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*Date: October 1, 2015*

## Introduction

People are often mesmerized by beautiful displays such as fireplaces, water flowing, etc. With this LED indicator effect, it actually becomes fun to "watch the water boil" in a teapot.

The bottom of this teapot has an added transparent box with LEDs mounted in it. After the teapot is switched on, the LED's go around and shine blue, which is associated with cold water. (See Appendix 3). As the water temperature rises, the LEDs color smoothly changes from 100% blue to 100% red (which is associated with hot water) and the visual "spinning" speed increases as well. All this is accomplished with a single 20-I/O GreenPAK IC, controlling 32 2-color LEDs with smooth color and spin speed changes.

## Design Configuration

First, let's consider temperature to voltage conversion (schematic is shown in Appendix 2). As we can see, there is an external voltage divider, which consists of a resistor and thermistor. The voltage applied to the 150k resistor is 5.1V. At a temperature equal to 25C on the thermistor (22k) we will get approximately 0.65V on the divider output. At 100C, the thermistor resistance will decrease down to 1.68k and voltage on the divider output will be 56mV. Resistance changing linearity provides a divider output voltage changing linearly within the mentioned temperature range.

Looking at configuring the GreenPAK IC circuitry, voltage from the divider output is applied to the PGA input, and from there to ADC, where the voltage value will be converted into an 8-bit code (see Figure 1). After that, the 8-bit code is compared with PWM0 register, which is equal to CNT8 current counter data (see Figure 2). This is how PWM for blue LEDs is made. So the conversion process is: low temperature – high divider voltage – big duty cycle (high brightness) and vice versa. Red LEDs are connected to the same outputs as blue LEDs with the only difference being opposite polarity. So for the remaining LEDs everything will be reversed: low temperature – low brightness and so on.

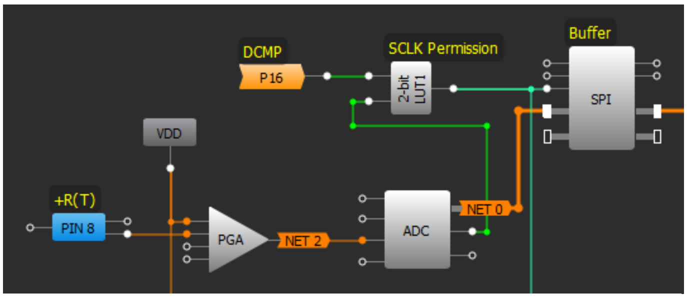



**Figure 1. ADC circuit**

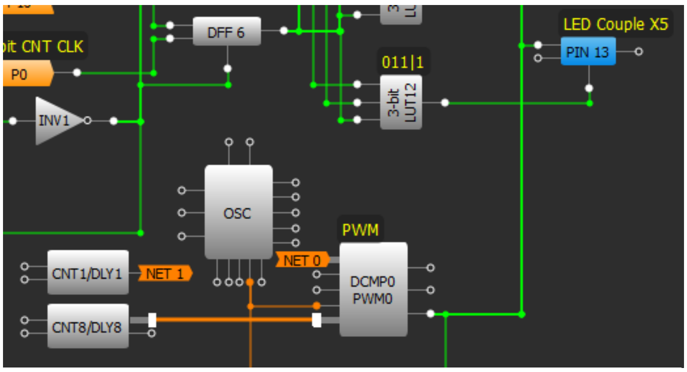



**Figure 2. PWM machine**

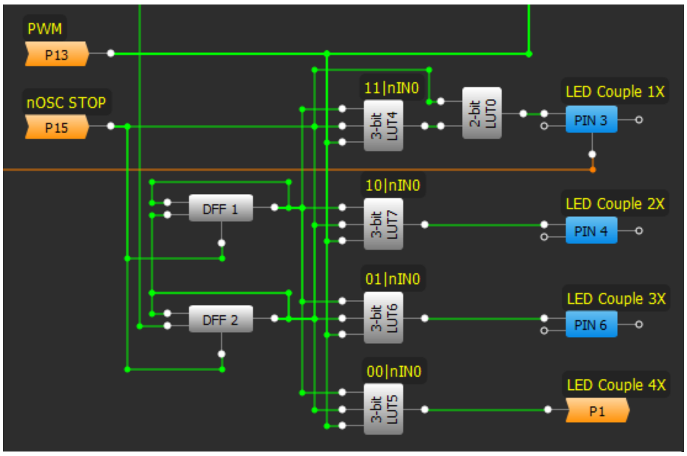



Figure 3. 2-bit counter

The next part of the effect concerns "light motion". Its essence lies in switching PWM signal between 32 LEDs one by one. Because of the limited number of IC outputs, LEDs were connected in a 4x8 matrix. For matrix control two counters, made of DFF's were created: one 2-bit for 4 columns control (see figure 3) and one 3-bit for 8 rows control (see figure 4). LEDs are located at the crossing of columns and rows as mentioned in Appendix2.

