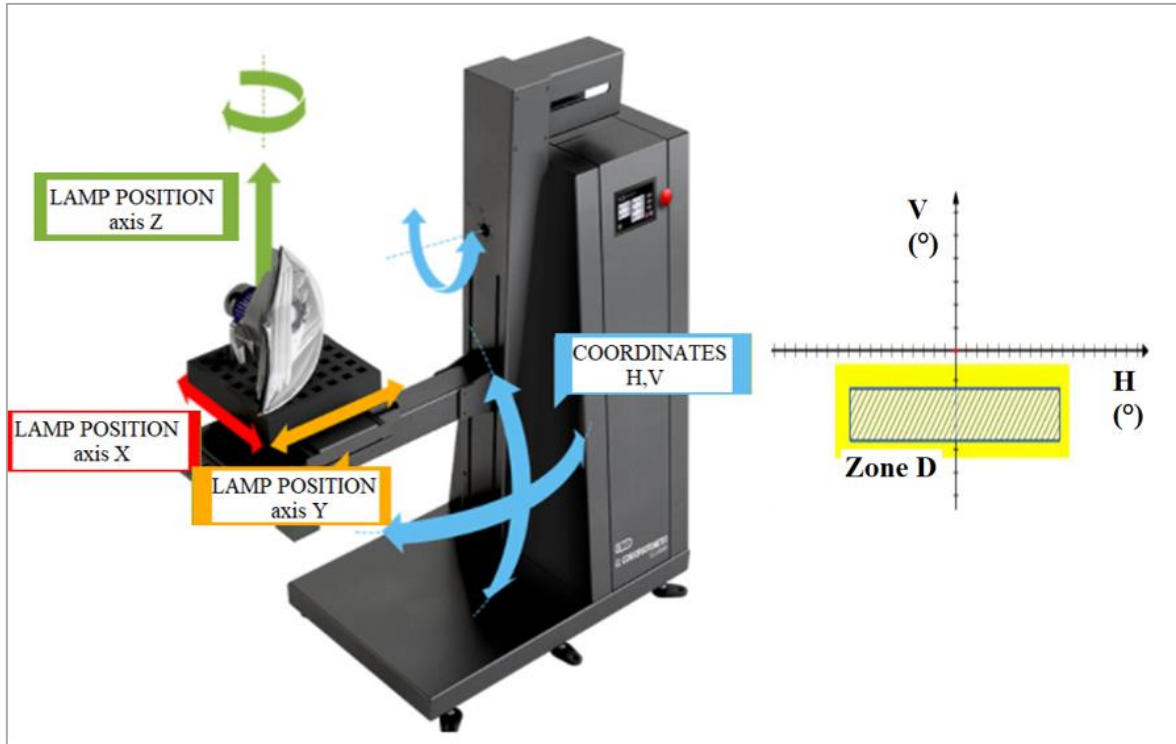


Figure 1.31: Spherical coordinates for goniophotometer [41].

A goniophotometer is a tool that allows us to measure the light intensity and color changes at the specified angle values by being programmed according to the desired specification and product requirements. The light and color change over time can be tested by moving the part in cylindrical coordinates. The test should be done.

Measurements should be made with a goniophotometer in a dark room. The reason why the tests are done in a dark room is that other light sources and reflective surfaces do not affect the test accuracy. Homologation tests are carried out at room temperature. Air temperatures changing from region to region should be verified according to numerical analysis methods and thermal analysis should be performed. While light changes that may occur in the LED in a hot region affect the drivers during use, homologation tests are performed at room temperature, so they do not give an accurate result in different temperature changes.

1.14 ELECTRONIC REQUIREMENTS

PCB is an abbreviation consisting of the letters "Printed Circuit Board". Double-layer Flame Retardant (Fr-4) material coded 6160 be used in project. The properties of various PCB materials are given below.

Fr-1 and Fr-2 are consists of prepreg lamination of materials such as phenol or kraft paper compounds. They are not resistant to vibrations. They are generally used in fixed systems [42].

Fr-3 is consists of cellulosic paper and epoxy. It is not suitable for multi-layer PCB production.

Fr-4 is consists of glass fiber and epoxy materials. It is resistant to heat. Multi-layer PCB production can be done with Fr-4 at affordable costs. It can be used up to 130 °C.

Fr-5 is an epoxy resin binder and glass fiber reinforcement. It has a softening temperature point at temperatures of 170 °C-180 °C. It can operate at average temperatures of 140° without any problems. It is suitable for multi-layer PCB production.

The properties of PCB circuit structure and production methods are one of the most important factors affecting conductivity. The dielectric material transmission coefficient and thickness used to bond the circuit paths are determined by the manufacturing method you choose. Laminate PCB production flow is shown in Figure 1.32.

One of the most important points here is the dielectric materials used. The points where the paths are cut in heat transfer are filled with a dielectric material. Especially in high conductivity, PCB circuits with copper or aluminum substrates such as MCPCB, the biggest obstacle to heat transfer is the dielectric material.

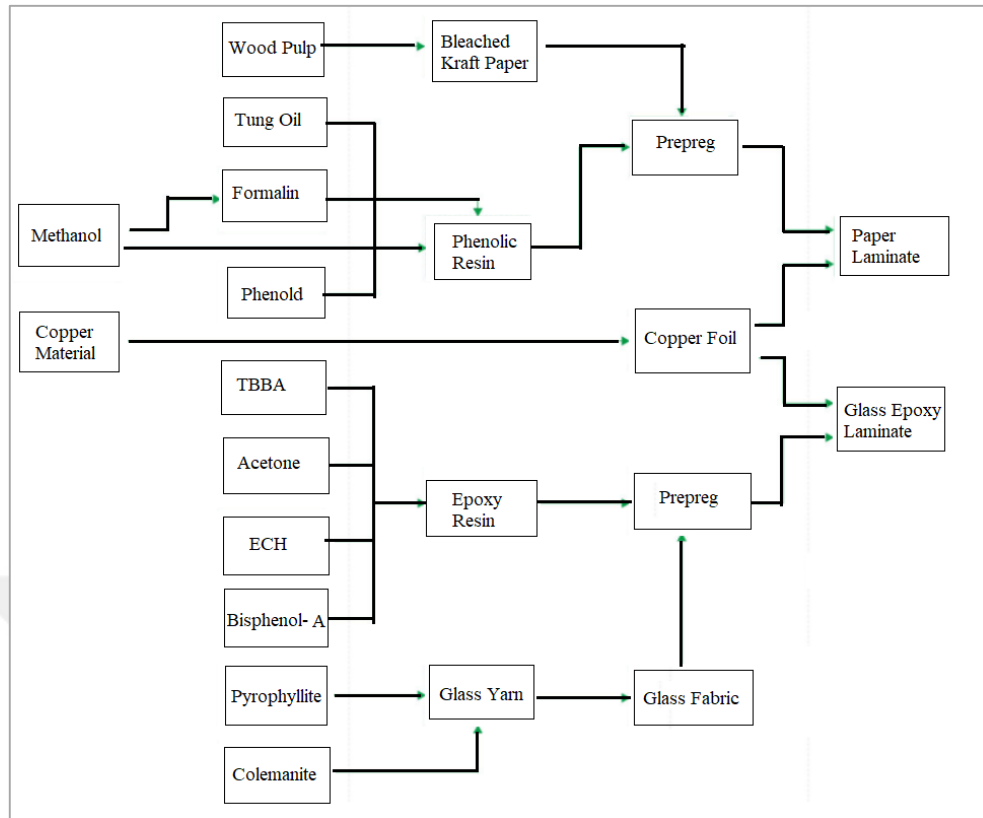


Figure 1.32: Laminate PCB product flow [44].

Figure 1.33 shows a double layer Fr-4 PCB and thermal vias.

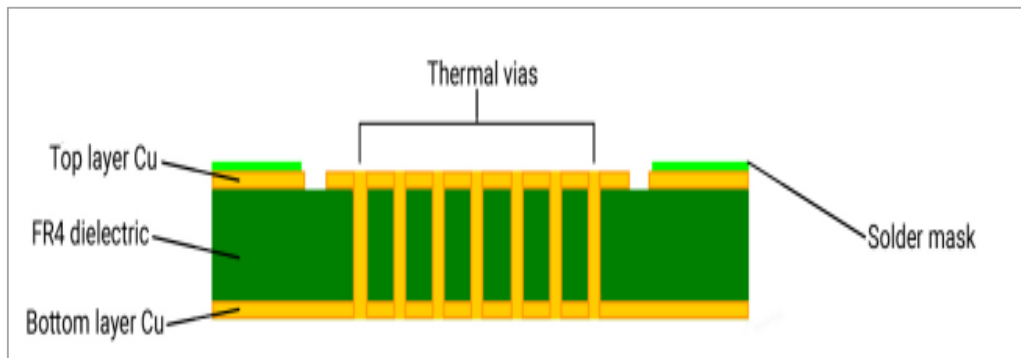


Figure 1.33: Double layer Fr-4 PCB and thermal vias [45].

Vias have many features. By using vias can combine a thin copper area in the upper path with a thick layer in the lower path so that can direct the heat to a larger area.

The vias are divided into 6 parts according to their production techniques and usage characteristics [46]. In Figure 1.34, there is a picture showing the types of vias and cost amounts. In the thesis, through type via be used

Cost	Standart	Standart	+\$	++	+++	+++
Duration	Standart	Standart	+🕒	+🕒	+🕒🕒	+🕒🕒
Type	Through Via 	Tented Via 	Blind Via 	Buried Via 	Stacked Via 	Via in pad 

Figure 1.34: Via options [46].

Figure 1.35 shows the thermocouples connected to measure the thermal resistances on the PCB depending on the copper thickness. T_c shows the temperature at the junction point. T_{hs2} shows the temperature behind the fin.

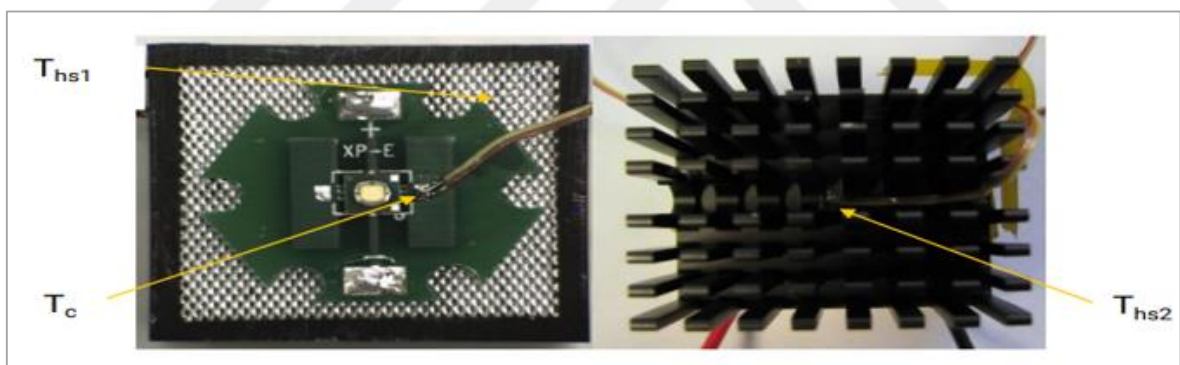


Figure 1.35: The locations of thermocouples on the PCB [47].

Table 1.8 shows the average of the measurement results taken by 5 different tests of different copper thicknesses.

Table 1.8: The average of the measurement results on the PCB [47].

Board	I _f (A)	V _f (V)	Power (W)	T _c (°C)	T _{hs} (°C)	T _a (°C)	Avg. Θ _{PCB} (°C/W)	Avg. Θ _{ca} (°C/W)	Avg. Θ _{hs-a} (°C/W)
1 oz. #1	0.7	3.31	2.32	69.64	45.73	22	9.39	19.99	10.60
1 oz. #2	0.7	3.26	2.28	70.29	48.03	22			
1 oz. #3	0.7	3.21	2.24	65.37	44.02	22			
1 oz. #4	0.7	3.22	2.25	66.34	47.65	22			
1 oz. #5	0.7	3.25	2.28	65.77	45.15	22			
2 oz. #1	0.7	3.32	2.32	71.69	48.19	22	9.61	19.90	10.28
2 oz. #2	0.7	3.34	2.34	68.6	45.34	22			
2 oz. #3	0.7	3.26	2.28	66.95	46.33	22			
2 oz. #4	0.7	3.34	2.34	66.36	44.37	22			
2 oz. #5	0.7	3.35	2.35	67.57	45.19	22			
4 oz. #1	0.7	3.31	2.32	64.35	45.80	22	8.40	19.68	11.28
4 oz. #2	0.7	3.34	2.33	68.31	48.75	22			
4 oz. #3	0.7	3.39	2.38	71.87	50.41	22			
4 oz. #4	0.7	3.26	2.28	66.63	47.87	22			
4 oz. #5	0.7	3.33	2.33	68.12	48.55	22			

Since the LEDs do not have an active cooling system, 2 ways are tried to remove the heat on the LEDs. One of them is to increase the thermal resistance by increasing the copper thickness of the PCB. The other way is to remove the heat from the environment by enlarging the copper areas.

The Cree company examined the thermal resistances and LED temperatures in different copper thicknesses in Table 1.9. As a result of the test, a 1 oz copper circuit has an average thermal resistance of 9.39 K/W, while the thermal resistance of a 4 oz copper PCB has decreased to 8.4 K/W. This shows that can reduce LED temperatures by increasing the copper thickness [48].

Cree company made measurements of PCB circuits of different widths to show the effect of the change of copper fields on thermal resistance. According to the results, the effect of road width on thermal resistance decreases after approximately 12 mm copper road thickness [49]. In the test of PCB thickness, it is seen that the thermal resistance of the 0.8 mm thick PCB circuit is lower. Figure 1.36 shows the thermal resistances on the PCB depending on the copper width.

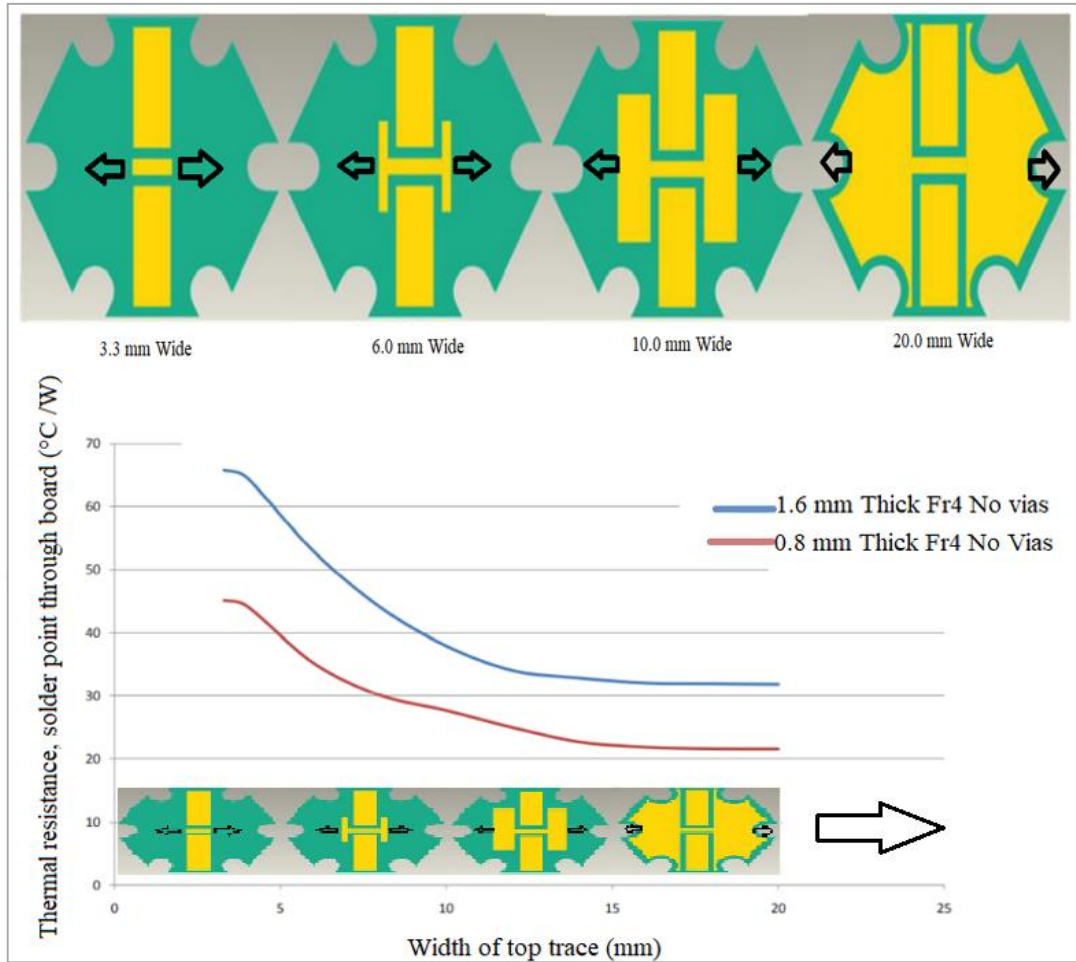


Figure 1.36: Fr-4 thickness and thermal resistance (trace wide) [49].

Increasing the Fr4 thickness from 0.8 mm to 1.6 mm in Figure 1.36 increased the thermal resistance of the system from 45 K/W to 65 K/W. It is seen that the thermal resistance of the system increase with the increase of Fr4 thickness. However, this lighting should be used as a last resort as it increases the cost of the product. The tests related to the subject are explained in the following sections [49].

The structure of copper paths has a significant effect on the stability of the system. The current to drive the LED to be used is determined as 350 mA. In Table 1.10 the min path widths that should be according to the current passing through the road are shown. In Table 1.9, at least 0.6-1 mm copper path width should be used for 350 mA current [50].

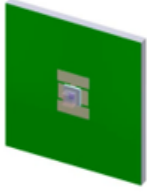
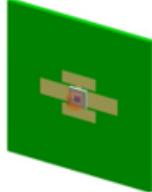
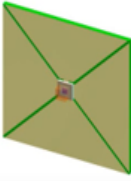
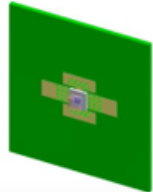
Table 1.9: Max current and copper path width [50].

Connection Path width (mm)	Max Current (mA)
0.20	100
0.50	300
1.00	2500
2.00	5000
3.00	6000
4.00	7000
5.00	9000

When the via and double layer Fr-4 PCB are used, the temperature rise drops to the aluminum PCB level, which is MCPCB. Metal Core PCBs are costlier circuit boards than Fr-4 based PCBs. The use of MCPCB cards is not recommended unless necessary.

In Table 1.10, Osram made experiments on 4 different PCB by changing the copper paths and adding vias. When the copper areas were maximized and the copper thickness was made to 2 oz, the temperature increase decreased from 53 °C to 35 °C [51].

Table 1.10: Thermal resistance and temperature increase for different PCB types [51].

	MCPCB	Single sided Fr4	Fr4 With maximized solder path	Double sided Fr4 with thermal vias
				
Solder pads	75 μm	35 μm	70 μm	70 μm
Rth SB (K/W)	3	45	28	8
Junction Temperature Rise (°C)	10	53	35	15

1.15 THERMAL REQUIREMENTS

The picture in Figure 1.37 shows that the positions of the LEDs in the stop lamp and fog lamp heat each other and the air heated by the PCB is prevented from going up.

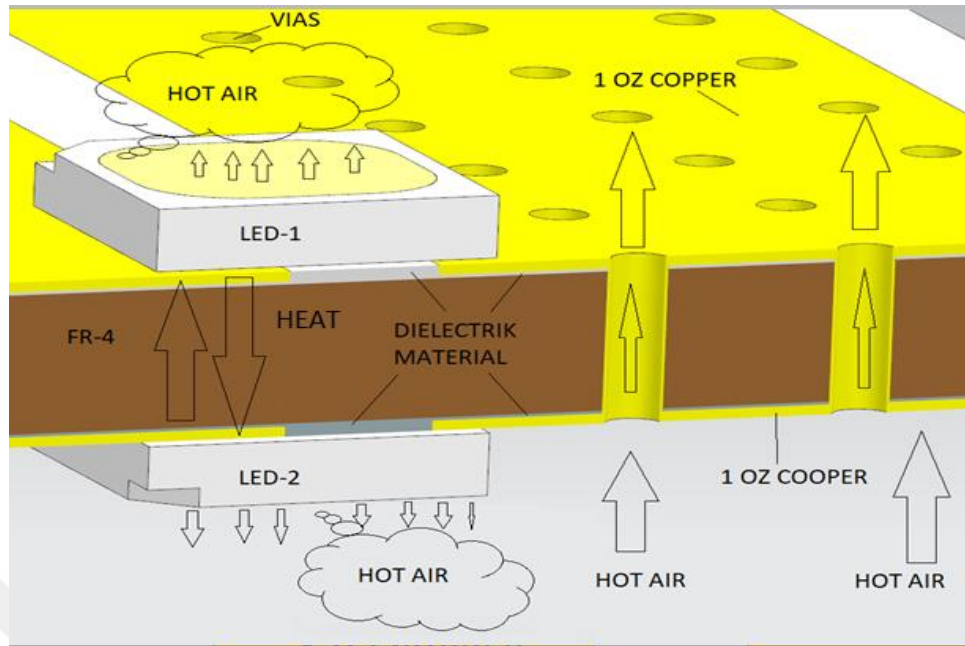


Figure 1.37: Stop lamp and fog lamp LED positions and air flow.

The vias help to reduce the thermal problem. It is used to move the heat from the system to the other side of the PCB. In heat transfer by conduction, the heat is rapidly removed from the environment by passing through copper paths. PCB boards used in the lighting product cover the product horizontally. In products such as stop lamps and fog lamps, the LEDs are at the same point in the lower and upper positions.

When the heated air is not removed from the environment, a significant temperature increase occurs in the ambient temperature. The LED positions specified by the optics engineer are one of the unchangeable issues of the system. The fact that the LEDs are in the same position brings serious problems in terms of calculation. The more heated LED heat the other circuit.

In Figure 1.38, it is shown that the hot air to be created by the LEDs in the lower part of the system is directed to the cold area with the vias on the PCB board.

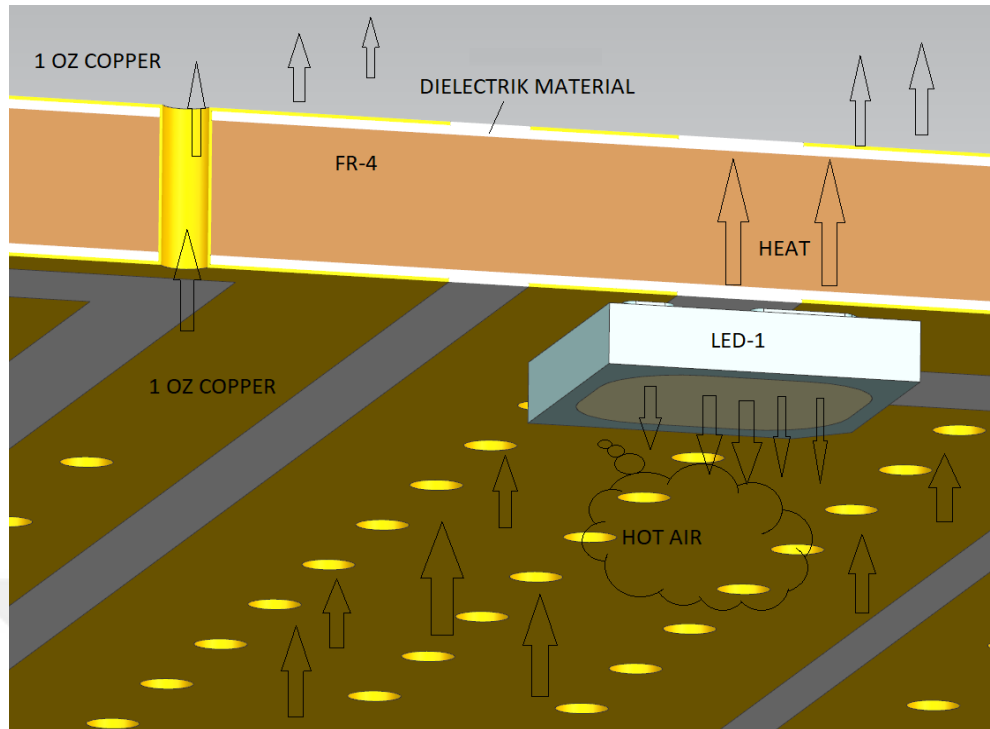


Figure 1.38: Reverse lamp and signal lamp LED positions and air flow.

Reverse and signal lamps are components with LEDs on 1 surface. The presence of LEDs at the bottom adversely affects the air flow.

Vias help to change the air in the system with the effect of temperature. The heat emitted by the LEDs can be removed from the system by copper paths up to a point. Since the product is a double-layer PCB, can protect the performance of the LED by transferring the heat in the LED regions to the copper areas in the lower and upper regions. The copper areas in the led regions have been designed together with the electronic team by making optimization studies to reduce the temperature of the LED.

1.16 PCB BOARDS PROTOTYPING

Prototype cards produced in Figure 1.39 can be seen.

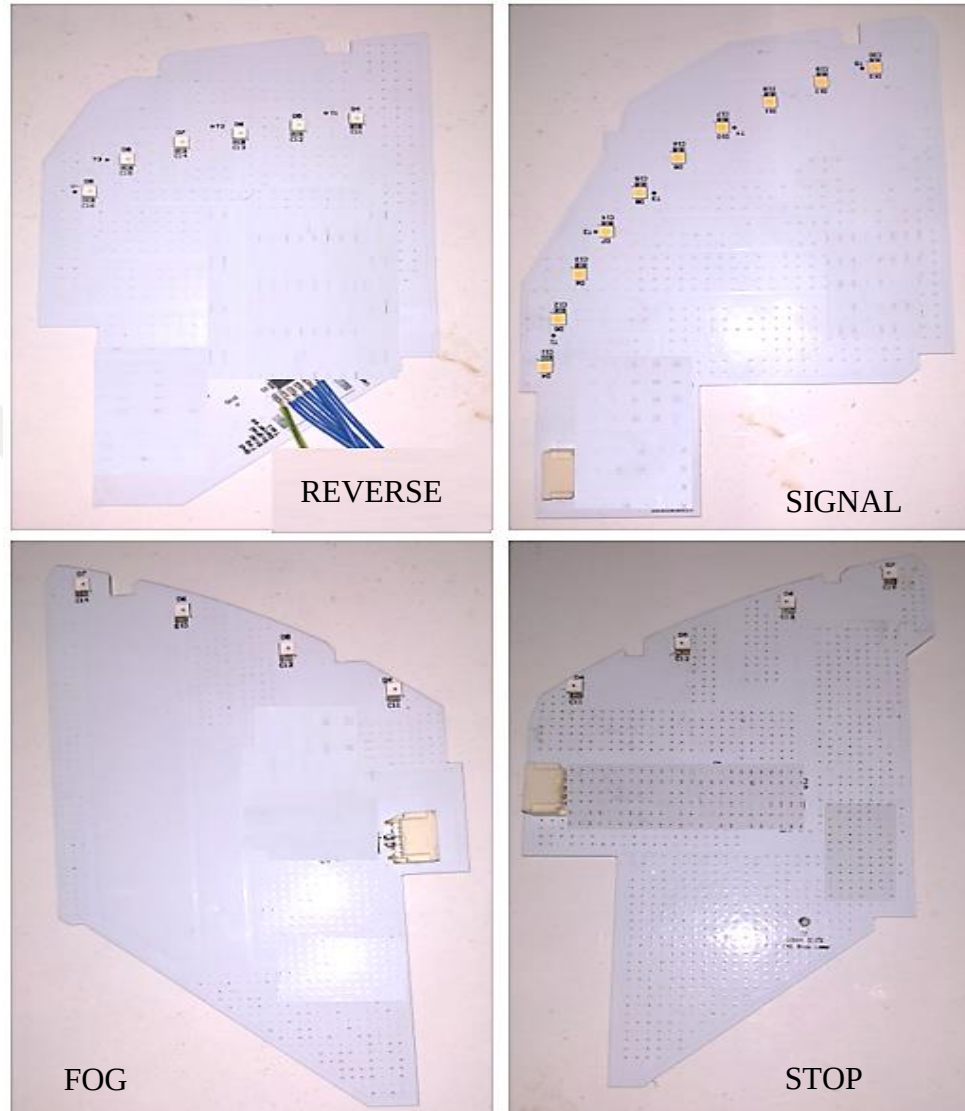


Figure 1.39: Circuit boards prototypings.

Although the heat-light efficiency of the LEDs is approximately 70%, the positions, colors, copper areas of the LEDs, and the air flow of the environment where the system is located affect this efficiency [52]. The circuit boards used in the project are designed to close the air flow. This creates many thermal problems. Vias are used to prevent this.

Before proceeding to the calculations, the LED efficiencies should be determined on the prototype cards and the simulations should be verified. Even if the same LED circuit is

desired to be used in a different product, prototype production is required as the copper paths change.

1.17 MATERIAL AND METHOD

The preparation of the thesis consists of two stages.

In the first stage, the effects of the temperature increase, which occur as a result of the passage of air in the inner loop formed by a large flow volume and 72 LED systems, on PCB, LEDs, and plastic have been examined. Since the calculation of this system with a 4-core computer would take a long time, a high-capacity computer, CFD program, and Solidworks program were used. The second stage consists of thermal and optical tests.

Computer specifications are shown in Table 1.11

Table 1.11: Computer specifications.

Part name	Part code
Processor (Core)	Intel Core i9-10980XE 36 cores
Random Access Memory (Ram)	128 GB
Read-only Memory (Rom)	M2 2Tb 5600/4300Mb SSD

1.17.1 CFD Program Features

Solidworks Flow simulation is a powerful CFD program that works integrated with drawing programs such as Solidworks, Catia, and Nx. It allows users to perform CFD analysis while designing and to see the regions that affect the air flow. In this way, the design time is shortened.

The flow simulation program does not want us to remove parts from the air flow field in the form of a rectangular prism, as conventional programs do to extract the flow volume. It automatically cleans the solid bodies from the flow field.

1.17.2 Equipment Used

One double layer of 1 oz Fr-4 PCBs is used in the thesis study. The electronic design of the cards was made by the team of Al-kor Electronic with the Altium Designer software. During the card design, the thermal paths were arranged by meeting with the electronic team. The power values to be consumed by the elements in the circuits have been calculated with the

Altium designer program. The necessary volt and current are adjusted according to the lumen value of the LEDs.

In the Altium Program, the circuit paths and 3d models of the equipment were taken the power values consumed by these circuit elements were entered into the Solidworks flow simulation program as analysis data. In the CFD program, analysis was made for each card, LED verifications were made and the test stage was started.

In Figure 1.40 a thermocouple that can be used with omega HH 1384 Data logger appears. Depending on these, the maximum temperatures that can be measured and the accuracy percentage are shown as C°.



Figure 1.40: Omega HH 1384 datalogger and thermocouple.

Temperature measurements on electronic cards were measured with the Omega hh1384 data logger and recorded over time. Omega HH 1384 thermometer specifications for thermocouple are shown in Table 1.12

Table 1.12: Omega HH 1384 thermometer specifications for thermocouple [53].

