بسم الله الرحمن الرحيم

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Graduation Project

Design of power cycling test set-up for Power devices

Project Team

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Hebron – Palestine
summer, 2008

Abstract

In this project, a power cycling test set-up has been designed. The power cycling test is used for life time prediction of power devices.

Main parts of the set-up are heating and cooling systems; heating operation is done by means of a current source to give a forward current to a power diode .This current raises the junction temperature to maximum, then heating is switched off and the cooling operation starts using an electrical fan to decrease junction temperature to minimum, in this way the power cycling test continues.

The junction temperature of devices under test is cycled between two extremes ($T_{j,max}$ and $T_{j,min}$), so the devices are heated by stressing them through a forward current until $T_{j,max}$ is reached, then cooling system is activated to cool the devices until $T_{j,min}$ is reached again, and so on.

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1.1 Overview

This chapter shows a general overview about the project and heat effect on power devices especially diodes. This overview describes problem definition, objectives, methodology, previous study, budget and contents of the project

When designing a system, many factors affect which parts to choose. The goal is to select the parts that offer the highest reliability under the set of conditions in which they will operate. The conditions to be considered include stress, environmental effects, load factors as well as the temperatures under which the system and its components operate and prediction life time of component.

Knowing the junction temperature T_j for different operating conditions and packages enables us to calculate thermal parameters such as thermal resistance for different package types and designs. And knowing the change in temperature Δt enables us to determine and prediction the maximum lifetime of the device, because thermal effects are major contributors to early device failure.

With the increase in power density resulting from advancements in semiconductor packaging technologies comes the issue of heat dissipation. Heat is generated as a result of electrical energy being converted to thermal energy during circuit activities. The junction temperature and change in junction temperature of a chip directly affects the performance of the circuits and the reliability of packages. It is very important therefore that the prediction the maximum lifetime of the device of each package be known as accurate as possible to responsibility of this device from the manufacturing companies.

Recently, it is important that the technique of tests to be universally applied to the industry in order to achieve meaningful and unbiased comparison of similar packages.

We can reliability prediction in power electronics especially life time prediction using accelerated aging tests that contains temperature cycling tests and power cycling tests. the power cycling tests is more accurately because in this way we increase the temperature by power stress (current stress) that is natural way to increasing the temperature, otherwise by using the temperature cycling test increasing the temperature using fan or something like this, here in our project we will building of power cycling test set-up.

1.1 Problem Definition and Methodology

Knowing reliability of power devices (life time) is very important to know when the device is failure. That affects directly in all technology applications such as elevator, machines and so on. So when the virtual life time is long (device stand high numbers of power cycling) this means high efficiency and less price (maintenance) for customers.

There for every company manufacture power devices effort to increase life time of devices throw research to get the optimal way of packaging.

When power diode operates, this result self heating due to the load current and switching losses, so if the diode operates under constant temperature, it will not be damaged. That means; the change in the temperature is the main reason of the damaging of the power electronics. So that the temperature of the power devices must be monitored to ensure that it is within normal limits.

Power device chip specially consist of more than one layer, each layer contains different material, each material has different physical characteristic from other like extended (expanded) coefficient.

The power devices chip (for example silicon type) contains silicon material (junction) and copper material (connecter) each material expanded and shrink with different coefficient, this cases split between the layers.

As the same way the welding material (used to twins between silicon and conductor) has own temperature coefficient different than silicon and copper that means the difference in temperature device is the major problem.

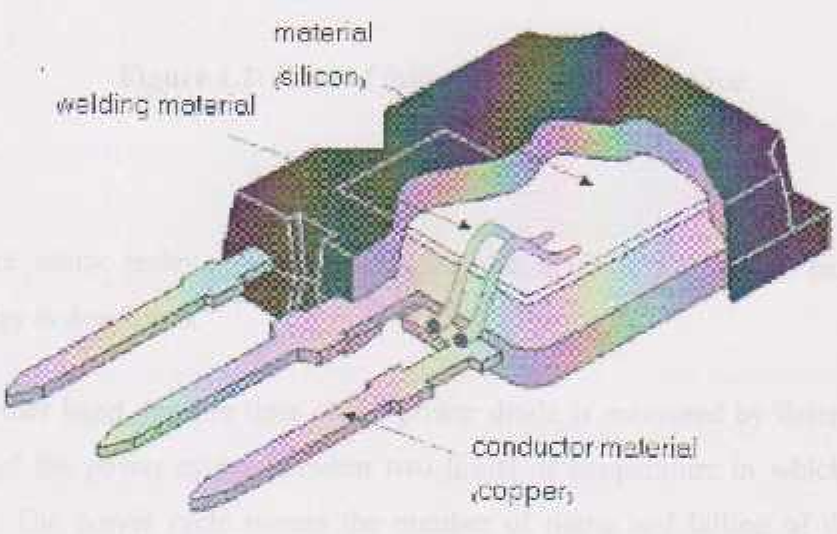


Figure 1.1: Structure of kind of power diode.

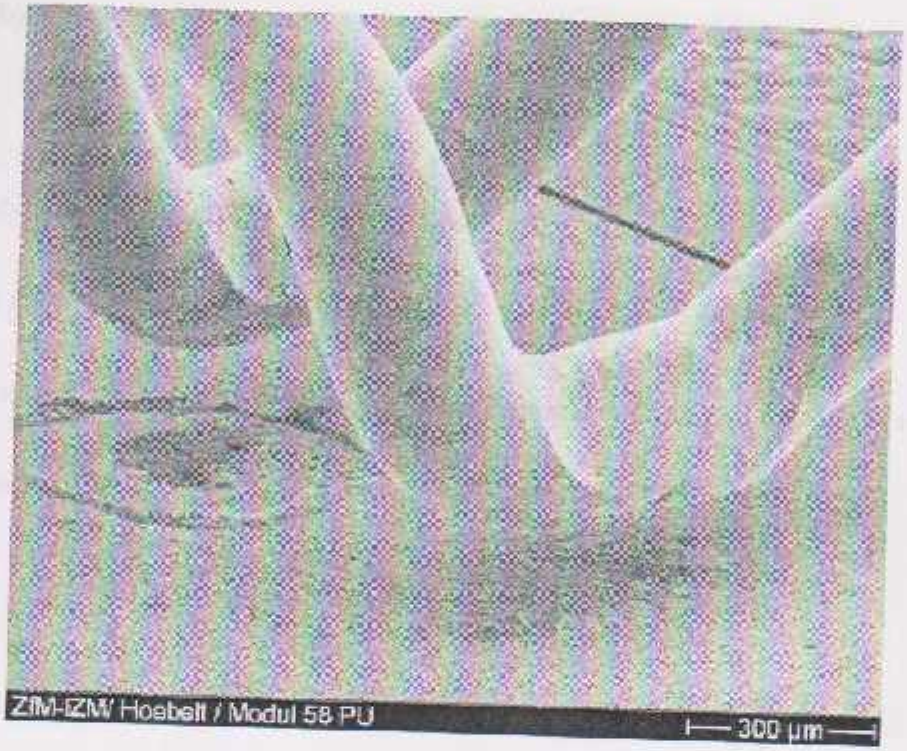


Figure 1.2: Kind of failure mechanism of device.

There are many techniques for packaging the devices, it will be better as the technology is developed.

On the other hand, the life time of the power diode is measured by determining the number of the power cycles between two limits of temperature in which the diode operates. The power cycle means the number of rising and falling of the junction temperature between two specific limited temperatures in power cycling test. The diode stressed with load current and the cooled to the ambient temperature thousands time to ensure the life time of the diode.

1.3 Objectives

1. Study temperature effects on power diodes.

2. Life time prediction for power devices.

3. To study power cycling importance in packaging technology of power electronic.

4. To design power cycling test set-up.

1.4 Previous studies

1.4.1 Power cycling capability of advanced packaging and interconnection technologies at high temperature swings, Dr. Raed Amro, 2006

This study uses of the measuring temperature of the junction as a part of determining the thermal measurements and analysis of the power electronics, the failure mechanism of power electronics, reliability prediction in power electronics (Lifetime prediction using accelerated aging tests) and the methods of measuring the junction temperature, temperature sensitive electrical parameter (TSEP) test for measuring T_j.

1.4.2 New Approach for Measuring the Temperature of P-N Junction, Ali Melhem and Husam Tamimi, 2007

According to the study there is a PN-junction (i.e. a diode) that can be used as a simple and easy used temperature sensor.

According to the diode equation:

$$I_D = I_S \left(e^{(qV/NKT)} - 1\right) \qquad (1.1)$$

Where,

I_D:diodecurrent.
I_s:saturationcurrent.
e:Euler'sconstant(2.71828).
q:Chargeofelectron($1.6 \cdot 10^{-19}$As).
V:Voltageacrossthediode.
N:"Non-ideality"coefficient(typicallybetween1and2).
k:Boltzmann'sconstant($1.38 \cdot 10^{-23}$).
T: Junction temperature in Kelvin.

The current through the diode depends on the Voltage V_D applied to the diode and its temperature. If you keep the current through the diode constant, the voltage decreases with increasing temperature. Assuming a current of 10 mA through the diode we can insert all known values into the diode equation and calculate the change of the voltage if the temperature changes by 1 Kelvin.

1.5 Budget

Table 1.1: Budget.

Task	Cost (NIS)
Internet	300
Printing	300
Transportation	200
Electronic devices	535
Diodes	60
Step down transformer	400
Variac	500
Fan (2)	75
Temperature controller (2).sensor and contactors	1050
relays	130
Counter	200
Switches and wires	230
Multimeters	200
Mechanical structure	960
Total	**5140**

1.6 Project contents

Our project composes six chapters and here is a general description of the contents of each chapter.

Chapter one: Introduction to the project, including a general description of the problem, methodology, main objectives of project, budget and previous studies.

Chapter two: Theoretical background, includes importance of knowing reliability (life time) of power device, structure of power devices and failure mechanism in the power devices.

Chapter three: Reliability prediction in power electronics that include temperature cycling test and focus in power cycling test.

Chapter four: Required Hardware Design for power cycling test set-up.

Chapter five: Results and conclusions.

Chapter six: Recommends and future work.

2.1 Structure of power devices

Electronic packaging is the combination of technologies required to convert an electronic circuit into manufactured assembly, with additional consideration that a power semiconductor chip can be much larger and dissipates much higher power level than a chip of a signal IC.

