The concept of innovation Active Cooling System for LED fixtures and power electronics,

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THE CONCEPT

OF "MP LIGHTING" ACTIVE COOLING MODULE (ACM)

During 2010-2012 years MP Lighting has performed a lot if experimental works which have been targeted on the improvement of thermal management of the LED fixtures.
This review is based on results of experimental works and prototyping performed at R&D Lab MP Lighting for development new concept of Active Cooling System (ACS) granted by US Patent #8070324 and Canadian Patent #2770394.
Actually we made the principal decision that cooling system for LED fixtures with input electrical power more than 20Wt has to be done on the base of active cooling system (with forced air). Just in this case we can expect to get reasonable values of the main output features of LED light engine: efficiency (Lm/Wt), temperature on LED PCB (T*s), weight, size and reliability. As main criterions for optimization the following parameters and features have been chosen:

1. The Average Thermal Resistance (Rt av) of ACM which determine the whole capability to transfer heat flow from thermal load of ACM (LED array or COB) to the ambient air. We used the following formula to calculate the value of Rt av in [*C/Wt]:

   Rt av=(((T*s+T*hs)/2)–T*a)/Pin=(T*av-T*a)/Pin (1)

   T*s - the hottest temperature on PCB ("solder point") where LED soldered (or mechanically connected) to the component side of PCB,
   T*hs – the lowest temperature of ACM (as usual the closest to fan point of heat sink),
   T*av = (T*s + T*hs)/2 – the average temperature of heat sink (or LED fixture)
   T*a – the temperature of ambient air during the test procedure od the ACM,
   Pin – input electrical power which is applied to LED load of ACM from power supply

2. The Specific Power Density (SPD) of ACM which refer to the size of ACM to provide the value of ATR by thermal convection process (from surface of heat sink mostly). We used the following formula to calculate the value of SPD in [Wt/ cm^3] :

   SPD = Pin / (Vhs + Vfan) (2)

   Pin – input electrical power from (1),
   Vhs – volume of heat sink (in cm^3),
   Vfan – volume of fan (in cm^3)

3. The Specific Power Weight (SPW) of ACM which refer to the weight of materials (the metal of heat sink mostly) of ACM to provide the value of ATR by thermal conductivity process in metal of heat sink and constructive elements of ACM. We used the following formula to calculate the value of SPW in [W /gram]

   SPW = Pin / W (3)

   W – weight of ACM (including PCB, heat sink and fan) in gram.

4. The Specific Light Density (SLD) of ACM which refer to capability of ACM to provide right thermal management for LED source of light at fixed volume of device (ACM itself) for effective light emitting. We used the following formula to calculate the value of SPW in [W /gram] :
   SLD = L / (Vhs + Vfan) (4)

   L – output light of the LED mounted on ACM,

   (Vhs + Vfan) – value is taken from (2).

5. The Specific Price Power (SPP) which refer to the price of manufacturing of ACM (accordingly to bill of materials) for effective dissipating of input power of ACM. We used the following formula to calculate the value of SPP in [$ /Wt]

   SPP = S / Pin

   S - price of manufacturing of ACM (in $),
   Pin - value is taken from (1)

Reliability of ACM could be expressed on the development stage by means of amount of electrical components (like items in the BOM) and mechanical details which should be soldered / assembled in the process of ACM manufacturing.
These criterions have been used in our prototyping and analyzing of ACM which allows comparing various configurations and modifications for the getting of optimal version of design.
The block diagram which describes the operation and main functions of ACM (together with LED source of light) and power supply is represented on FIG. 1