Type	Range		Accuracy
	Min. °C	Max. °C	
K	-200	-150	$\pm 3.0\text{ }^{\circ}\text{C}$
	-150	-100	$\pm 2.0\text{ }^{\circ}\text{C}$
	-100	999	$\pm 0.05\text{ }^{\circ}\text{C} - \pm 1.0\text{ }^{\circ}\text{C}$
	1000	1370	$\pm 0.2\text{ }^{\circ}\text{C} - \pm 1.0\text{ }^{\circ}\text{C}$
T	-200	-150	$\pm 3.0\text{ }^{\circ}\text{C}$
	-150	-100	$\pm 0.15\text{ }^{\circ}\text{C} - \pm 2.5\text{ }^{\circ}\text{C}$
	-100	400	$\pm 0.1\text{ }^{\circ}\text{C} - \pm 1.0\text{ }^{\circ}\text{C}$

A thermal camera and thermocouples were used while testing the product. Thermocouples are equipment used to measure temperature in the shortest time and accurately.

Thermocouples can measure temperature by calculating the millivoltage difference between the tip at the hot contact point and the cold terminal connected to the device.

While the temperature at the ends of the wires made of two different materials of the same length and diameter is the same, the voltage difference caused by the wires connected to the thermometer made of different materials allows for reading the temperature.

Figure 1.41 shows a schematic view of temperature measurement with a thermocouple [54]

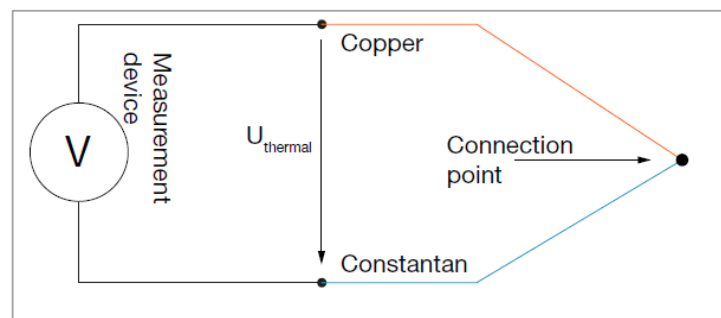


Figure 1.41: Schematic view of temperature measurement with a thermocouple [54] voltage control [50].

Figure 1.42 shows the K-type thermocouple structure. Thermocouples can read temperatures at different levels depending on the materials used. Each type of thermocouple creates a different voltage difference to the tip of the thermometer against increasing temperature.

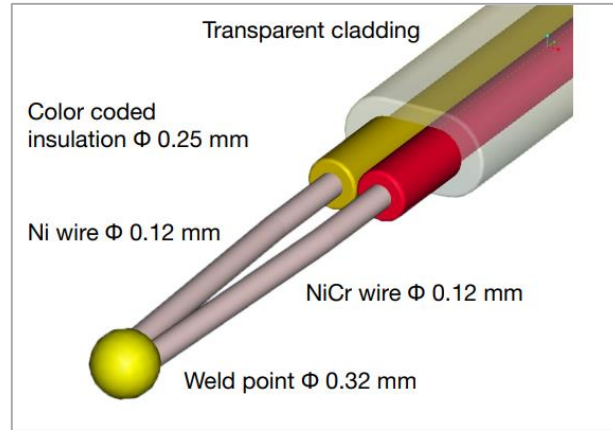


Figure 1.42: K-type thermocouple schematic view [55].

T-type thermocouple, which is the most sensitive, was used in the thesis study. K-type thermocouple was used to measure the ambient temperature.



Figure 1.43: Tt-t-echni-c Dc power supply mch-305d.

The "TT-T-ECHNI-C DC POWER SUPPLY MCH-305D" power supply is used in the thesis; the device is seen in Figure 1.43.

The power supply can produce 0-30 volt output voltage and 0-2 ampere current. It has 2 outputs. Changing current values can be displayed on the LCD screen. The product has overload protection. Voltage and current can be adjusted precisely.

The thermal furnace is shown in Figure 1.44.



Figure 1.44: Nuve FN 400 thermal test furnace.

Nuve Fn 400 branded thermal furnace is used to examine the thermal effects of the thesis product under different temperatures. In this way, damage to plastics and electronic components can be seen during the test and necessary corrections can be made.

Figure 1.45 shows the shape change that occurs when the materials to be used in the product are kept above the Vicat temperature in the oven for 30 minutes. The temperature point at which the plastic material begins to deform under temperature is called the Vicat temperature.

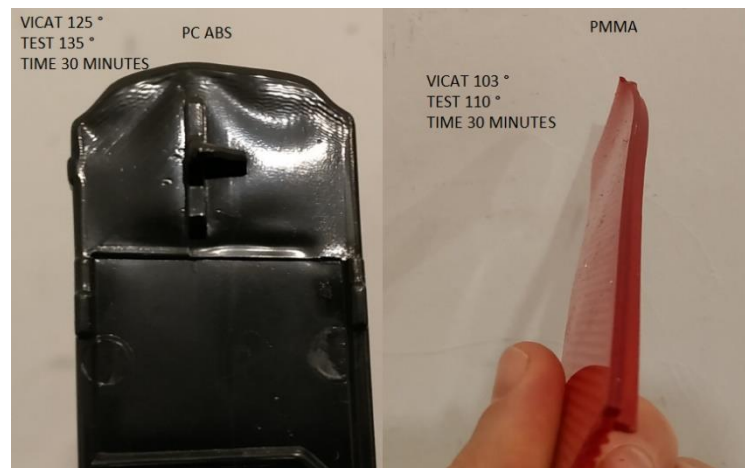


Figure 1.45: Deformation of plastics above softening temperature- PC+ABS and PMMA.

In the thesis, PC+ABS and PMMA plastics are used as general weight. To see the deformations that may occur above the maximum Vicat temperature that they can withstand

in the thermal oven, the lens and housing material of the same material thickness have been tested by placing them in the oven.

As a result of the test, while shape changes occurred in PMMA material, melting occurred in PC+Abs material.

Since the PC+ABS material is located on the LEDs, it is in the region that is exposed to the heat the most. The shape changes in this material can cause the shift of the PCBs' positions or deterioration on the optical surfaces.

As the lens material, PMMA is located on the visual outer surface, it may cause yellowing and failing homologation tests.

For the safety of the tests, the temperatures have been used at approximately 10 °C below the Vicat values.

Figure 1.46 shows the Goniophotometer. Photometric tests were performed with the Optronic Goniophotometer opt3000. By connecting the product to the vehicle position with a fixture, optical values were obtained with a Goniophotometer using the sensors on the front.



Figure 1.46: Optronic Goniophotometer opt300.

The measurement is made in a dark room so that the sensors to be measured are not affected by other light sources and light reflections.

At the end of the measurement, a test report is created according to the desired homologation values and current adjustment is made with the electronic and thermal analysis team.

PCB-led measurements were made with Fluke Ti 100 thermal camera. Figure 1.47 shows the thermal camera used.

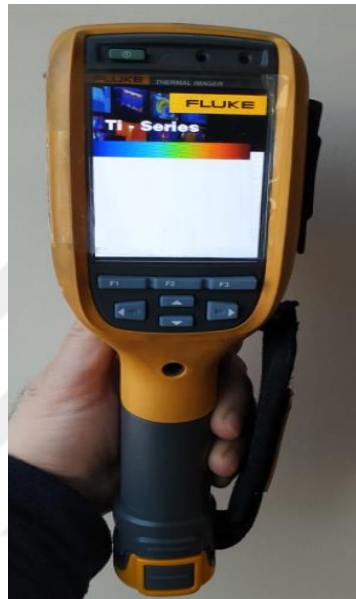


Figure 1.47: The thermal camera used in measuring.

Table 1.13 shows the thermal camera features used. The thermal camera can scan horizontal 22.5° and vertical 22.5° areas.

Table 1.13: The thermal camera specifications.

Property	Value
Temperature range	-20 °C +200 °C
Accuracy	±2 °C
Field of view horizontal angle	22.5 °
Field of view vertical angle	31°

While the device was measuring, the temperature on the surfaces was measured with a thermocouple and the emissivity values were taken as 0.90 and the emissivity calibration was made with a thermometer. Figure 1.48 shows the verification of the thermal camera with the datalogger. To avoid temperature errors, the thermometer and the camera should be calibrated.



Figure 1.48 Thermal camera and thermocouple calibration.

Table 1.14 shows thermal conductivity and emissivity values of materials at 25°C.

Table 1.14: Thermal conductivity and emissivity values of materials at 25 °C [56].

Material	Thermal conductivity (W/mK)	Approximate emissivity
Acrylic	0.2	0.94
Air	0.024	Not applicable
Aluminum	120 - 240	0.02 -0.9 (depending on finish)
Alumina	15 - 40	0.4 -0.7
Aluminum nitride	100 - 200	0.9
Copper	401	0.05 -0.8 (depending on finish)
Diamond	2000	1.0
FR4	0.2	0.7 -0.8
Glass	1.5	0.6 -0.97
Silicon	150	0.6
Silicon carbide	350	0.85
Silver	429	0.02 -0.074
Water	0.58	0.85 - 0.99
Wood	0.17	0.8 - 0.9

2. SIMULATION AND TESTS

2.1 SIMULATION

The thesis simulation study was carried out by applying certain boundary conditions and making some assumptions. The applied boundary conditions and assumptions are as follows:

- a. Led efficiencies have been determined for each PCB board by a test at room temperature, and a simulation is made at 80 °C temperature with the efficiency value found.
- b. The inner parts of the LEDs were accepted as full and the values given by the manufacturer were used by turning them into two resistor models.
- c. During the simulation, it is assumed that the air inside the product cannot escape increasing the simulation safety.
- d. Cooling of the system be by natural convection.
- e. The voltage and current values of the LEDs are also introduced to the system for each card. The LEDs on the card are connected in series.
- f. The thermal resistance values of the LEDs are taken from the led datasheets.
- g. Efficiency calculations were made according to the LED colors used.
- h. Dielectric and copper thicknesses on the PCB were added to the analysis to ensure the accuracy of the simulation.
- i. Since the amount of radiation on the LED is very low and the calculation time of 72 LEDs takes a very long time, the analysis is calculated using only the transmission and convection method.
- j. For simulation safety, the analysis was made with the data of the LEDs received from the manufacturer.

Materials exceeding the Vicat value as a result of the simulation be deemed to have remained from the simulation.

- a. ISO 75-1/2 thermal deflection values be accepted for the Vicat test.
- b. Data simplification has been made so that mesh can be removed in some areas of plastic parts.
- c. Specific heat and conductivity coefficient values of plastic materials are introduced into the system depending on the temperature.
- d. The simulation was carried out at the vehicle mounting position.

- e. For simulation safety, the starting temperature of the product parts was added to the analysis as 80 °C.
- f. The ambient air flow rate in the simulation is assumed to be 0 (zero) in all directions to prevent external cooling of the system.

2.2 LED POWER AND EFFICIENCY CALCULATIONS

It is known in the literature that LEDs have an average of 70% heat and 30% light value.

In reality, the efficiency of the LEDs may vary according to their color, PCB material, copper thickness, the heat transmission capacity of the copper paths, and the discharge of the air of the environment from the environment.

The general mistake in calculations is to multiply volts and amps directly. Then, 70% of the value found is taken and the definition is made into the system. To increase the calculation accuracy, it should be subtracted from the total power value by multiplying the min lumen value and radiation coefficient depending on the color of the led.

There is a library where LEDs can be defined in Floefd. In this library, a realistic result can be obtained by entering the heat and light values, voltage and current variable values of the LED in the Tera led system.

This method, which is extremely expensive in terms of cost, can be used in cases where the real efficiency value of the LED cannot be found.

The tera LED system is seen in Figure 2.1.



Figure 2.1: Teraled LED control product [57].

2.3 SIGNAL LAMP LED EFFICIENCY

Table 2.1 shows the Electro-optical characteristics values of the Stapc1 lx coded Led device used in the signal lamp. Stapc1lx gives 33 lumens of light from 150 mA.

Table 2.1: Stapc1lx LED Electro-optical characteristics [58].

Parameter	Symbol	Type	Unit
Forward Voltage	V_f	3.10	V
LED source	I_f	150	mA
Luminous Flux	Φ_V	33	lm
Viewing Angle	2θ	120	deg. [°]
Real thermal resistance	R_{thJS}	7.9	K / W
Junction Temperature	T_j	150	° C

Due to the production tolerance of the LEDs, there are light values from 28 lumens to 47.5 lumens as given in Table 2.2. This may cause the LEDs on the PCB circuit to light up at different brightness and cause an irregular light appearance [56].

In Table 2.2 the maximum lumen values that the Stapc1lx code Led device can give in different bin codes are indicated. to stay safe in the calculations, a maximum of 32 lumen LEDs with P2 bin code were selected.

Table 2.2: Stapc1lx led the maximum lumen values [59].

Part Number	Luminous Flux [lm]		
	Bin Code	Min.	Max.
STAPC1LX	P2	28.0	32.0
	Q1	32.0	36.5
	Q2	36.5	41.5
	R1	41.5	47.5

2.3.1 Signal Lamp Electrical Power

Figure 2.2 shows the voltage and drive current values of the Stapc1lx coded LED at 25°C.

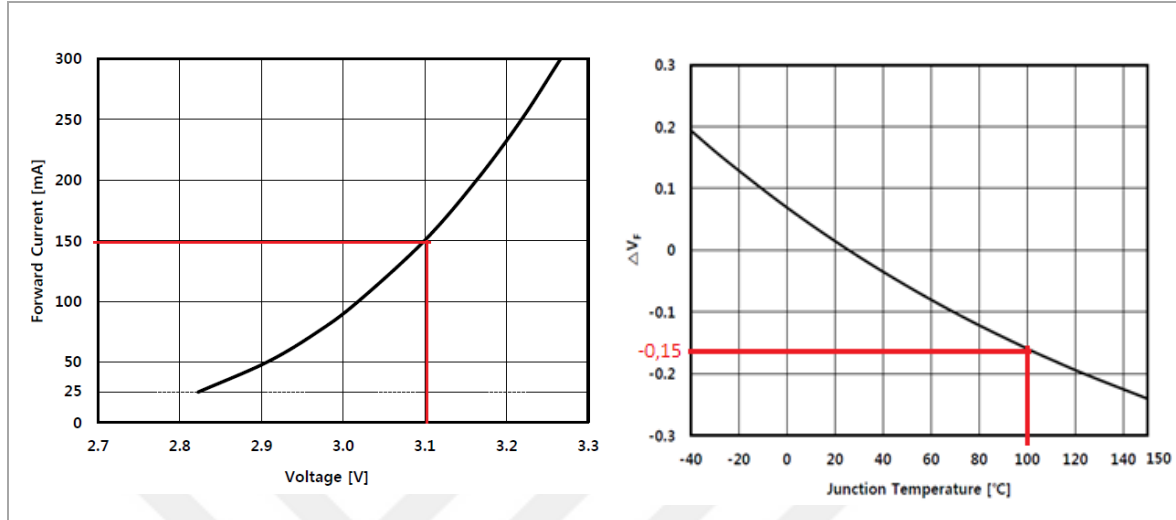


Figure 2.2: Stapc1lx LED voltage-forward and voltage shift [60].

There are two different voltage values at 25 °C temperature and 100 °C temperature in the voltage change graph of the LEDs according to the temperature [60]. This affects the electrical power (P_{el}) values. Equation 2.1 shows the equation used to calculate electrical power (P_{el}) values.

$$P_{el} = V_f \cdot I_F$$

(2.1) Eq. (2.1) is known as Electrical Power.

Temperature = 25 ° C:

$$I_F = 0.15 \text{ A} \quad \text{typ. } V_f = 3.10 \text{ V} \quad P_{el} = (0.15 \text{ A}) \cdot (3.2 \text{ V}) = 0.465 \text{ W}$$

Temperature = 100 ° C:

$$I_F = 0.15 \text{ A} \quad \text{typ. } V_f = 3.1 \text{ V} - 0.15 \text{ V} \quad P_{el} = (0.15 \text{ A}) \cdot (2.95 \text{ V}) = 0.442 \text{ W}$$

When the calculation is made at 25°C for 3.1 Volt and 0.15 mA current, 0.465 watts of electrical power is generated. When the temperature is 100 °C, there is a -0.15 Volt drop in voltage in Figure 2.2 In this case, 0.442 watts of electrical power occurs.

2.3.2 Signal Lamp Radiant Power

Figure 2.3 shows the radiant power, which changes depending on the temperature, and the radiant power value according to the driven current. According to Table 2.2, the P2 bin code LED is driven with 150 mA at 25° C and gives 32 lumens of light with full efficiency.

According to Figure 2.3, when the temperature rises to 100 °C, 15% of the light value is lost. By increasing the current value, the lumen value can reach up to 180%. To achieve these values, liquid cooled-type cooling systems should be used. Since this is not possible in practice, it be more economical and practical to use 2 LEDs instead of 1 for the required lumen.

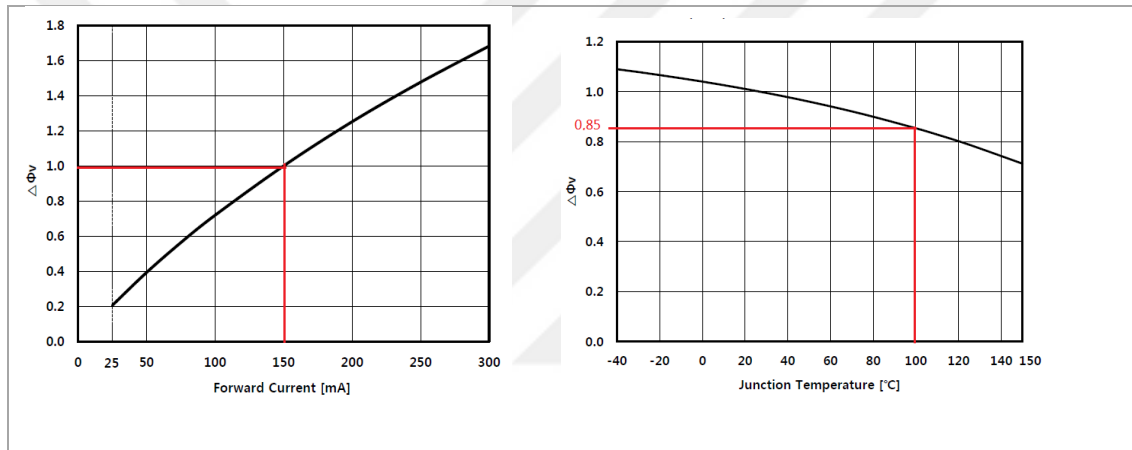


Figure 2.3: Stapc1lx LED voltage shift-forward and junction temperature [61].

Radiant power means the power value to be spent for the minimum lumen value of the LED. Table 2.3 shows the luminous efficacy of radiation values that should be used for LEDs of different colors. Equation 2.2 shows the equation used to calculate radiant power (P_{opt}) values.

$$P_{opt} = \Phi_e = \eta \cdot P_{el} \quad (2.2)$$

Eq. (2.2) is known as radiant power.

where Φ_e is the radiant power. η indicates the luminous efficiency. As the temperature increases, the luminous efficiency decreases.

Temperature = 25° C:

$$\text{min. } \Phi_V \sim 32 \text{ lm} \quad \Phi_V / \Phi_e = 180 \text{ lm/W} \quad \Phi_e (32 \text{ lm}) = 0.177 \text{ W}$$

Temperature = 100 ° C:

$$32 \text{ lm} \cdot \%85 = 27.20 \text{ lm} \quad \Phi_V / \Phi_e = 180 \text{ lm/W} \quad \Phi_e (27.20 \text{ lm}) = 0.151 \text{ W}$$

Table 2.3 shows the typical luminous efficiency values of the radiation of LEDs of different colors.

Table 2.3: The typical luminous efficacy of radiation [62].

Device	Color	Φ_V / Φ_e
LA	Amber	240 lm
LS	Super Red	130 lm
LO	Orange	180 lm
LY	Yellow	480 lm
LUW	White	325 lm

2.3.3 Signal Lamp Heat Dissipation

When the LED is powered, heat and light emerge. The value of the heat and light generated is subtracted from each other and the remaining power value is calculated by including it in the analysis. Equation 2.2 shows the equation used to calculate heat dissipation (P_{heat}) values.

$$P_{\text{heat}} = V_f \cdot I_F - \Phi_e \quad (2.3)$$

Eq. (2.3) is known as heat dissipation.

Temperature = 25 °C:

$$P_{\text{heat}} = 0.465 \text{ W} - 0.177 \text{ W} = 0.288 \text{ W}$$

Temperature = 100 °C:

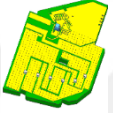
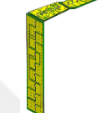
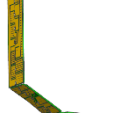
$$P_{\text{heat}} = 0.442 \text{ W} - 0.160 \text{ W} = 0.291 \text{ W}$$

The difference between the power values at 25 °C and 100 °C is such a small value that it does not affect the analysis result. Values at 25°C should be used for LED power calculations.

2.4 THE PCB CIRCUITS AND LED CALCULATIONS

The PCB circuits used in the thesis and the number of LEDs, their power values, and the total lumen values formed by the LEDs are shown in Table 2.4.

Table 2.4: The PCB circuits and LEDs used in the thesis study.

PCB NAME	STOP LAMP	REVERSE LAMP	SIGNAL LAMP	FOG LAMP	DRL UPPER	DRL LOWER
						
LED (1 PIECE)	0.44W	0.31W	0.465W	0.44W	0.165W	0.165W
LED NAME	STDRC1LX	STW0C1LX	STAPC1LX	STDRC1LX	STDRC1LX	STDRC1LX
						
TOTAL LED	8	6	10	8	21	21
COLOR	RED	WHITE	ORANGE	RED	RED	RED
FLUX (lm) MAX	28	62	33	28	12	12
TOTAL FLUX (lm)	224	372	330	224	252	252
ELECTRICAL POWER (W)	0.44	0.31	0.465	0.44	0.165	0.165
LUMINOUS EFFICACY (lm)	130	325	180	130	130	130
RADIANT POWER (W)	0.215	0.191	0.183	0.215	0.092	0.092
HEAT DISSIPATION (W)	0.225	0.119	0.282	0.225	0.073	0.073

2.5 MATERIAL LIST

The stop lamp consists of PCB and plastic parts. The parts used in the product and their exploded image are shown in Figure 2.4 [2D Drawing].

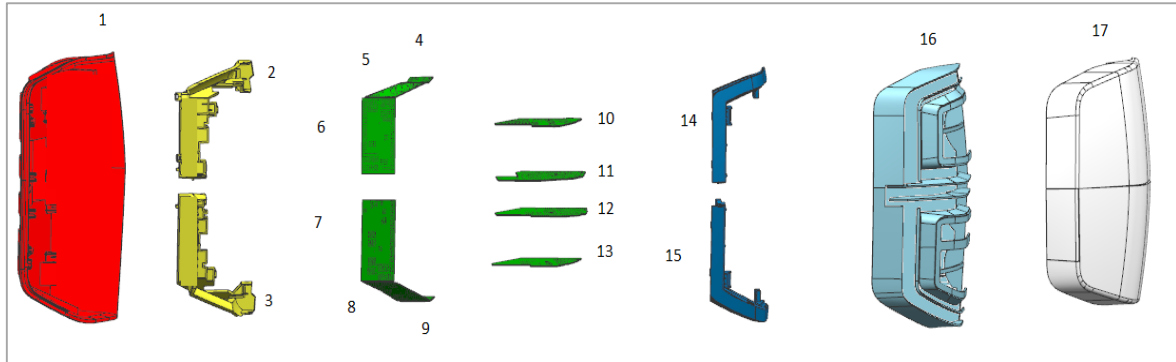


Figure 2.4: Product assembly parts.

Product mounting parts and thermal properties are shown in Table 2.5.

Table 2.5: Product assembly parts and thermal properties.

No	Part name	Material	Vicat temperature (°C)	Thermal conductivity (W/mK)	Specific Heat (J/kg K)
1	Main housing	PC+ABS	135	0.21	1290
2	Inner housing upper	PC+ABS	135	0.21	1290
3	Inner housing lower	PC+ABS	135	0.21	1290
4	Upper park PCB-1	Fr-4	150	0.5	1000
5	Upper park PCB-2	Fr-4	150	0.5	1000
6	Upper park PCB-3	Fr-4	150	0.5	1000
7	Lower park PCB-3	Fr-4	150	0.5	1000
8	Lower park PCB-2	Fr-4	150	0.5	1000
9	Lower park PCB-1	Fr-4	150	0.5	1000
10	Stop lamp PCB	Fr-4	150	0.5	1000
11	Reverse lamp PCB	Fr-4	150	0.5	1000
12	Signal lamp PCB	Fr-4	150	0.5	1000
13	Fog lamp PCB	Fr-4	150	0.5	1000
14	Inner Cover upper	PMMA	108	0.161	1388
15	Inner Cover lower	PMMA	108	0.161	1388
16	Reflector	PC+ABS	135	0.21	1290
17	Lens	PMMA	108	0.161	1388

Specific heat and thermal conductivity values of the PC+ABS material used in the analysis were entered into the analysis program depending on the temperature. Figure 2.5 shows the variation of specific heat values with temperature.

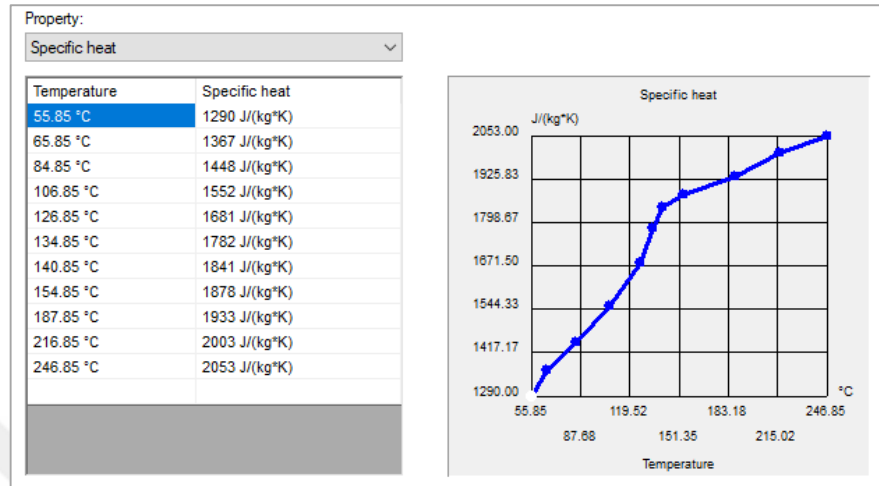


Figure 2.5: PC+ABS specific heat and temperature.

Figure 2.6 shows the variation of thermal conductivity with temperature.

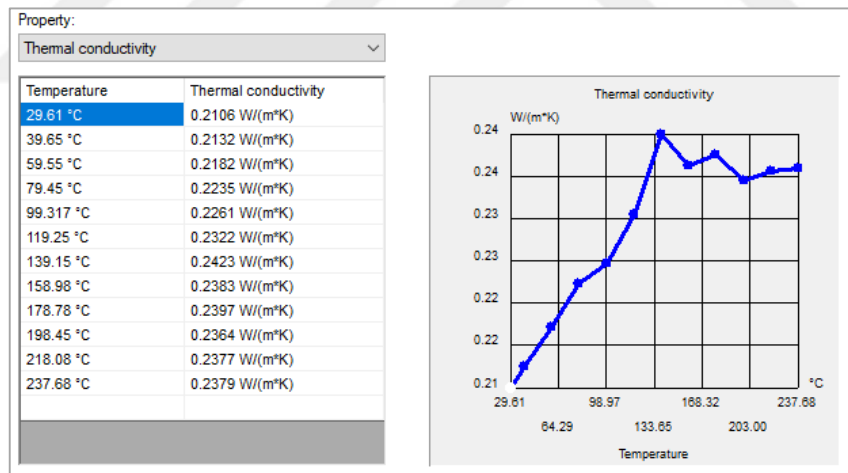


Figure 2.6: PC+ABS thermal conductivity and temperature.

PC+ABS is a material with very good impact resistance at low temperatures. Due to its low shrinkage, its mold sensitivity is extremely good. It can be used at temperatures up to 135 °C. Since it is a hard material, it has good workability.

PC+ABS heat transfer coefficient and specific heat values are given according to temperature.

Specific heat and thermal conductivity values of the PMMA material used in the analysis were entered into the analysis program depending on the temperature. Figure 2.7 shows the variation of specific heat values with temperature.

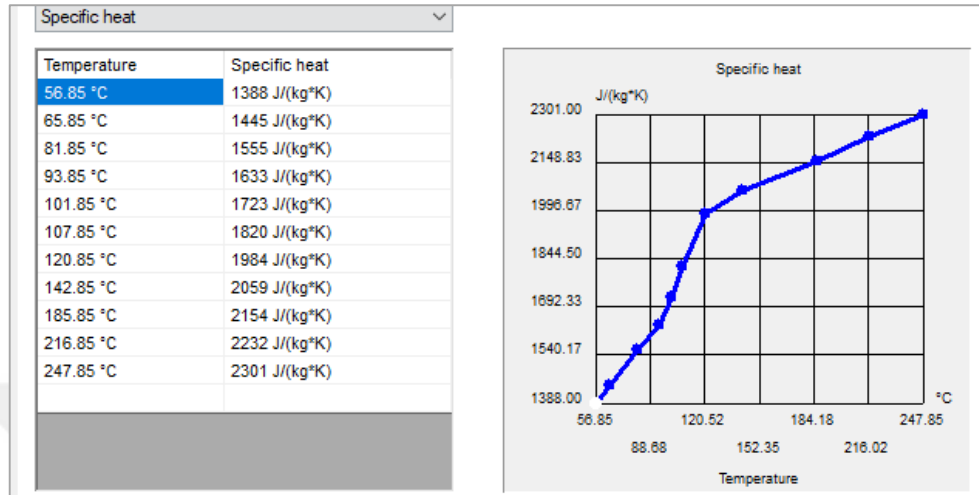


Figure 2.7: The variation of specific heat values with temperature in the PMMA material.

Figure 2.8 shows the variation of thermal conductivity with temperature.

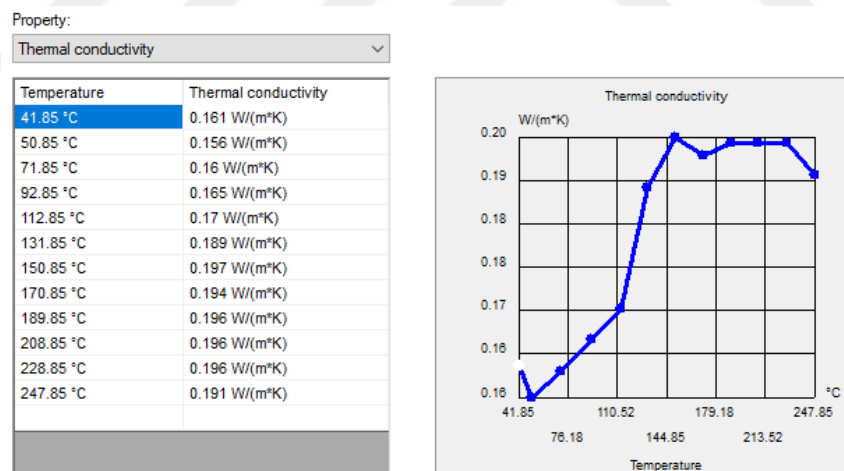


Figure 2.8: The variation of thermal conductivity with temperature in the PMMA material.

PMMA is extensively used in the automotive industry on the outer parts of headlights and lighting parts. There are PMMAs with 95% light transmittance. It is used in visual places where transparency is required. Temperature resistance is not very good. It starts to soften between 103°C-110 °C temperature. Although it is a high-strength product the product has a low pour point.

Copper paths serve as electrical conduction and heat carrier in PCB circuits. By making changes in copper paths, the thermal resistance of the system can be reduced. To reduce the cost in led PCB circuits, usually, 1 oz copper is used. In case the power in the circuit increases, the copper thickness can also be changed. Figure 2.9 shows the specific heat capacity of copper versus temperature.