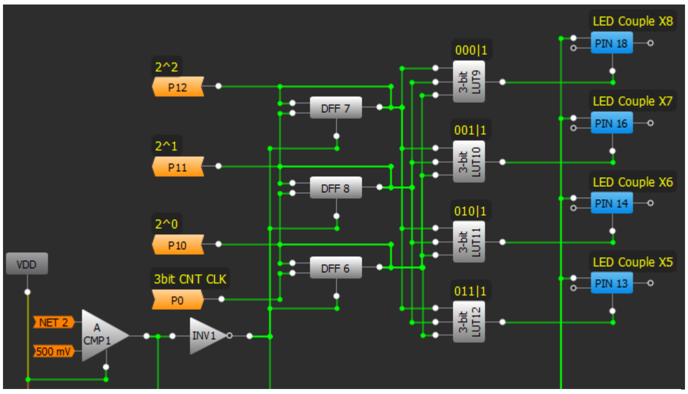



Figure 4. 3-bit counter

The switching process is as follows: 2-bit counter generates 4 2-bit combinations which are monitored by 3-bit LUT4 – LUT7, which outputs are connected to appropriate columns.

Each LUT is configured in the way to output an inverted PWM signal for one 2-bit counter combination. For other combinations, it outputs a non-inverted PWM signal. So we get an inverted PWM for 4 columns one by one, when at the same time on the other 3 columns we get non-inverted PWM.

The non-inverted PWM signal is output on 8 LEDs rows, but thanks to 3-bit LUTs all these outputs except for one, which is controlled by the LUT with combination, which corresponds with 3-bit counter code, stay in Hi-z mode. So we get 8 rows in Hi-Z state, and non-inverted PWM signal is supplied to each row one by one.

For the FSM never to store "$00000000_2$" value, SPI in buffer mode between ADC and FSM is used, CLK input of which becomes disconnected when DCMP detects that ADC digital code becomes equal to "$00000001_2$". Thanks to that "$00000000_2$" code can't be transmitted through the SPI buffer and light motion effect doesn't stop (see Figure 5).

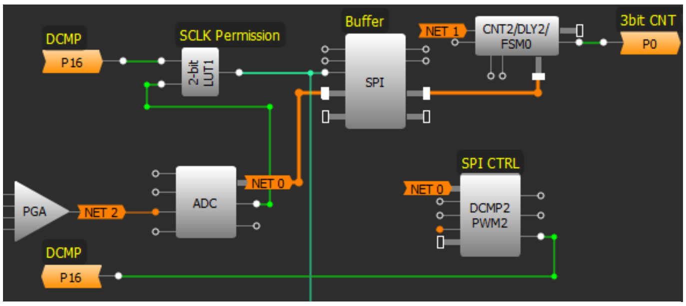



Figure 5. SPI buffer

Using this method we get alternate illumination of each LED (red + blue) pair, switching speed dependent on the water temperature inside the teapot. The pair of LEDs which are at the crossing of the column with inverted PWM signal and the row with non-inverted PWM signal will be active (see

Figure 6), while all other LEDs will be inactive at this moment. The bigger PWM duty cycle is, the less bright blue LED is and the more bright red LED is. So while temperature and consequently PWM duty cycle changes, backlight color of the teapot changes.