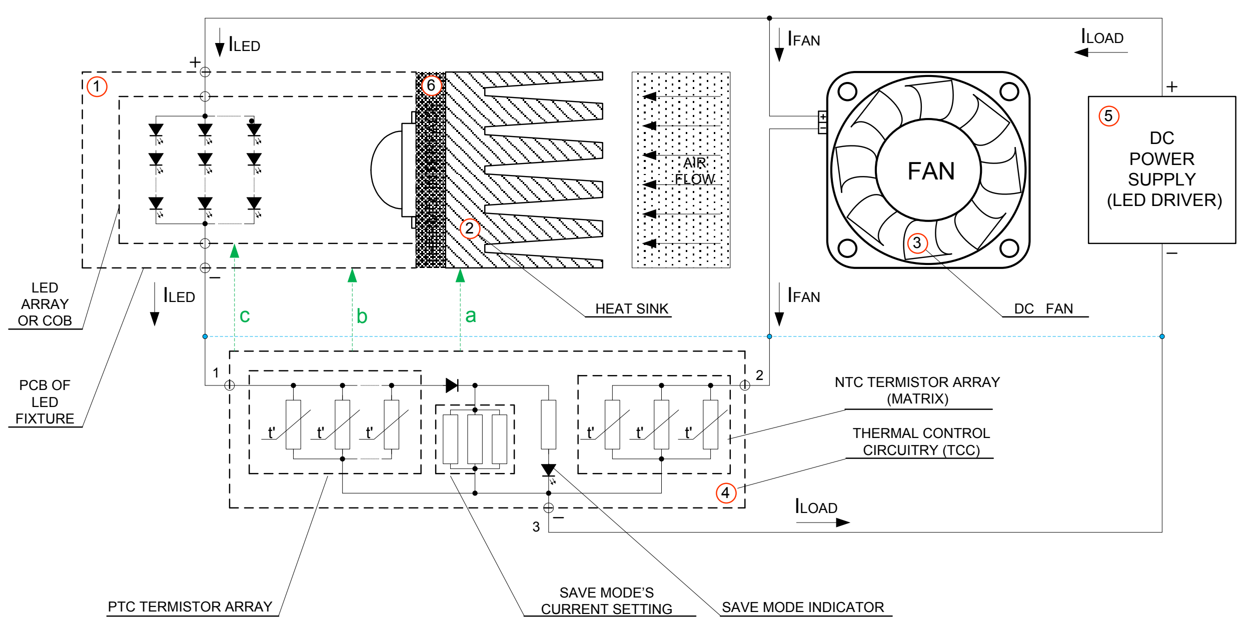

FIG. 1

ACM itself consist of three main parts: heat sink **2**, fan **3**, thermal control circuitry (TCC) **4**. The LED source of light could be performed as LED array soldered on PCB **1**, or COB mechanically fitted to PCB **1**. In the terms of thermal management PCB **1** represents the thermal load for ACM because of significant part of input electrical power for LED powering is being converted in heat which should be transferred by ACM away from LED to avoid its overheating. That's why PCB **1** should be thermally coupled (mostly by means of thermal interface **6**) with heat sink **2**. The main function of the heat sink **2** is to transfer heat (by means of thermal conductivity process in metal as aluminum for example) from thermal load (PCB**1**) to the peripheral area of heat sink **2** (like pins or fins) and to dissipate heat into ambient air by means of thermal convection process. It's important to emphasise that some part of heat energy will be accumulated in the heat sink **2** indeed because of effect of thermal capacitance of metal which keeps average temperature T*av of ACM between T*s and T*a (see formula 1). In our methodology of design and prototyping of heat sink itself this ratio between accumulated and dissipated thermal energy is used for rating the efficiency of ACM during the design stage and making right choose of ACM construction. The main function of fan **3** is intensifying of convection heat transfer by forced air through heat sink **2** structure. In this way the coefficient convectional heat transfer **h** could be increased in (3 – 5) times more than in calm air case. Because of coefficient **h** depends significantly on various combination of constructive elements (such as pins, fins, openings) of heat sink **2** the additional positive effect could be performed by means of creating "vortex generators" which caused turbulence into heat sink **2** area and increase the heat dissipation from surface of heat sink **2**. This is attractive alternative against increasing mass and size of the heat sink **2** in traditional applications. That's why the successful integration heat sink **2** and fan **3** is becoming the main factor in the ACM design. The main function of the thermal control circuitry (TCC) **4** is sensing and regulating operation in the control loop between heat sink **2** and fan **3** which means technically speed control of the fan **3** rotation depending on changes of temperature of heat sink **2**. TCC operation is based on principle patented by MP Lighting (US patent 8070324) and implemented in new design our LED fixtures. The main innovation idea is using NTC thermistors