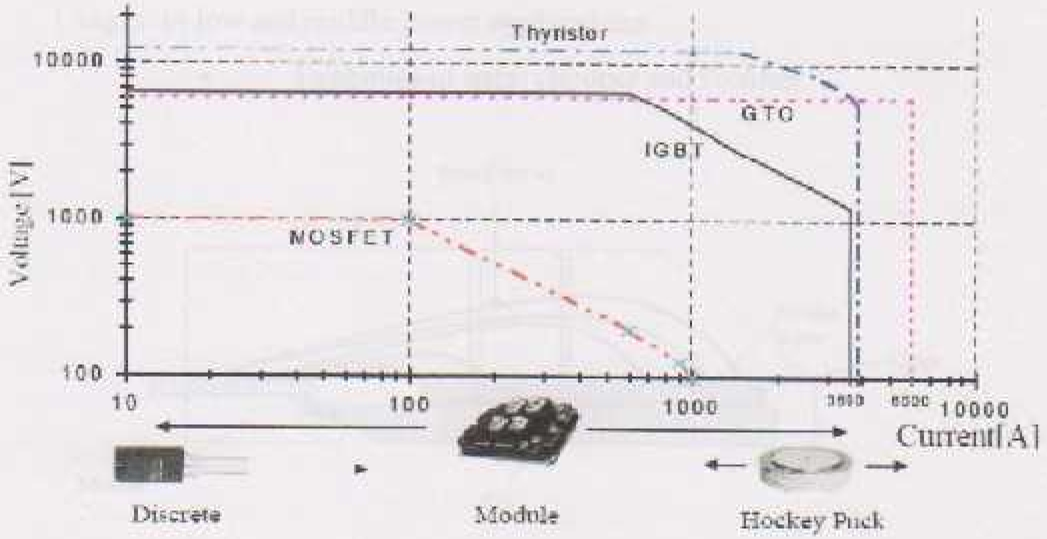


Fig. 2.1: Voltage and current levels for packaging concepts.

A package of power electronic must be achieving specific functions such as removal the heat dissipated within the chip and protection of the assembly against the environment. The packaging concepts in the power electronic applications are divided into two major type discrete devices and power modules. When selection of convenient packaging architecture must take considerations the voltage and current levels and mainly the thermal stress generated. Figure 2.1 shows packaging concepts and applications in power devices.

2.1.1 Discrete devices

Discrete devices are the primary packaging form in power electronics .The most important packaging forms of discrete devices are TO-family and DCB based. Hockey puck.

2.1.1.1 TO-family

- Usages: in low and middle power applications.
    - Examples of uses: chopper and rectifier.

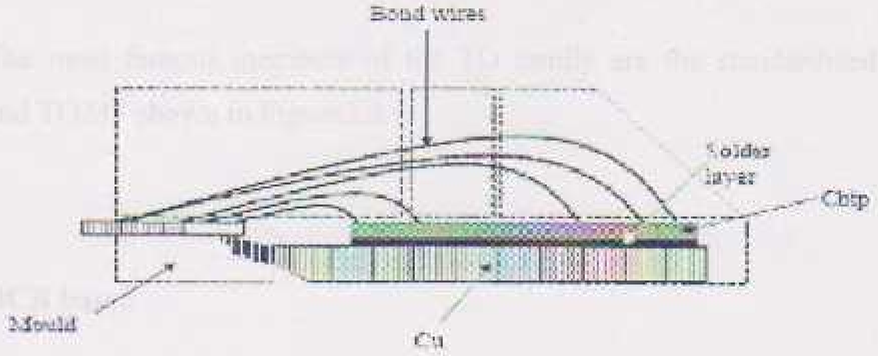


Figure 2.2: Internal structure of TO cases.

- Internal structure: Chip is mounted on a metal lead frame (mostly made of copper alloy) which presents the electrical contact of the bottom side of the chip; Top side connection is established by aluminum bond wires. For mechanical and electrical protection, subassembly, excepting the lead frame, is transfer molded by a plastic molding compound. Figure2.2 shows the internal structure of TO cases.

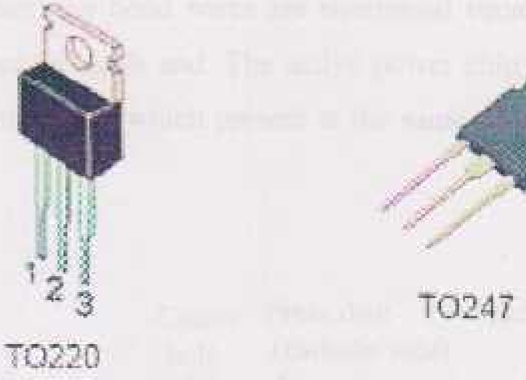


Figure 2.3: Forms of TO family.

- The most famous members of the TO family are the standardized TO220 and TO247 shown in Figure2.3.

2.1.1.2 DCB based

In this technology, the bottom side of the power chip is not soldered onto copper lead-frame, but on the upper copper layer of DCB (**D**irect **C**opper **B**onded) substrate. Its topside is wire bonded towards DCB patterns and pins. The package can be attached to heat sink via spring clips directly without external isolator.

2.1.1.3 Hockey puck packages

- Hockey puck or disc cells are the member of the discrete devices.
- Uses: in the high power application.

- Internal structure: the bond wires are eliminated because it is based on the pressure contact principle and. The active power chip is embedded between two molybdenum disks which present at the same time the contacts for load current.

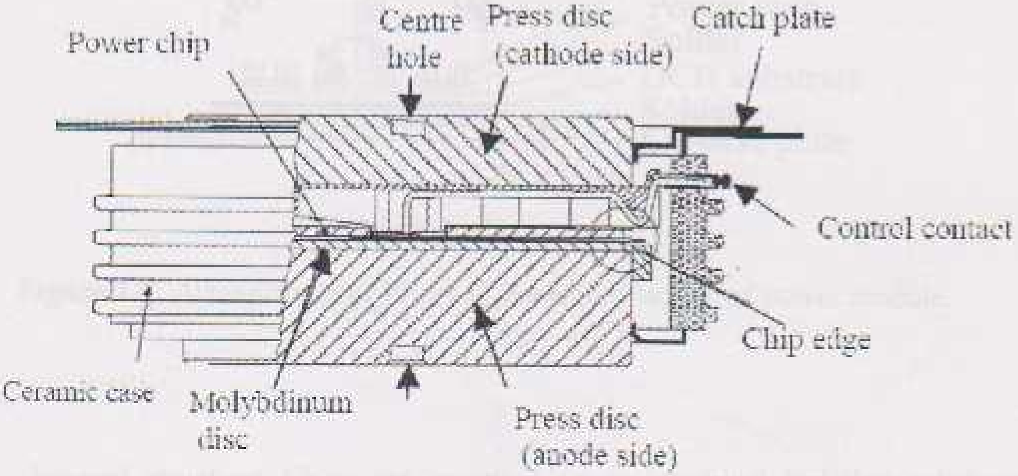


Figure 2.4: Internal structure of Hockey puck or disc cell.

The internal structure of Hockey puck or disc cell is shown in Figure 2.4. Due to the large area of current contacts and the ability of double-sided cooling, disk cells allow the integration of power devices which can handle currents up to 6000 A and reverse voltages up to 12 kV.

2.1.2 Power modules

- Power modules are used for power electronics applications above 1kW.

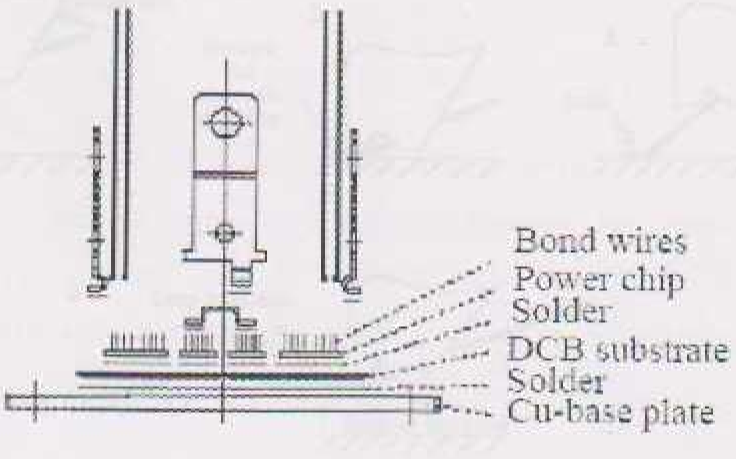


Figure 2.5: Arrangement of layers in internal structure of power module.

- Internal structure: Chips are mounted on an electrical isolating substrate, mostly DCB, which allows the integration of several chips to build a defined function block. Top side connections of chips are established by aluminum bond wires. For mechanical protection a silicon gel over lay is obtained and a plastic case is adhered to the base plate, Figure 2.5 shown the arrangement of layers in internal structure of power module.

2.1.3 Bond wires

Bond wires connection power silicon chip to the substrate, pins or other chips. The thickness of bond wires up to 750 µm and made of pure aluminum hardened by adding of alloying elements like silicon and nickel for corrosion control

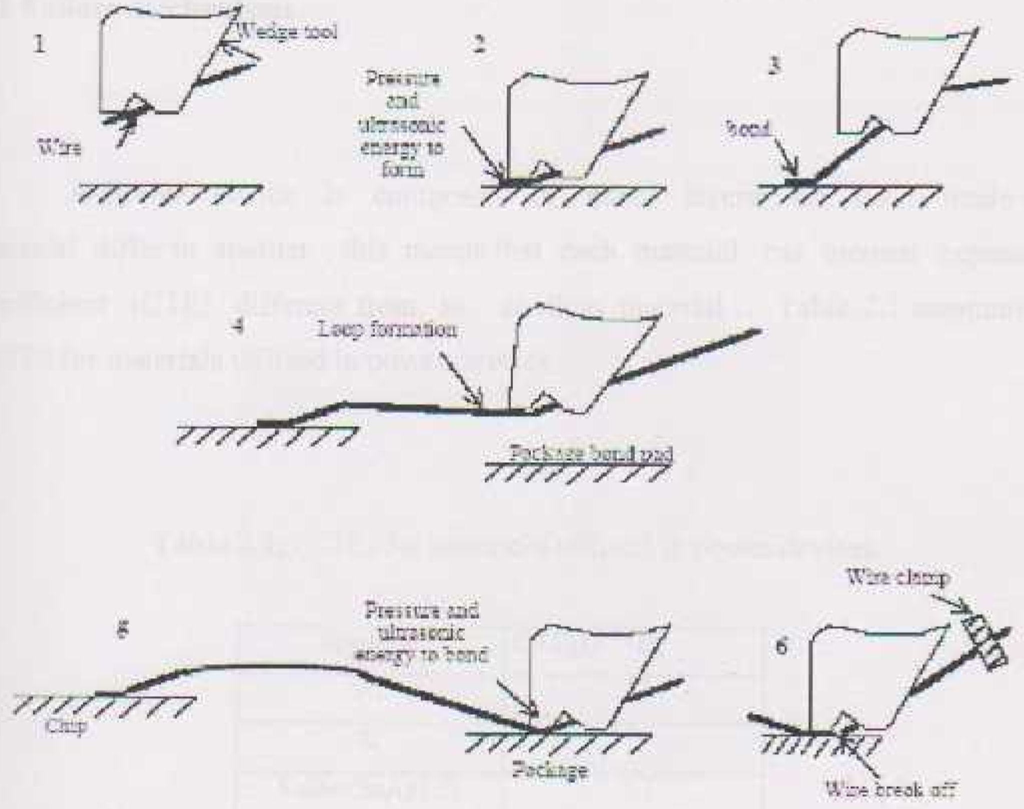


Figure 2.6: Steps for making ultrasonic wire bond between chip-bond pad and package.