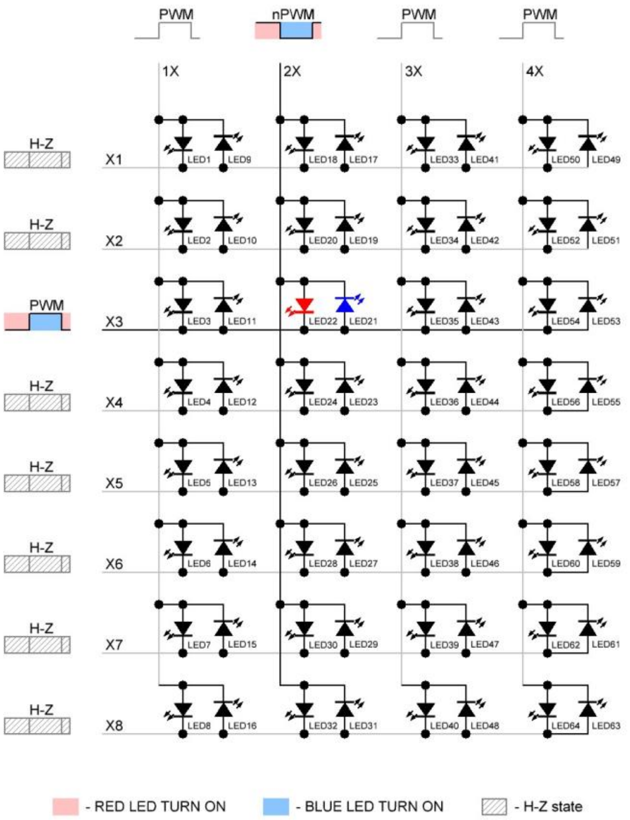



**Figure 6. Bicolor LED matrix**

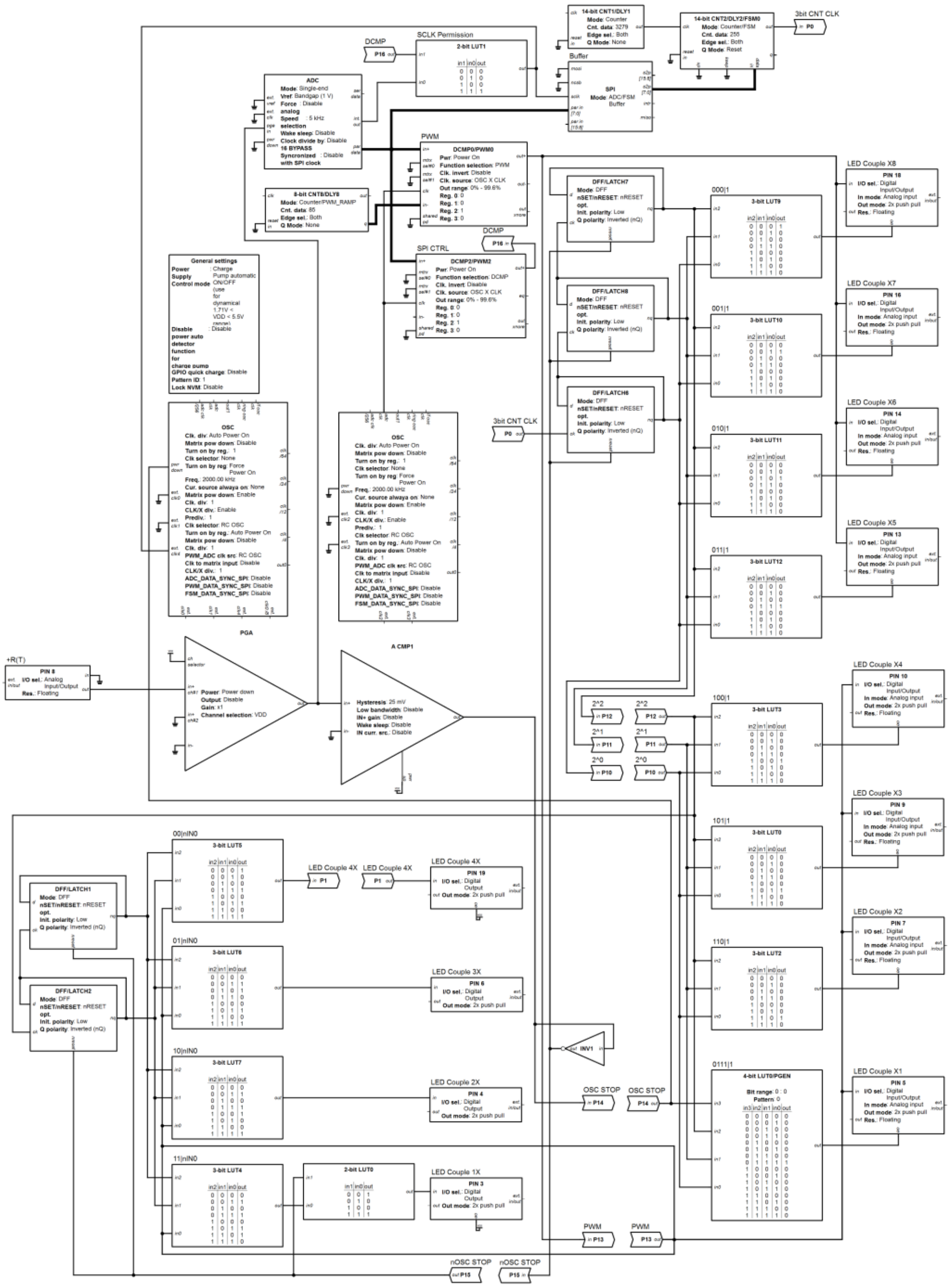
Detailed design configuration can be found in Appendix 1.