not just for sensing of temperature of heat sink **2** (like in traditional circuitry for fan's speed control) but also for direct current control of the fan **3** by means of connecting NTC thermistor array (matrix) directly in the power line between fan **3** and power supply **5** (instead of processing signal from NTC temperature sensor, amplifying it, etc like in traditional circuitry). This technical solution simplifies extremely the control loop (actually BOM consist of just one item – NTC thermistor !), reduces size and weight of circuitry and increase the reliability of ACM in whole. The matrix configuration of NTC thermistor array protects this circuitry from self-overheating by fan's current which running through it in this case. However the size of NTC thermistor array is small enough (because of SMD type of NTC thermistor could be applied) which allows to place this array close to LED light source on the same PCB. The goal is that we can provide also good thermal coupling (by means of soldering SMD thermistors) for the sensing of LED's temperature (T*s) and dynamic response for control loop. TCC has additional circuitry for protection LED light source from overheating and over current mode from the side of power supply (LED driver) or ambient temperature T*a and also additional circuitry for indication these abnormal modes in the operating of LED fixture in terms of thermal management. Thermal protection of LED is based on PTC thermistors (posistors) which connected electrically in series directly in power line between (-) terminal of LED light source and (-) power bus of power supply **5** and are placed on PCB close to LED. If the temperature of PCB will be increased for some reason (could be caused by LED driver or ambient temperature T*a) up to specified value (trip point of posistor) the internal resistance of PTC will increase sharply in many times (~ 100 and more) and current through LED load will be reduced significantly which will protect LED from overheating and damage consequently. In that abnormal mode the voltage drop on posistor will be sharply increased also and this effect is used for indication of failure of thermal management of LED

fixture. That indication performed by simple electronic circuitry and miniature LED indicator which could be placed easy even on PCB of LED fixture.
In the practical realization of concept of ACM which is described above the key point is the performance of TCC **4** ant its placement in the construction of LED fixture. We can consider at least four versions of this realizations and each of them has own advantages and disadvantages in the terms of manufacturing, repairing and maintenance of the LED fixtures.