The wires are adhered to the bond pad on the metallization of the chip or the substrate by an ultrasonic bonding process, where the metal is softened by ultrasonic energy, and subsequently a clamping force deforms the softened wire against equivalently softened bond pad. Steps of this process are shown in Figure 2.6.

The most important bond process parameters :

- Clamping force.
- Ultrasonic energy.
- Frequency and duration of weld time.

2.2 Failure mechanisms

A power device is composed of many layers , all layer made of material differ to another , this means that each material has thermal expansion coefficient (CTE) different from to another material . Table 2.1 summarizes (CTE) for materials utilized in power devices.

Table 2.1: (CTE) for materials utilized in power devices.

Material	CTE[10^{-6}/K]
Al	22
Si	3
Solder(SnAg3,5)	5,7
Al_2O_3-Substrate	8,3
AlN- Substrate	5,7
Cu	17,6

In the following, forms of failure mechanisms:

- Failure mechanisms of bond wires.
- Solder-joints degradation.
- Electromigration.
- Reconstruction of the Al metallization.
- Electrical and mechanical aging of DCB.
- Die fracture.

2.2.1 Failure mechanisms of bond wires

The effect of power cycling tests on bond wire wear-out mechanisms mostly are Bond wire lift-off and Bond wire heel crack.

Figure 2.7: Lift-off pattern as result of power cycling of the device

Figure 2.7 Shown the lift-off Pattern of power cycling of the devices.

2.2.1.1 Bond wire lift-off

We notice in Table 6.1that the thermal expansion coefficient of alumiInium the very largest in comparison with thermal expansion coefficient of silicon .This causes the greatest thermo mechanical stress during power cycling where the device is usually heated up and cooled down, is observed at the connection zone between bond wire and the upper side of the silicon chip.

There are two aspects associated with bond wire lift-off:

1. Leaves large sized aluminum grains at the outer bond region and small sized ones in the center and this is related to the bond process itself.
2. The wire terminations where the wire is unable to flex and this is related to the region of the maximal thermo mechanical stress namely.

When wire lift-off occurs, the current density in the surviving wires increased significantly leading finally to their melting. Figure1.2 shows a lifted-off bond wire as result of power cycling of the devices.

2.2.1.2 Bond wire heel crack

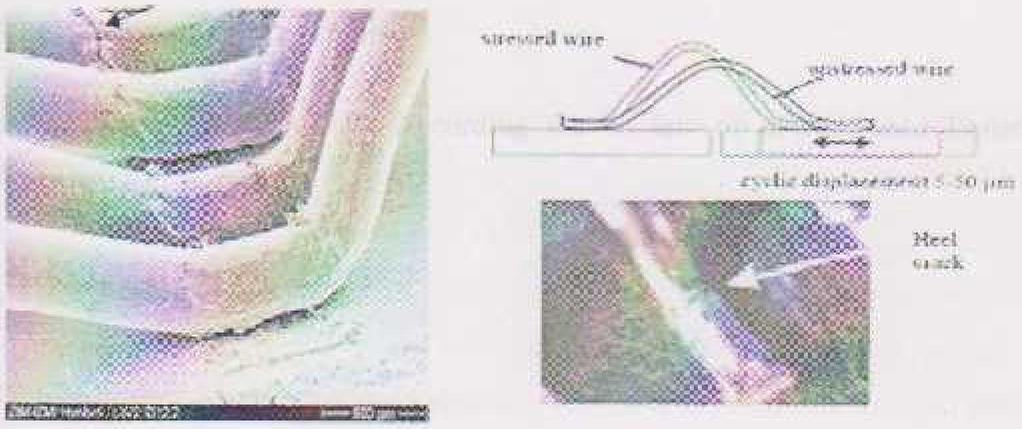


Figure 2.8: The bond wire heel crack as a result of power cycling.

- Heel crack is initiation slay often in the bonding process and infrequent observed bond wire weak out, Figure 2.8.shown the bond wire heel crack as result of power cycling.
- Bonding machine vibration during or after the bonding tool lifts-up from the first bond; or the rapid tool movement after making the first bond can open up a crack.
- The amplitude of the wire strain $\Delta\varepsilon_f^n$ can be calculated according to the following equation:

$$\Delta\varepsilon_f^n = \frac{r}{\rho_0}\left(\frac{\arccos((\cos\psi_0)(1-\Delta\alpha\Delta T))}{\psi_0}-1\right) \qquad (2.1)$$

$\Delta\alpha$: difference in the CTE of chip and wire.

r: wire radius.

$\rho 0$: initial curvature of the wire.

$\psi 0$: angle between wire and chip.

Heel crack can be calculated, According the on law of power based Equation following:

$$N_f = A\Delta\varepsilon_f^n \qquad (2.2)$$

Where,

Nf: Number of cycles till heel crack occur due to bending stress.

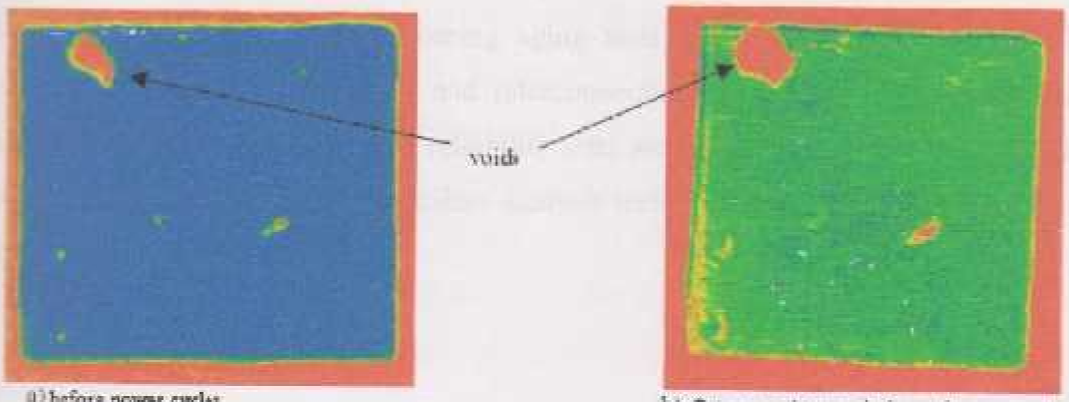
A: Material dependent constant.

n: Material dependent constant.

2.2.2 Solder-joints degradation

Solder layers represent a critical interface in power assemblies especially in the packaging type of power modules with copper base plate.

Degradation of solder joints can be divided into:



a) before power cycles

b)after many thousands times of power cycles

Figure 2.9: Shown the solder joints degradation as resulted to voids formation.

- Voids formation: A void is an empty volume in the solder layer and can be formed already during the joining process .Figure 2.9 shown the solder joints degradation as resulted to void formation.
- Solder fatigue: The solder alloys contain usually a combination of several materials like silver, tin or lead which enhance the electrical, thermal and flow characteristic of the final alloy. The bond between the soldered partners is mainly provided by the formation of one or more inter-metallic phase.

3.1 Introduction

Power devices have to exhibit the ability to perform the required electrical function under very harsh conditions over the whole lifetime which can reach up to 30 years. Hence the developing time of power devices is wide shorter than their lifetimes, standardized time-honouring aging tests are performed to evaluate the reliability of a given packaging and interconnection concept. In this chapter the principles of the most performed reliability tests are presented with focusing on the power cycling tests. Finally the failure analysis techniques which also were used in this work are presented.

The mostly applied methods are tests based on thermal stressing of the devices where the thermal aging is accelerated by cycling of the devices back and forth between two temperature extremes.

Tests are usually stopped either after standardized failure criteria are reached or a required number of cycles are fulfilled. The main approaches of thermal aging tests are temperature and power cycling.

3.2 Temperature cycling tests

In temperature cycling tests the temperature of the devices under test (DUT) is changed by variation of the ambient temperature and without electrical stressing where the temperature extremes are defined by the maximal and minimal allowed storage temperature. Temperature cycling tests are usually slow because of firstly the required dwelling time at each temperature extreme to ensure the thermal equilibration and secondly to allow solder joints to creep to the fullest possible extent. The automotive electronic council (AEC) stipulates minimal 1000 temperature cycles between -55 °C and 150°C for discrete devices where power modules have to withstand at least 100 cycles between -40°C and 125 °C. A typical course of the junction temperature during temperature cycling test is depicted in Figure 3.1.

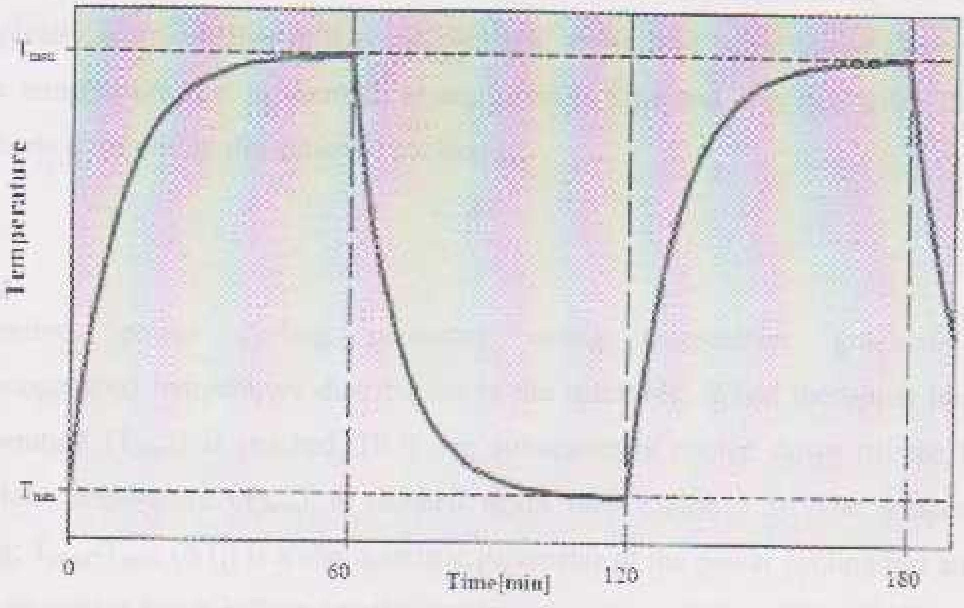


Figure 3.1: Typical behavior of the temperature of DUT during temperature cycling.