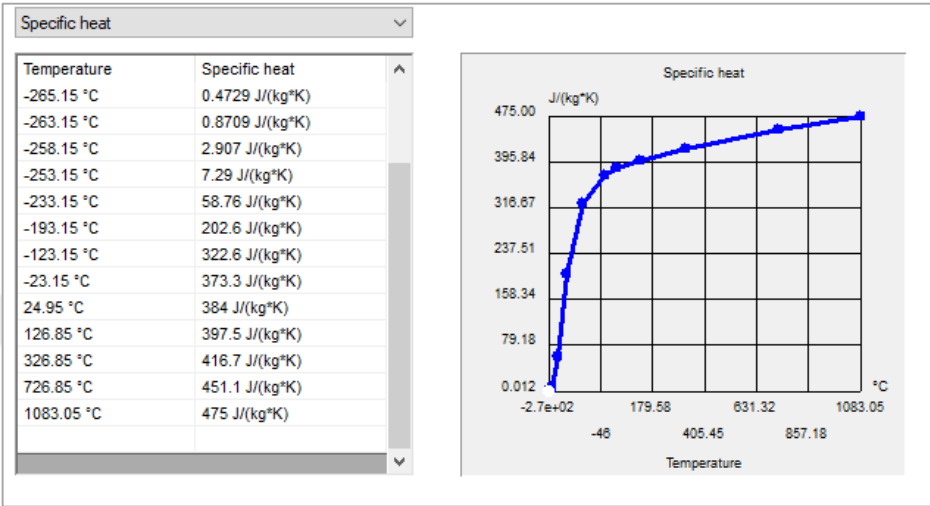


Figure 2.9: The variation of specific heat values with temperature in the copper material.

Figure 2.10 shows the variation of thermal conductivity with temperature.

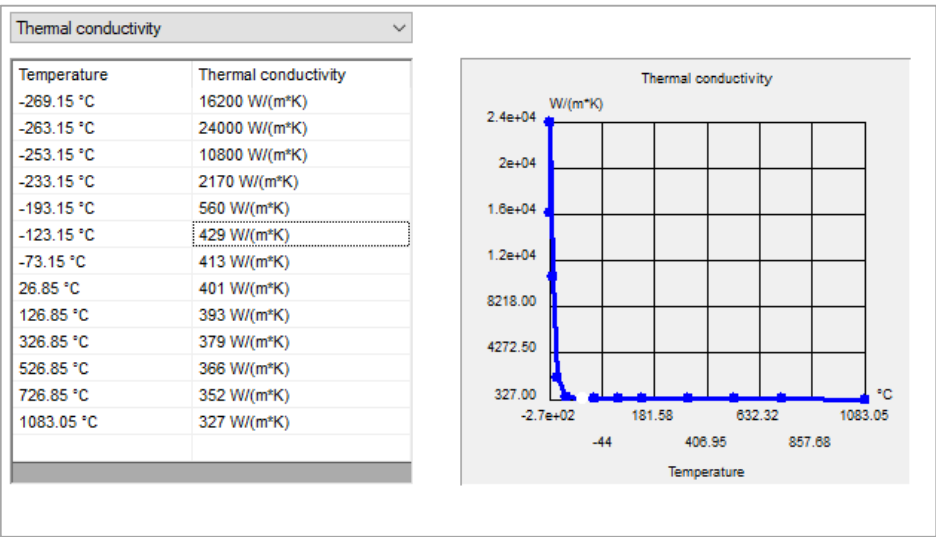


Figure 2.10: The variation of thermal conductivity with temperature in the copper material.

2.6 TEST CONDITIONS

To check the accuracy of the heat and light losses of the LEDs Prototypes of PCB circuits were created and tested. Thermal analysis was carried out under the same conditions, and the necessary heat loss control was made for each card.

Since thermal camera images of the PCB circuits could not be taken in the assembled parts, the PCB circuits were operated in a closed box for 30 minutes without being affected by the external environment.

Thermocouples were connected to the LEDs and the values in the thermal camera were checked.

In the automotive industry, the ambient temperature is taken as 80 °C.

An optimization study was carried out in regions with high temperatures by making simulation verification with a thermal camera.

By changing the positions of the PCB copper paths, optimum distribution of heat has been insured. After the simulation and test verifications at room temperature (22 °C), the power losses on the PCB were checked and thermal analysis was carried out under 70 °C temperature conditions.

Vicat values of non-transparent plastic parts used are 135 °C. Transparent plastics, on the other hand, 108 °C Vicat temperature is accepted.

When plastic materials are exposed to high temperatures, they can change shape depending on time. The temperature at which plastic materials begin to deform is the Vicat temperature. The Vicat temperature varies depending on the thickness of the part and the material type. ISO 75 1-2 Vicat values are used to control the Vicat temperature.

2.7 PCB THERMAL TESTS

The copper areas used in PCB cards are designed to dissipate the heat. The copper areas can absorb the heat up to a certain distance from the environment. Since the analyzes made depending on time take a very long time, the heat dissipation capacity of the copper areas can be seen depending on time by making a prototype. Figure 2.11 shows the temperature

over time of the prototype operation of the signal lamp on the PCB board. Each picture was taken for 1 minute.

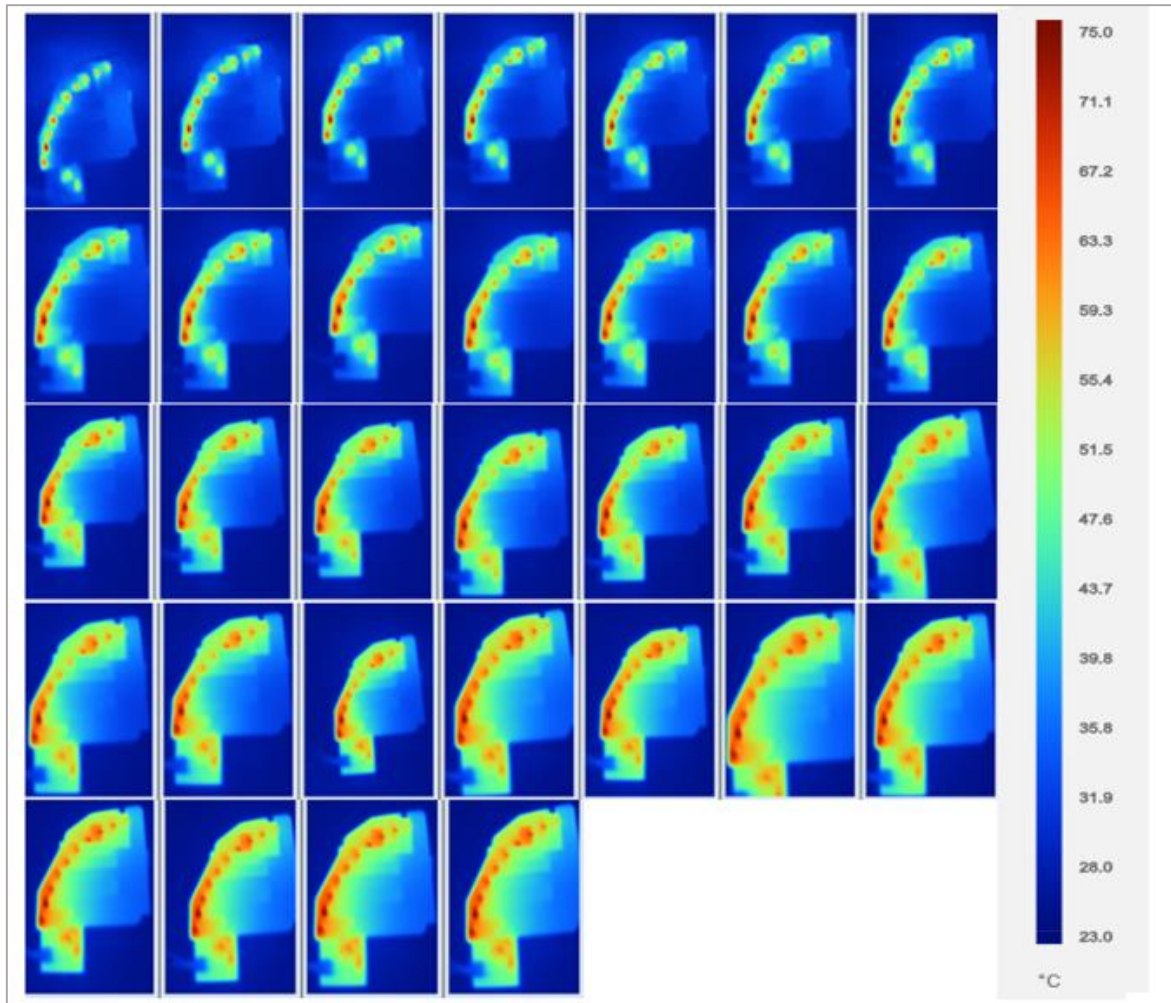


Figure 2.11: Signal lamp thermal image.

As a result of the test, it has been observed that the heat distribution of the signal PCB copper areas is balanced. The temperature flow from the red areas to the blue areas can be seen in Figure 2.11. From the pictures taken over time, it is seen that the temperature disperses quickly on the card. As a result of the test, a temperature of 75.56 °C was formed. The measured temperature value is used to control the simulation results.

The heat dissipation capacity of copper areas depending on time was investigated by making a prototype on the reverse card. Since the LEDs are in the middle of the PCB circuit, the board distributes the heat homogeneously. Figure 2.12 shows the temperature over time of the reverse lamp prototype work on the PCB board. Each picture was taken for 1 minute.

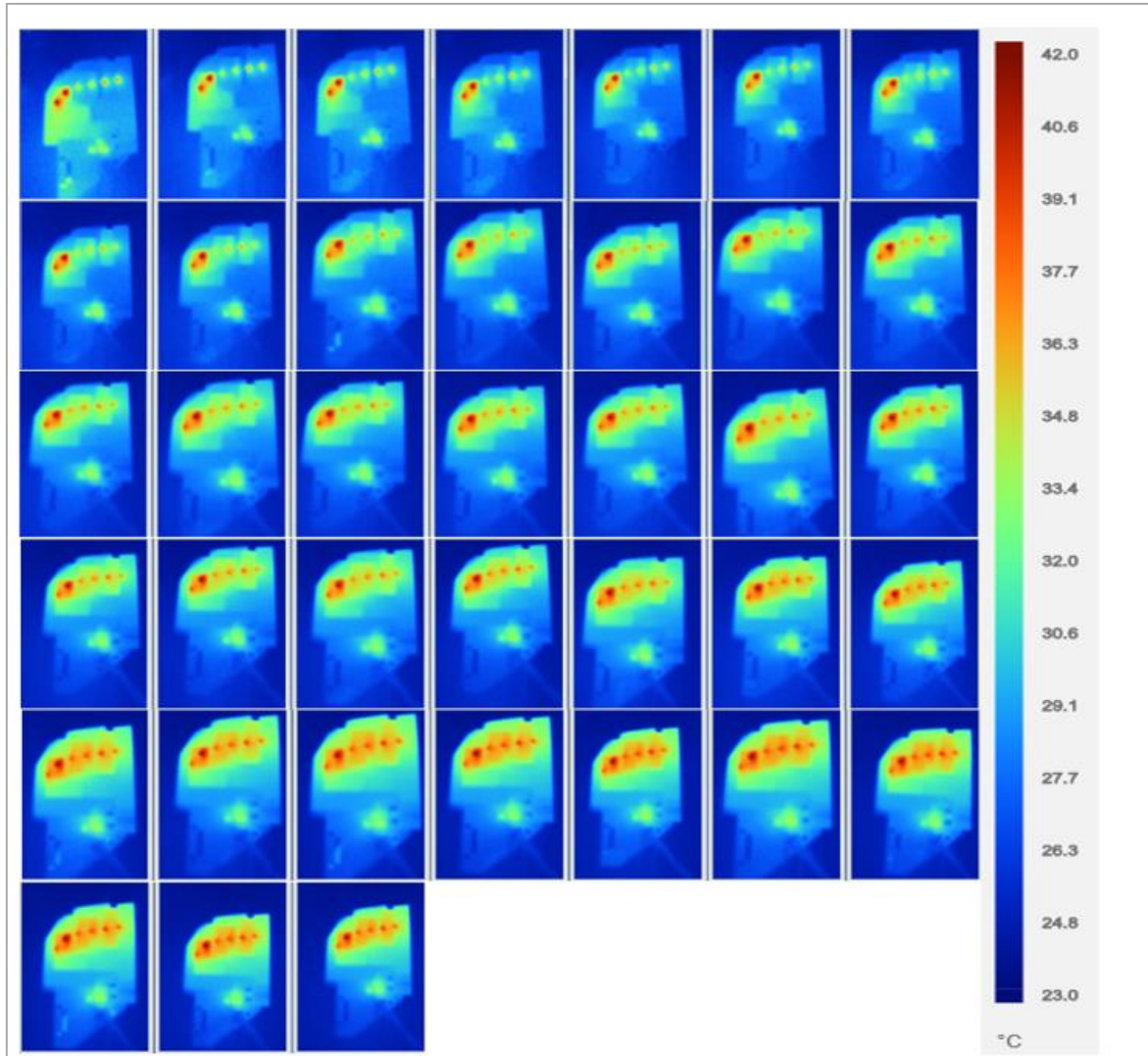


Figure 2.12: Reverse lamp thermal image.

As a result of the test, it was observed that the heat distribution of the reverse PCB copper areas was balanced. The heat flow from the red areas to the blue areas can be seen in Figure 2.12. From the pictures taken over time, it can be seen that the heat dissipates rapidly on the card. As a result of the test, a temperature of 42.11 °C occurred. The measured temperature value is used to check the simulation results.

The LEDs in the fog lamp are located at the end of the PCB circuit. The fact that the LEDs are aligned in the lower and upper positions can cause the circuit to heat up rapidly and damage the LEDs. It is necessary to check that the copper areas created in the fog PCB with the prototype transmit the temperature in the desired direction. In Figure 2.13, there are images of the fog lamp depending on time. Each figure was taken after 2 minutes.

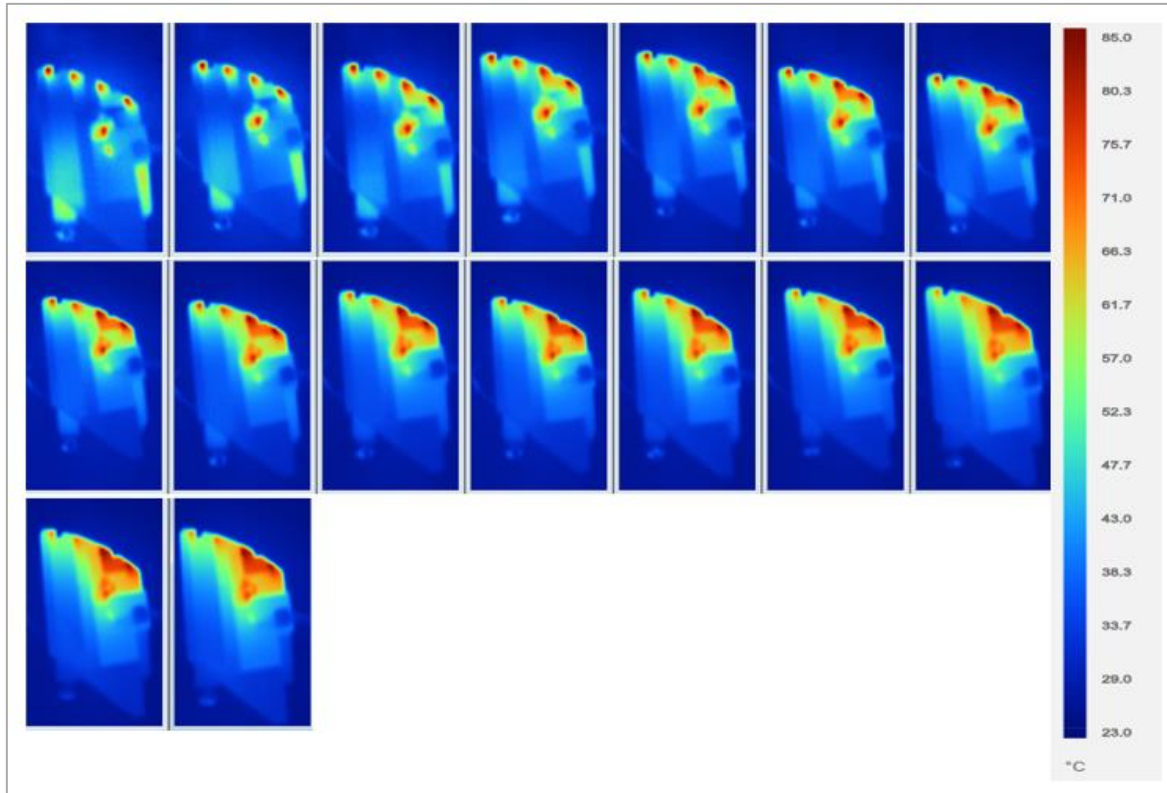


Figure 2.13: Fog lamp thermal image.

It is seen in Figure 2.13 that the heat trapped in the Fog PCB ends cannot move downwards. In this region, it is necessary to carry the heat formed by the copper paths to the cold parts of the PCB circuit. As a result of the test, a temperature of 85.26 °C has occurred. Since the LEDs used are red, they are extremely badly affected by the heat. There may be light losses due to the heat increase in the LEDs.

The LEDs in the stop lamp are located at the end of the PCB. A different way has been tried to carry the temperature formed in the environment to the lower parts of the PCB. The temperature of the LED has been tried to be reduced by using PCB with different copper thicknesses. It has been tested with 1 oz and 3 oz double layer PCB. The temperature graph of the 1oz Copper PCB circuit depending on time is shown in Figure 2.14. T1-T2-T3-T4 values in Figure 2.14 shown the thermocouples connected to the PCB.

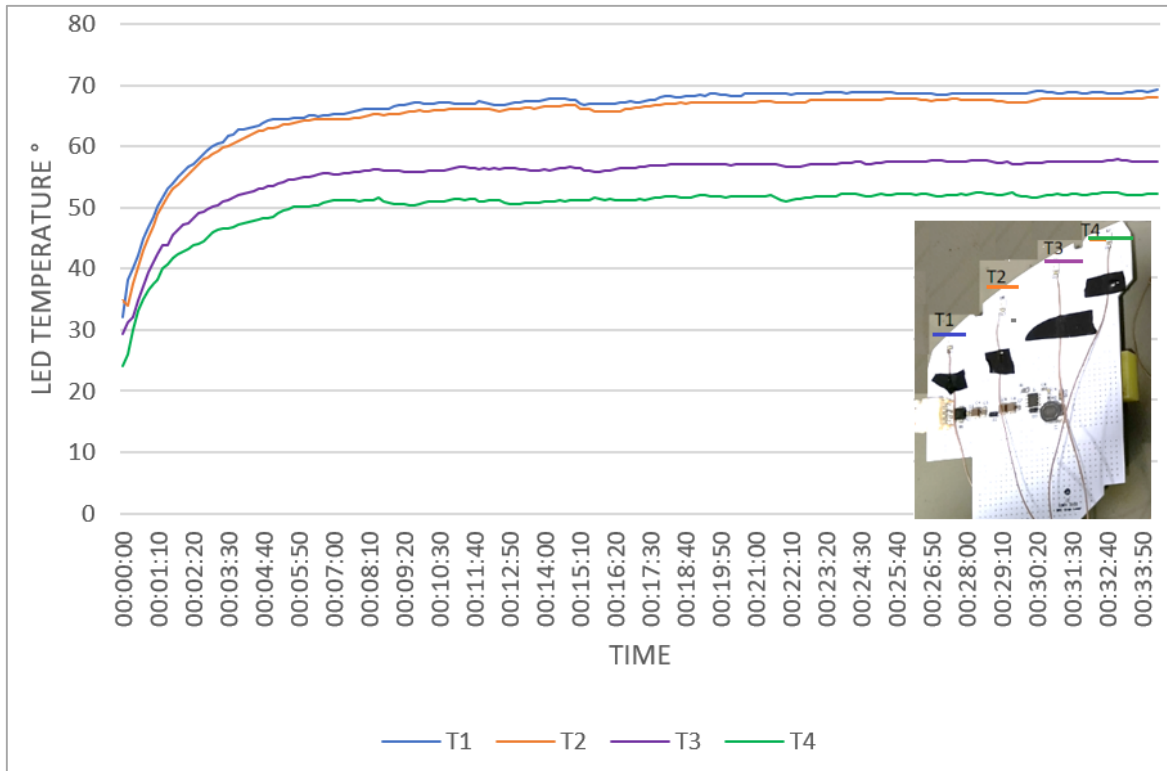


Figure 2.14: The temperature graph of the 1 oz copper PCB circuit depending on time.

The test period lasted 34 minutes. After 20 minutes, it was observed that there was no significant change in the LED temperature values. The positions of the probes are shown in Figure 1.40. It has been observed that the LEDs in T1 and T2 positions cannot dissipate the heat on them. The temperature difference of the LEDs on the same PCB circuit is approximately 18°C.

The temperature graph of the 3 oz copper PCB circuit depending on time is shown in Figure 2.15. T1-T2-T3-T4 values in Figure 2.15 shown the thermocouples connected to the PCB.

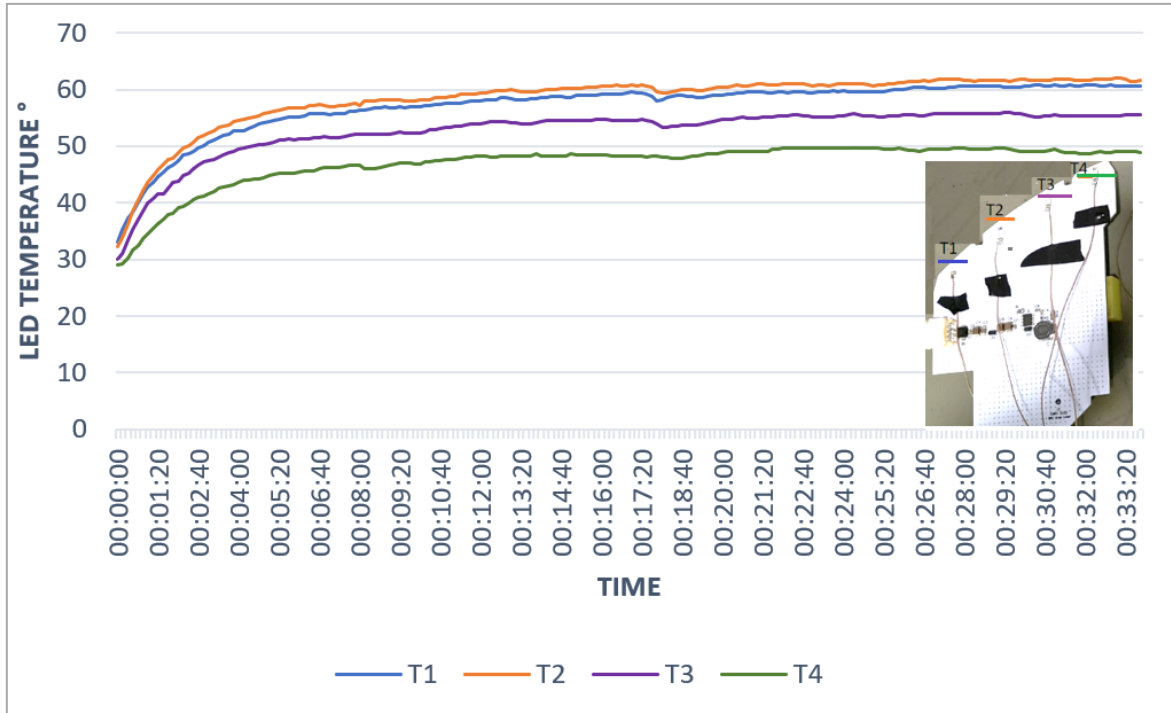


Figure 2.15: The temperature graph of the 3 oz copper PCB circuit depending on the time.

The test period lasted 33 minutes. After 20 minutes, it was observed that there was no significant change in the LED temperature values. The positions of the probes are shown in Figure 1.40. The temperature of the LEDs decreased by 10 °C. The temperature difference of the LEDs on the same PCB in a 3 oz copper circuit is significant compared to a 1 oz PCB circuit. There was no change. In 3 oz copper, the LED temperature difference has been seen approximately 17°C.

2.7.1 Reverse PCB Card Temperature Test

The simulation verifications have been done at room temperature because they are practical. The LEDs of the reverse lamp have been driven at room temperature. It has waited for 30 minutes and the temperature values have been measured with a thermometer and a thermal camera. Figure 2.16 shows reverse PCB board and thermal camera shots. The reverse card consists of 6 LEDs.

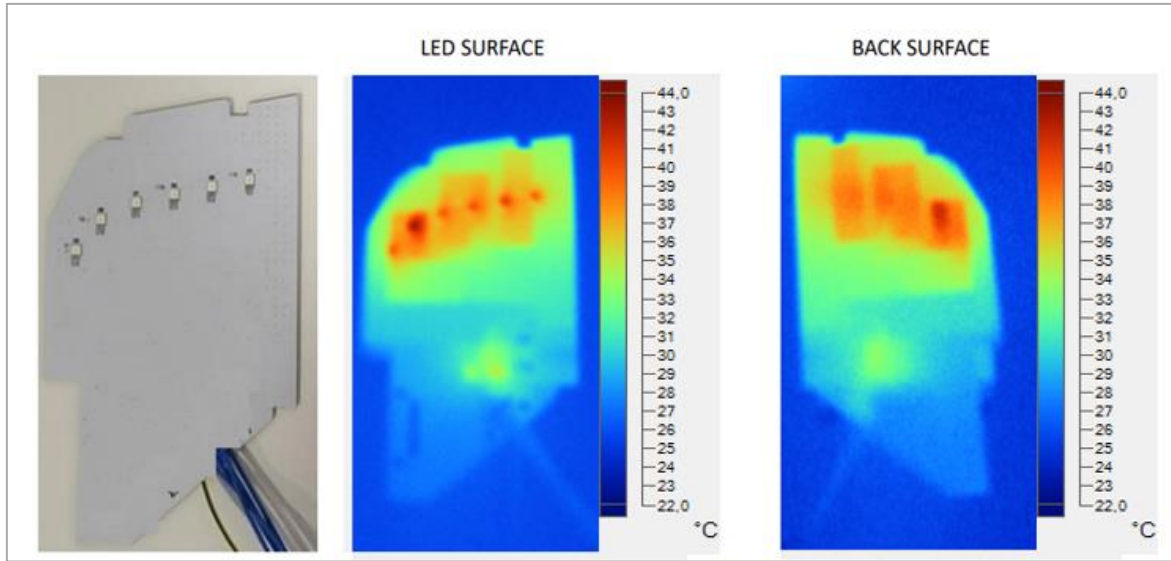


Figure 2.16: Reverse lamp PCB thermal test

Thermal camera shots were taken 30 minutes after the PCB board was energized. A temperature of 42.11 °C was reached in the thermal camera images taken from the PCB board and LED surface.

Since the LEDs are located in the middle of the PCB, they are in the most suitable position in terms of heat dissipation.

To prove the accuracy of the calculated power values of the LEDs used in the reverse PCB, the simulation results and thermal camera images were matched. To reduce the errors in the thermal camera, the thermocouple and the thermal camera were verified. Figures 2.17 show the verification of the simulation result of the reverse lamp with a thermal camera on the LED surface.

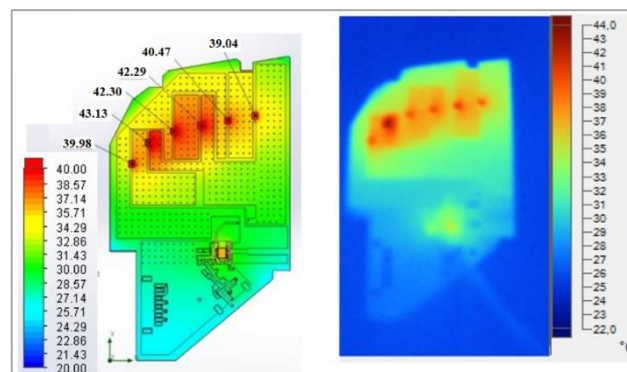


Figure 2.17: The verification of the simulation result of the reverse lamp with a thermal camera on the LED surface.

Figures 2.18 show the verification of the simulation result of the reverse lamp with a thermal camera on the back surface.

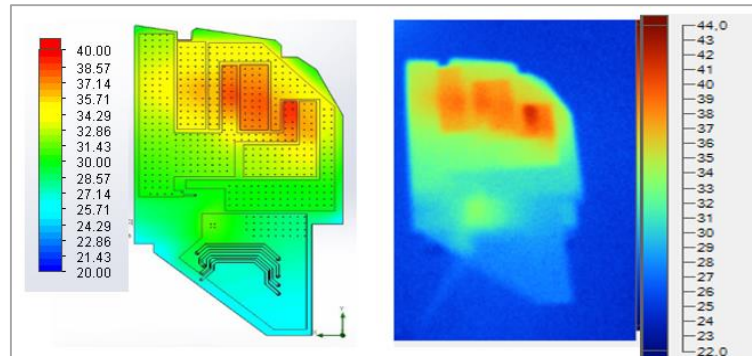


Figure 2.18: The verification of the simulation result of the reverse lamp with a thermal camera on the back surface.

Simulation results, thermal camera images, and thermocouple values are shown in Table 2.6.

Table 2.6: Reverse lamp simulation result comparison with thermal camera and thermocouple.

Reverse lamp	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6
Simulation temperature (°C)	39.98	43.13	42.30	42.29	40.47	39.04
Thermal camera temperature (°C)	38.25	42.11	40.36	41.65	39.52	37.36
Thermocouple temperature (°C)	38.62	42.75	41.29	42.11	39.85	38.54
Difference (%)	4.33	2.36	4.59	1.51	2.35	4.30

There is no problem with the LED power values calculated in the reverse PCB circuit. There is a maximum difference of 4.59%. This difference is negligible in LED calculations. The temperature distribution is balanced. The thermal camera image and the simulation image look similar to each other.

2.7.2 Signal PCB Card Temperature Test

Simulation validations were performed at room temperature as it was practical. The LEDs of the signal lamp have been driven at room temperature. After 30 minutes, the temperature values have been measured with a thermometer and a thermal camera. Figure 2.19 shows the signal PCB board and thermal camera shots. Signal PCB board consists of 10 LEDs

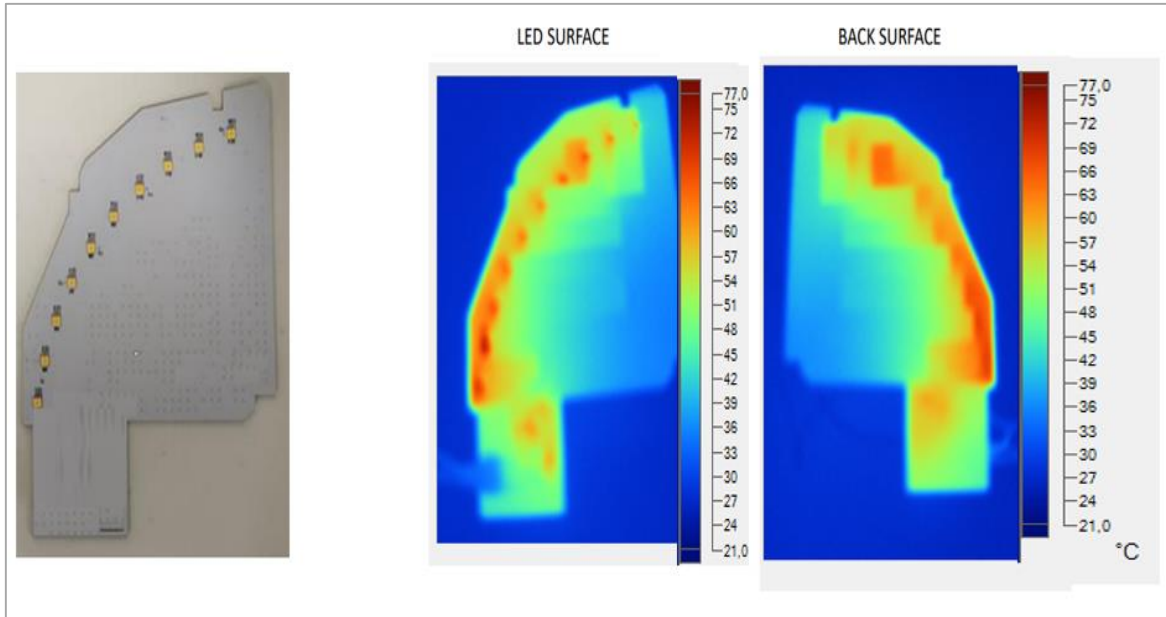


Figure 2.19: Signal lamp PCB thermal test.