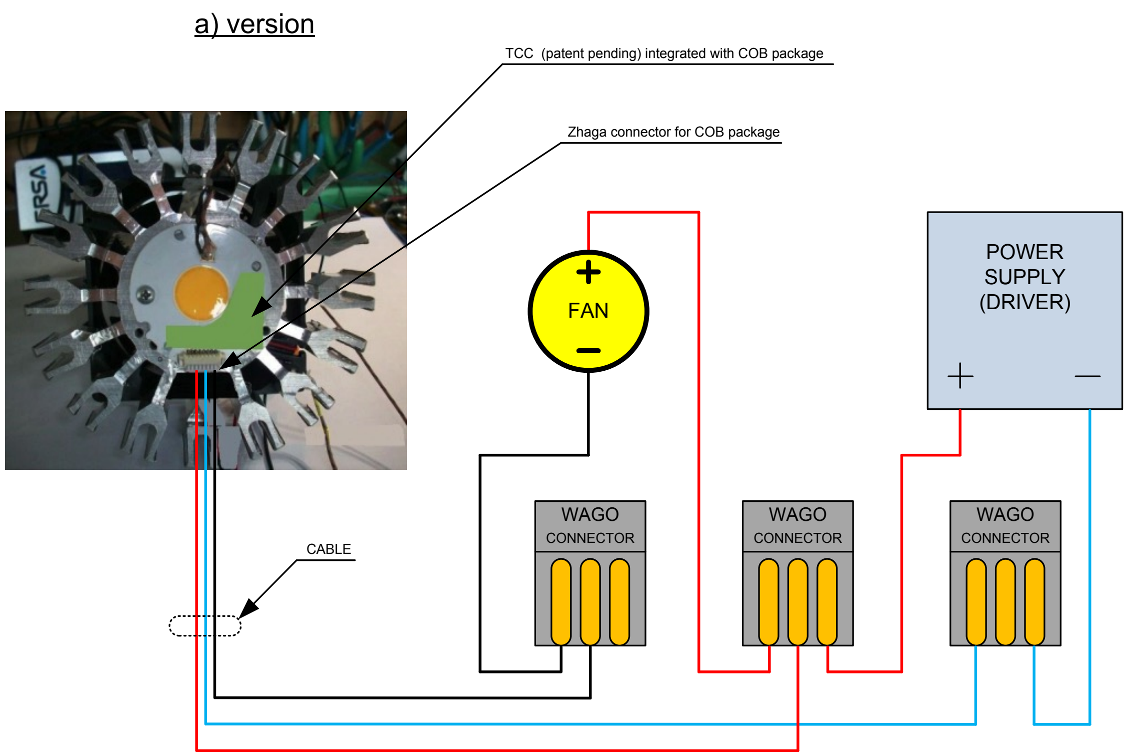

Fig.2

Version a)

In this configuration (Fig. 2) the electronic components of the thermo control circuitry (TCC) is integrated with LED COB package by soldering them on common PCB close to LED array of COB and external output of TCC is provided by Zhaga connector for LED COB. The external connections between LED light sources (LED COB), fan and power supply can be performed by means of WAGA connectors for Active Cooling System (ACS) completing.

As advantages of this configuration we can consider the follow features:

- the best of possible thermal coupling between source of heat – LED COB itself and TCC,
- high flexibility in the changing of ACS for various LED fixture: the same COB package can be used with different types fans and heat sinks just by means of external electrical connection (without de soldering/soldering) and mechanical fitting of COB package to new type of heat sink;

- relatively low volume of assembling work;

As disadvantage we can consider:

- the necessity 3 WAGO connector's usage.
- TCC belongs to LED COB and can not to be used separately as part of ACS
- relatively long time and organization efforts for integrating TCC in package with LED COB manufacturers on the cooperation base.
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This configuration could be recommended for well-established LED COB manufacturers.