3.3 Power cycling tests

The principle difference between temperature cycling and power cycling tests is that in the latter devices are heated by the power dissipated as result of electrical stressing of the chip.

Users of semiconductor packages are not only interested in the component-level reliability, but also the board-level (or solder joint) reliability of the packages designed into their systems. Thermal cycling (TC) in air is the industry standard for assessing the solder joint reliability.

When compared to thermal distributions in an actual application, TC is not completely representative in that the package, joints, and board are at close to the same temperature (i.e. isothermal) at any point in time and only negligible thermal gradients exist within the mounted package

Therefore, power cycling generates strong temperature gradients and inhomogeneous temperature distribution in the assembly. When the upper junction temperature (T_{jmax}) is reached, DUT are subsequently cooled down till the lower junction temperature (T_{jmin}) is reached again (see Figure 3.2). The temperature swing: T_{jmax}-T_{jmin} (ΔT_j) is a characteristic parameter of the power cycling test and the most important factor influencing the number of cycles to failure (N_f) of DUT.

The load current should be adjusted in the range of the rated current. After the maximum junction temperature is reached, the load current is turned off and the chip

[illegible]

In the last decade, power cycling tests were performed mainly to evaluate the first level connections of power devices, meanly bond wires and metallization, and to understand the relating failure mechanisms. However, with increasing demand to [illegible] cools down fast due to its small thermal mass until it reaches the heat sink temperature and then continues to cool with a characteristic determined by the heat sink time constant. The duration of the cooling phase depends on the efficiency of the employed cooling system.

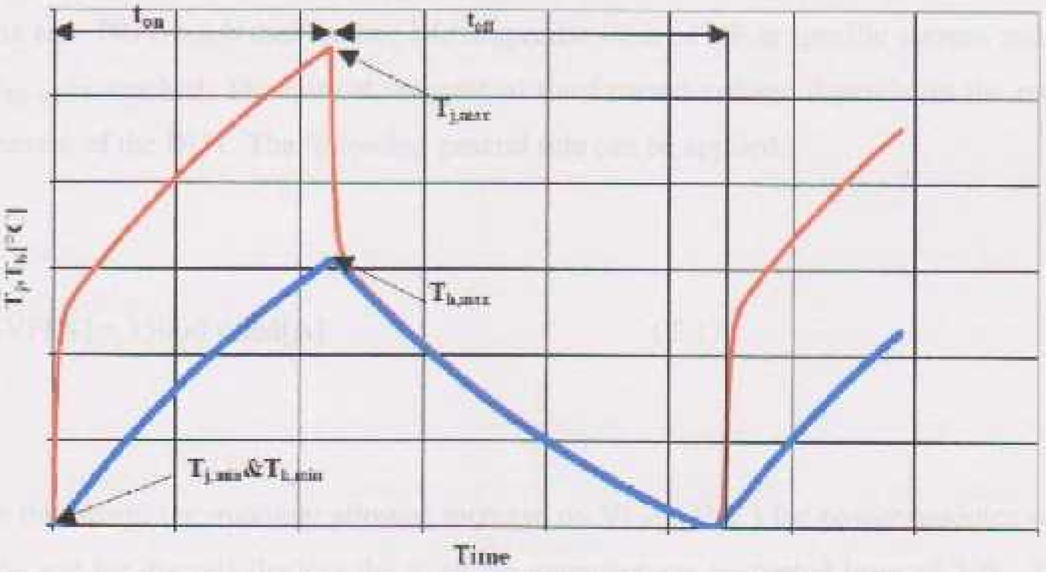


Figure 3.2: Typical behavior of temperature of DUT during power cycling.

In the last decade, power cycling tests were performed mainly to evaluate the first level connections of power devices, meanly bond wires and metallization, and to understand the relating failure mechanisms. However, with increasing demand to alternative reliable solders, power cycling tests with the scope of evaluation of whole critical components of the power assembly including solder layers are increasingly performed.

The most observed failures occurs as result of power cycling tests are: firstly the degradation of the bonding area between the aluminum bonding wires and secondly degradation affecting the solder layers between chip and substrate and in case of power modules with base plate, solder layer between substrate and the copper base plate. The forward voltage (V_F ; V_{CE}) and the thermal resistance between junction and a reference point ($R_{thj\text{-}ref}$) of the DUT are indicators for these failures respectively. Therefore these two parameters must be observed and registered during the test. DUT reach their end-of-life if specific limit of VF at specific current and of $R_{thj\text{-}ref}$ is reached. The critical increase of the forward voltage depends on the rated current of the DUT. The following general rule can be applied.

$$\Delta VF[\%] - 1500/I\ \mathrm{rated}[A] \qquad (3.1)$$

In this work, the maximal allowed increase on V_F (or V_{CE}) for power modules was 5% and for discrete devices the from the manufacturer suggested limit of 20%. The limit of the increase of $R_{thj\text{-}ref}$ amounted 20%.

4.1 Introduction

This chapter presents practical system of control and power circuits for designing power cycling test set-up. In this project there are two techniques for controlling the operations of heating and cooling, with two power circuits, one for the current source and the other is for the fan. Hence; each one of the previous techniques of control are capable of switching ON or OFF both circuit (current source & fan).

4.2 Block diagram

The general block diagram of the closed loop control system describes sequence of work of the cooling system (fan) and the heating system (current source) figure 4.1.

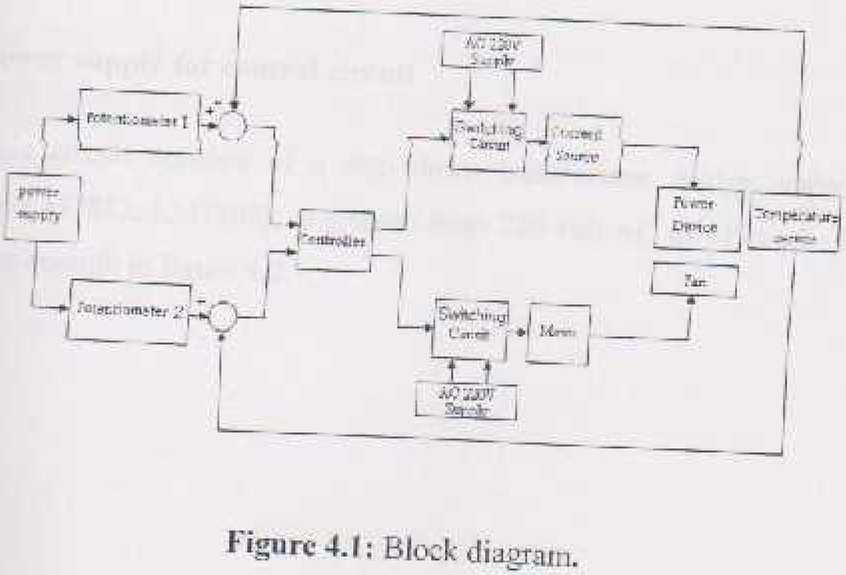


Figure 4.1: Block diagram.

4.3 Control system

There are two methods to control the operation of cooling and heating systems, the first one which is the main control circuit that is used in the natural condition.

But when any problem occurred, there should be another technique for swapping with another circuit which is called a Stand-By circuit. Converting process between the two circuits is done manually by means of a selector switch.

4.3.1 Main control circuit

The main control circuit is to organize the operation of heating and cooling using a temperature sensor (LM35), comparators, Schmitt triggers, logic gates and flip flops, also using potentiometers to adjust the range of temperature between two limits.

4.3.1.1 Power supply for control circuit

This circuit consists of a step down transformer, bridge, capacitors and regulators (LM7812, LM7805), to convert from 220 volt AC to +12 and +5 volt DC, this is clear enough in figure 4.2.

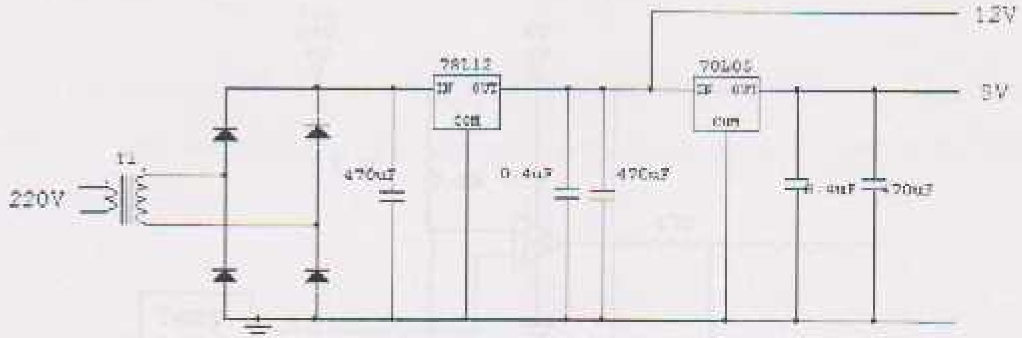


Figure 4.2: Power supply circuit.

The transformer is to give 12 volt AC is entered to bridge rectifier to convert from AC to DC then make filtration the waveform to get pure DC then entered this DC waveform to the positive voltage regulators (LM7812, LM7805) to get only 12 volt DC and make another filtration to get pure 12 volt and 5 volt DC.

4.3.1.2 Analog circuit

The following figure represents the analog circuit used for the comparison between two reference voltages, which are for T_{min} and T_{max}.

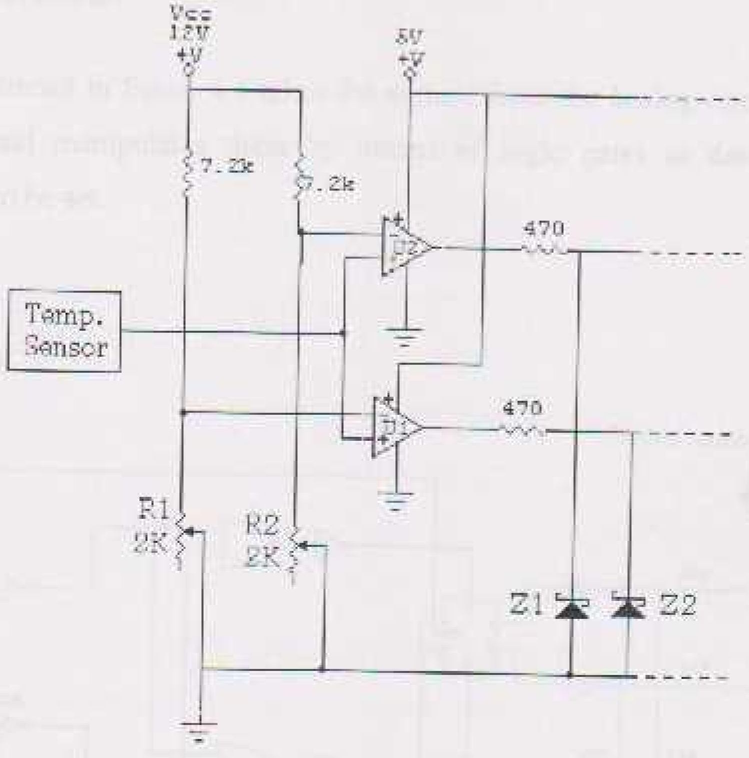


Figure 4.3: Analog circuit.