Thermal camera shots were taken 30 minutes after energizing the PCB board. In the thermal camera images taken from the back of the PCB board and by the LED, the temperature was measured as 75.56 °C.

Since the LEDs remained on the edge of the PCB, the heat distribution was not evenly. However, the thermal camera shots and the simulation results were compatible with each other.

To prove the accuracy of the calculated power values of the LEDs on the PCB used in the signal lamp, the simulation results were matched with the thermal camera images.

Thermocouple and thermal imager have been validated to reduce errors in the thermal imager. Figure 2.20 shows the verification of the simulation result of the signal lamp with the thermal camera on the LED surface.

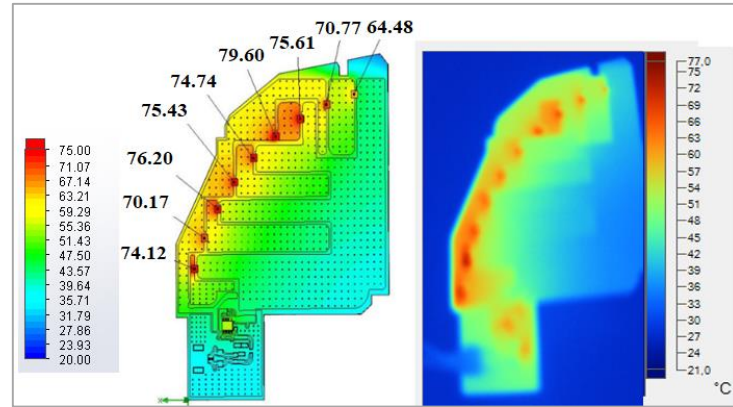


Figure 2.20: Signal lamp PCB simulation result comparison LED surface.

Figures 2.21 show the verification of the simulation result of the signal lamp with a thermal camera on the back surface.

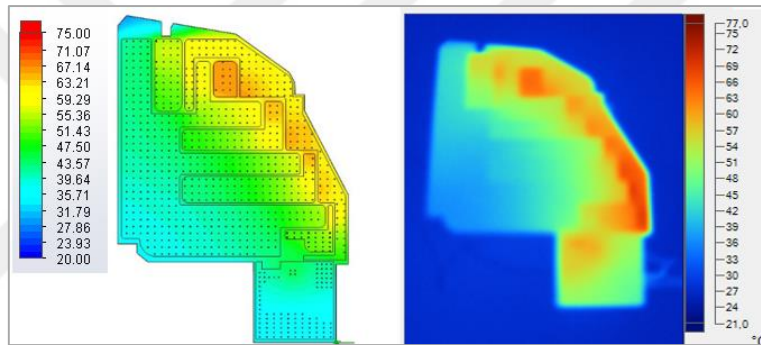


Figure 2.21: Signal lamp PCB simulation result comparison back surface.

Simulation results, thermal camera images, and thermocouple values are shown in Table 2.7.

Table 2.7: Signal lamp simulation result comparison with thermal camera and thermocouple.

Signal lamp	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8	Led-9
Simulation temperature (°C)	74.12	70.17	76.20	75.43	74.74	79.60	75.61	70.77	64.48
Thermal camera temperature (°C)	70.28	66.33	72.35	71.47	70.44	75.56	71.52	67.21	60.87
Thermocouple temperature (°C)	71.46	68.38	74.64	72.39	71.21	76.61	72.65	69.33	62.48
Difference (%)	5.18	5.47	5.05	5.25	5.75	5.08	5.41	5.03	5.60

There is no problem with the calculated LED power values in the reverse PCB circuit. There is a maximum difference of 5.75%. This difference is negligible in LED calculations. The temperature distribution is balanced. The thermal camera image and the simulation image are similar to each other.

2.7.3 Fog PCB Card Temperature Test

4 LEDs are placed in the lower position and 4 LEDs in the upper position on the PCB to provide homologation values. The fog PCB board consists of 8 red LEDs. These LEDs lose their light value significantly when exposed to heat.

Simulation validations were performed at room temperature. After 30 minutes, the temperature values are measured with a thermometer and a thermal camera. Figure 2.22 shows the fog PCB board and thermal camera shots.

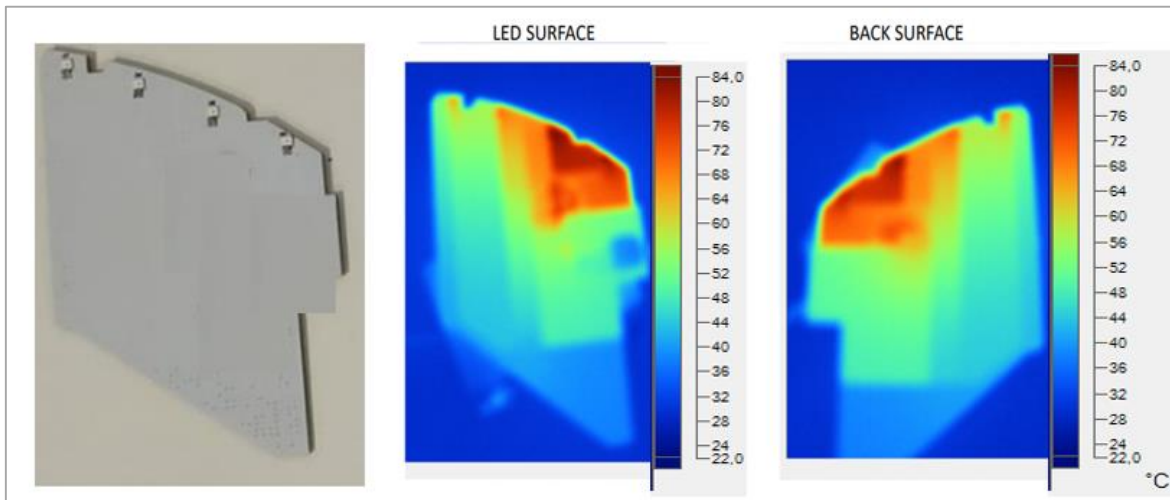


Figure 2.22: Fog lamp PCB thermal test.

Thermal camera shots were taken 30 minutes after the fog PCB board was energized. To prove the accuracy of the calculated power values of the LEDs on the PCB used in the fog lamp, the simulation results were matched with the thermal camera images. The temperature in the thermal camera images taken from the back of the PCB board and by the LED was measured 85.69 °C.

It has been observed that the LEDs cause an increase in temperature by heating each other. However, thermal camera shots and simulation results are compatible with each other.

Thermocouple and thermal camera have been validated to reduce errors in the thermal camera. Figure 2.23 shows the verification of the simulation result of the fog lamp with the thermal camera on the LED surface.

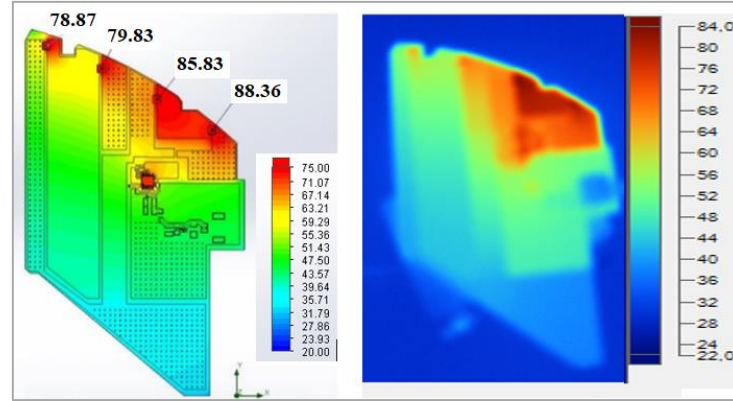


Figure 2.23: Fog lamp simulation result comparison in the front surface.

Figures 2.24 show the verification of the simulation result of the fog lamp on the back surface.

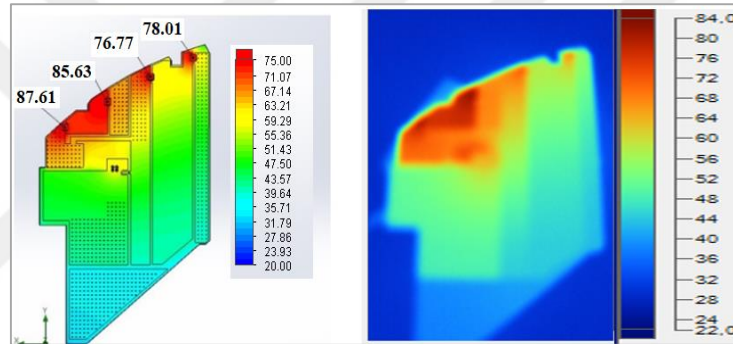


Figure 2.24: Fog lamp simulation result comparison in the back surface.

Table 2.8: Fog lamp simulation result comparison with thermal camera and thermocouple

Fog lamp	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8
Simulation temperature (°C)	88.36	85.83	79.28	78.87	87.61	85.63	76.77	78.01
Thermal Camera temperature (°C)	83.25	82.10	75.36	74.45	85.26	82.25	72.35	74.57
Thermocouple temperature (°C)	83.55	82.36	75.80	74.86	85.69	82.45	72.65	69.87
Difference (%)	5.78	4.34	4.94	5.60	2.68	3.94	5.75	4.40

Simulation results, thermal camera images, and thermocouple values are shown in Table 2.8.

It has been observed that the heat is not distributed towards the lower regions in the fog PCB circuit. Especially in the LED area, which is 88.36 °C, the temperature must be removed from the environment by changing the copper paths. There is no problem with the LED power values calculated in the fog PCB circuit. There is a maximum difference of 5.75%. This difference is negligible in LED calculations.

2.7.4 Stop PCB Card Temperature Test

The stop PCB board consists of 8 red LEDs. These LEDs lose their luminous value significantly when exposed to heat.

Simulation validations were performed at room temperature. After 30 minutes, the temperature values have been measured with a thermometer and a thermal camera. Figure 2.25 shows the fog PCB board and thermal camera shots.

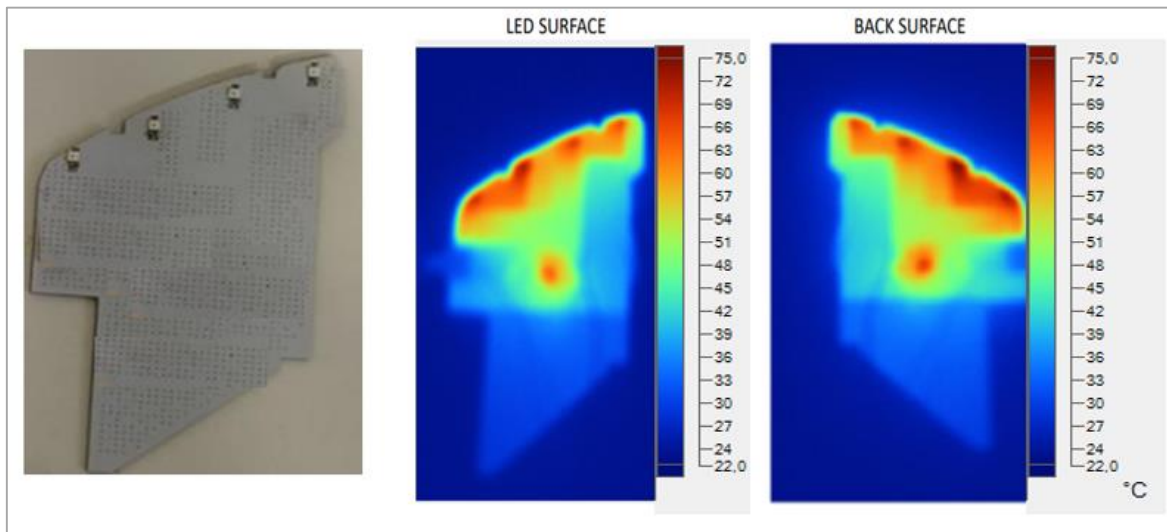


Figure 2.25: Stop lamp PCB thermal test.

Thermal camera shots were taken 30 minutes after the stop PCB board was energized. Simulation results were matched with thermal camera images to prove the accuracy of the calculated power values of the LEDs on the PCB used in the stop lamp. In the thermal camera images taken from the back of the PCB board and by the LED, the temperature was measured at a maximum of 75.50 °C.

It has been observed that LEDs cause temperature increase by heating each other. However, thermal camera shots and simulation results are compatible with each other.

Thermocouple and thermal camera have been validated to reduce errors in the thermal camera. Figure 2.26 shows the verification of the simulation result of the stop lamp with the thermal camera on the LED surface.

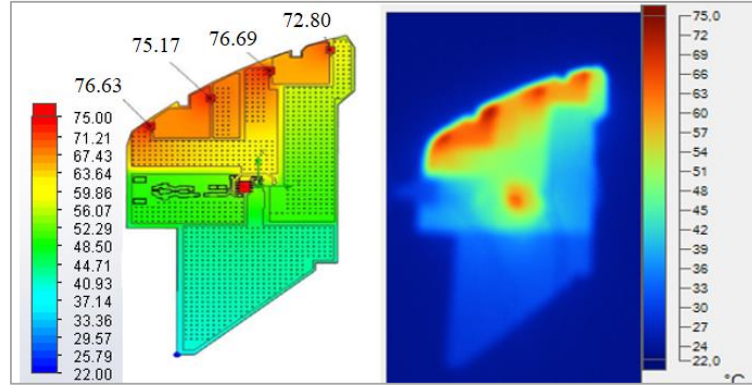


Figure 2.26: Stop lamp simulation result comparison in the front surface.

Figure 2.27 shows the verification of the simulation result of the stop lamp on the back surface.

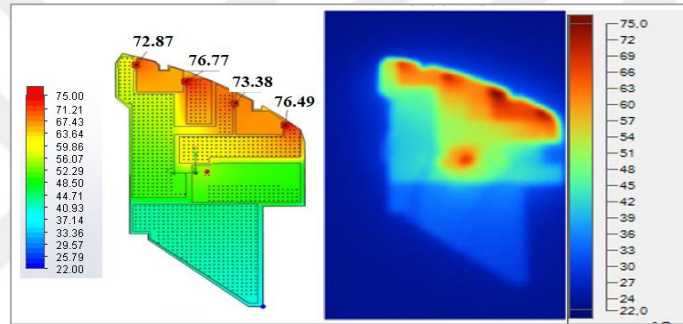


Figure 2.27: Stop lamp simulation result comparison in the back surface.

Simulation results, thermal camera images, and thermocouple values are shown in Table 2.9.

Table 2.9: Stop lamp simulation result comparison with thermal camera and thermocouple.

Stop lamp	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8
Simulation temperature (°C)	76.63	75.17	76.69	72.80	76.49	73.38	76.77	72.87
Thermal camera temperature (°C)	73.40	73.30	72.10	69.30	73.5	75.5	74.5	68.40
Thermocouple temperature (°C)	74.5	73.60	71.60	70.20	74.6	71.1	72.8	71.10
Diffirence (%)	2.78	2.09	6.64	3.57	2.47	3.11	5.17	2.43

Although there are LED power values in the stop and fog light, the temperature of the fog light is 10°C higher due to the change in copper areas. The distribution of the temperature in the stop PCB circuit does not look bad. In the LED area of 75.5 °C, the temperature can be dissipated from the environment by changing the copper paths. There is no problem in the LED power values calculated in the stop PCB circuit. There is a maximum difference of 6.64%.

2.8 THERMAL SHOCK ANALYSIS VALUES AT THE 70 °C

As a result of testing and simulation verification on PCB prototypes, it was observed that the simulation temperature was higher, on average 6%.

To secure the LEDs, it was decided to use thermal analyzes at the calculated values.

Since the main heat source in the system is LEDs, the material of the reflector part used in the area closest to the LEDs was chosen as PC ABS from a group with a high vicat value.

To stay on the safe side in optical tests, the optical engineer gives an average of 30% more LED power value.

LED value is accepted as 30% higher due to reasons such as shape difference and transparency values of the plastic part during the injection.

After the optical tests, the excess in the light values is reduced by the electronics team to ensure that the LEDs are on the safe side.

If there is no problem in the operating temperature of the LEDs as a result of the simulation, the Vicat values of the plastic parts are checked and it is decided whether the materials in the upper-temperature group should be selected or not.

Cost is the most important factor in automotive R&D studies. Plastic groups with high Vicat temperature can significantly increase the cost.

The most important point here is to prevent the LEDs from getting too hot by providing the light values given in optical tests at an average light intensity between minimum and maximum. After the optical values are secured, the vicat temperature of the plastic materials is controlled and the safety of the system is ensured.

The effect of thermal analysis at 70 °C on plastic parts and PCB circuits is shown below.

2.8.1 Housing Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype boards. Since the temperature values on the plastic material are different when the cards are open, they have been checked separately. In the thermal analysis, the ambient temperature

and the part temperature were taken as 70 °C. Figure 2.28 shows the thermal analysis result of the plastic housing, park lamps, and the stop lamp in the on position.

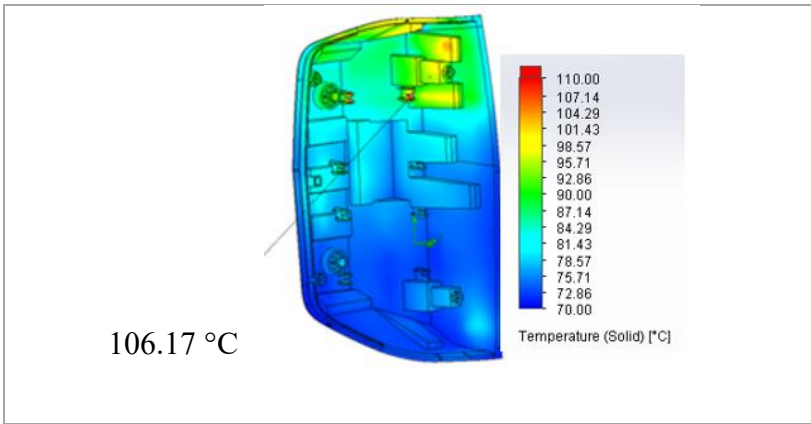


Figure 2.28: Park and stop LED on, in housing at the 70° C.

Housing plastic part is made of PC+ABS material. The maximum temperature is seen as 106.17 °C when the stop lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.29 shows the thermal analysis result of the plastic housing, the park lamps and the signal lamp in the on position.

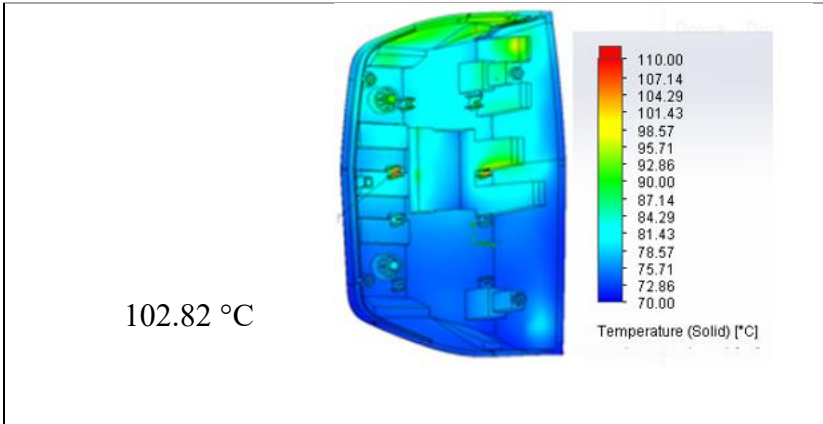


Figure 2.29: Park and signal LED on, in housing at the 70° C.

Housing plastic part is made of PC+ABS material. The maximum temperature is seen as 102.82 °C when the signal lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.30 shows the thermal analysis result of the plastic housing, the park lamps, and the reverse lamp in the on position.

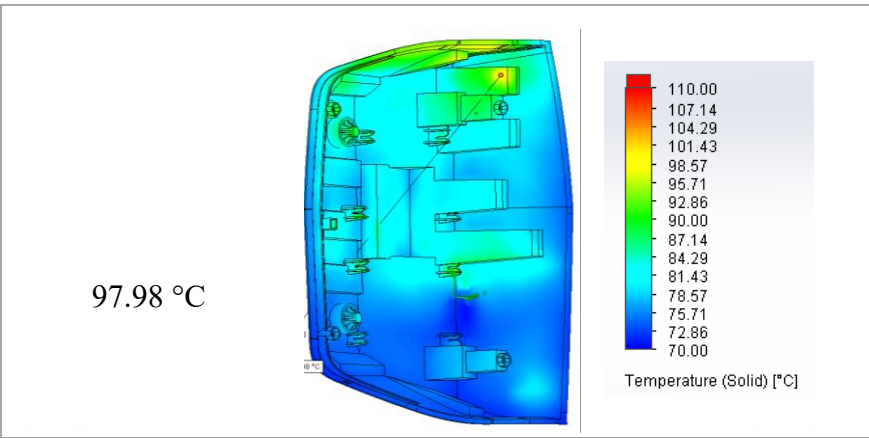


Figure 2.30: Park and reverse LED on, in housing at the 70° C.

Housing plastic part is made of PC+ABS material. The maximum temperature is seen as 97.98 °C when the reverse lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.31 shows the thermal analysis result of the plastic housing, the park lamps and the fog lamp in the on position.

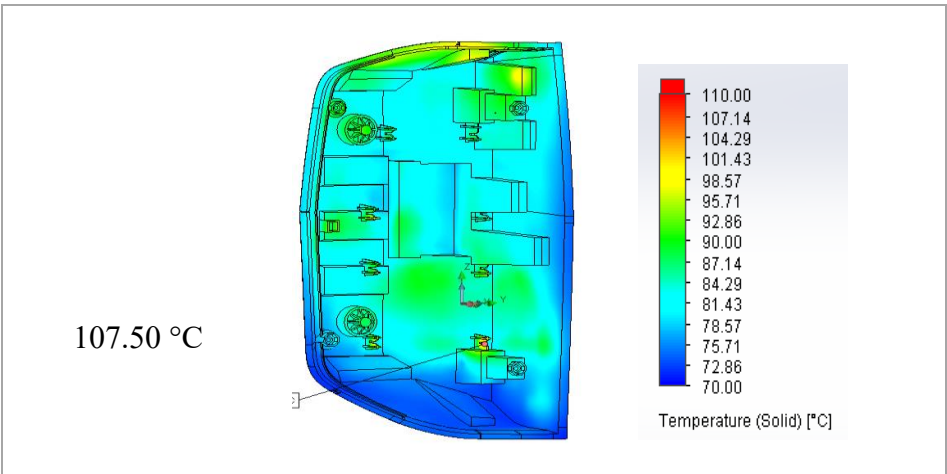


Figure 2.31: Park and fog LED on, in housing at the 70° C.

The highest temperature increase in the housing occurred when the fog lamp was on. Housing plastic part is made of PC+ABS material. The maximum temperature is seen as 107.50 °C when the fog lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

2.8.2 Lens Thermal Shock Analysis Values at the 70 °C

The lens is a transparent plastic piece that protects the LEDs from the external environment and provides illumination by transmitting the light of the LEDs. This material has low resistance to temperature. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.32 shows the thermal analysis result of the plastic lens, park lamps and the stop lamp in the on position.

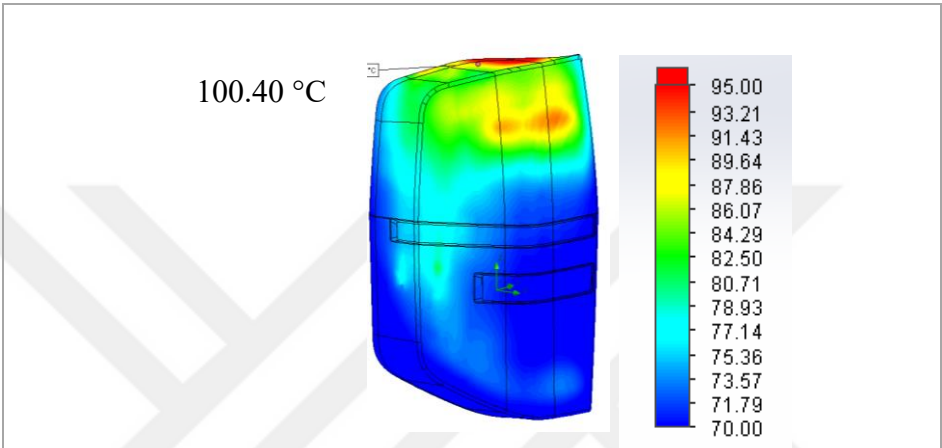


Figure 2.32: Park and stop LED on, in lens at the 70° C.

Lens material is chosen as transparent PMMA. Vicat temperature is 103 °C. In the position where the stop and the park LED is on, it has reached a maximum temperature of 100.40 °C. The simulation temperature is below the Vicat temperature. No problems are expected at 70°C.

Figure 2.33 shows the thermal analysis result of the plastic housing, the park lamps and the signal lamp in the on position.

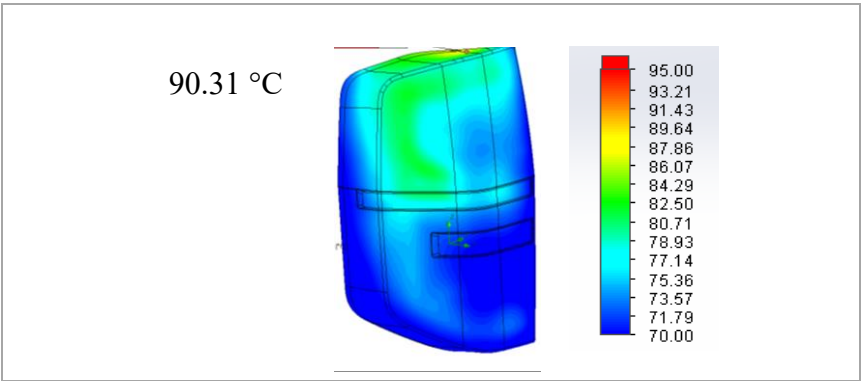


Figure 2.33: Park and signal LED on, in lens at the 70° C.

Lens material is chosen as transparent PMMA. Vicat temperature is 103 °C. In the position where the stop and the park LED is on, it has reached a maximum temperature of 90.31 °C. The simulation temperature is below the Vicat temperature. No problems are expected at 70°C.

Figure 2.34 shows the thermal analysis result of the plastic housing, the park lamps, and the reverse lamp in the on position.

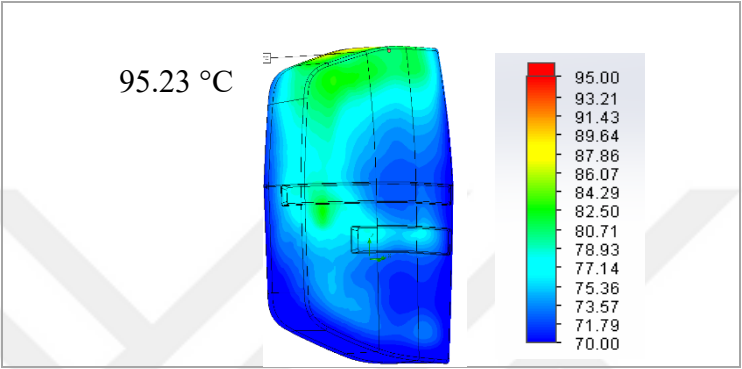


Figure 2.34: Park and reverse LED on, in lens at the 70° C.

Lens material is chosen as transparent PMMA. Vicat temperature is 103 °C. In the position where the reverse and the park LED are on, it has reached a maximum temperature of 95.23 °C. The simulation temperature is below the Vicat temperature. No problems are expected at 70°C.

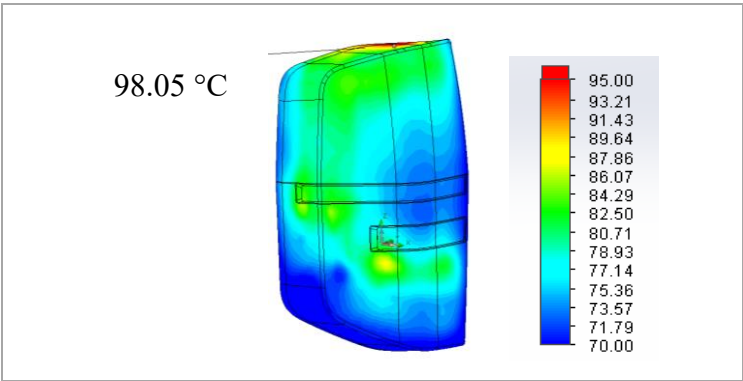


Figure 2.35: Park and fog LED on, in lens at the 70° C.

Figure 2.35 shows the thermal analysis result of the plastic housing, the park lamps and the fog lamp in the on position

Lens material is chosen as transparent PMMA. Vicat temperature is 103 °C. In the position where the reverse and the park LED are on, it has reached a maximum temperature of 98.05 °C. The simulation temperature is below the Vicat temperature. No problems are expected at 70 °C.

2.8.3 Reflector Thermal Shock Analysis Values at the 70 °C

The reflector ensures that the scattered light escaping from the LEDs is collected by focusing. To minimize the scattering of light, the reflector is in the closest position to the LED position. This indicates that the reflector is the plastic most exposed to heat. In the thermal analysis, the ambient temperature and the temperature of the part are taken as 70 °C.

Figure 2.36 shows the thermal analysis result of the plastic reflector, the park lamps and the stop lamp in the on position.

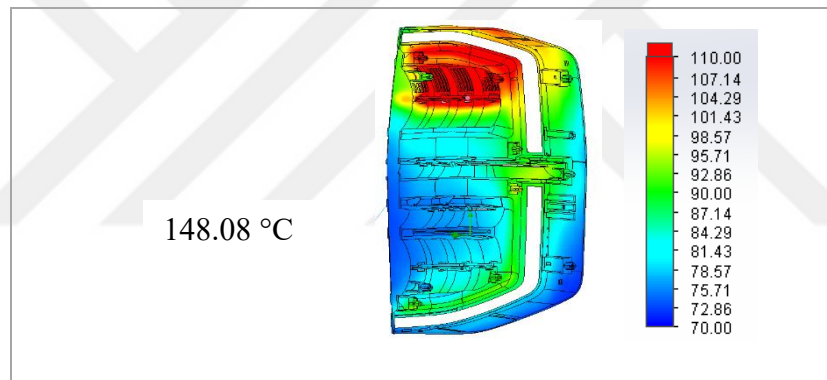


Figure 2.36: Park and stop LED on, in reflector at the 70° C.

The reflector plastic part is made of PC+ABS material. The maximum temperature is seen as 148.08 °C when the stop lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, the problem is expected at 70 °C ambient condition. The analysis value is greater than the Vicat value.