b) version

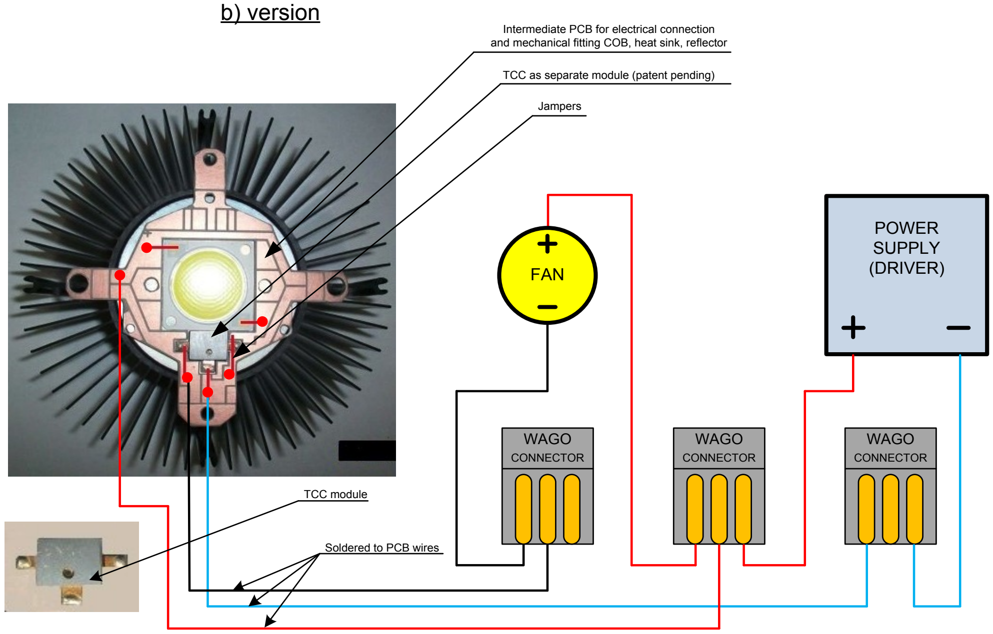


Fig.3

Version b)

TCC could be performed also as small (20 x 14 mm, for example) separate PCB in individual housing (as module or IC even in the future) and then could be placed on some intermediate PCB (Fig.3) together with LED COB package in the special nests which should be cut in accordance to their size and shape. Electrically T-shape TCC module has three terminals: left – "minus Fan", center – "common minus", right – "minus LED/COB/LED array". To realise the electrical connections for this configuration of ACS we need to set at least 5 soldered jumpers (in the simplest way) on the pads of intermediate PCB: two between "+" and "-" terminals of LED COB, and three between the terminals of TCC accordingly. Three wires should be soldered to intermediate PCB for external electrical connections (by WAGA connectors) to complete electrical diagram of ACS. In some modifications three different connectors could be set on intermediate PCB for external connections of ACS: two pins for the FAN, two pins for the POWER SUPPLY and three pins for TCC module. In another modification the electronic component of TCC could be soldered on intermediate PCB directly which reduces internal and external electrical connections (as jumpers, connectors). Mechanically, LED COB and TCC module could be fitted to the surface of the heat sink directly through the nests in the intermediate PCB accordingly.

As advantages of this configuration we can consider the follow features:
- the highest degree of functional flexibility for variations with different types if LED COB packages, heat sinks and FANs in the ACS structure;
- easy maintenance if we need to replace some main parts of ACS for LED fixture.

As disadvantage we can consider:
- relatively complicate structure (as intermediate PCB, electrical jumpers, connectors, wires, assembling works);
- the necessity to design and manufacturing individual TCC module (as T-shape, for example)

This configuration could be recommended for prototyping, manufacturing some engineering samples and early stages of volume manufacturing LED fixtures.