1. Temperature sensor: (LM35) is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature in siliceous degree, this sensor has a sensitivity of (10 mV /1 C°), used to provide the actual value of feedback signal from device to the input of the comparator it indicate the heat sink temperature that can be translating to junction temperature by make calibration using the (V.T) characteristic with low current.
2. Comparator (LM324): to compare the reference voltage which adjusted by potentiometer with the feedback signal from the temperature sensor.
3. Zener diode: to regulate the voltage and give 5 volt.

4.3.1.3 Digital circuit

The circuit in figure 4.4 takes the signals from the analog circuit previously mentioned and manipulates them by means of logic gates to determine which operation is to be set.

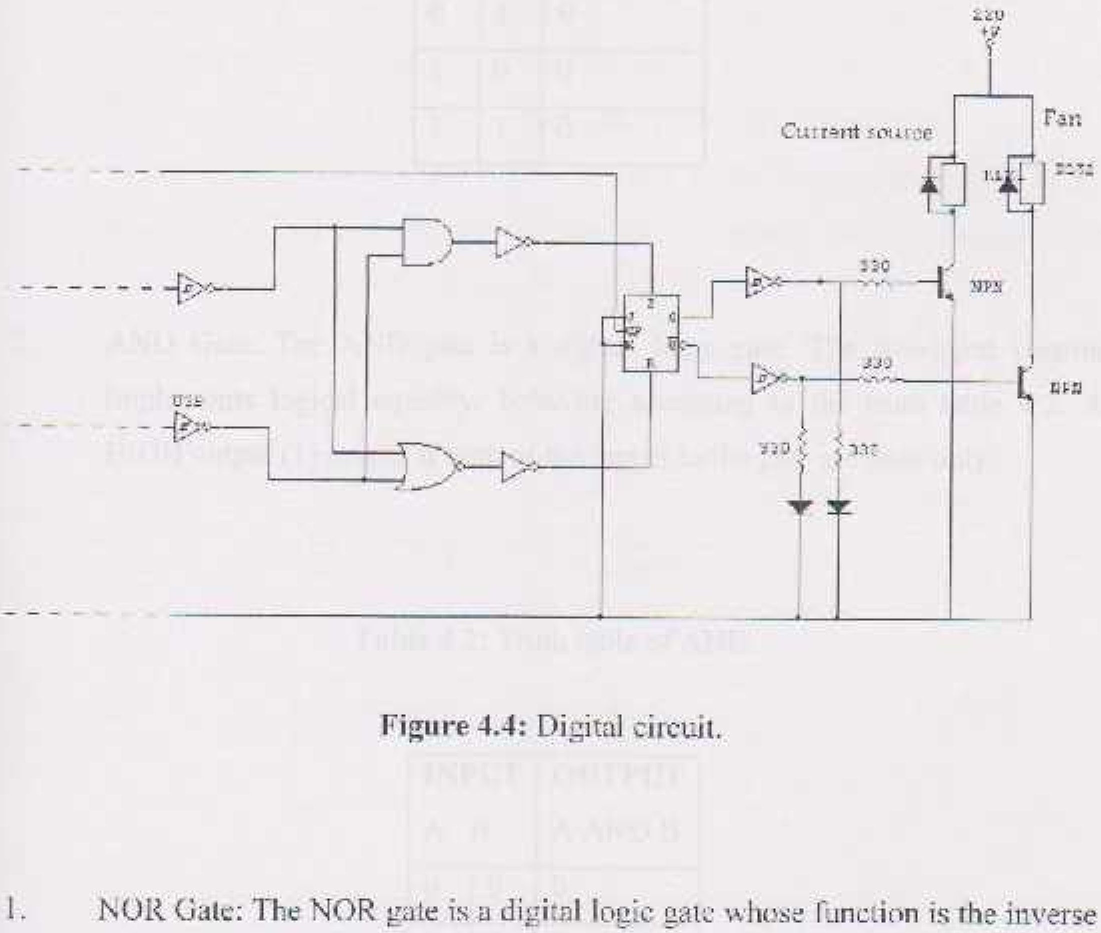


Figure 4.4: Digital circuit.

1. NOR Gate: The NOR gate is a digital logic gate whose function is the inverse of the (OR) gate. The two-input version implements logical equality, behaving according to the truth table 4.1. A HIGH output (1) results if both of the inputs to the gate are zeros only.

Table 4.1: Truth table of NOR.

INPUT		**OUTPUT**
A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

2. AND Gate: The AND gate is a digital logic gate. The two-input version implements logical equality, behaving according to the truth table 4.2. A HIGH output (1) results if both of the inputs to the gate are ones only.

Table 4.2: Truth table of AND.

INPUT		**OUTPUT**
A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

3. Schmitt trigger is an integrated circuit work as inverter, but because of the Schmitt action, it has different input threshold levels for positive or negative signals and gives two outputs zero volt or 5 volt

4. JK flip flop: The JK flip-flop augments the behavior of the SR flip-flop by interpreting the S = R = 1 condition as a "flip" or toggle command. Specifically, the combination J = 1, K = 0 is a command to set the flip-flop; the combination J = 0, K = 1 is a command to reset the flip-flop; and the combination J = K = 1 is a command to toggle the flip-flop, i.e., change its output to the logical complement of its current value. Setting J = K = 0 does NOT result in a D flip-flop, but rather, will hold the current state. To synthesize a D flip-flop, simply set K equal to the complement of J. The JK flip-flop is therefore a universal flip-flop, because it can be configured to work as an SR flip-flop, a D flip-flop or a T flip-flop.

Table 4.3: Truth tables of JK flip flop.

J	K	Comment
0	0	hold state
0	1	reset
1	0	set
1	1	toggle

4.3.1.4 Complete main control circuit

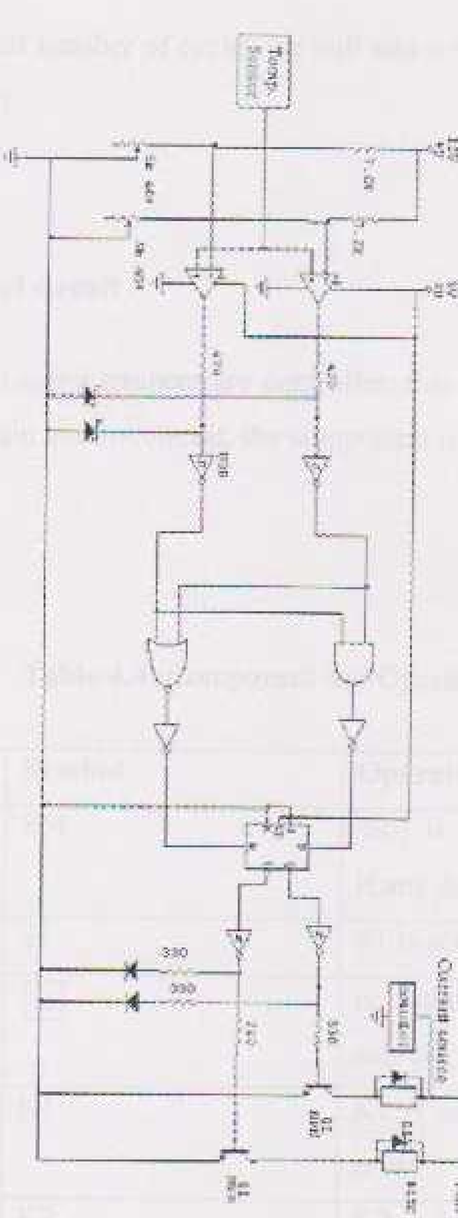


Figure 4.5: Show complete main control circuit.

Used Schmitt trigger to canceling the range between 0 and 5 volt and the value was to get in to relays to switching on a suitable operation

Counter: Used to count number of cycles we will add it to take signal from relay that detect maximum limit.

4.3.2 Stand by control circuit

Control circuit using temperature controller, this is a stand by control circuit used if any fault in main control circuit. the component of this circuit is shown below in the table:

Table 4.4: Component and Operation.

Component	Symbol	Operation
Emergency switch	S01	S01 is pressed, the circuit turn-off if any danger
Selector switch	S1	S1 is activated the circuit is turn-on
Temperature sensor controller		is activated when temperature achieve set point value
Contactors1	K1	K1 is activated the heating system is on
Contactor2	K2	K2 is activated the cooling system is on
Power supply	A	Heating
Fan	B	Cooling

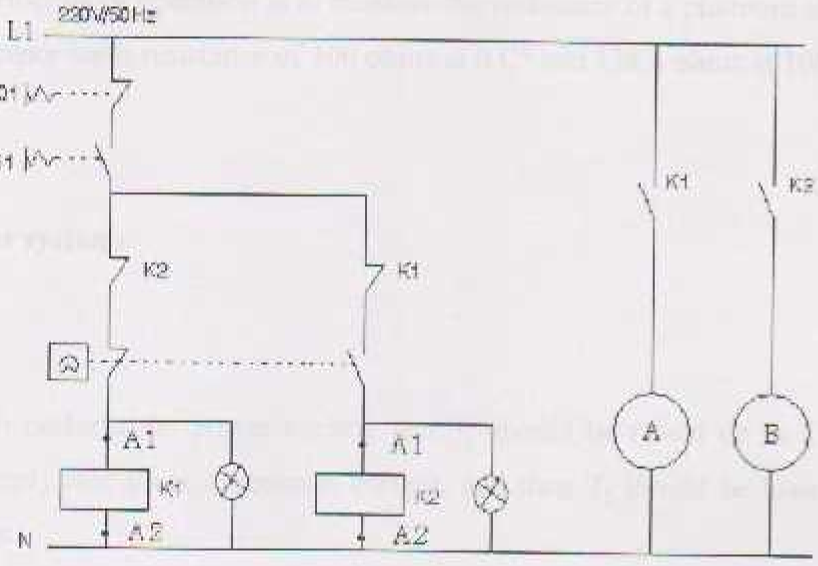


Figure 4.6: Stand-by control circuit.

