بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering & Technology
Electrical and Computer Department

Graduation Project

New Approach for Measuring the Temperature of P-N Junction

Project Team
Husam Yousef Tamimi
Ali M. Yaseen Melhem

Project Supervisor: Dr Raed Amro

Hebron – Palestine

May, 2007

Abstract

Thermal design of power electronics systems is more significant importance to know the junction temperature, there are two methods to know the junction temperature direct and indirect, the method we introduce is the indirect which depends on TESP.

We have introduced the methods of measuring the junction temperature and thermal resistance concept. The project shows a test that defines the thermal characteristic of a power diode which makes junction temperature of a specific device is known through forward voltage across the diode under constant low current, sufficient to make forward bias to the diode.

The first step in this method is calibration of the power diode to define the relation between the temperature of junction and the forward voltage; we present the calibration operation and the design of a hardware used in the calibration.

Other part of project is application of this test, using the power diode as sensor, because it's accurate, low cost, may used in high temperature measurements, which don't need an interfacing circuit like other sensors, and it's practical in some application than others. The other application to determining the junction temperature itself when it operates in its normal operation, to prevent it from failure.

Contents

List of Tables

List of Figures

Chapter One

Introduction

1. Introduction

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

1.1 Overview

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, and load factors as well as the temperatures under which the system and its components operate.

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. This is important when you design a particular operating condition to ensure 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 of a chip directly affects the performance of the circuits and the reliability of packages. It is very important therefore that the junction temperature of each package be known as accurately as possible through direct measurement. It is further important that such measurement to be repeatable, and comparable to measurements made on other packages since it constitutes a measure of performance. Lastly, it is important that the technique of measurement to be universally applied to the industry in order to achieve meaningful and unbiased comparison of similar packages.

Thermal design is indispensable when using the semiconductor for high power application or using it under high operating temperature. Semiconductor devices normally operate as long as the temperature does not exceed an upper limit (specified as the ambient temperature and the temperature of the junctions inside the semiconductor). When this upper limit is exceeded, the semiconductor stops operating normally and becomes damaged. Therefore, it is necessary to successfully dissipate the generated heat so as to keep the temperature within specified level.

The increased power dissipation of today's integrated circuits has made knowledge of thermal resistance important to those who manufacture and use these devices. Thermal resistance is a device parameter (i.e. semiconductor chip mounted in a package) that is used to calculate junction temperature if the device power dissipation is known or can be estimated. This parameter is a measure of heat flow from the chip junction to some defined point under specific environmental conditions. The measurement of thermal resistance is simplistic in concept but difficult in practice.

1.2 Problem Definition and Methodology

The power electronics, especially power diode consists of one PN-junction or more, which is considered the major part of the power electronics, Placed on copper plate or ceramic substrate and connected by aluminum bond wires to the pins of the whole diode.

PN-junction consists of minority and majority curriers that conduct when applying enough forward voltage. Their behaviors as the pneumatic valves, when applying reverse voltage, block the voltage and its current approach to zero.

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 limit.

On other hand, the life time of the power diode is measured by determining the number of the power cycles 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.

The datasheet of specific diode or power devices gives the maximum of the junction temperature it self, for this; reason the junction temperature must be known, which differs from the case temperature.

In general there are two methods of measuring the PN- junction.

Direct method: There are mainly two approaches employed for directly measurement of T_j. Firstly: by infrared camera which absorb and thermally evaluate the infrared radiation emission from the measured devices. Secondly: by liquid crystal imaging where the devices to be measured are coated with liquid crystal which begins to reflect visible light with varying wavelength defined by the object temperature. The direct methods allow capturing the whole temperature map but they exhibit some disadvantages which limit their applications in many thermal evaluation processes. Some of these disadvantages are:

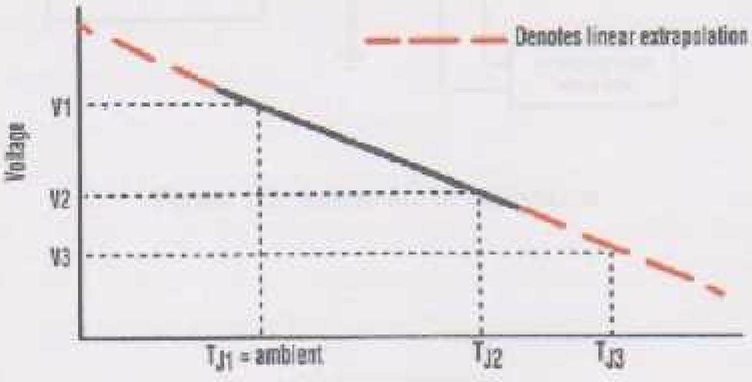
- Devices to be measured must be opened and unobstructed which results into changing, of the circuit cooling conditions
- Devices to be measured must be coated with suitable surface of uniform and known emissivity.

Indirect method: This method uses the junction itself as temperature sensor and is widely used in measuring of T_j. It is based on monitoring of Temperature Sensitive Electrical Parameter (TSEP), like the forward voltage. Threshold voltage $V_{GE,th}$ in MOSFETs and IGBTs can be used too. The TSEP method utilizes an intrinsic property of semiconductor, meanly the linear relationship between temperature and forward conduction voltage at small constant sense current. This method allows accurate and non destructive measuring of T_j in static and dynamic conditions.

The devices to be measured must be heated to known temperatures and the forward voltage at sense current is sensed at each temperature. Then a calibration curve of TSEP is established, and the temperature can be calculated by curve fitting. The temperature calibration function up to specific temperature is generally expressed as follows:

$$T_j = mV_f + T_0 \qquad \text{Eq 1.1}$$

The slope *m* (K/mV) is always negative and its reciprocal is designated as the 'K' factor. The temperature intercept T_0 is always positive and is theoretically the junction temperature at which the forward voltage becomes zero. So the general temperature calibration function of a power diode is depicted in Figure 1.1, where the slope differs from device to others.



This graph depicts the linearity of junction temperature versus forward voltage drop.

Figure 1.1: T_j-V_f characteristic of power device.

The calibration of V_F versus T_J is accomplished by monitoring voltmeter for the required value of current source at low constant current as the environmental temperature, and is varied by external heating. The magnitude of current source shall be chosen so that V_F is a linearly decreasing function over the normal T_J range of the device. Current source value must be large enough to ensure that the diode junction is turned on but not large enough to cause significant self-heating. An example of the measurement method and resulting calibration curve is shown on Figure 1.1, Figure1.2.

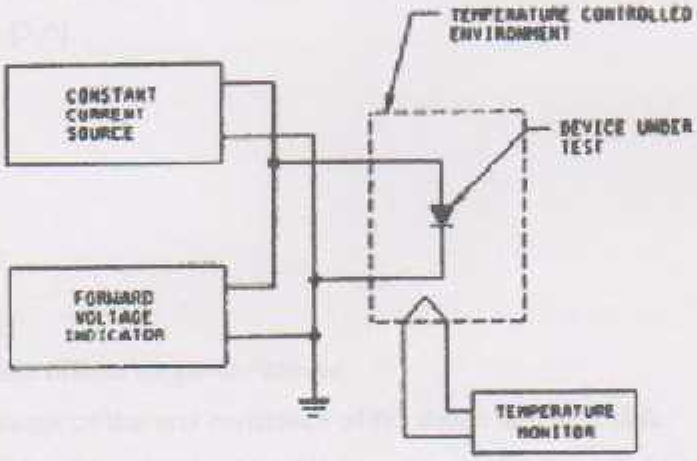


Figure 1.2. Schematic of calibration

When the diode under is normal operation as in rectifiers, inverter and other applications use diodes as switching devices in the dynamic behavior. It's important to know the junction temperature it's self since the datasheet gives the maximum rating of the junction temperature and not the overall package of the diode; so if we can use another sensors like thermocouples, thermistors offer us the package temperature.