## Conclusion

This boiling teapot effect indicator design vividly demonstrates some of the capability of GreenPAK programmable mixed-signal ASIC's. This project can be adapted to various designs where many LEDs are used. Thanks to the GreenPAK flexibility, it is possible to create different LED effects with many LEDs based on this design method.

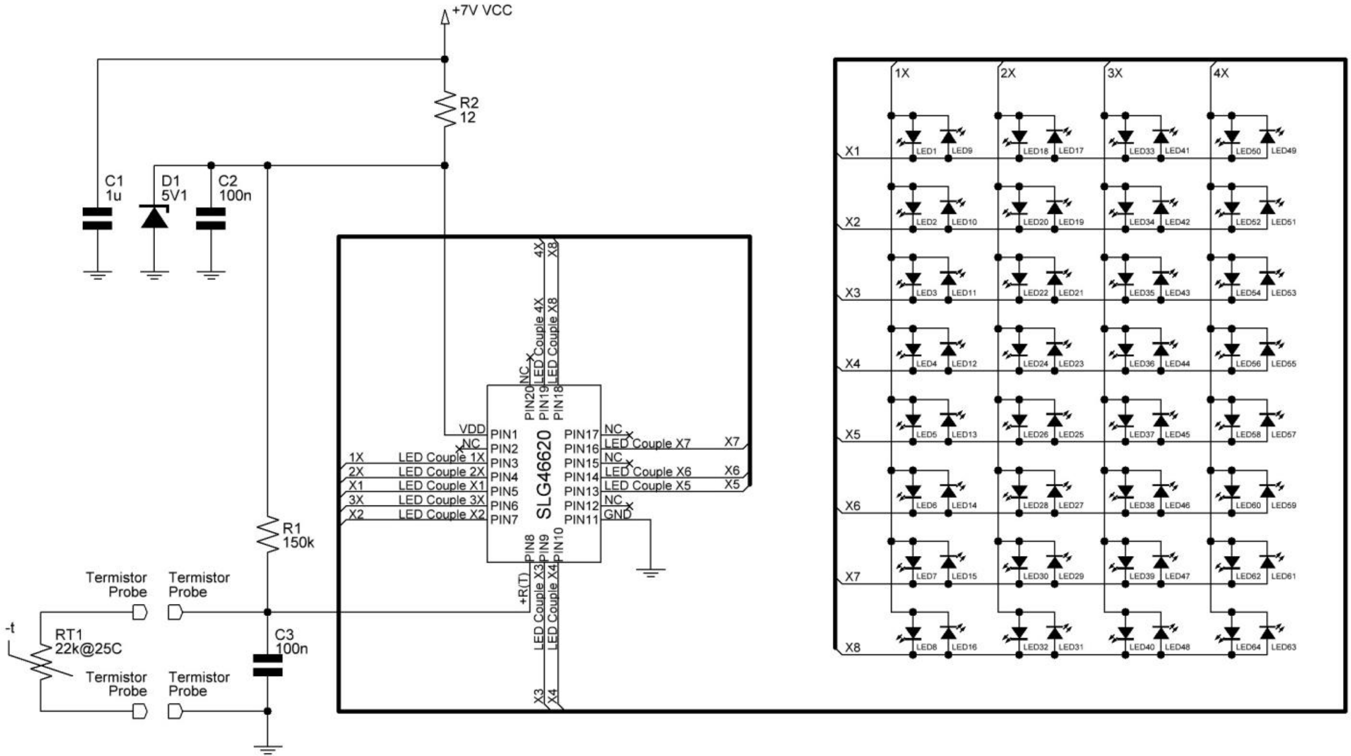