Figure 2.37 shows the thermal analysis result of the plastic reflector, the park lamps and the signal lamp in the on position.

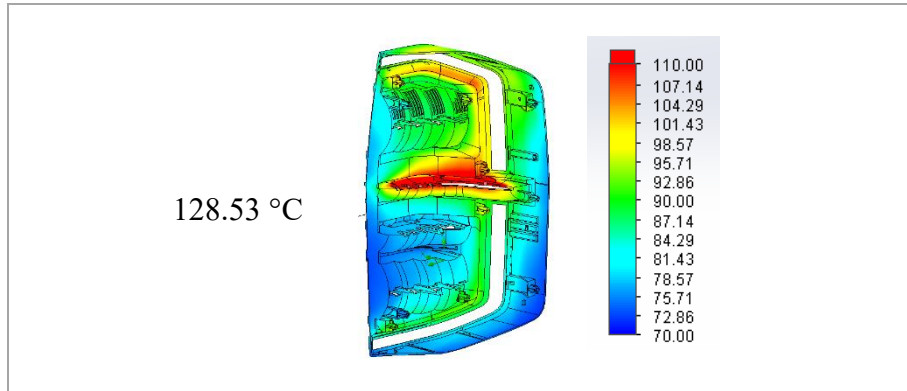


Figure 2.37: Park and signal LED on, in reflector at the 70° C.

The reflector plastic part is made of PC+ABS material. The maximum temperature is seen as 128.53 °C when the signal lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.38 shows the thermal analysis result of the plastic reflector, the park lamps and the reverse lamp in the on position.

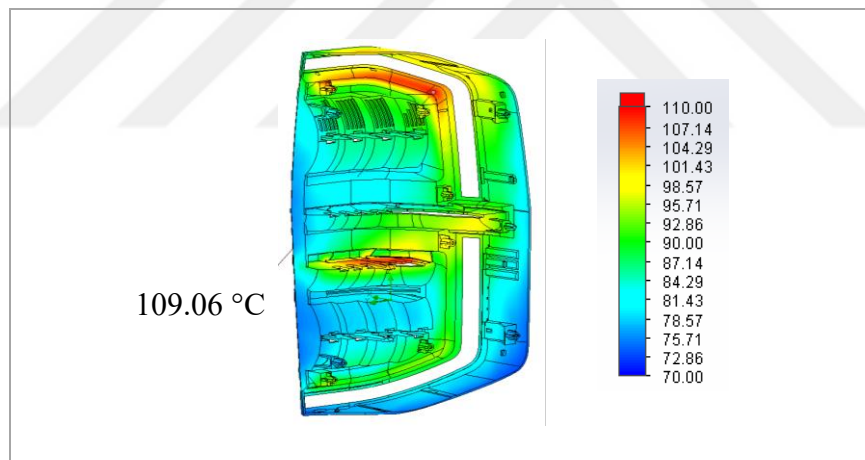


Figure 2.38: Park and reverse LED on, in reflector at the 70° C.

The reflector plastic part is made of PC+ABS material. The maximum temperature is seen as 109.06 °C when the reverse lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.39 shows the thermal analysis result of the plastic reflector, the park lamps and the fog lamp in the on position.

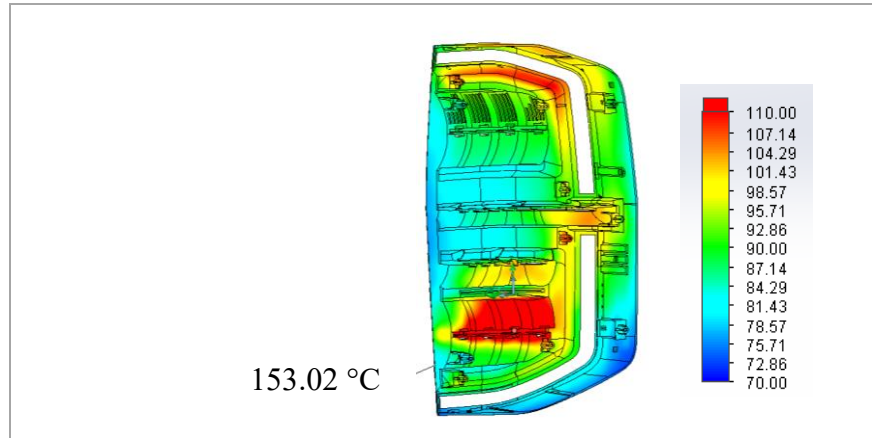


Figure 2.39: Park and fog LED on, in reflector at the 70° C.

The reflector plastic part is made of PC+ABS material. The maximum temperature is seen as 153.02 °C when the fog lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, problem is expected at 70 °C ambient condition. Analysis value is greater than the Vicat value.

2.8.4 Inner Housing Upper Thermal Shock Analysis Values at the 70 °C

The inner housing upper is located to provide the parking LED positions on the upper part. Since the PCB circuits inside are always on, the temperature is constantly present inside. On the outside, it affects the temperature of this part the most when the stop lamp is on. The PCB gets hot outside due to the circuits. Holes were drilled on the part to remove the air temperature formed in the interior. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.40 shows the thermal analysis result of the plastic inner housing upper, the park lamps and the stop lamp in the on position.

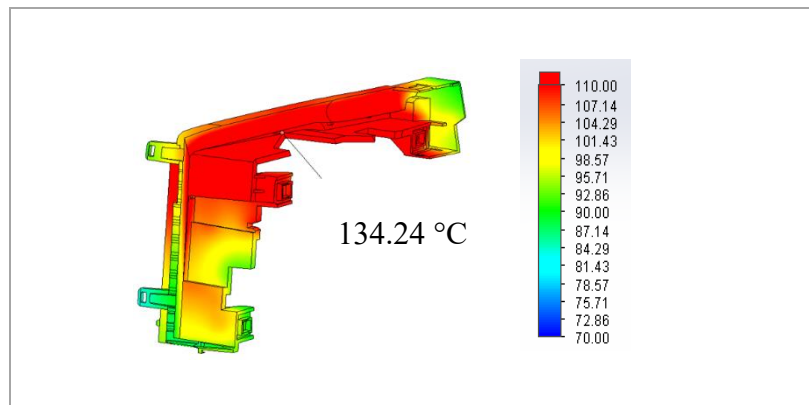


Figure 2.40: Park and stop LED on, in inner housing upper at the 70° C.

The inner housing upper plastic part is made of PC+ABS material. The maximum temperature is seen as 134.24 °C when the stop lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, problem is expected at 70 °C ambient condition. Analysis value is greater than the Vicat value.

Figure 2.41 shows the thermal analysis result of the plastic inner housing upper, the park lamps and the signal lamp in the on position.

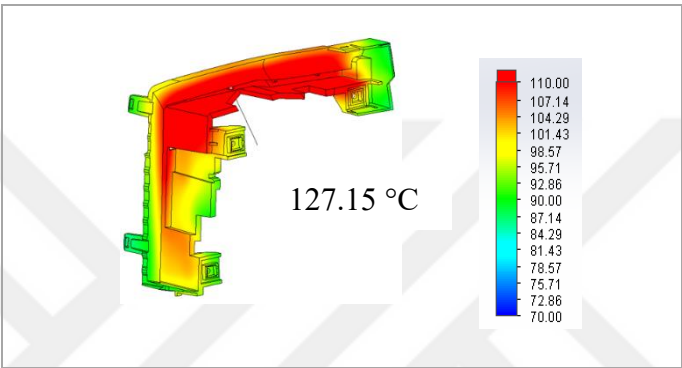


Figure 2.41: Park and signal LED on, in inner housing upper at the 70° C.

The inner housing upper plastic part is made of PC+ABS material. The maximum temperature is seen as 127.15 °C when the signal lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.42 shows the thermal analysis result of the plastic inner housing upper, the park lamps and the reverse lamp in the on position.

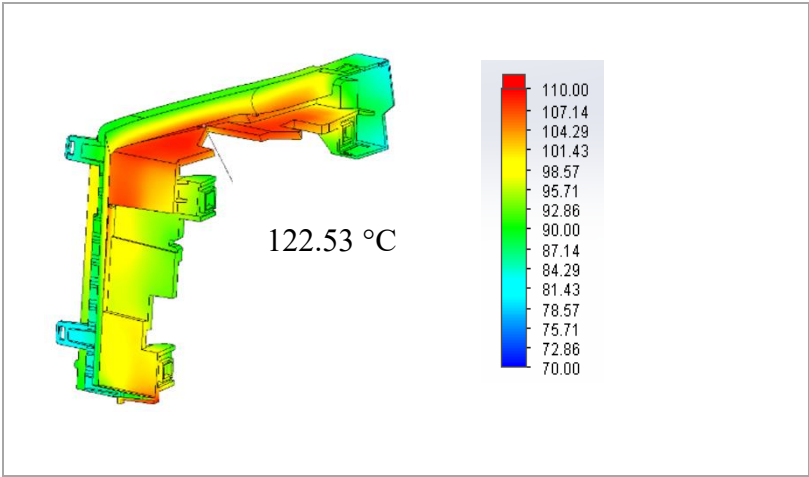


Figure 2.42: Park and reverse LED on, in inner housing upper at the 70° C.

The inner housing upper plastic part is made of PC+ABS material. The maximum temperature is seen as 122.53 °C when the reverse lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.43 shows the thermal analysis result of the plastic inner housing upper, the park lamps and the fog lamp in the on position.

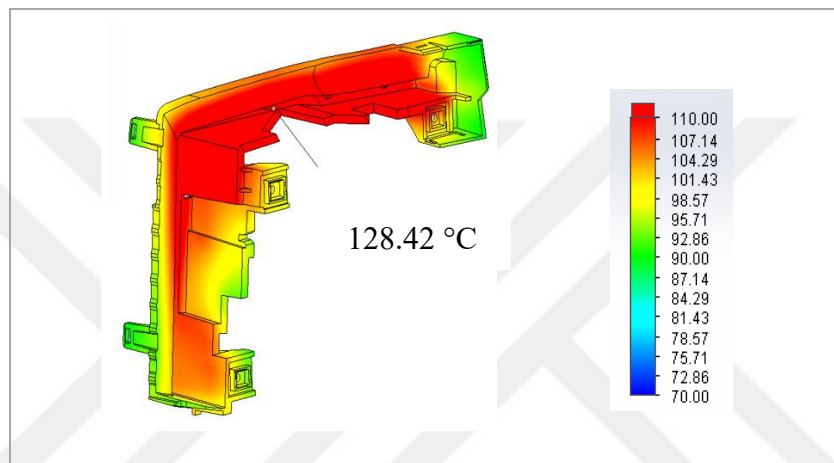


Figure 2.43: Park and fog LED on, in inner housing upper at the 70° C.

The inner housing upper plastic part is made of PC+ABS material. The maximum temperature is seen as 122.53 °C when the fog lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

2.8.5 Inner Housing Lower Thermal Shock Analysis Values at the 70 °C

The inner housing lower is located to provide the parking LED positions on the lower part. Since the PCB circuits inside are always on, the temperature is constantly present inside. On the outside, it affects the temperature of this part the most when the fog lamp is on. Although the fog lamp gives power similar to the stop lamp, the airflow in the fog lamp is from the bottom up. The temperature is reduced by allowing the heated air to go up. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.44 shows the thermal analysis result of the plastic inner housing lower, the park lamps and the stop lamp in the on position.

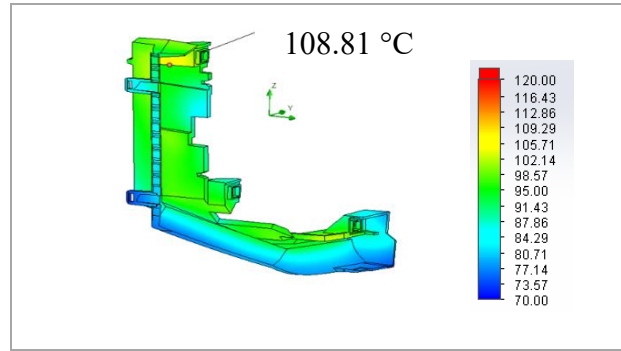


Figure 2.44: Park and stop LED on, in inner housing lower at the 70° C.

The inner housing lower plastic part is made of PC+ABS material. The maximum temperature is seen as 108.81 °C when the stop lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.45 shows the thermal analysis result of the plastic inner housing lower, the park lamps and the signal lamp in the on position.

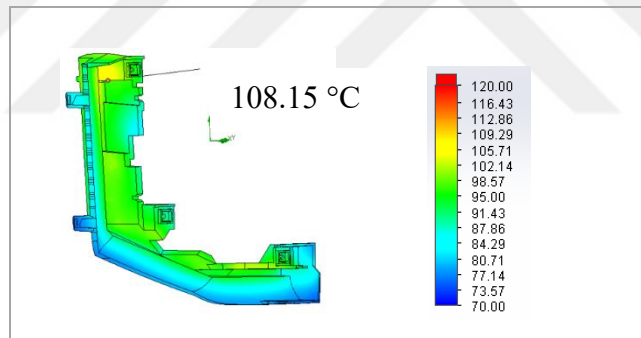


Figure 2.45: Park and signal LED on, in inner housing lower at the 70° C.

The inner housing lower plastic part is made of PC+ABS material. The maximum temperature is seen as 108.15 °C when the signal lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.46 shows the thermal analysis result of the plastic inner housing lower, the park lamps and the reverse lamp in the on position.

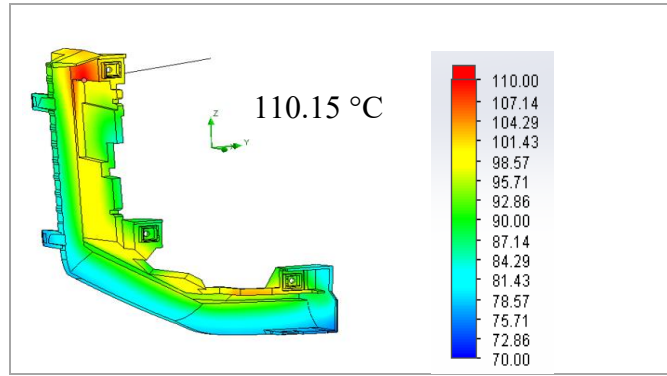


Figure 2.46: Park and reverse LED on, in inner housing lower at the 70° C.

The inner housing lower plastic part is made of PC+ABS material. The maximum temperature is seen as 110.15 °C when the reverse lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

Figure 2.47 shows the thermal analysis result of the plastic inner housing lower, the park lamps and the fog lamp in the on position.

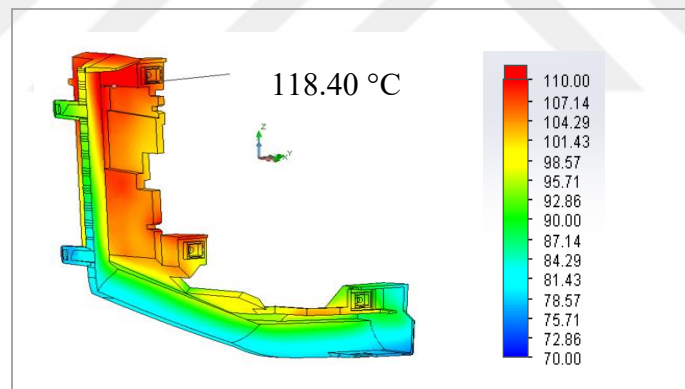


Figure 2.47: Park and fog LED on, in inner housing lower at the 70° C.

The inner housing lower plastic part is made of PC+ABS material. The maximum temperature is seen as 118.40 °C when the fog lamp and the park lamp are working at the same time. Since the Vicat value is 135 °C, no problem is expected at 70 °C ambient condition.

2.8.6 Inner Cover Upper Thermal Shock Analysis Values at the 70 °C

The inner cover upper is a transparent plastic piece that protects the LEDs from the internal environment and provides illumination by transmitting the light of the LEDs. This material

has low resistance to temperature. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.48 shows the thermal analysis result of the plastic inner cover upper, park lamps and the stop lamp in the on position.

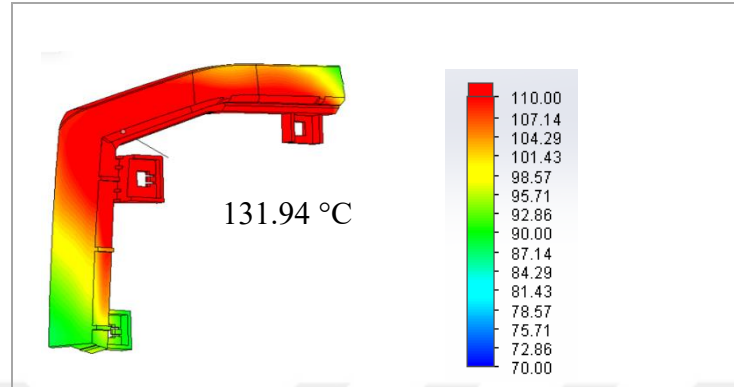


Figure 2.48: Park and stop LED on, in inner cover upper at the 70° C.

The inner cover upper material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the stop and the park LED is on, it has reached a maximum temperature of 131.94 °C. problems are expected at 70°C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.49 shows the thermal analysis result of the plastic inner cover upper, park lamps and the signal lamp in the on position.

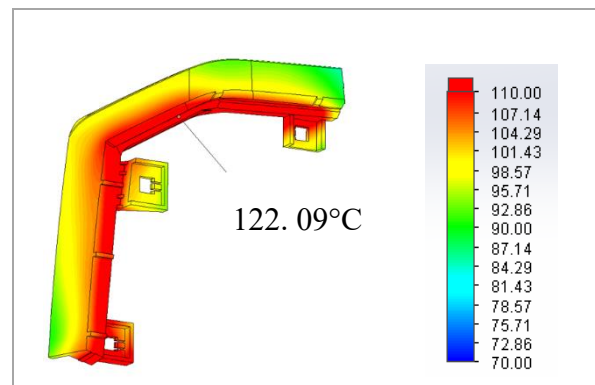


Figure 2.49: Park and signal LED on, in inner cover upper at the 70° C.

The inner cover upper material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the signal and the park LED are on, it has reached a maximum temperature of 131.94 °C. problems are expected at 70°C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.50 shows the thermal analysis result of the plastic inner cover upper, park lamps and the reverse lamp in the on position.

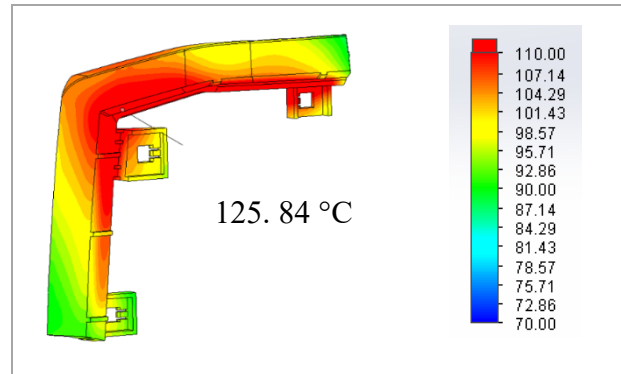


Figure 2.50: Park and reverse LED on, in inner cover upper at the 70° C.

The inner cover upper material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the reverse and the park LED are on, it has reached a maximum temperature of 125.84 °C. problems are expected at 70°C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.51 shows the thermal analysis result of the plastic inner cover upper, park lamps and the fog lamp in the on position.

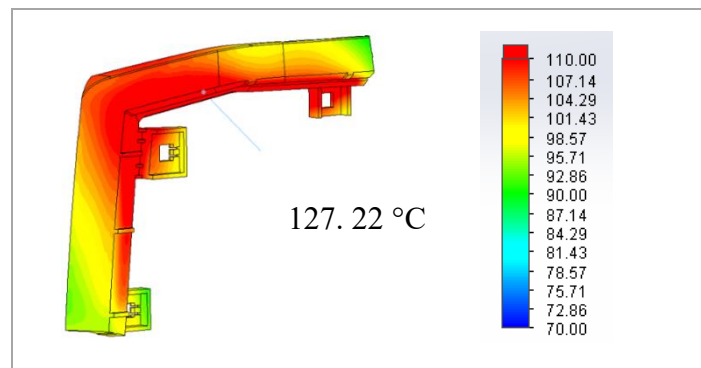


Figure 2.51: Park and fog LED on, in inner cover upper at the 70° C.

The inner cover upper material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the fog and the park LED are on, it has reached a maximum temperature of 125.84 °C. problems are expected at 70°C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

2.8.7 Inner Cover Lower Thermal Shock Analysis Values at the 70 °C

The inner cover lower it is a transparent plastic piece that protects the LEDs from the internal environment and provides illumination by transmitting the light of the LEDs. This material has low resistance to temperature. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.52 shows the thermal analysis result of the plastic inner cover lower, park lamps and the stop lamp in the on position.

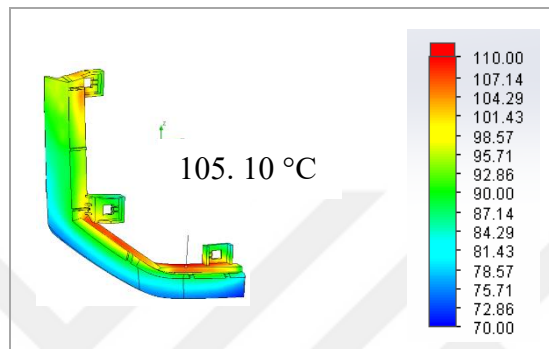


Figure 2.52: Park and stop LED on, in inner cover lower at the 70° C.

The inner cover lower material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the stop and the park LED are on, it has reached a maximum temperature of 105.10 °C. problems are expected at 70 °C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.53 shows the thermal analysis result of the plastic inner cover lower, park lamps and the signal lamp in the on position.

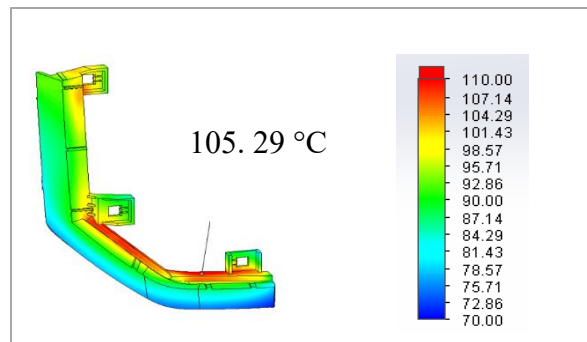


Figure 2.53: Park and signal LED on, in inner cover lower at the 70° C.

The inner cover lower material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the signal and the park LED are on, it has reached a maximum

temperature of 105.29 °C. problems are expected at 70 °C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.54 shows the thermal analysis result of the plastic inner cover lower, park lamps and the reverse lamp in the on position.

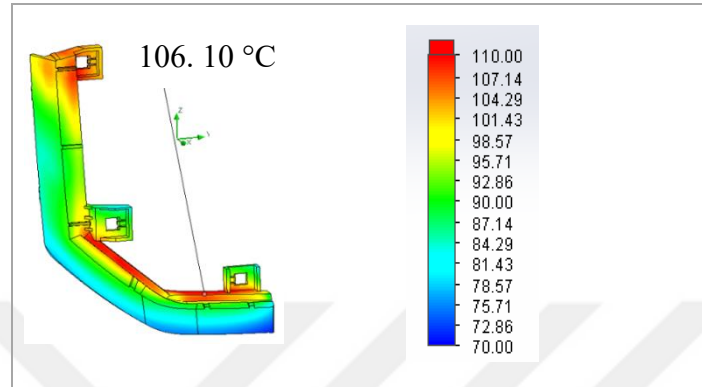


Figure 2.54: Park and reverse LED on, in inner cover lower at the 70° C.

The inner cover lower material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the reverse and the park LED are on, it has reached a maximum temperature of 106.10 °C. problems are expected at 70 °C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

Figure 2.55 shows the thermal analysis result of the plastic inner cover lower, park lamps and the fog lamp in the on position.

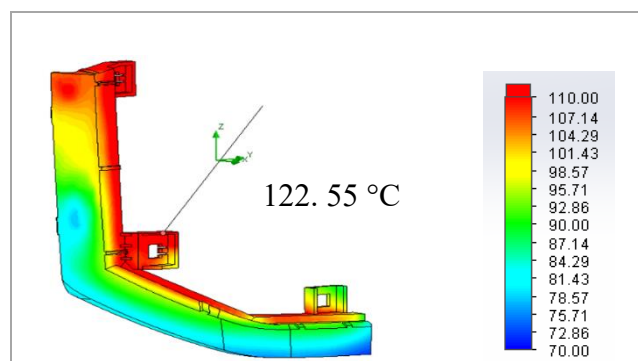


Figure 2.55: Park and fog LED on, in inner cover lower at the 70° C.

The inner cover lower material is chosen as transparent PMMA. The Vicat temperature is 103 °C. In the position where the fog and the park LED are on, it has reached a maximum

temperature of 122.55 °C. problems are expected at 70 °C. The analysis value is greater than the Vicat value. In this case, the PMMA material should be changed to PC.

2.8.8 Upper Park PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.56 shows the thermal analysis result of the plastic upper park, park lamps and the stop lamp in the on position.

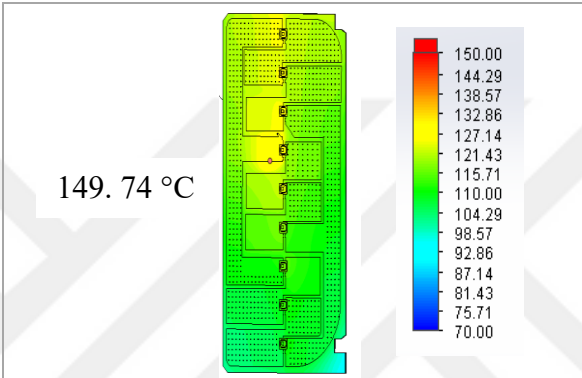


Figure 2.56: Park and stop LED on, in upper park PCB at the 70° C.

The upper park PCB part is made of Fr-4 material. The maximum temperature is seen as 149.74 °C when the stop lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.57 shows the thermal analysis result of the upper park PCB, park lamps and the signal lamp in the on position.

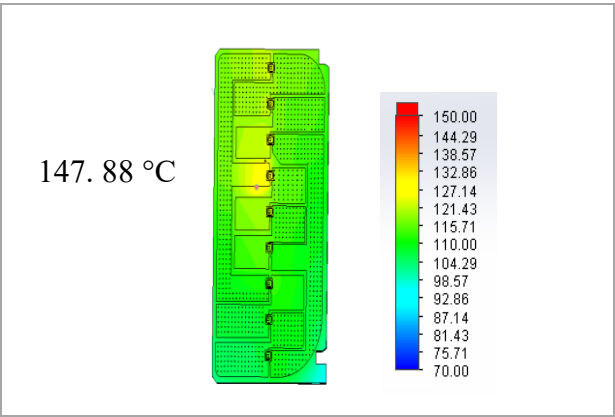


Figure 2.57: Park and signal LED on, in upper park PCB at the 70° C.

The upper park PCB part is made of Fr-4 material. The maximum temperature is seen as 147.88 °C when the signal lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.58 shows the thermal analysis result of the upper park PCB, park lamps and the reverse lamp in the on position.

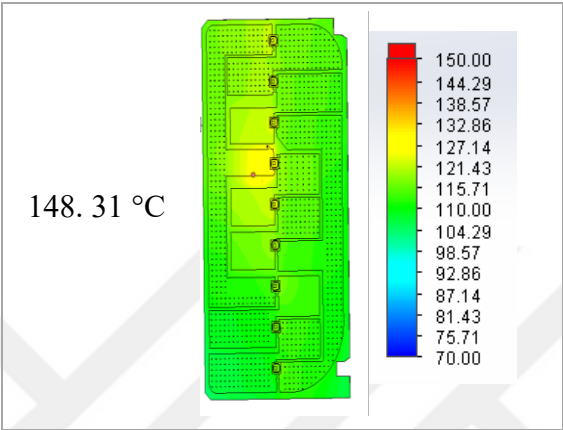


Figure 2.58: Park and reverse LED on, in upper park PCB at the 70° C.

The upper park PCB part is made of Fr-4 material. The maximum temperature is seen as 148.31 °C when the reverse lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.59 shows the thermal analysis result of the upper park PCB, park lamps and the fog lamp in the on position.

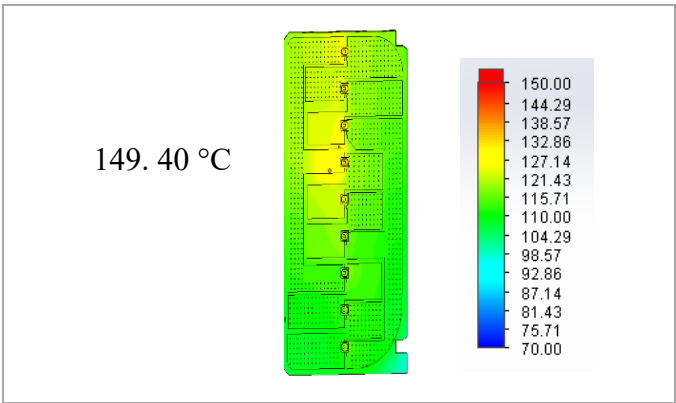


Figure 2.59: Park and fog LED on, in upper park PCB at the 70° C.

The upper park PCB part is made of Fr-4 material. The maximum temperature is seen as 149.40 °C when the fog lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

2.8.9 Lower Park PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.60 shows the thermal analysis result of the plastic lower park, park lamps and the stop lamp in the on position.

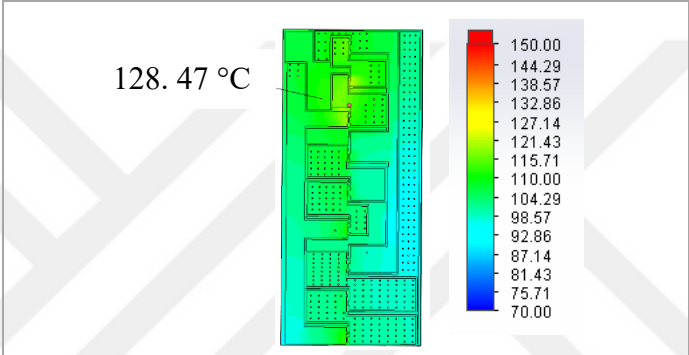


Figure 2.60: Park and stop LED on, in lower park PCB at the 70° C.

The lower park PCB part is made of Fr-4 material. The maximum temperature is seen as 128.47 °C when the stop lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.61 shows the thermal analysis result of the lower park PCB, park lamps and the signal lamp in the on position.

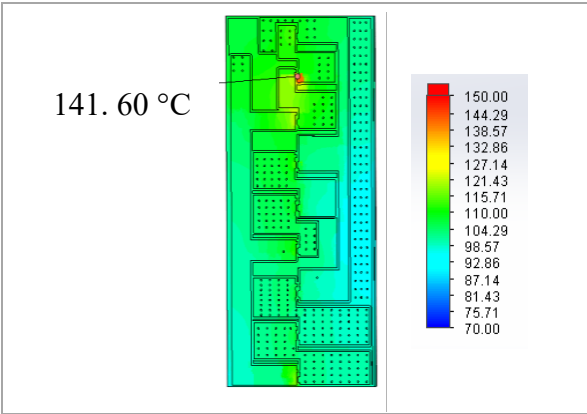


Figure 2.61: Park and signal LED on, in lower park PCB at the 70° C.

The lower park PCB part is made of Fr-4 material. The maximum temperature is seen as 141.60 °C when the stop lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.62 shows the thermal analysis result of the lower park PCB, park lamps and the reverse lamp in the on position.