1. The voltage source used in this circuit is 220V/50Hz.
2. Selector switches to switching on the control circuit using temperature controller.
3. Temperature controller: it is an on-off controller that is one form of temperature control devices. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the setpoint. For heating control, the output is on when the temperature is below the setpoint, and off above setpoint.
4. Two contactors: which is an electrically controlled switch (relay) used for switching a power circuit.
5. Temperature sensor (PT100): Platinum resistance thermometers offer excellent accuracy over a wide temperature range (from -200 to +850 C°), this is available from many manufacturers with various accuracy specifications and numerous packaging options to suit most applications The

principle of operation is to measure the resistance of a platinum element. This sensor has a resistance of 100 ohms at 0 C° and 138.4 ohms at 100 C°.

4.4 Power systems

To perform the power cycling test T_j should be raised up to T_{jmax} using a power supply that gives a constant current, and then T_j should be lowered to T_{jmin} using fans.

4.4.1 Power supply

It is used to supply the power device with a rated current to stress it, and raises the temperature to maximum degree allowable.

4.4.1.1 Variac transformer

Variac transformer is a variable transformer that has many industrial and laboratory applications as a basic component for controlling voltages, currents, power, heat, speed, light and electromechanical force.

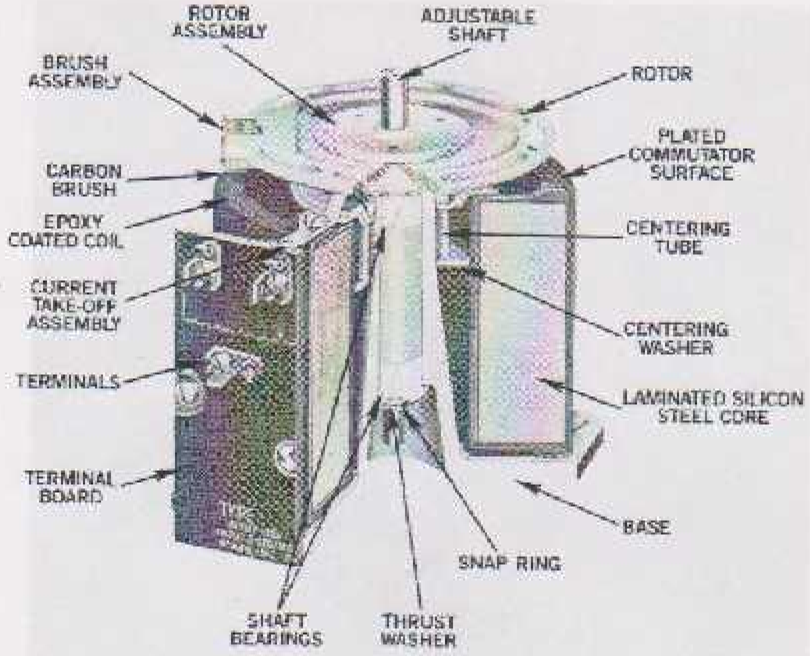


Figure 4.7: A cross section of a Variac transformer.

A basic variable transformer consists of a single layer, magnetic wire, winding on a toroidal core of laminated silicon steel.

A carbon brush connected to an output lead is rotated over a precision ground, plated commutator track to tapp off voltage at any turn from zero to the maximum output voltage of the windings. Figure 4.8 describes the Outside control platform of a Variac transformer.

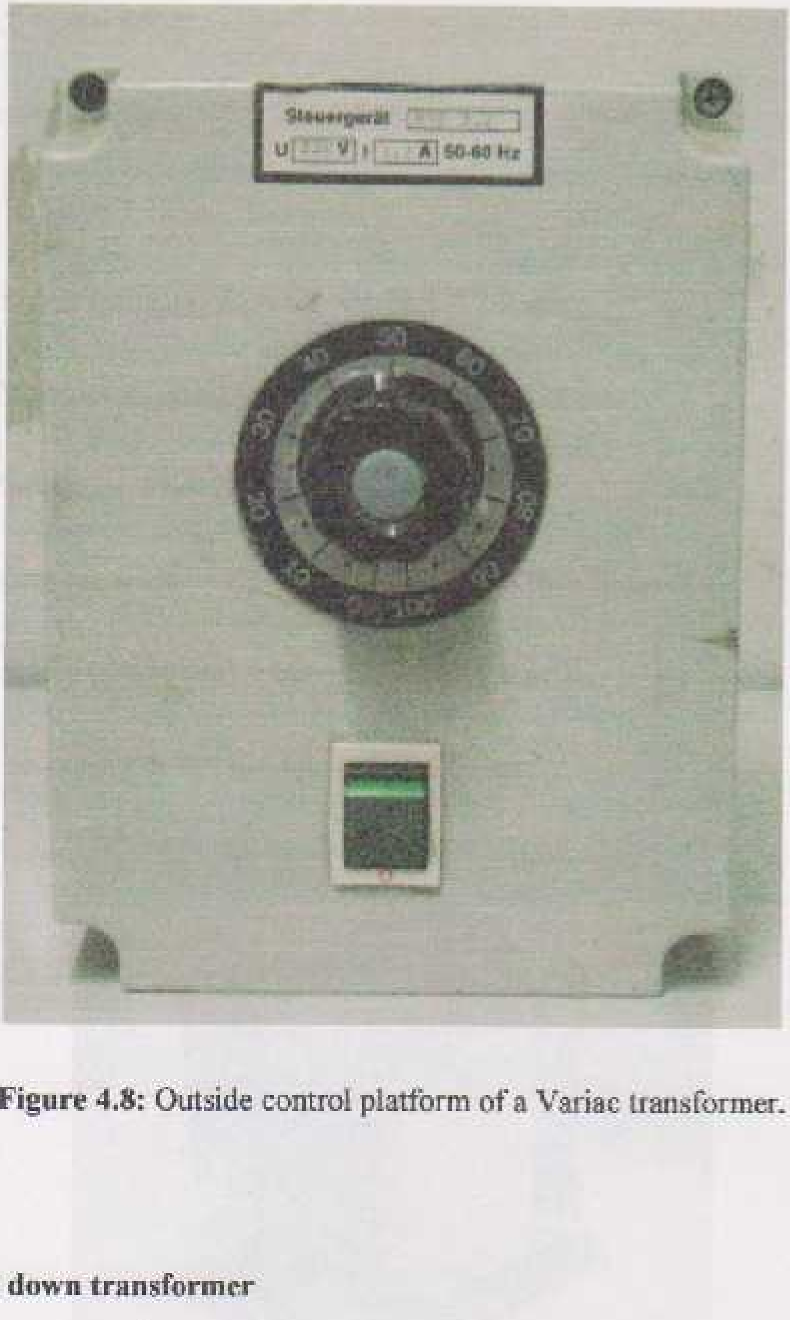


Figure 4.8: Outside control platform of a Variac transformer.

4.3.1.2 Step down transformer

A transformer in general is a device that is used for voltage and current conversion, and when it is used for lowering the output voltage than the input terminal voltage, it is known as a step down transformer. Figure 4.9 describes Outside construction of step down transformer.

$S = V*I = 12 * 50 = 600$ VA

Number of turns (primary) $N1 = 220 * 1.532 = 337$ turns.

$I = S/V = 600/220 = 2.72$ A

Cross section area (primary) $A_1 = I/S = 2.72/3 = 0.9$ mm^2.

Diameter of conductor (primary) $d_1 = \sqrt{(A/0.785)} = 0.99$ mm

Diameter of primary $= I/S = 2.72/3 = 1.07$ mm

Number of turns (secondary) $N_2 = 12 * 1.613 = 19.356 = 20$ turns.

Cross section area (secondary) $= I/S = 50/3 = 16.6$ mm^2.

Diameter of secondary $d_2 = \sqrt{(16.6/0.785)} = 4.59$ mm

Figure 4.9: Outside construction of step down transformer.

4.4.1.3 Combination between the two transformers

First, Variac should be calibrated until the device's rated current is reached, and in this project, it has been used a diode with a rated current of 30 A, then; a low power current source and a voltmeter are connected on parallel with the diode in a way that when the maximum temperature is reached, the power supply is turned off automatically, but the current source should stay in operation. The whole process is appeared in figure 4.10.

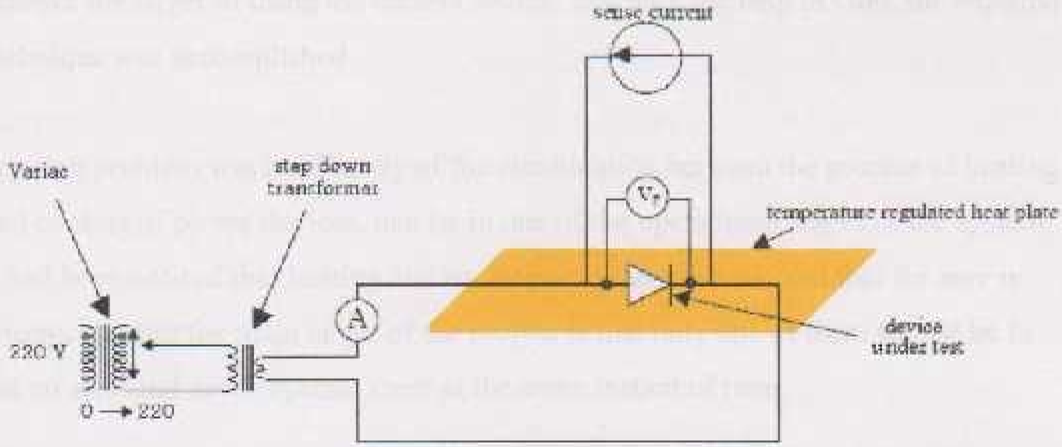


Figure 4.10: Combination between the two transformers.

By means of the voltmeter align with the calibration curve the forward voltage across the diode can be determined, and then the junction temperature can be also realized.

4.4.2 Cooling system (fan)

Driven by motor; used to decrease the temperature of device.

4.5 Problems encountered during the project

The main problem that had been encountered during the project is the way of attain a current source, the searching process lasted for about six months, during that period of time, all companies interested in the field of educational electrical equipments were contacted whole over the region, but unfortunately the efforts being exerted were useless.

From this point, it had been concluded that there should be another technique to achieve the target of using the current source, and with the help of God, the required technique was accomplished.

Another problem was a difficulty of the combination between the process of heating and cooling of power devices, that is: in one of the operational stages of the system, it had been noticed that heating and cooling operates together, and that for sure is wrong, because the main target of the project is that only one of them should be in the on state and never operate them at the same instant of time.

To appear this problem clearly, the following table illustrates what the problem was exactly.

Table 4.5: Sequence of stages for system.

Minimum Temp. Tjmin	Maximum Temp. Tjmax	Operation
0	0	Current source
1	0	Current source
1	1	Fan
1	0	Fan
0	0	Current source

In the process, it had been noted that when Tjmin is reached and Tjmax not yet, the current source is in operation. The second case, the temperature was less than Tjmax and higher than Tjmin, the fan is in operation also, to solve that problem, a storaging device is to be used for keeping the previous value, as appeared in the control circuit diagram.