# Appendix 1

### Block Diagram for Design



## Appendix 2

**Schematic**



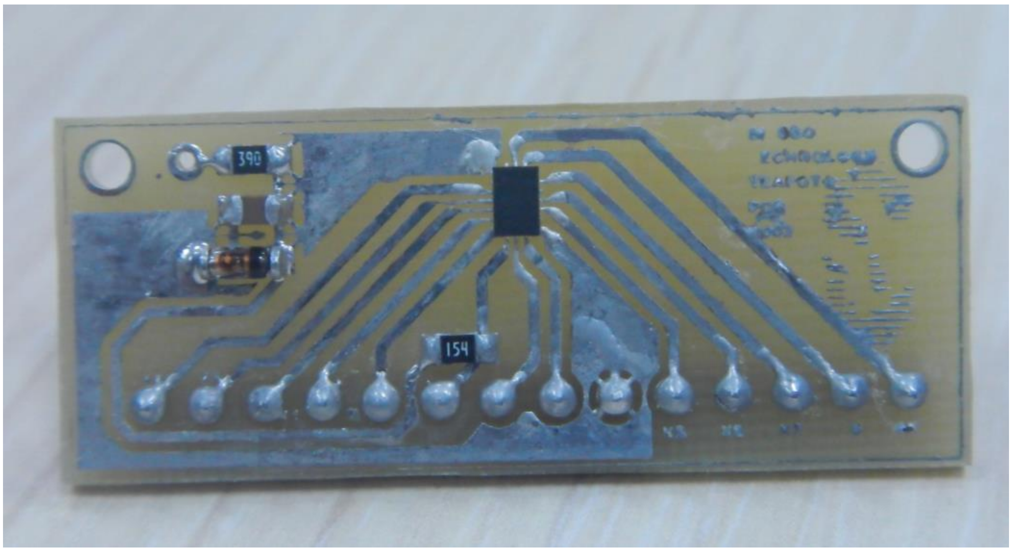
## PCB pictures

1. LED Top Layer

## PCB pictures

2. LED Bottom Layer

3. Master PCB

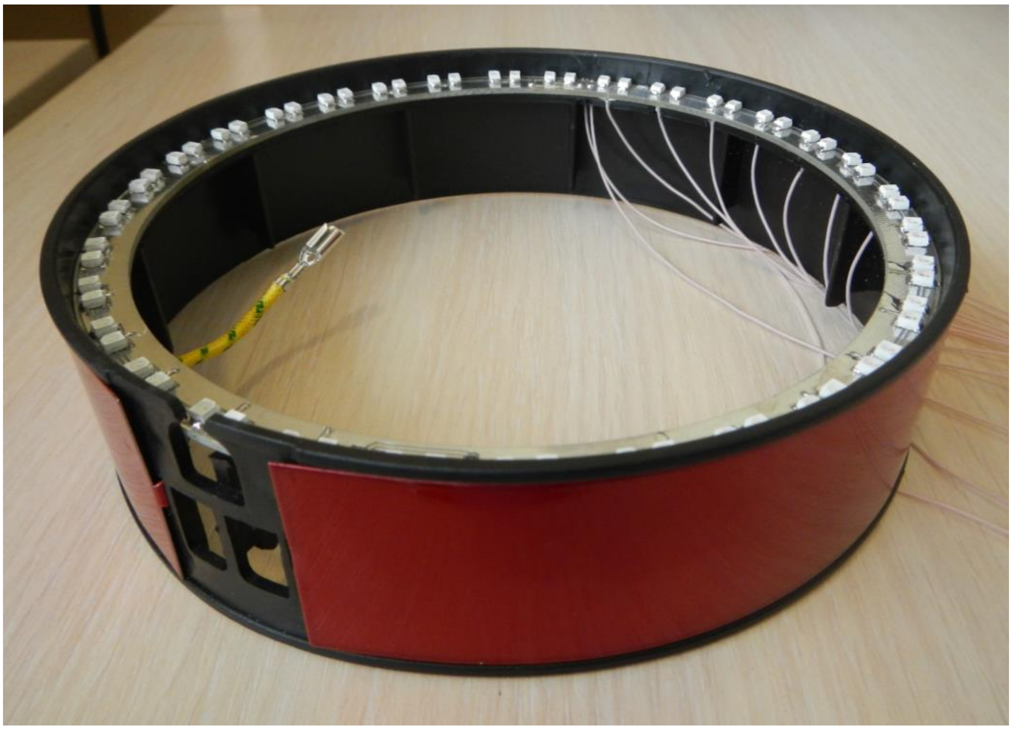


# Appendix 3

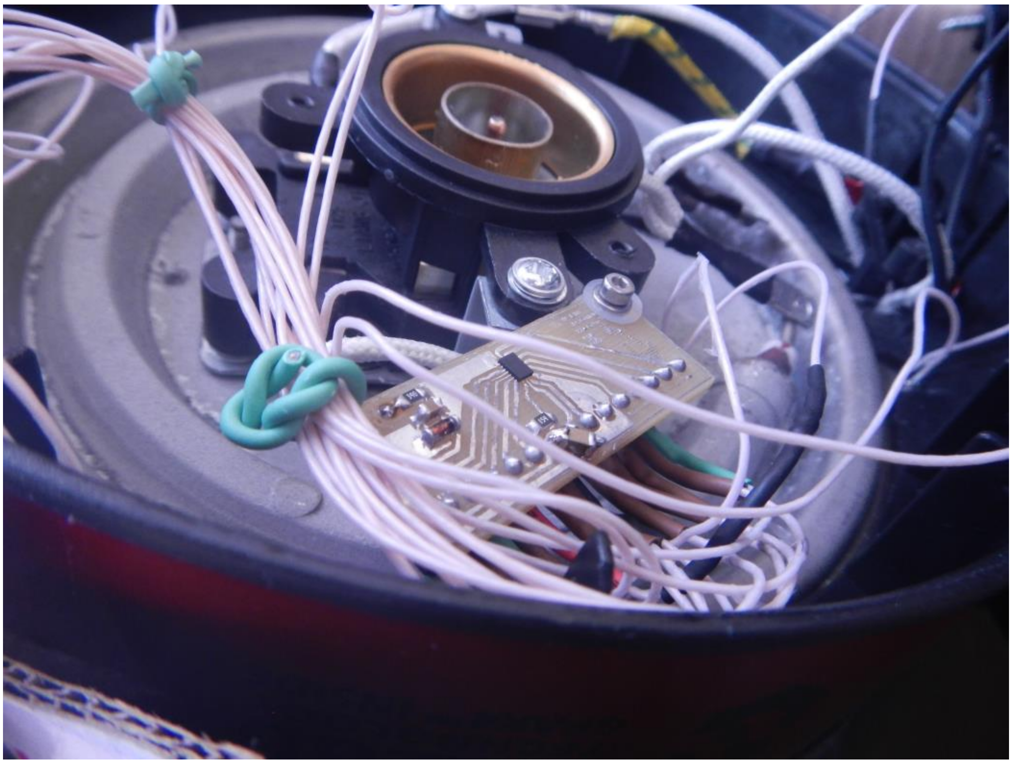
### Device pictures

1. General view

2. LED PCB installation in progress