c) version

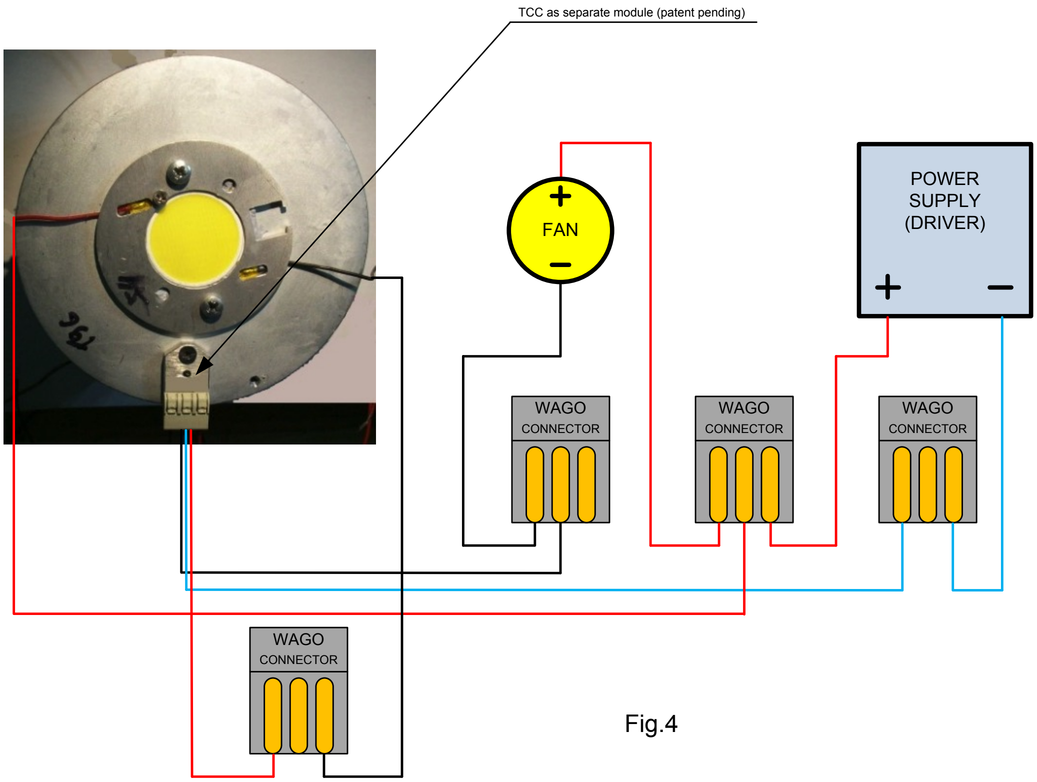


Fig.4

Version c)

In this configuration (Fig. 4) the electronic components of the thermo control circuitry (TCC) are soldered on small separate PCB (MCOB) together with 3-pin connector (TE connector, for example) and metal cover with small window for LED “ALARM” indicator. TCC module can be fitted mechanically by screw to heat sink or some another critical thermally metal element of the LED fixture.

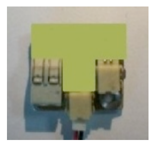
As advantages of this configuration we can consider the follow features:

- the flexibility for choosing of placement of TCC on the heat sink and construction of LED fixture in general;
- solder less electrical connections between main parts of ACS for LED fixture which makes easy assembling work ;
- needless intermediate PCB (as version b) in the LED fixture assembly;

As disadvantage we can consider:

- relatively low grade of thermal coupling between TCC and source of heat (LED COB, for example);
- the necessity to increase amount of connectors in BOM of LED fixture
- the necessity to design and manufacturing individual TCC module with additional connector.

Another modification this version can be done to combine TCC PCB with all external 2-pins connectors of LED fixture: for COB, for FAN, for POWER SUBBLY; but it increases TCC dimensions.