The third problem was in the input voltage range to the digital circuit, which was between 1.6 and 2.6 V, theoretically when circuit maker simulation was used, everything was okay, but from the practical point of view, it's wrong. Practically it is required to have only two values (0 or 5 V), and this problem was overcame using a Schmitt trigger, which is basically an inverter.

4.6 Mechanical construction

The general mechanical construction contain three parts, part 1 include device under test, sensors, heat sink and fans for cooling, part 2 include control circuits, multimeters, switches and counter, part 3 include current power supply figure 4.11(A), figure 4.11(B) shows the right and front view.

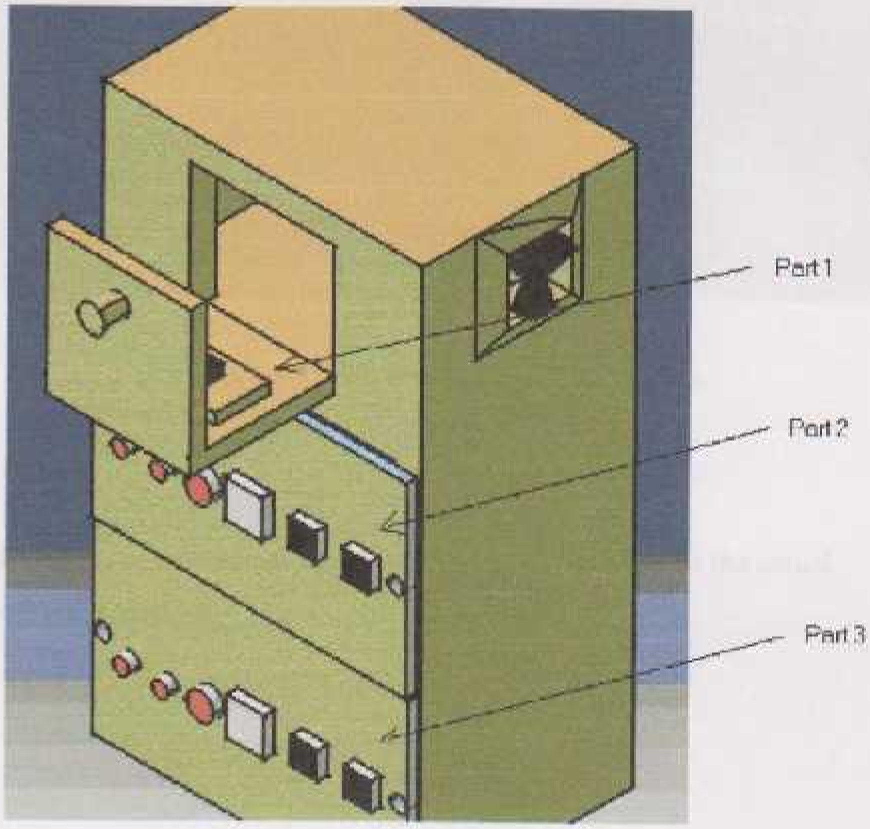


Figure 4.11(A): mechanical construction

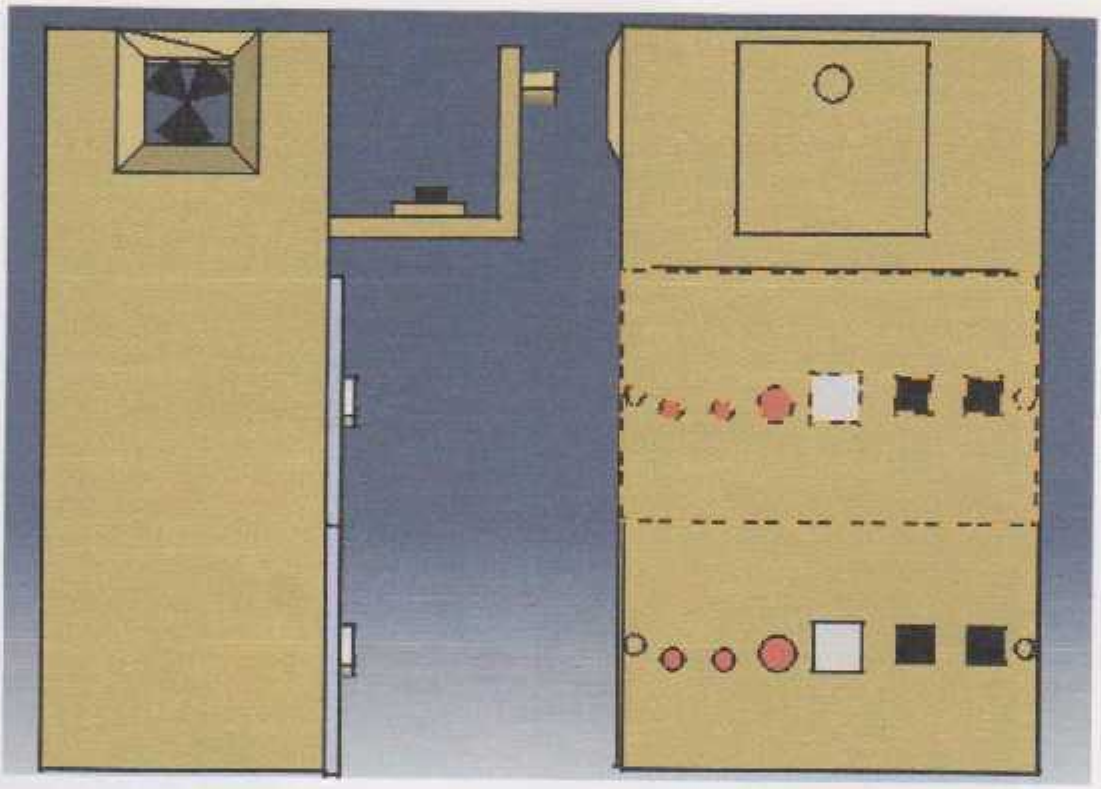


Figure 4.11(B): mechanical construction.

After designing the mechanical construction, figure 4.12 shows the actual mechanical construction.

Figure 4.12: Actual mechanical construction

Results and Conclusions

- To make a power cycling test for a certain device, first of all, the operational nature of that device should be studied carefully, specially the thermal behavior, that is what maximum and minimum temperature values applied on the power device during a certain period of time, meanwhile; how many times the device heats up or cooled down in a specific period. The test is to be done depending on the two temperature limits as previously stated.
- The PN junction of a power device can be known from the forward voltage between the diode terminals after applying small current, and that can be attained referring to the characteristic curve which was mentioned in a previous project to the same diode.

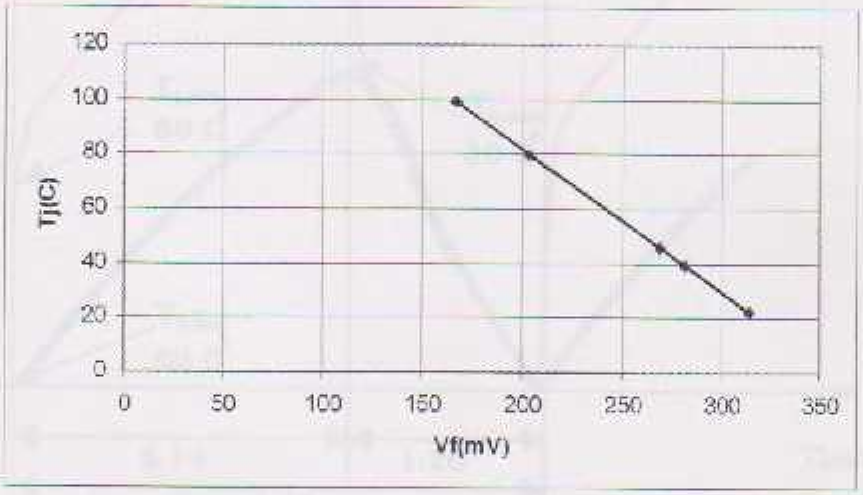


Figure 6.1: SBD3040 calibration curve after applying 30mA.

- After the calibration process, it has been concluded that if the heat sink temperature is 40 C°, the PN junction temperature will be other value can be known from the forward voltage between the diode terminals after applying small current, and if it is 80 C°, the junction temperature will be known from the same process.
- When the practical side was accomplished, a behavioral characteristic curve was derived, which relates between time and the switching states of the power device, whether ON or OFF. The curve is as follows.

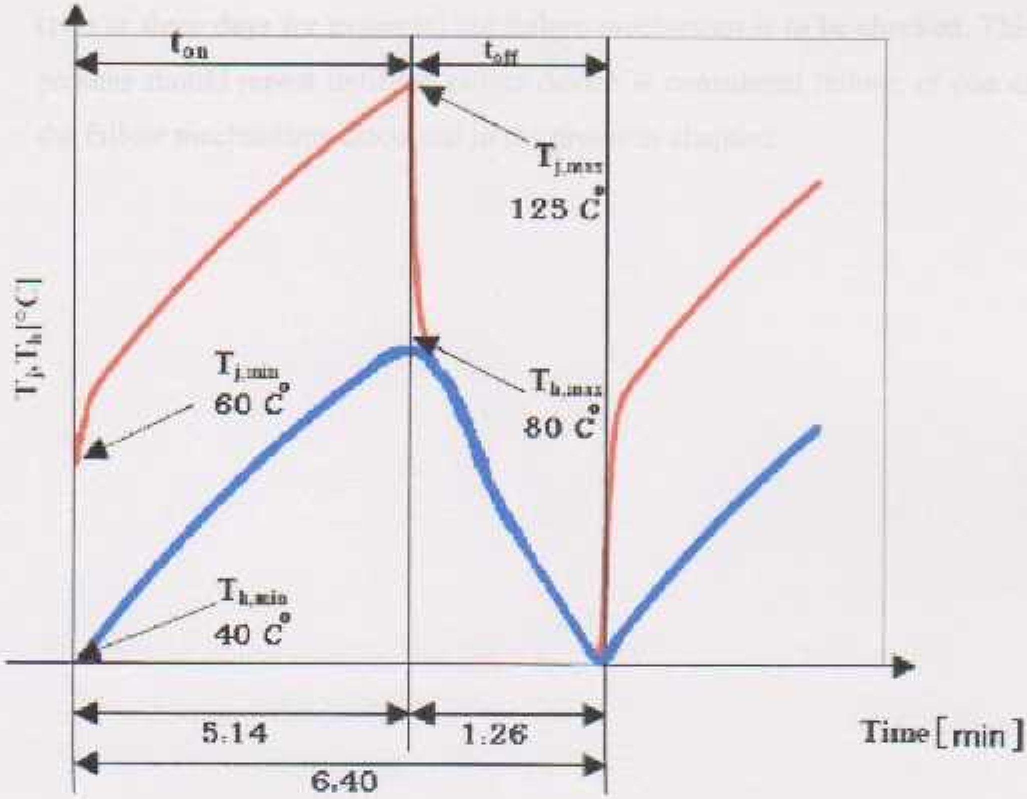


Figure 6.2: Practical behavior of temperature of DUT during power cycling.