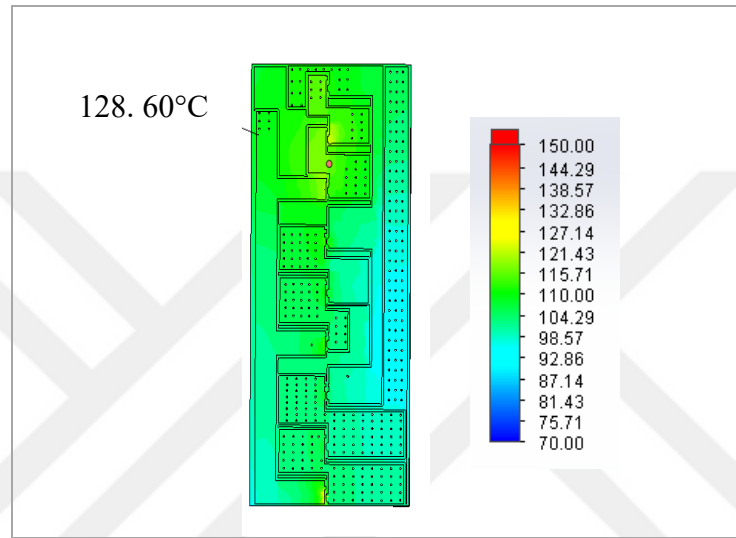


Figure 2.62: Park and reverse LED on, in lower park at the 70° C PCB.

The lower park PCB part is made of Fr-4 material. The maximum temperature is seen as 128.60 °C when the reverse lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

Figure 2.63 shows the thermal analysis result of the lower park PCB, park lamps and the fog lamp in the on position.

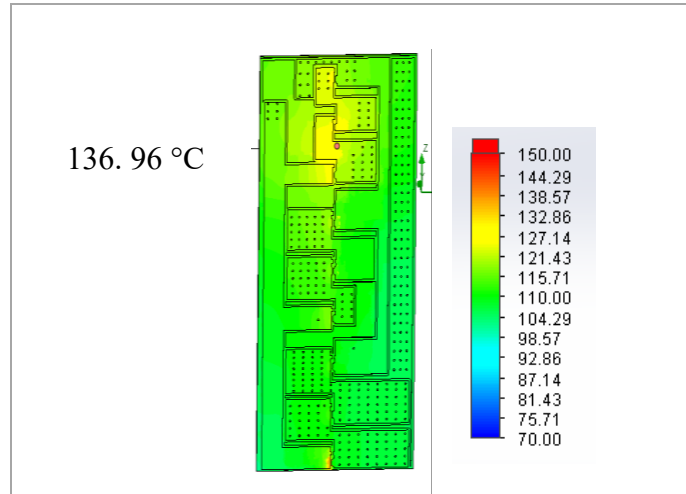


Figure 2.63: Park and fog LED on, in lower park PCB at the 70° C.

The lower park PCB part is made of Fr-4 material. The maximum temperature is seen as 136.96 °C when the fog lamp and the park lamp are working at the same time. Since the LED failure value is 150 °C, no problem is expected at 70 °C ambient condition.

2.8.10 Stop PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.64 shows the heat distribution on the front surfaces of the stop lamp. By keeping the temperature scale at a max of 150 °C, regions that could be affected by the heat were tried to be determined.

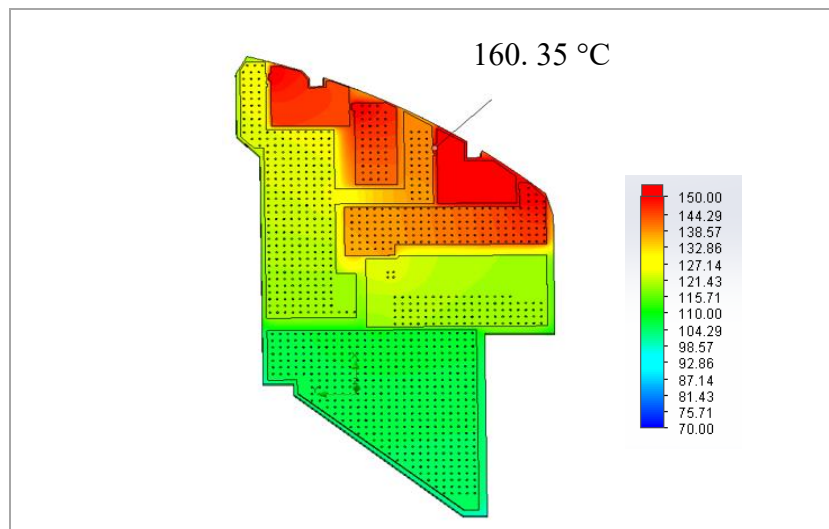


Figure 2.64: Stop LED card on, front surface at the 70° C.

Junction temperatures occurring in the stop LED at 70 °C temperature are shown in Table 2.10.

Table 2.10: Stop lamp simulation results at 70 °C ambient temperature.

	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8
Simulation temperature (°C)	155.6	160.3	152.7	150.8	150.9	152.4	160.2	155.5

As it is above 150 °C junction temperature in LEDs 2 and 7, where the maximum temperature is, it failed from the thermal analysis. The stop lamp is one of the most working lamps. Since the LEDs are red, they are sensitive to heat. The temperature increase at the junction point causes a change in the optical values of the LED.

According to the analysis result, the temperature at the junction point appears to be 160.35 °C. Due to the position of the LEDs, the two LEDs heat each other. The LEDs can withstand a temperature of (100 H) 175 °C for a short time. optimization should be done. The copper areas should be tried to be enlarged more. According to the results of the optical tests, the light values of the stop lamp should be reduced.

2.8.11 Signal PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.65 shows the heat distribution on the front surfaces of the signal lamp. By keeping the temperature scale at a max of 150 °C, regions that could be affected by the heat were tried to be determined.

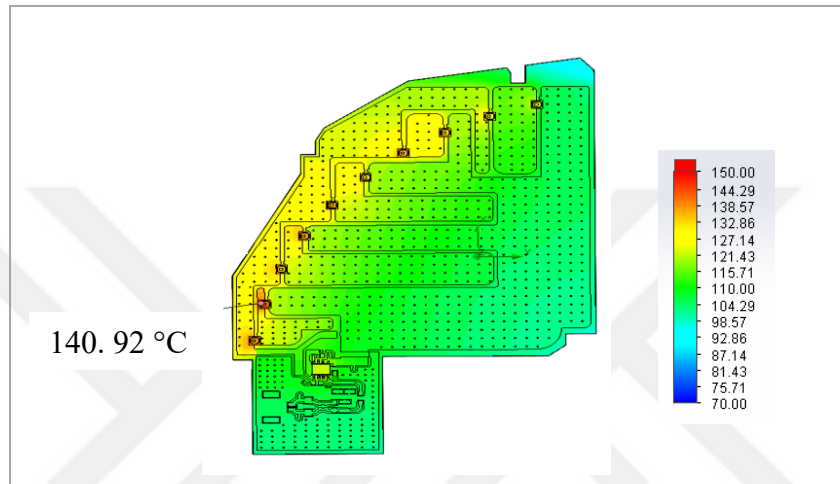


Figure 2.65: Signal LED card on, front surface at the 70° C.

Junction temperatures occurring in the LED at 70 °C temperature are shown in Table 2.11.

Table 2.11: Signal lamp simulation results at 70 °C ambient temperature.

	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8	Led-9	Led-10
Simulation temperature (°C)	138.0	140.9	135.2	135.9	134.5	132.6	135.6	133.4	127.6	121.6

All of the LEDs have passed thermal analysis as they are below the junction temperature of 150 °C.

Orange-colored LEDs were used in the signal lamp. During the analysis, the LEDs are operated in the open position continuously for analysis safety. Signal lamps are used in real life as 20 ms on 20 ms off according to customer request.

According to the results of the analysis, the LEDs reached a temperature of 140.92 °C. The orange LEDs numbered STAPC1LX –3030X can withstand up to 150 °C junction point. According to the analysis result, no problem is expected.

2.8.12 Fog PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.66 shows the heat distribution on the front surfaces of the fog lamp. By keeping the temperature scale at a max of 150 °C, regions that could be affected by the heat were tried to be determined.

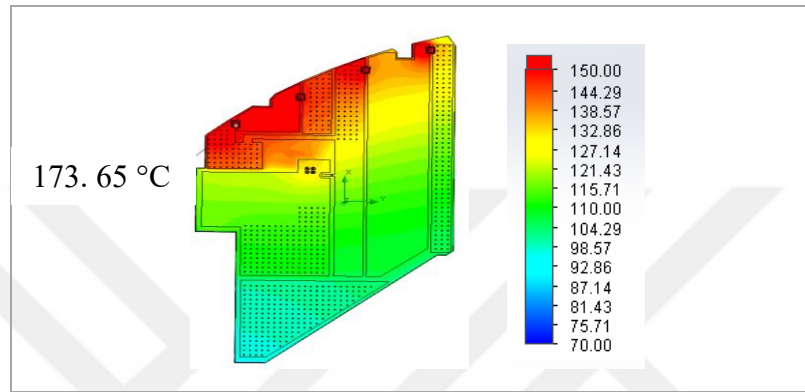


Figure 2.66: Fog LED card on, front surface at the 70° C.

Junction temperatures occurring in the LED at 70 °C temperature are shown in Table 2.12.

Table 2.12: Fog lamp simulation results at 70 °C ambient temperature.

	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6	Led-7	Led-8
Simulation Temperature (°C)	159.6	159.3	164.8	173.6	158.2	158.6	166.7	172.9

According to the simulation result, the LEDs failed the thermal analysis as they were above the junction temperature of 150 °C.

The fog lamp is driven with a high current to provide the light power requirements specified in the homologations. Since the LED used in the fog lamp is red in color, the luminous efficiency against temperature is extremely low. The LED no. 3030_STDRC1LX used in the PCB card loses 80% of the light it emits at 150 °C temperature.

Since it is in a risky area, it should be tried to obtain more light at a lower current by making an optimization study. The temperature zone scale is set to show 150 °C above red. At the ends, the LEDs cannot transmit the heat on them. Since the LEDs are in the same position

at the top and bottom, the two LEDs heat each other. According to the optical tests, the temperature of the led can be changed by changing the light intensity.

2.8.13 Reverse PCB Thermal Shock Analysis Values at the 70 °C

Thermal analysis was made with the LED power values taken by controlling the prototype PCB. In the thermal analysis, the ambient temperature and the part temperature were taken as 70 °C. Figure 2.67 shows the heat distribution on the front surfaces of the reverse lamp. By keeping the temperature scale at a max of 150 °C, regions that could be affected by the heat were tried to be determined.

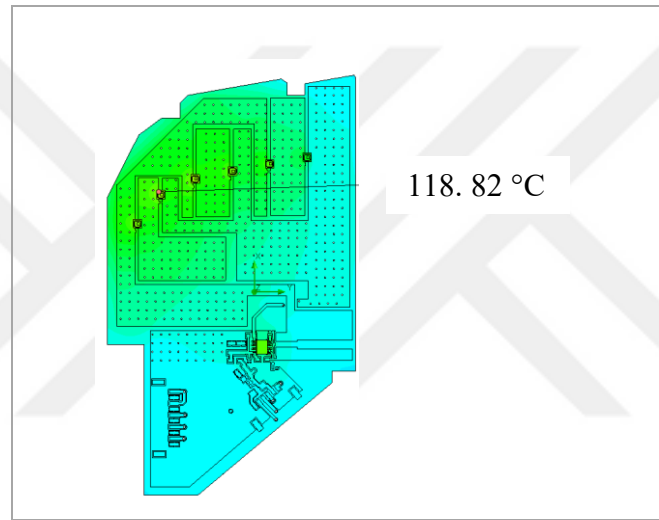


Figure 2.67: Reverse LED card on, front at the 70° C.

Junction temperatures occurring in the LED at 70 °C temperature are shown in Table 2.13.

Table 2.13: Reverse lamp simulation results at 70 °C ambient temperature.

	Led-1	Led-2	Led-3	Led-4	Led-5	Led-6
Simulation temperature (°C)	116.9	118.8	118.0	116.8	114.2	109.3

According to the simulation result, the LEDs have passed thermal analysis since they are below the junction temperature of 150 °C.

Since the light angle values specified in the reverse lamp homologations are different from the others, the LEDs are gathered in the middle of the circuit board. In this way, the heat distribution has become perfect to be 360°. The light efficiency against temperature is extremely good due to the white color of the LED used in the reverse lamp. LED no.

STW0C1LX –3030X loses 20% of the light it emits at 150 °C temperature. This loss can be considered normal.

Figure 2.67 shows the simulation result. The temperature zone is set to show red above the scale of 150 °C. According to thermal analysis, there is no problem.

2.9 OPTICAL TEST AND OPTICAL SIMULATION

Before starting the product design, the first determining element in the lighting product is the LED and the location of this LED. The distance of the area to be illuminated and the amount of lux that must be met in this area have been reported with international regulations. LEDs are selected according to the required lighting capacity according to the intended use of the product to be made, and the center of the optical surfaces is LED.

Simulation and test images of the park lamp are shown in Figure 2.68.

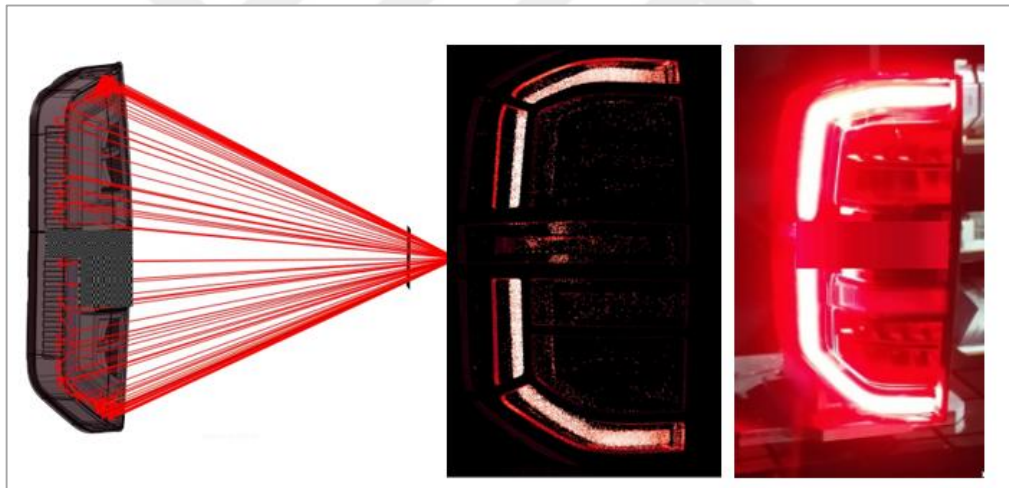


Figure 2.68: Park lamp photometric simulation and test sample.

Optical simulations are performed by determining the required amount of light and by taking approximately 30% more than the values specified in the lighting regulations, optical defects that may occur from real part errors are tried to be eliminated. Optical simulations are made by the optics team with the optics program.

The lighting product is connected to the Goniophotometer with a fixture to determine its position.

Figure 2.69 shows the connection of the stop lamp and product to the device via fixture.



Figure 2.69: Stop lamp, product photometric test sample.

To take the position on the H and V axes to the 0 point, the relevant LEDs are turned on and the part is moved by the lasers on the Goniophotometer and the LED position and the laser center are matched. The center of the function to be measured becomes the optical center of the measuring device. Which function is to be measured, the relevant regulated values are selected through the Goniophotometer intermediate program and the test is started. Since the heat transfer in the LEDs equalize after approximately 30 minutes, most of the optical tests take 30 minutes. In this way, the light losses on the LED be seen as a result of the test.

The abbreviations specified in photometry tests are given in Table 2.14

Table 2.14: The abbreviations specified in photometry tests.

Abbreviation	Meaning
H	Horizontal direction
V	Vertical direction
R	Right direction
L	Left direction
U	Up
D	Downward

Tested at the distance specified by homologation for light loss measurements in the product. Light loss tests are performed at room temperature. Since the LEDs are always on during the test, they heat up and lose their light values.

Figure 2.70 shows the light image of 5 functions.



Figure 2.70: Light image of 5-function lamp.

2.9.1 Park Lamp Photometric Test Reports

It is connected to the measuring fixture at room temperature to measure the light values of the park lamp with the Goniophotometer. Figure 2.71 shows the on position of the park lamp.

LEDs driven with 27.99 V and 0.15 mA current have been tested to whether they provide the desired light intensity at the positions specified by homologation.

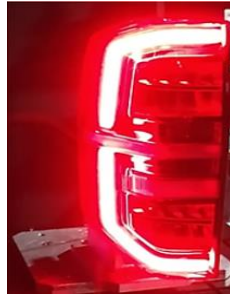


Figure 2.71: Park lamp on, in the photometric test.

Table 2.15 shows the photometric test report of the park lamp result.

Table 2.15: Park lamp photometric test report.

H V Position			Limits (candela)		Value (candela)
Park lamp	H (°)	V (°)	min.	max.	
10U / 5L	-5	10	0.8	17	6.53
10U / 5R	5	10	0.8	17	10.42
5U / 20R	20	5	0.4	17	15.41
5U / 10R	10	5	0.8	17	12.44
5U / V	0	5	2.8	17	8.81
5U / 10L	-10	5	0.8	17	4.74
5U / 20L	-20	5	0.4	17	2.85
H / 10L	-10	0	1.4	17	4.77
H / 5L	-5	0	3.6	17	6.69
H / V	0	0	4.0	17	8.75
H / 5R	5	0	4.0	17	10.57
H / 10R	10	0	1.4	17	12.42
5D / 20R	20	-5	0.4	17	15.20
5D / 10R	10	-5	0.8	17	12.25
5D / V	0	-5	2.8	17	8.60
5D / 10L	-10	-5	0.8	17	4.63
5D / 20L	-20	-5	0.4	17	2.84
10D / 5L	-5	-10	0.8	17	6.36
10D / 5R	5	-10	0.8	17	10.12

Position abbreviations in the measurement report are shown in Table 2.15. According to the photometric result of the parking lamp, the product seems to have the maximum light value in many positions. By reducing the light values, the parking lamp temperature can be reduced.

2.9.2 Reverse Lamp Photometric Test Reports

It is connected to the measuring fixture at room temperature to measure the light values of the reverse lamp with the Goniophotometer. Figure 2.72 shows the on position of the reverse lamp. LEDs driven with 28 V and 0.085 mA current have been tested to whether they provide the desired light intensity at the positions specified by homologation.



Figure 2.72: Reverse lamp on, in the photometric test.

Table 2.16 shows the photometric test report of the reverse lamp result.

Table 2.16: Reverse lamp photometric test report

H V POSITION			Limits (candela)		Value (candela)
Reverse lamp	H (°)	V (°)	min.	max.	
10U / 10L	-10	10	10.0	300	58.11
10U / V	0	10	15.0	300	76.24
10U / 10R	10	10	10.0	300	87.59
5U / 45R	45	5	15.0	300	104.50
5U / 10R	10	5	20.0	300	154.00
5U / V	0	5	25.0	300	144.20
5U / 10L	-10	5	20.0	300	109.60
H / 30L	-30	0	25.0	300	49.67
H / 10L	-10	0	50.0	300	116.20
H / V	0	0	80.0	300	151.40
H / 10R	10	0	50.0	300	158.40
H / 30R	30	0	25.0	300	113.00
H / 45R	45	0	15.0	300	99.51
5D / 45R	45	-5	15.0	600	72.22
5D / 30R	30	-5	25.0	600	77.73
5D / 10R	10	-5	50.0	600	107.50

Position abbreviations in the measurement report are shown in Table 2.16. According to the photometric result of the reverse lamp, the product seems to have the maximum light value

in many positions. By reducing the light values, the reverse lamp temperature can be reduced.

2.9.3 Stop Lamp Photometric Test Reports

It is connected to the measuring fixture at room temperature to measure the light values of the stop lamp with the Goniophotometer. Figure 2.73 shows the on position of the stop lamp. LEDs driven with 24 V and 0.11 mA current have been tested to whether they provide the desired light intensity at the positions specified by homologation.



Figure 2.73: Stop lamp on, in the photometric test.

Table 2.17 shows the photometric test report of the stop lamp result.

Table 2.17: Stop lamp photometric test report.

H V POSITION			Limits (candela)		Value (candela)
Stop lamp	H (°)	V (°)	min.	max.	
10U / 5L	-5	10	12	365	44.94
10U / 5R	5	10	12	365	50.67
5U / 20R	20	5	6	365	38.06
5U / 10R	10	5	12	365	79.84
5U / V	0	5	42	365	77.15
5U / 10L	-10	5	12	365	64.66
5U / 20L	-20	5	6	365	29.35
H / 10L	-10	0	21	365	74.06
H / 5L	-5	0	54	365	82.08
H / V	0	0	60	365	87.47
H / 5R	5	0	54	365	89.88
H / 10R	10	0	21	365	89.19
5D / 20R	20	-5	6	365	38.18
5D / 10R	10	-5	12	365	80.02

Position abbreviations in the measurement report are shown in Table 2.17. According to the photometric result of the stop lamp, the product seems to have the maximum light value in many positions. By reducing the light values, the stop lamp temperature can be reduced.

2.9.4 Signal Lamp Photometric Test Reports

It is connected to the measuring fixture at room temperature to measure the light values of the signal lamp with the Goniophotometer. Figure 2.74 shows the on position of the signal lamp. LEDs driven with 27.99 V and 0.12 mA current have been tested to whether they provide the desired light intensity at the positions specified by homologation.



Figure 2.74: Signal lamp on, in the photometric test.

Table 2.18 shows the photometric test report of the signal lamp result.

Table 2.18: Signal lamp photometric test report.

H V POSITION			Limits (candela)		Value (candela)
Signal lamp	H (°)	V (°)	min.	max.	
10U / 5L	-5	10	10.0	250	43.22
10U / 5R	5	10	10.0	250	51.36
5U / 20R	20	5	5.0	250	100.09
5U / 10R	10	5	10.0	250	106.60
5U / V	0	5	35.0	250	99.39
5U / 10L	-10	5	10.0	250	77.61
5U / 20L	-20	5	5.0	250	45.35
H / 10L	-10	0	17.50	250	77.95
H / 5L	-5	0	5.0	250	88.31
H / V	0	0	10.0	250	98.36
H / 5R	5	0	35.0	250	103.90
H / 10R	10	0	10.0	250	106.80
5D / 20R	20	-5	10.0	250	85.75
5D / 10R	10	-5	50.0	250	80.02

Position abbreviations in the measurement report are shown in Table 2.18. According to the photometric result of the signal lamp, the product seems to have the maximum light value in many positions. By reducing the light values, the signal lamp temperature can be reduced.

2.9.5 Fog Lamp Photometric Test Reports

It is connected to the measuring fixture at room temperature to measure the light values of the fog lamp with the Goniophotometer. Figure 2.75 shows the on position of the fog lamp. LEDs driven with 24 V and 0.12 mA current have been tested to whether they provide the desired light intensity at the positions specified by homologation.



Figure 2.75: Fog lamp on, in the photometric test.

Table 2.19 shows the photometric test report of the fog lamp result.

Table 2.19: Fog lamp photometric test report.

H V POSITION			Limits (candela)		Test value (candela)
Fog lamp	H (°)	V (°)	min	max	
10U / 5L	-5	10	150	300	164.94
10U / 5R	5	10	150	300	150.67
5U / 20R	20	5	75	300	138.06
5U / 10R	10	5	75	300	79.84
5U / V	0	5	75	300	77.15
5U / 10L	-10	5	75	300	94.66
5U / 20L	-20	5	75	300	89.35
H / 10L	-10	0	150	300	174.06
H / 5L	-5	0	150	300	182.08
H / V	0	0	150	300	187.47
H / 5R	5	0	150	300	189.88
H / 10R	10	0	150	300	189.19
5D / 20R	20	-5	75	300	78.18
5D / 10R	10	-5	75	300	80.02
5D / V	0	-5	75	300	96.81
5D / 10L	-10	-5	75	300	95.92
5D / 20L	-20	-5	6	300	49.80

Position abbreviations in the measurement report are shown in Table 2.19. According to the photometric result of the fog lamp, the product seems to have the maximum light value in many positions. By reducing the light values, the fog lamp temperature can be reduced.

3. CONCLUSION

Within the scope of the project, the effects of PCB product design and the air flow effect on the plastic material were carefully examined. The simulation results and test values of the LEDs on the PCBs were compared and it was stated that the error rate was 6% and the product remained within the safety limits, considering that this error would not affect the simulation results.

It was determined that the light values of the red-colored LEDs in the stop fog and park lamp parts decreased with the temperature increase and the PCB copper paths were optimized and the heat density was directed to other ways of the PCB circuit.

While performing the thermal analysis, the park lamp was taken to the on position and the other PCB circuits were placed in the on position, respectively, and how the effect affected other plastic components depending on the air flow was verified by analysis.

For the orange-colored LEDs on the signal card not to reduce the light effect under heat, the positions of the LEDs are spread over a wide area.

The via holes were opened according to the areas where the LEDs are concentrated and the area where the LEDs on the PCB are located at the bottom, allowing the air flow to go from the lowest area to the upper areas.

In addition, loss of function, which is one of the success criteria in prototype tests, and deformation on the plastic part surface was not observed.

In the optical tests performed on the product, the light values were examined and according to the optical test result, it was seen that the amount of light was sufficient at every point in the specified coordinate axes and the LED light losses met the international regulations. No significant change in light quality has been confirmed by optical tests

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APPENDIX A

[2D DRAWING]

In Appendix A, technical drawings of plastic and PCB materials used in the Stop lamp are shown. 2D pictures were drawn to show the dimensions of the parts used in the study.

A.1 APPENDIX SECTION

Figure A.1 shows the 2d technical drawing of the product.

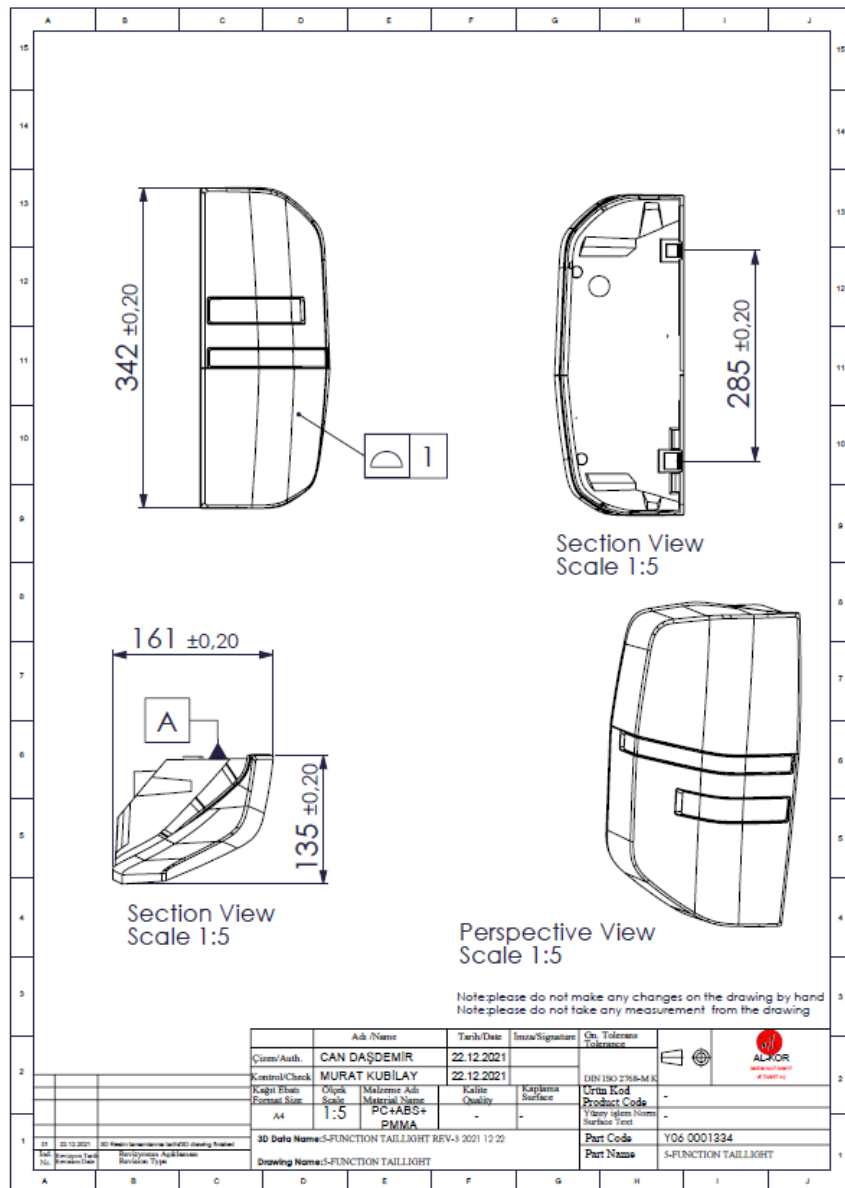


Figure A.1: Product 2D technical drawing

Figure A.2 shows the 2d technical drawing of the lens.

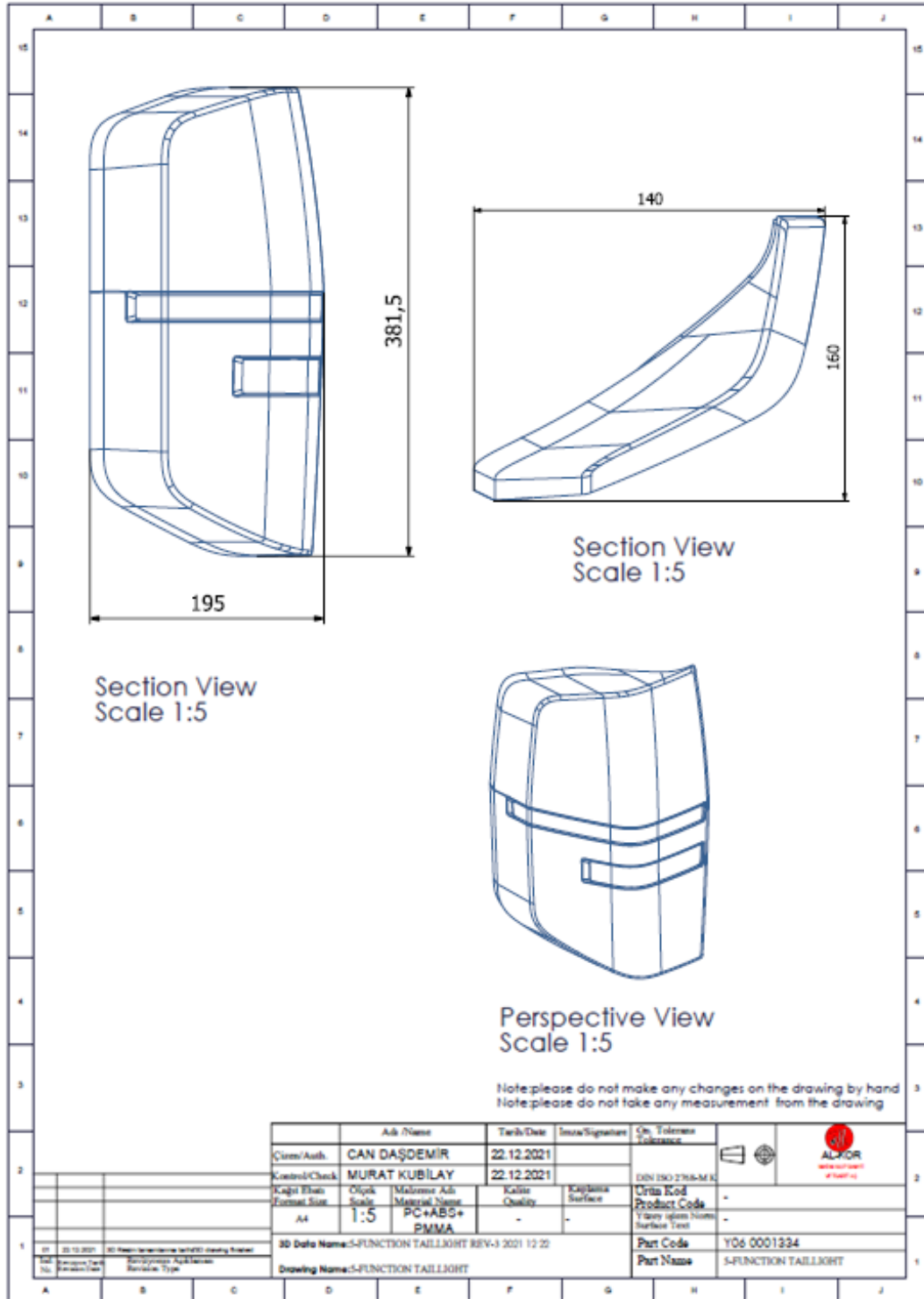


Figure A.2: Lens 2D technical drawing

Figure A.3 shows the 2d technical drawing of the housing.