d) version

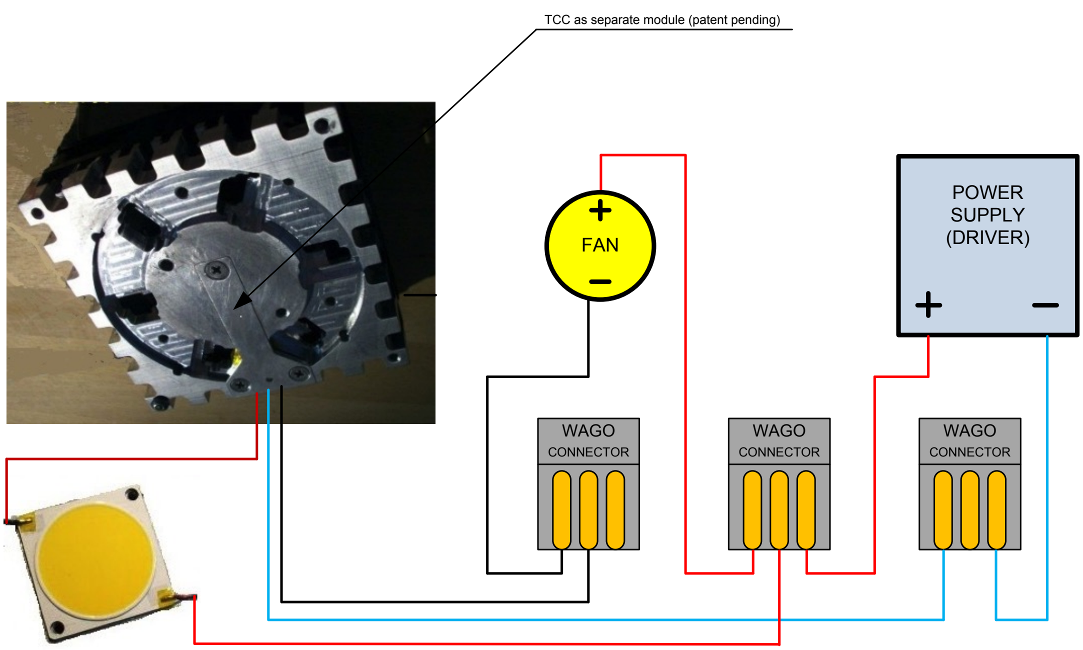


Fig.5

Version d)

TCC can be thermally coupled properly with heat source (as COB, for example) by placing into body of heat sink directly underneath LED COB package (Fig. 5). This version is presented cooling device with completed control loop (because TCC is becoming the integral part of heat sink and provides physical feedback by temperature for ACS) which can be named as Active Cooling Module (ACM). ACM can operate with various types of heat loads in the frame of specified cooling capability (power). In such a way not only LEDs but other electronic devices those heat emit, could be cooled just by fitting it's mechanically on the surface of heat sink of ACM.

As advantages of this configuration we can consider the follow features:

- the flexibility for application of ACM to different types of LED COB packages, PCB with LED array and another types electronics as thermal load;
- proper thermal contact between thermal load, TCC and heat sink ;
- needless to change configuration or electrical connection of ACM with different heat loads ;

As disadvantage we can consider:

- relatively complicated construction of heat sink;
- the necessity of additional machining of heat sink (nest for TCC PCB inside body);
- the necessity to design and manufacturing individual TCC PCB with special shape.

This configuration could be recommended for implementing as advanced product in manufacturing of cooling devices which based on combination of FAN and heat sink (FANSINK).

We can see here some pictures which are presented as illustration of operating TCC (performed in different versions) in “ALARM” mode with indicating of the overheating of LED fixtures.

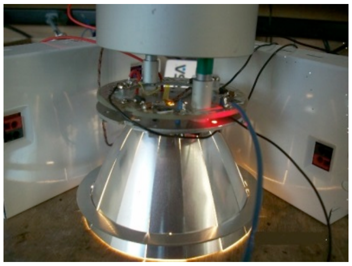


Fig.6

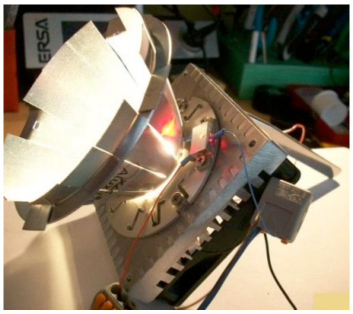


Fig.7

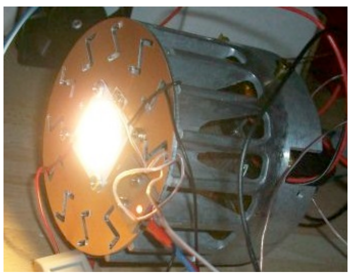


Fig.8

Fig.9

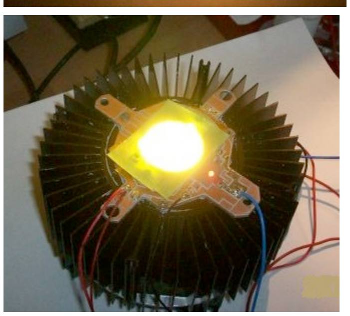


Fig.10