- From the above curve it is concluded that the power cycling test between 40C° and 80 C° lasted for 6minutes and 40 seconds, whereas heating time was about 5 minutes and 14 seconds and cooling time was about 1 minute and 26 seconds.

  T_{jmax} was measured according to the voltage drop across the diode after applying a low power current source which was about 120 mV. Referring to figure 6.1; T_{jmax} was about 125 C°.

- This cycle operates for thousands of times, and within a certain period of time (two or three days for example) the failure mechanism is to be checked. This process should repeat until the power device is considered failure, of one of the failure mechanisms discussed in the previous chapters.

Recommendations and Future work

- Power cycling duration can be decreased by increasing the heating and cooling power, either by means of a full-rectified DC current source or an air condition system
- The measuring system (measuring of Vf,Rth) can be computerized.
- Establishment of a research unit exclusively for power devices according to life time, protection and thermal behaviors.
- Encouraging the students to handle such projects that treat with this field of science as it is considered very important for technological development.

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Appendix. A:

Symbols and Constant

A.1 Symbols:

AC: Alternating Current.

DC: direct Current.

CTE: **C**oefficient of **T**hermal **E**xpansion

DCB: **D**irect **C**opper **B**onded

DUT: Device Under Test.

LESIT: **L**eistungs**e**lektronik **S**ystemtechnik und **I**nformations**t**echnologie

IC: Integrated Circuit.

LED: Light Emitting Diode.

R_{th}: Thermal resistance.

T_J: PN-junction temperature.

V_F: Forward voltage.

V_{ref}: Reference voltage.

PT100: Platinum resistance thermometers

A.2 Constants:

e: Euler's constant (2.71828…).

K: Boltzmann's constant (1.38×10^{-23}).

N: Non-identity constant between 1 and 2.

q: Electrons charge (1.6×10^{-19} As).

Appendix .B

Datasheet

LM35 (Precision Centigrade Temperature Sensors)

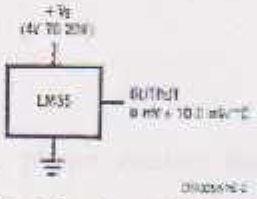
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of +1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

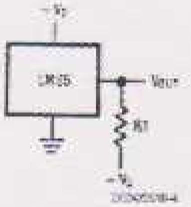
Features

- Calibrated directly in ° Celsius (Centigrade).
- Linear + 10.0 mV/°C scale factor.
- 0.5°C accuracy guarantee able (at +25°C).
- Rated for full −55° to +150°C range.
- Suitable for remote applications.
- Low cost due to wafer-level trimming.
- Operates from 4 to 30 volts.
- Less than 60 µA current drain.
- Low self-heating, 0.08°C in still air.
- Nonlinearity only ±1/4°C typical.
- Low impedance output, 0.1 W for 1 mA load.

Typical Applications



Basic Centigrade Temperature Sensor
(+2°C to +150°C)



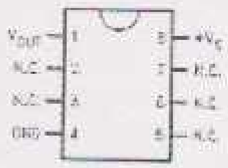
Choose $R_1 = -V_S/50\ \mu A$
$V_{OUT} = +1,500$ mV at +150°C
= +250 mV at +25°C
= −550 mV at −55°C

Full-Range Centigrade Temperature Sensor

Connection Diagrams

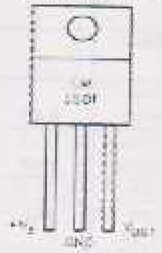
TO-46
Metal Can Package*

SO-8
Small Outline Molded Package



TO-92
Plastic Package

TO-220
Plastic Package*



Absolute Maximum Ratings

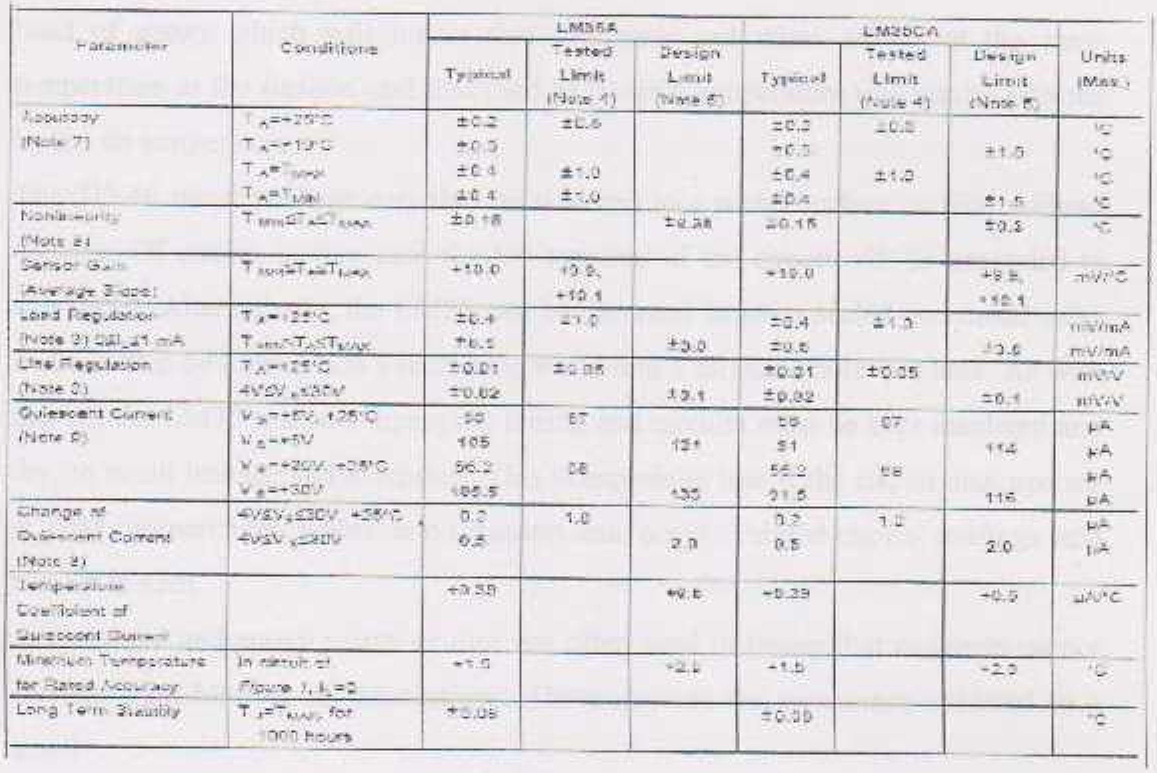
If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	−6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C

SO-8 Package, −65°C to +150°C

TO-220 Package, −65°C to +150°C

Electrical Characteristics



Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	$T_A=+25°C$	±0.2	±0.5		±0.2	±0.5		°C
	$T_A=-10°C$	±0.3			±0.3		±1.0	°C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN}\le T_A\le T_{MAX}$	±0.18		±0.35	±0.15		±0.3	°C
Sensor Gain (Average Slope)	$T_{MIN}\le T_A\le T_{MAX}$	+10.0	+9.9, +10.1		+10.0		+9.9, +10.1	mV/°C
Load Regulation (Note 3) 0≤I_L≤1 mA	$T_A=+25°C$	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}\le T_A\le T_{MAX}$	±0.5		±3.0	±0.5		±3.0	mV/mA
Line Regulation (Note 3)	$T_A=+25°C$	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V\le V_S\le 30V$	±0.02		±0.1	±0.02		±0.1	mV/V
Quiescent Current (Note 9)	$V_S=+5V$, +25°C	56	67		56	67		μA
	$V_S=+5V$	105		131	91		114	μA
	$V_S=+30V$, +25°C	56.2	68		56.2	68		μA
	$V_S=+30V$	105.5		133	91.5		116	μA
Change of Quiescent Current (Note 3)	$4V\le V_S\le 30V$, +25°C	0.2	1.0		0.2	1.0		μA
	$4V\le V_S\le 30V$	0.5		2.0	0.5		2.0	μA
Temperature Coefficient of Quiescent Current		+0.39		+0.5	+0.39		+0.5	μA/°C
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, $I_L=0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature. This presumes that the ambient air temperature is almost the same as the surface temperature: if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is especially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature. To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections. These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

LM78XX (Series Voltage Regulators)

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents. The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating. Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply. For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

- Output current in excess of 1A.
- Internal thermal overload protection.
- No external components required.
- Output transistor safe area protection.
- Internal short circuit current limit.

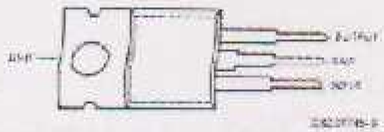
- Available in the aluminum TO-3 package.

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

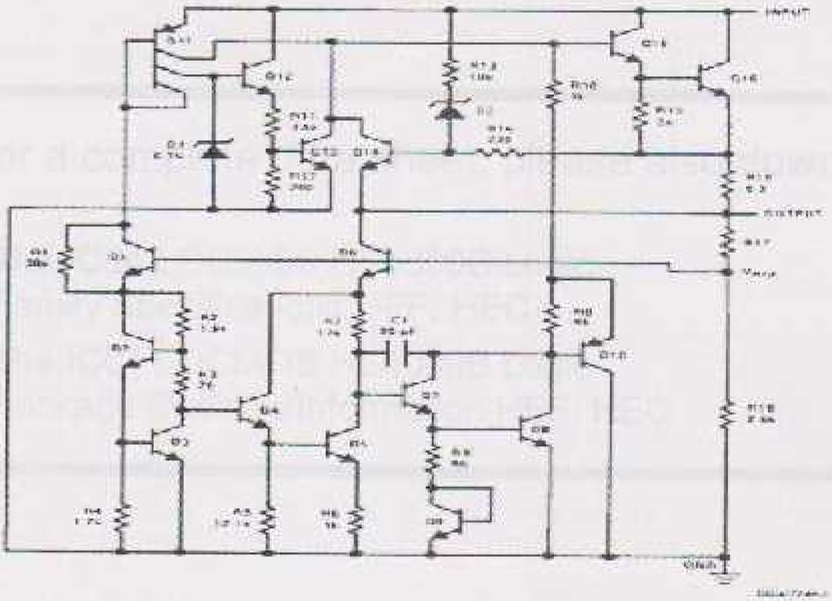
Connection Diagrams

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Schematic



Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage:	(VO = 5V, 12V and 15V).
Internal Power Dissipation:	Internally Limited.
Operating Temperature Range (TA):	0°C to +70°C.
Maximum Junction Temperature:	150°C.
Storage Temperature Range:	−65°C to +150°C.