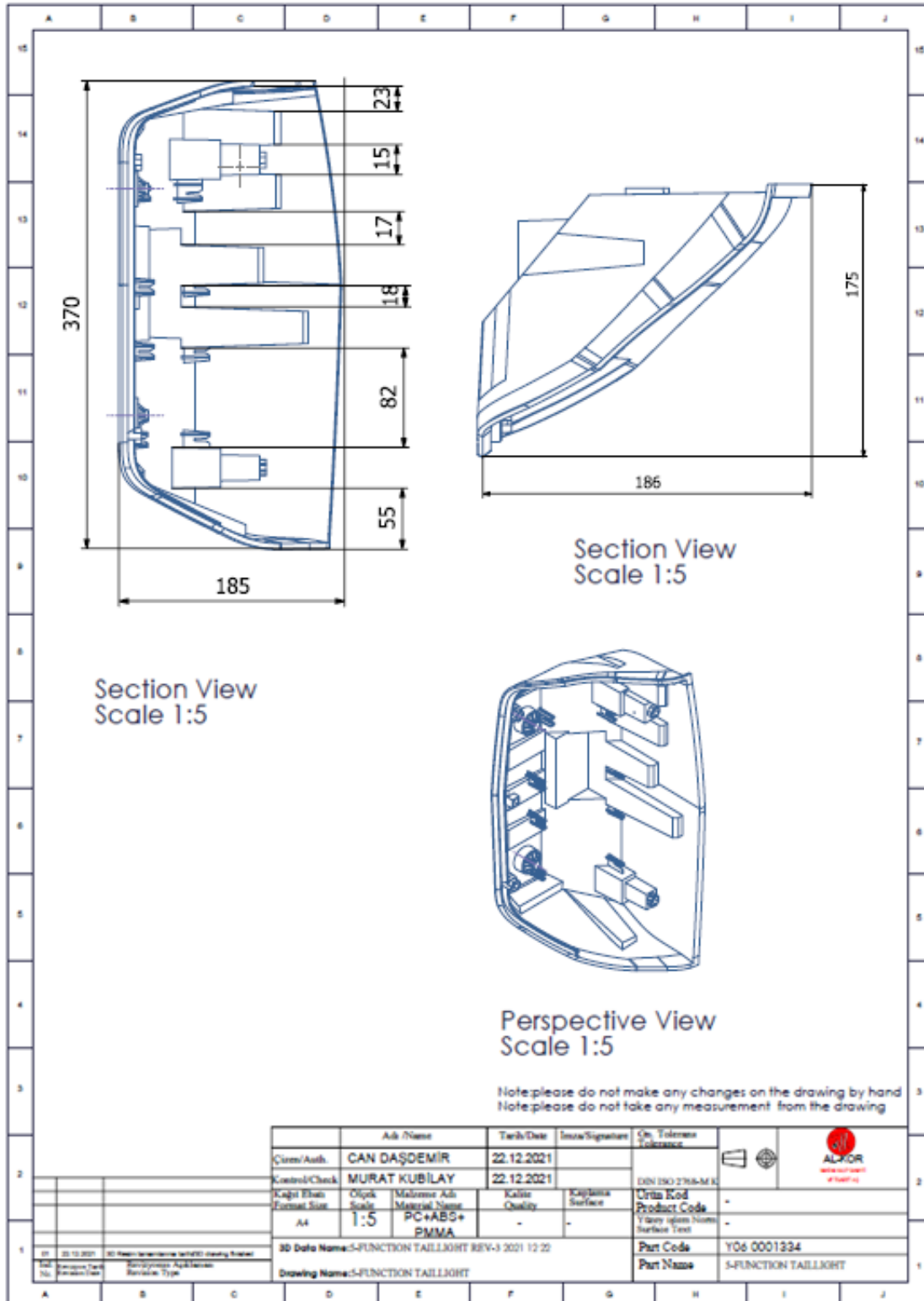


Figure A.3: Housing 2D technical drawing

Figure A.4 shows the 2d technical drawing of the reflector.

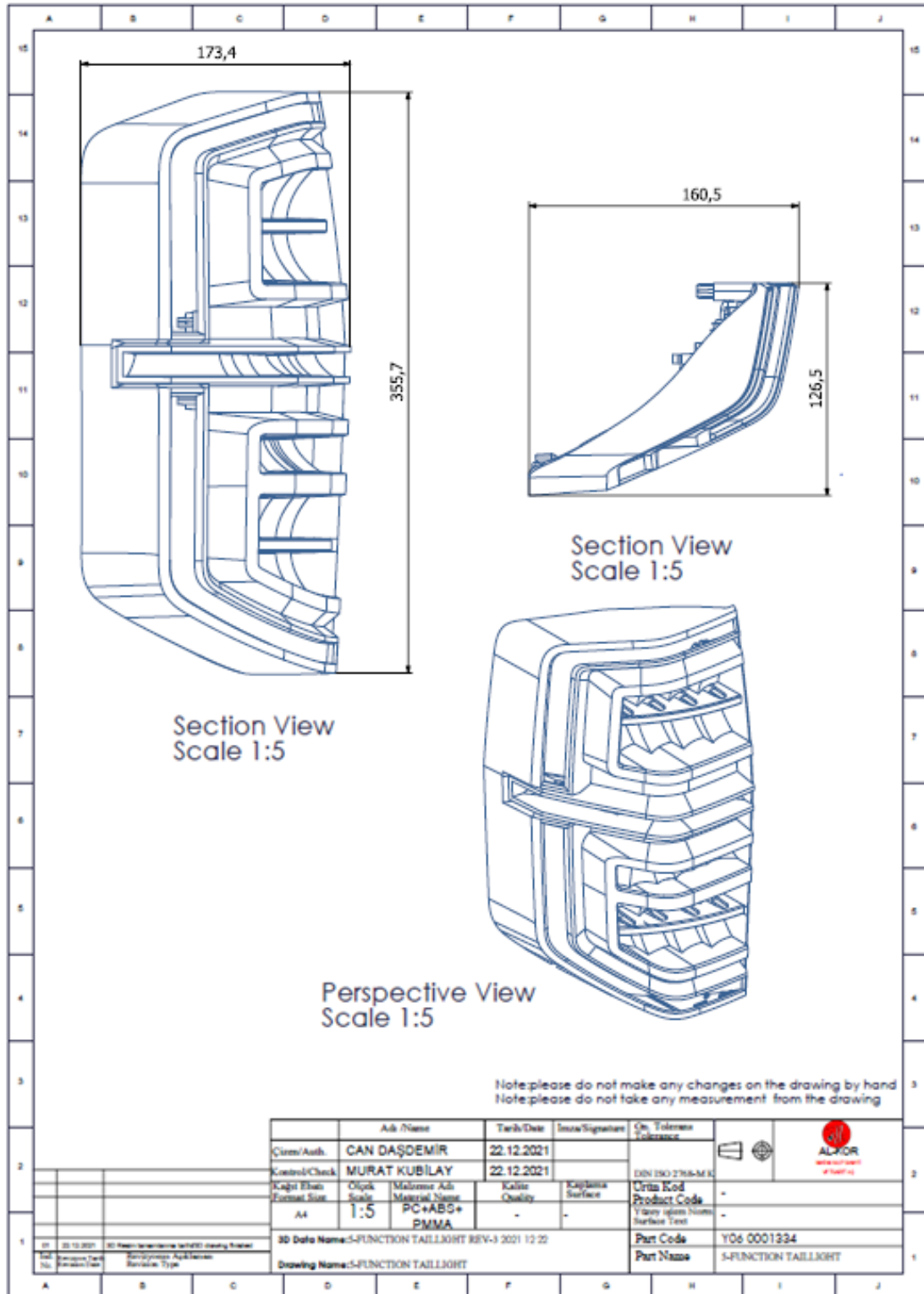


Figure A.4: Reflector 2D technical drawing

Figure A.5 shows the 2d technical drawing of the inner cover upper.

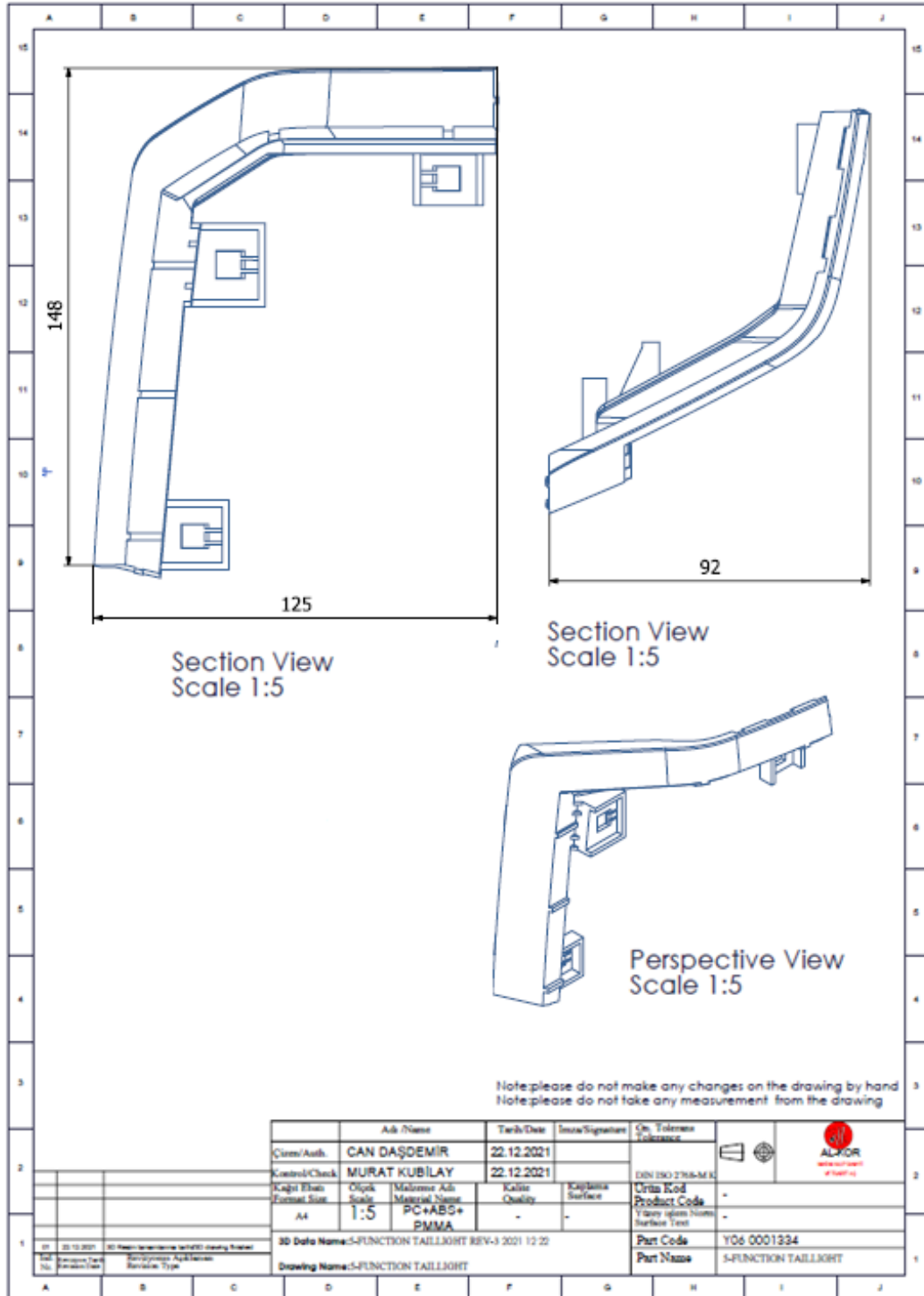


Figure A.5: Inner cover upper 2D technical drawing

Figure A.6 shows the 2d technical drawing of the inner cover lower.

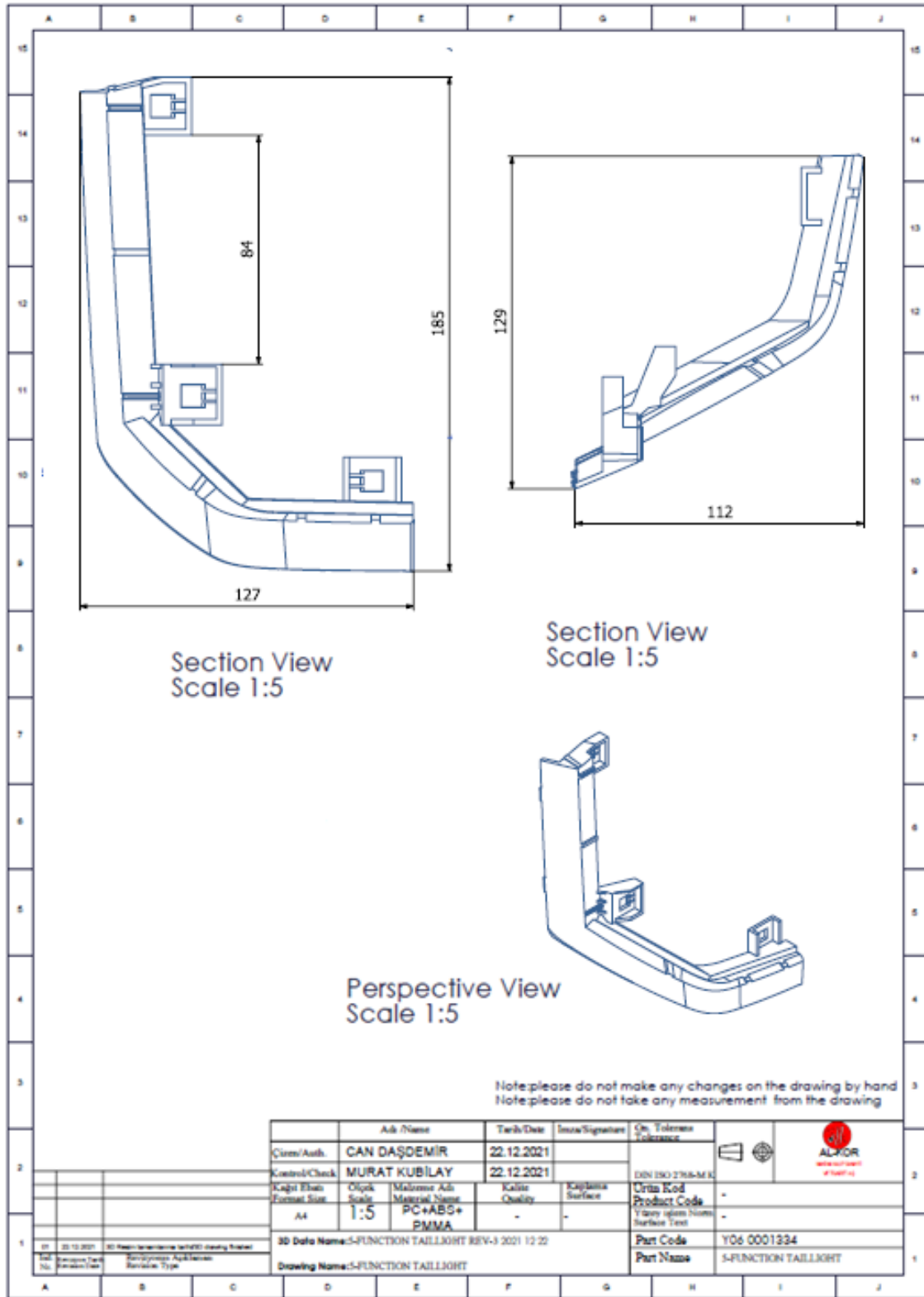


Figure A.6: Inner cover lower 2D technical drawing

Figure A.7 shows the 2d technical drawing of the inner housing upper.

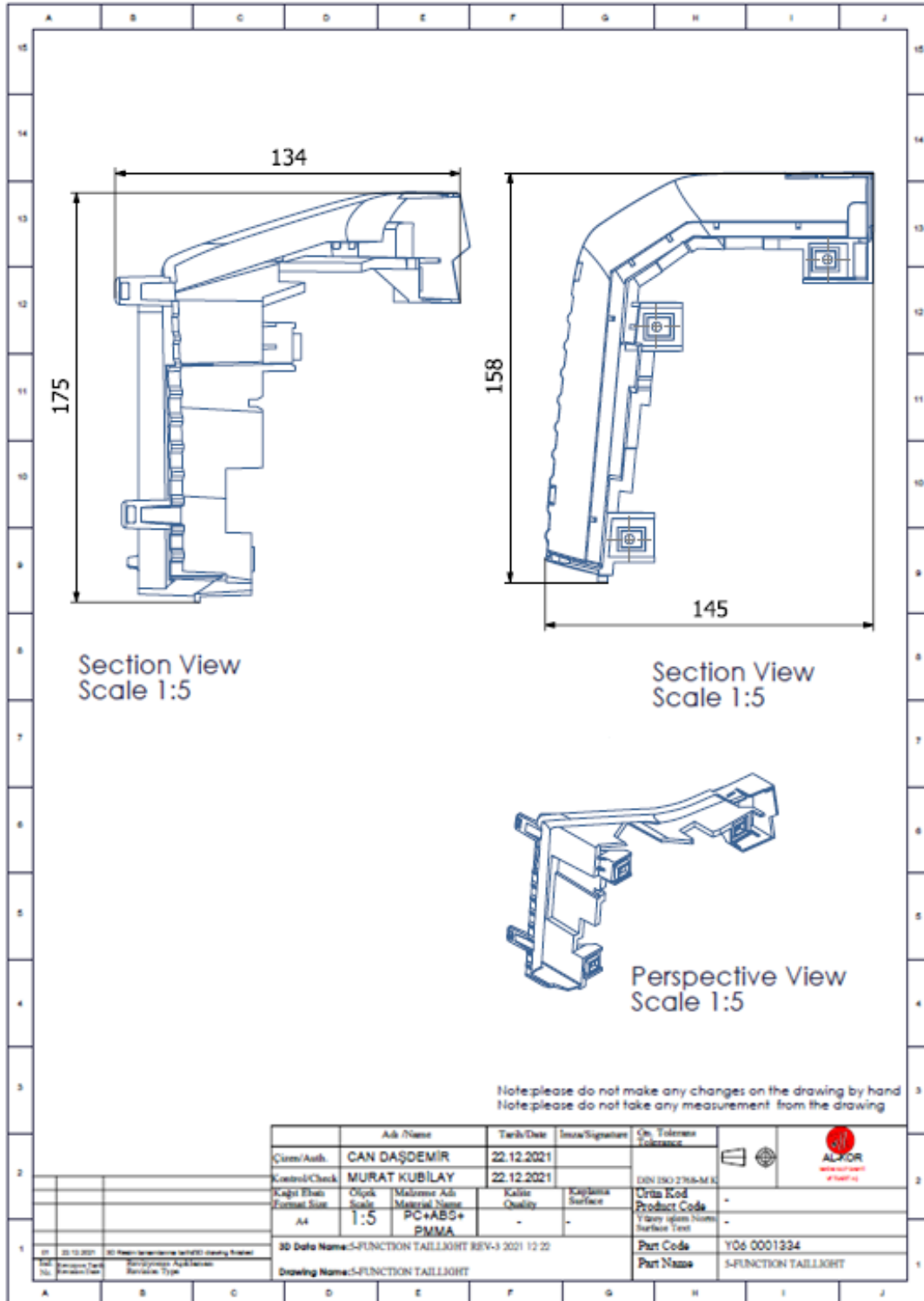


Figure A.7: Inner housing upper 2D technical drawing

Figure A.8 shows the 2d technical drawing of the inner housing lower.

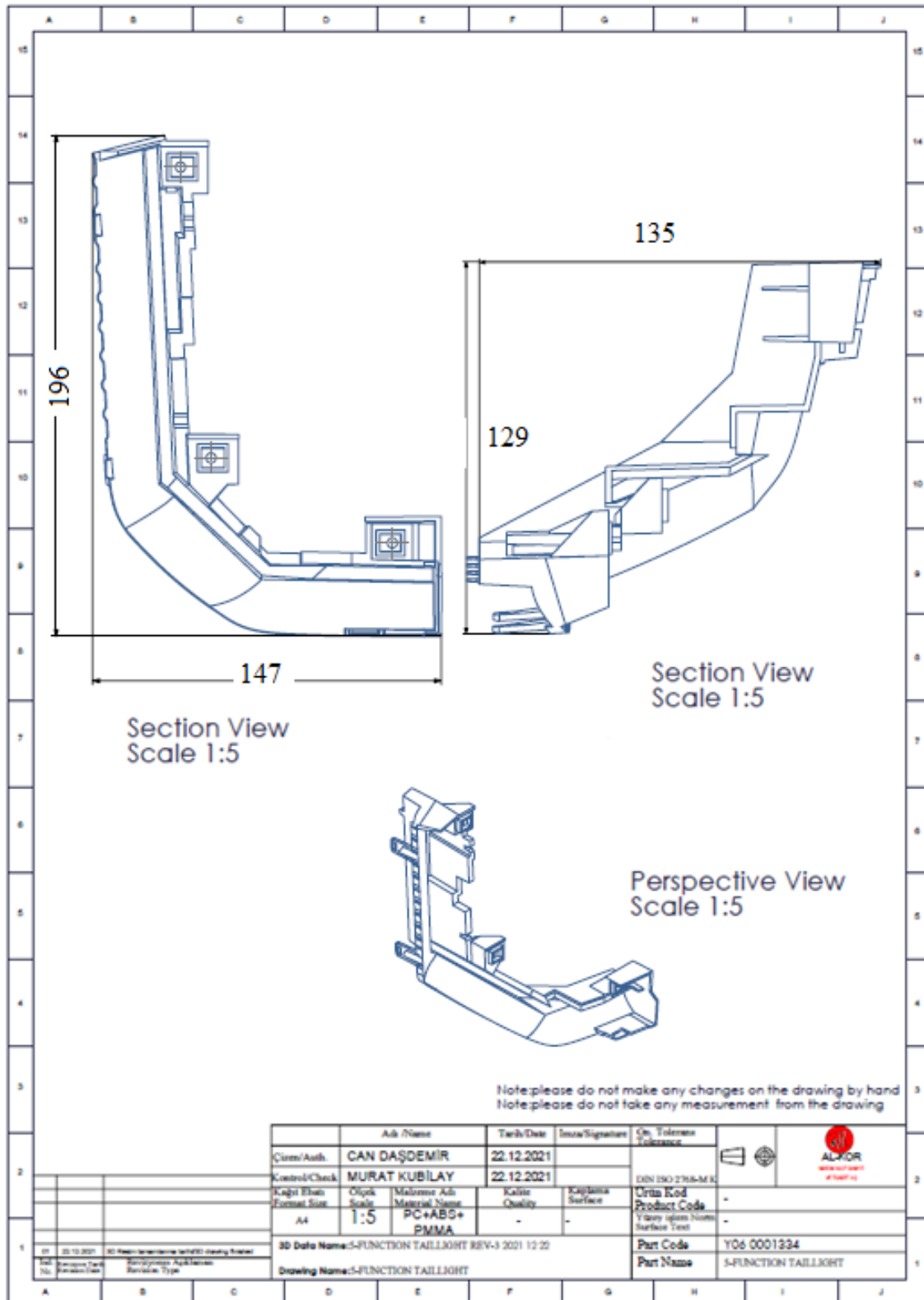


Figure A.8: Inner housing lower 2D technical drawing

Figure A.9 shows the 2d technical drawing of the stop lamp PCB.

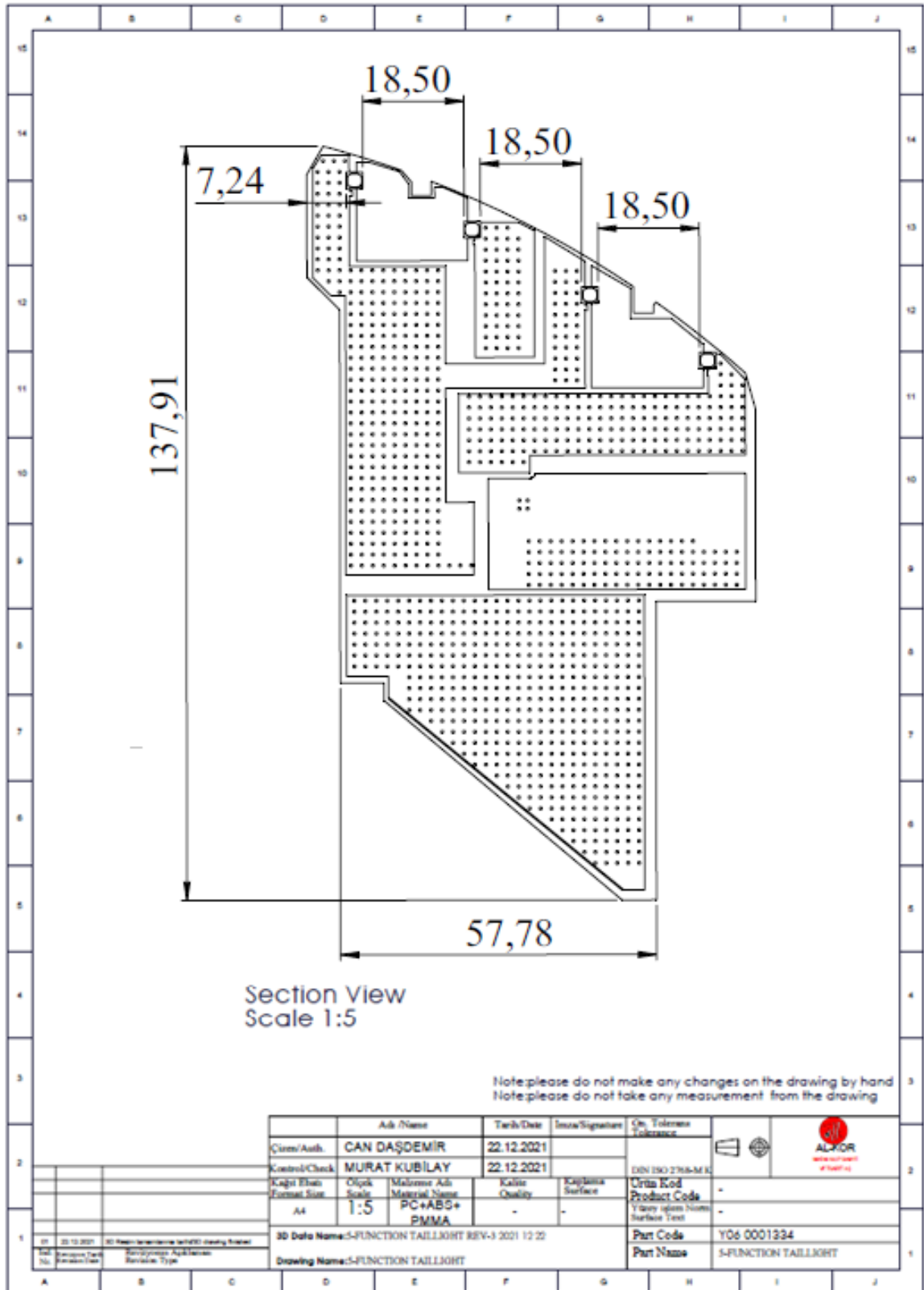


Figure A.9: Stop lamp PCB 2D technical drawing

Figure A.10 shows the 2d technical drawing of the signal lamp PCB.

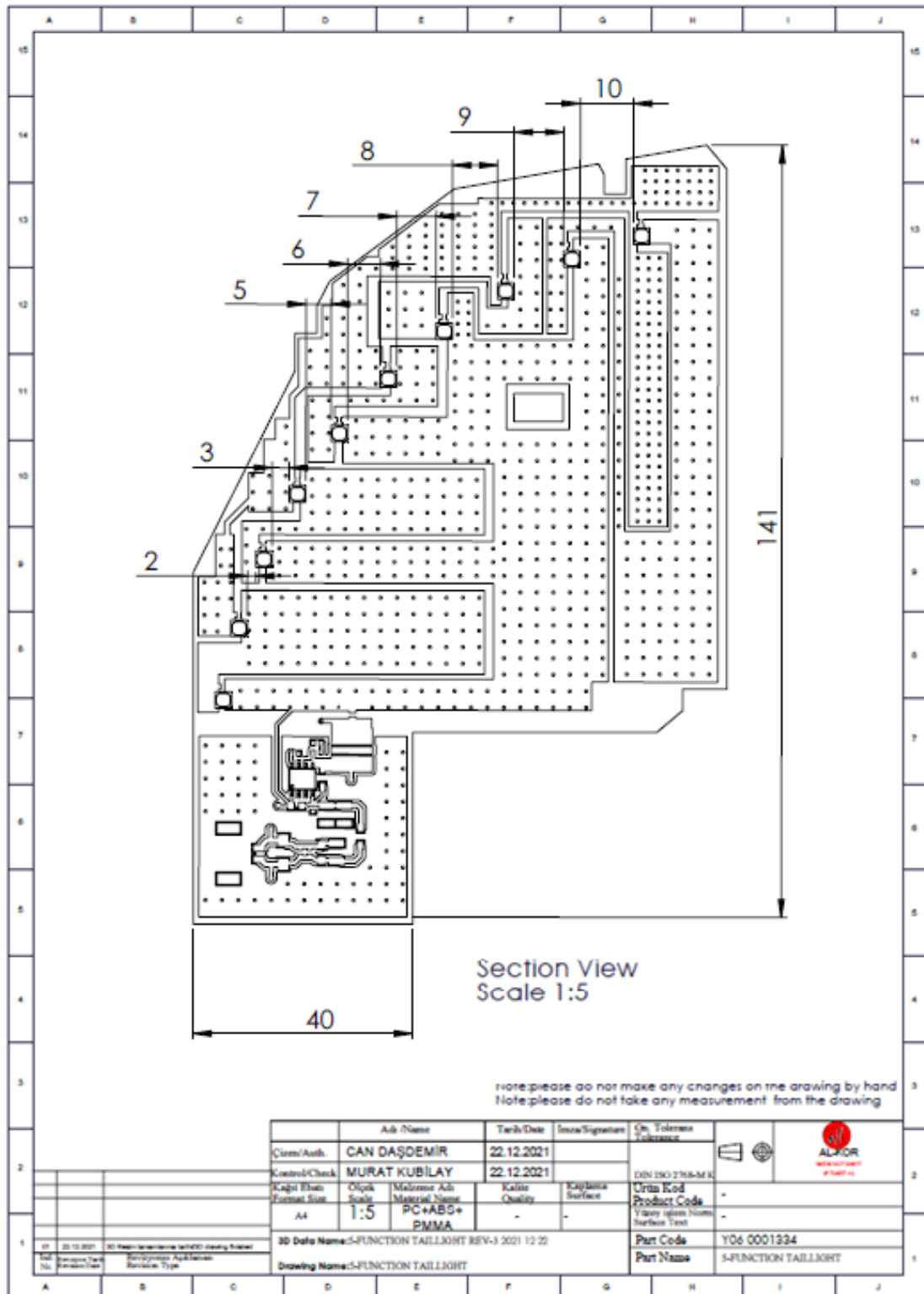


Figure A.10: Signal lamp PCB 2D technical drawing

Figure A.11 shows the 2d technical drawing of the fog lamp PCB.