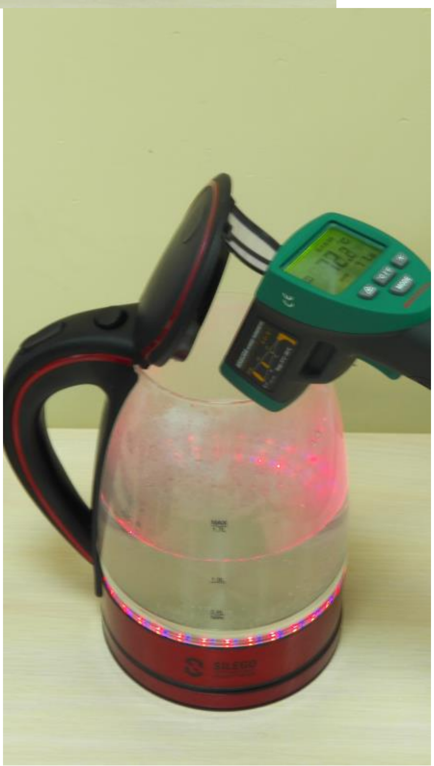


3. Master PCB installation in progress



4. LED effect at 29$^{O}$C[1] 5. LED effect at 45$^{O}$C[1] 6. LED effect at 54$^{O}$C[1]

7. LED effect at 67$^{O}$C[1] 8. LED effect at 72$^{O}$C[1] 9. LED effect at 93$^{O}$C[1]



[1]Thermometer Accuracy is ±2.5 $^{O}$C

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