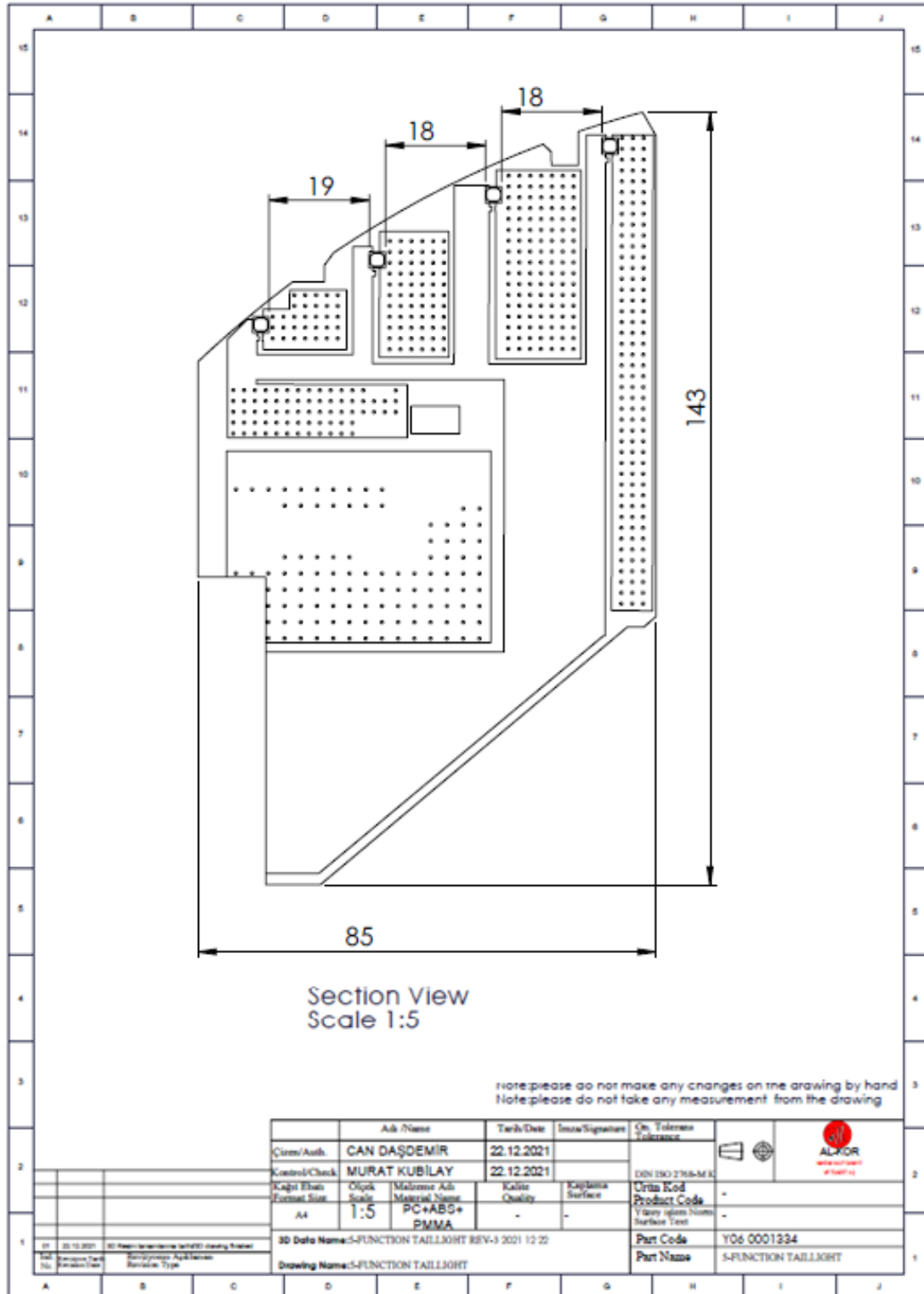


Figure A.11: Fog lamp PCB 2D technical drawing

Figure A.12 shows the 2d technical drawing of the reverse lamp PCB.

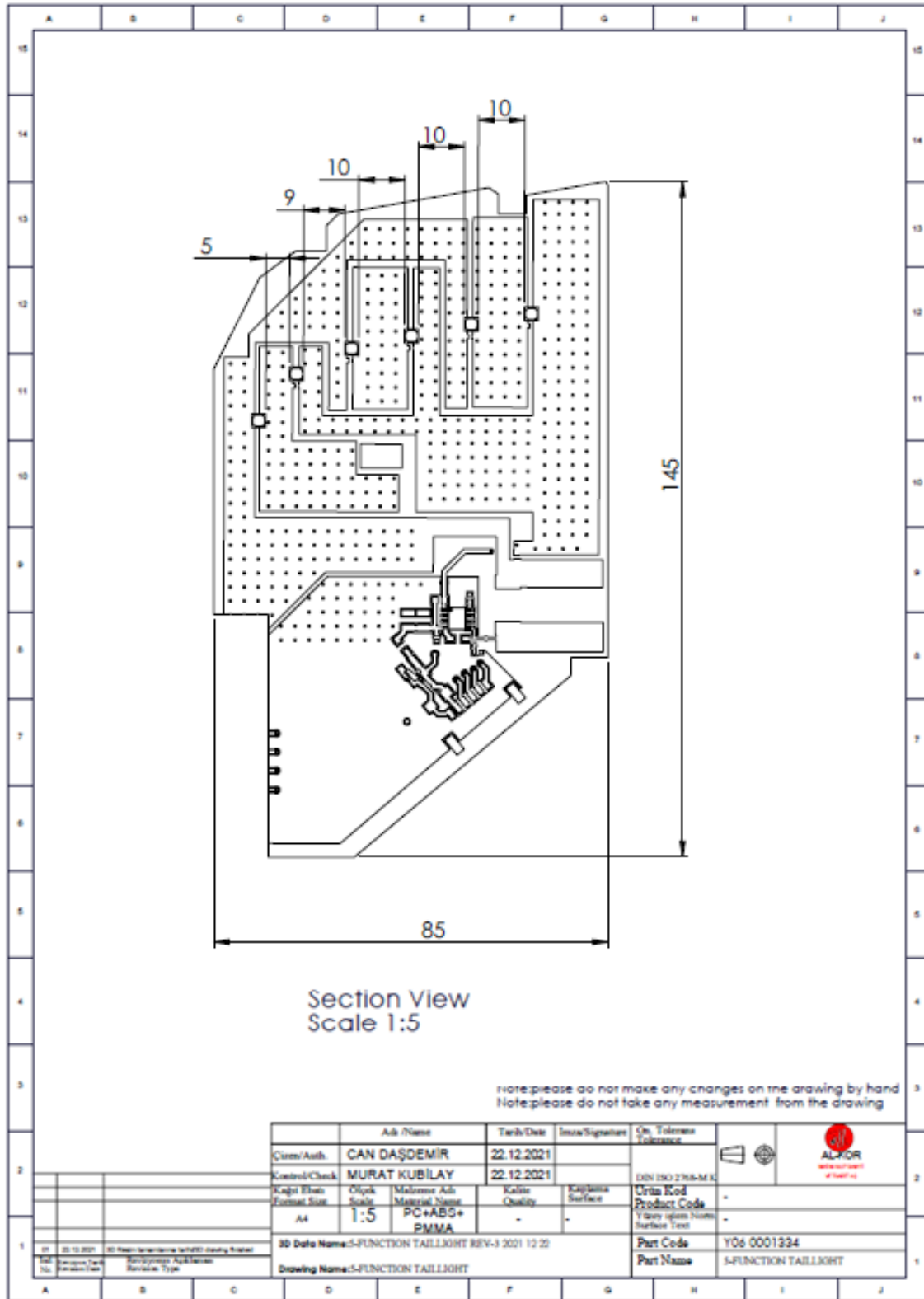


Figure A.12: Reverse lamp PCB 2D technical drawing

Figure A.13 shows the 2d technical drawing of the lower park PCB-1 lamp PCB.

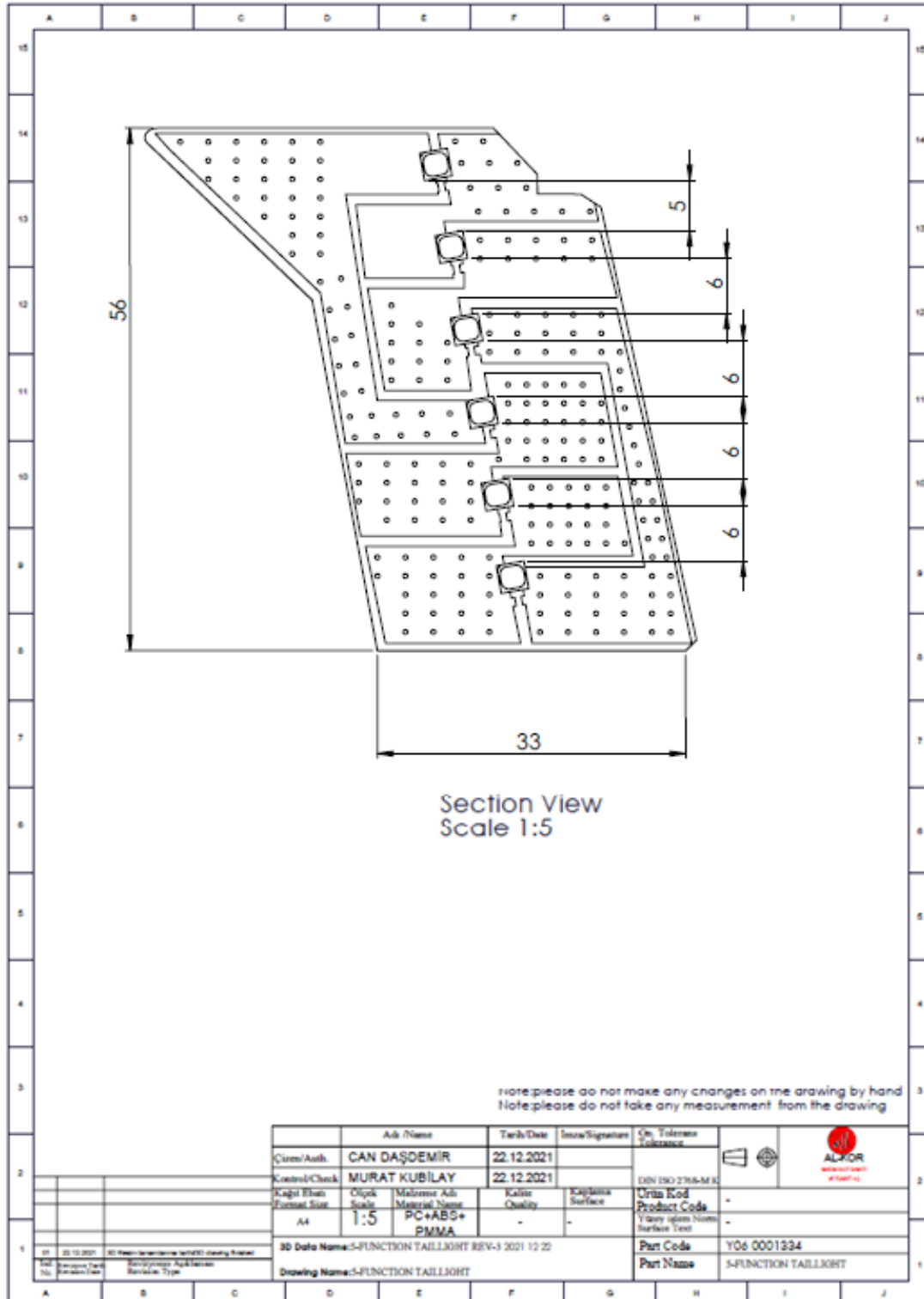


Figure A.13: Lower park PCB-1 lamp PCB 2D technical drawing

Figure A.14 shows the 2d technical drawing of the lower park PCB-2 lamp PCB.

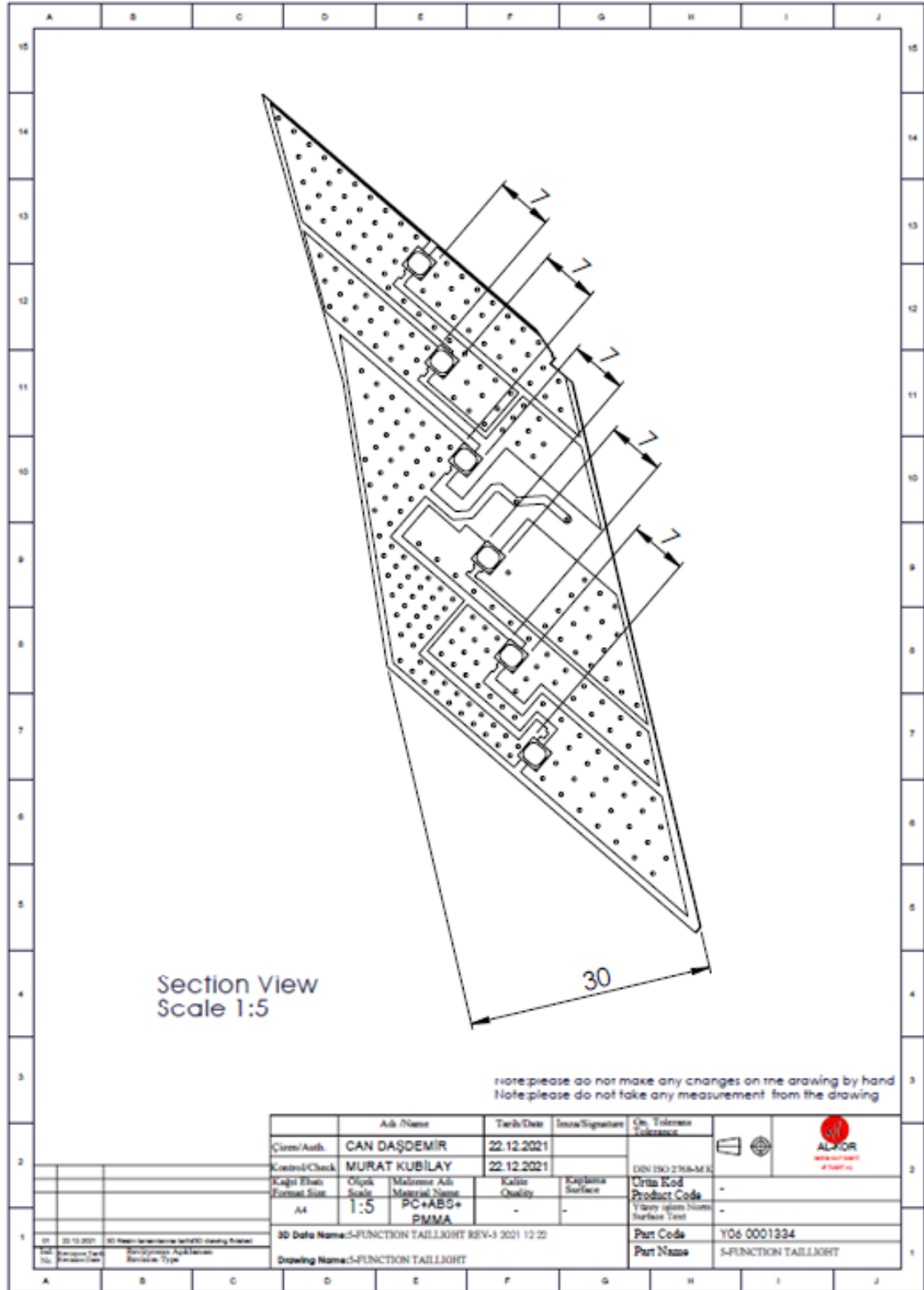


Figure A.14: Lower park PCB-2 lamp PCB 2D technical drawing

Figure A.15 shows the 2d technical drawing of the lower park PCB-3 lamp PCB.

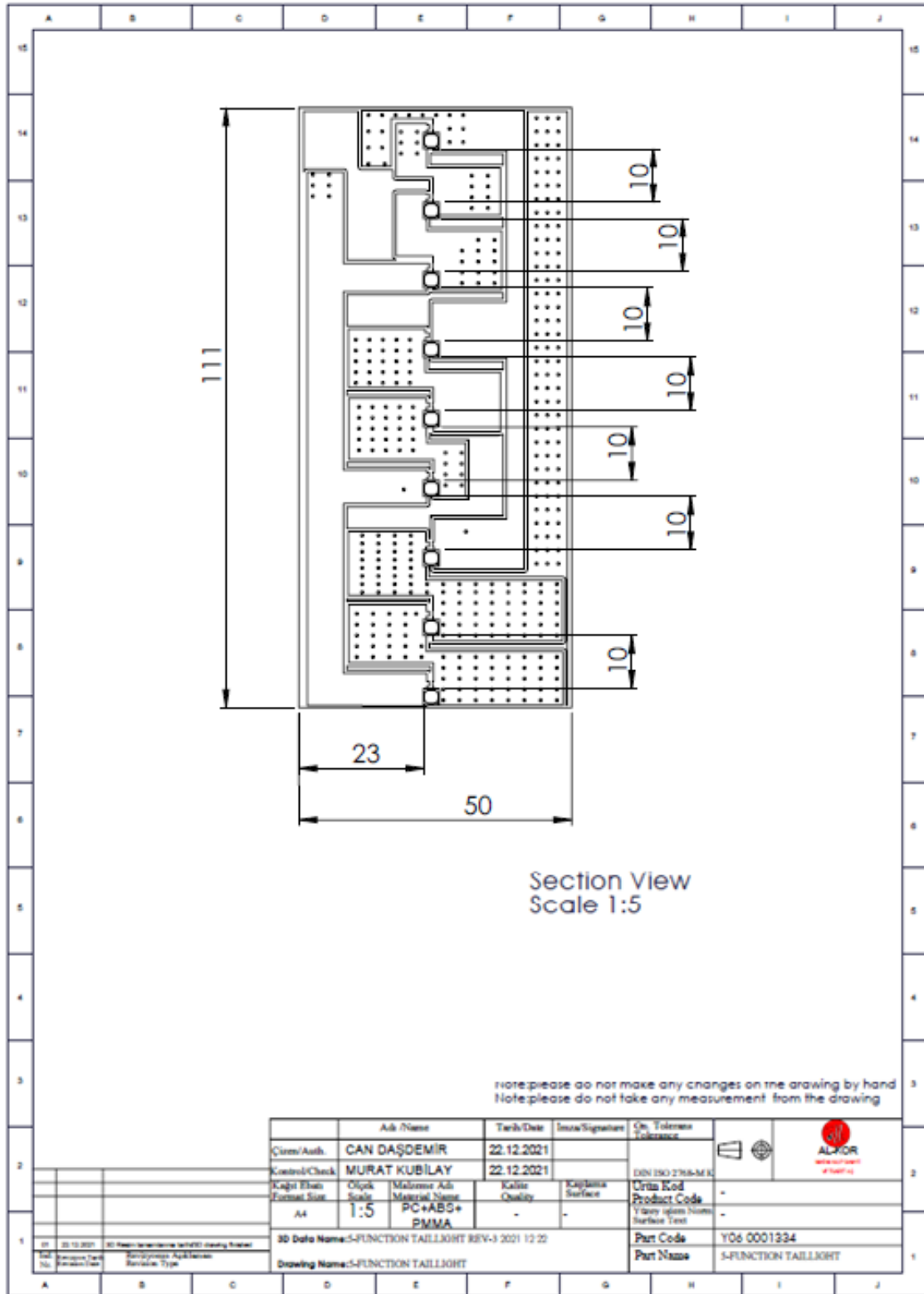


Figure A.15: Lower park PCB-3 lamp PCB 2D technical drawing

Figure A.16 shows the 2d technical drawing of the upper park PCB-1 lamp PCB.

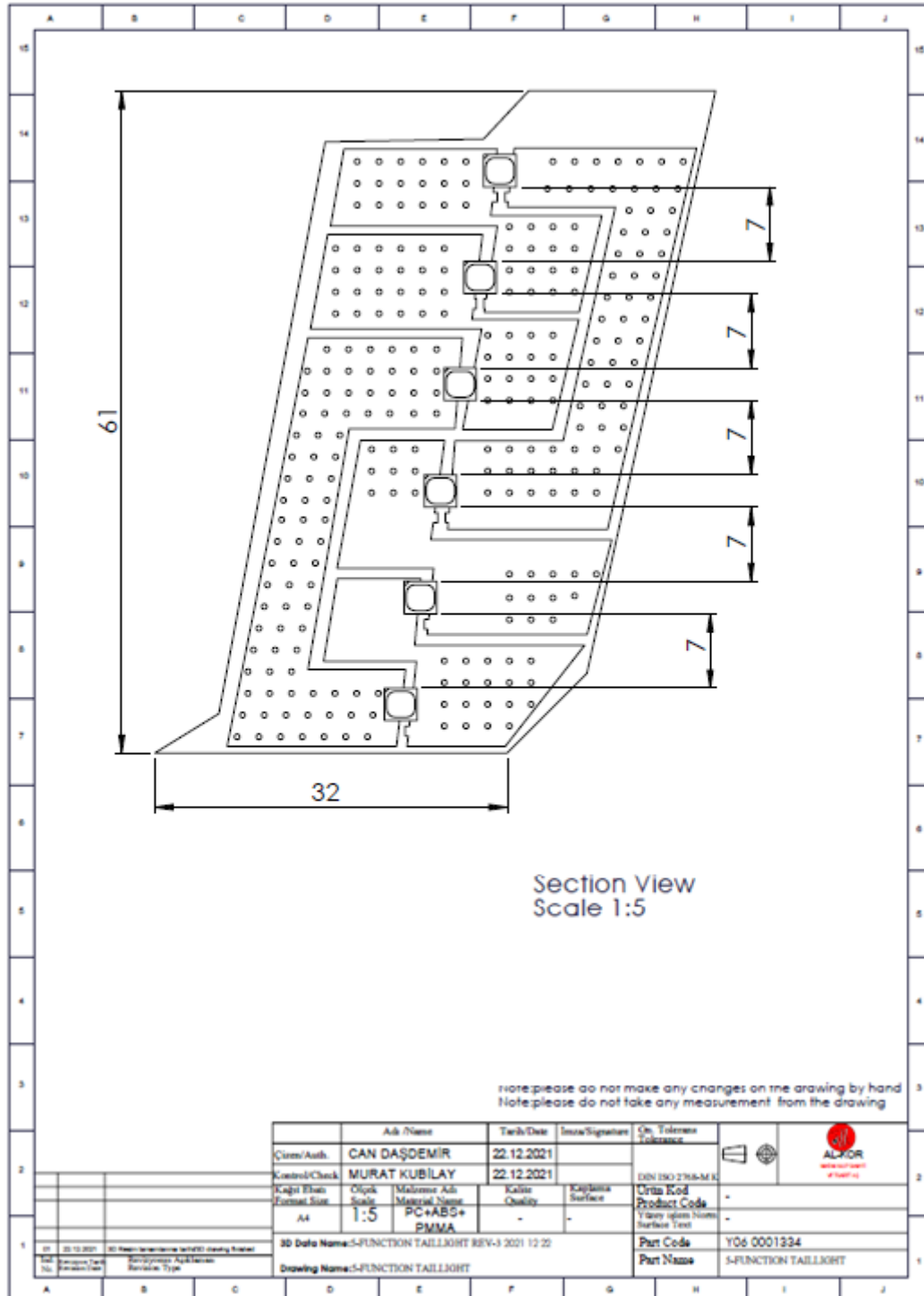


Figure A.16: Upper park PCB-1 lamp PCB 2D technical drawing

Figure A.17 shows the 2d technical drawing of the upper park PCB-2 lamp PCB.

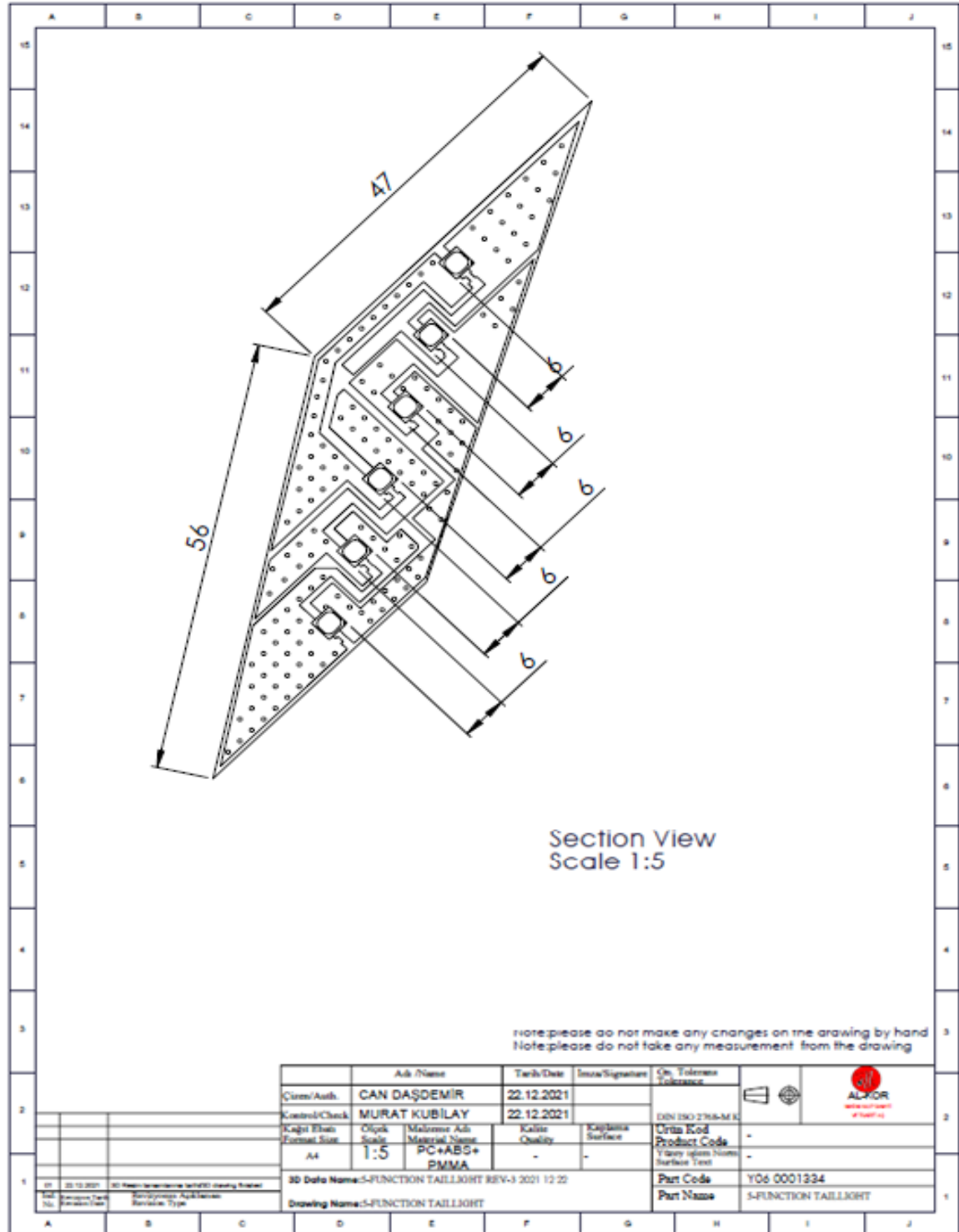


Figure A.17: Upper park PCB-2 lamp PCB 2D technical drawing

Figure A.18 shows the 2d technical drawing of the upper park PCB-3 lamp PCB.

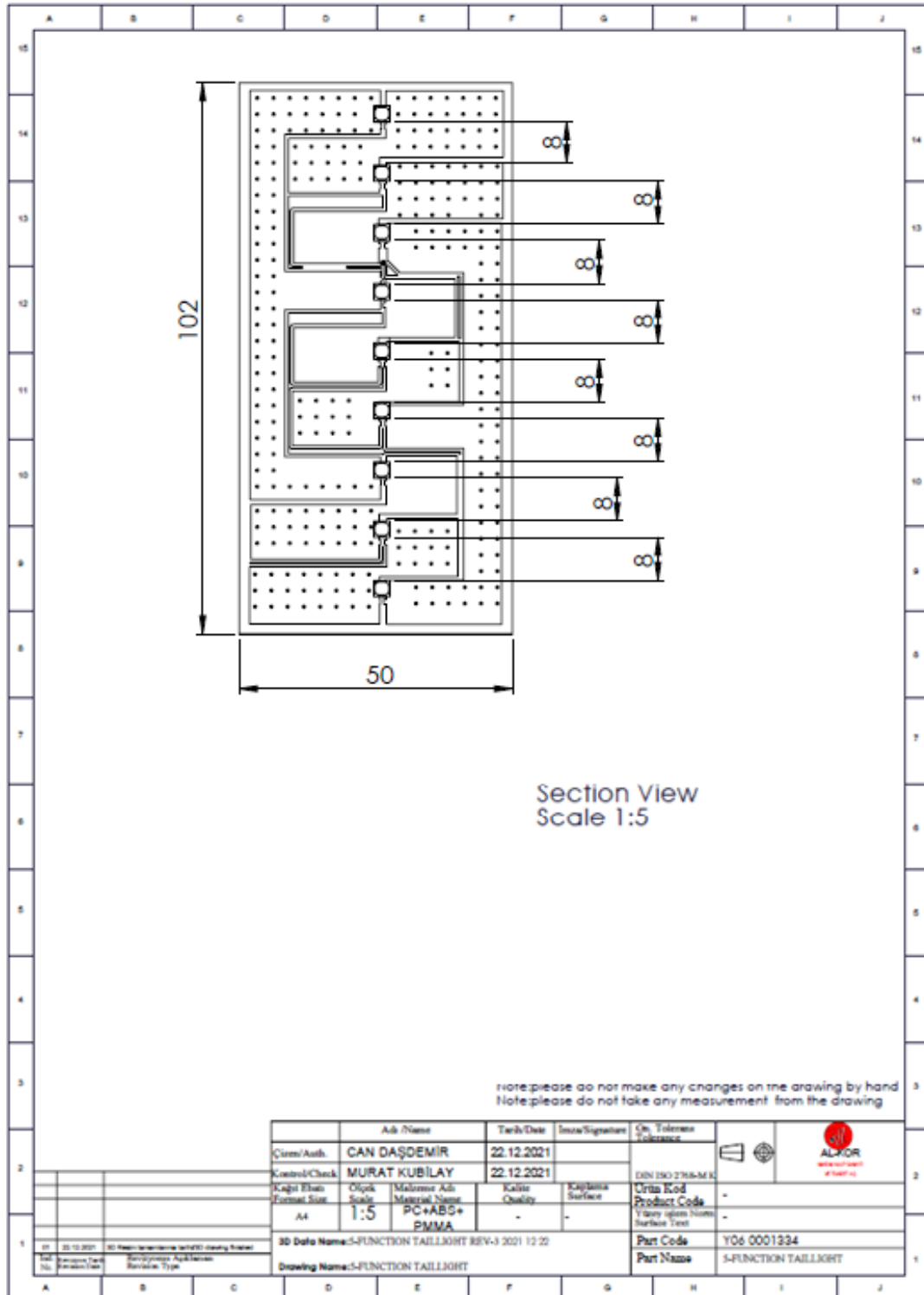


Figure A.18: Upper park PCB-3 lamp PCB 2D technical drawing