However it will not be enough accurate, and takes extra hardware to the system; so the T_j-V_f calibration will be suitable to knowing the temperature of the junction itself

The diode used in the rectifiers or other applications must be calibrated to define its temperature from the forward voltage at low constant current. Then, diode will unloaded of the operation load current because the load current doesn't give a linear relation of the T_j- V_f correlation and causes an extra heating for the system. Then the selected current source must be applied to the diode after waiting enough time (recovery time) to let the diode to regain its natural conduction properties, then applying the calibrated curve to the diode and taking the forward voltage to get the junction temperature value [5,6].

1.3 Objectives:

1. Study temperature effects on power diodes.
2. To examine concept of thermal resistance of the diode and heat sink.
3. Study the methods of determining the PN-junction temperature and its advantages.
4. Measure the PN-junction temperature using indirect method.
5. Calibrate power diode to get the PN-junction temperature related to forward voltage.
6. Design a regulated heat plate with accurate temperature values from 25 to 110°C, in order to use it in calibration process.
7. Design controlled current source from 20 to 120mA.
8. Design temperature sensor using power diode and current source.
9. Determine the junction temperature of the power diode in normal operation, such as rectifiers and inverters.
10. Describes the life time of power diode.

1.4 Previous studies

1.4.1 Use Forward Voltage Drop To Measure Junction Temperature

Jason Chonko, 2005

According this study, employing the junction itself as a temperature sensor. With most materials, there's a strong correlation between the forward voltage drop of a junction and the temperature of that junction. The point at which a junction becomes nonlinear with respect to junction temperature depends on the material of the junction, as well as its design. It's safe to assume linearity for most materials in normal operating environments up to 80° to 100°C. Nonlinearity can be determined experimentally by measuring the voltage at higher and higher ambient temperatures until there are a deviation from linearity. This relationship is nearly linear for most devices [10].

1.4.2 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, and the methods of measuring the junction temperature direct and indirect methods, temperature sensitive electrical parameter (TSEP) test for measuring Tj [5].

1.4.3 Pn-Junction as Temperature Sensor, Tony R Kuphaldt, FEEE

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

$$I_D = I_S\,(e^{(qV/NKT)} - 1) \qquad \text{Eq 1.2}$$

Where,

I_D ... diode current

I_s ... saturation current

e.... Euler's constant (2.71828...)

q.... Charge of electron ($1.6 * 10^{-19}$ As)

V.... Voltage across the diode

N.... "Non-ideality" coefficient (typically between 1 and 2)

k .... Boltzmann's constant ($1.38 * 10^{-23}$)

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 1K [11].

1.4.4 Method and a measuring circuit for determining temperature from a PN junction temperature sensor, and a temperature sensing circuit comprising the measuring circuit and a PN junction, Evaldo M. Miranda, John A. Cleary and Elizabeth A. Lillis

According to the study there is provided a method for determining temperature of a device which exhibits an exponential relationship between temperature and voltage in response to an excitation current, comprising the acts of: sequentially applying at least three excitation currents of different values to the device along a current path in a predetermined current sequence for sequentially exciting the device for developing successive voltage values across the device in response to the excitation currents, sensing successive voltages developed across two sensing nodes in the current path on opposite sides of the device in response to the excitation currents, and combining the differences of the successive sensed voltages for determining a voltage indicative of the temperature of the device, wherein, the predetermined current sequence is selected so that as the differences of the successive sensed voltages developed across the two sensing nodes in the current path are being combined, the cumulative effect, in the sensed voltages, of voltage components resulting from series resistance in the current path between the two sensing nodes through the device is minimized, and the number of times the device is subjected to excitation by the excitation currents during the predetermined current sequence is selected so that the effect of the voltage components resulting from the series resistance in the current path between the two sensing nodes in the determined voltage indicative of the temperature of the device is substantially eliminated [12].

1.5 Time plane:

Activities	2006		2007				
	11	12	1	2	3	4	5
Problem Definition	🟪	🟪					
Literature review	🟥	🟥	🟥	🟥	🟥		
Design project circuits and making tests wanted					🟩	🟩	🟩
Discussion of results					🟩	🟩	🟩
Conclusion and recommendation							🟦
Writing the report		🟦	🟦	🟦	🟦	🟦	🟦

1.6 Budget:

Task	Cost (NIS)
Using internet	200
Printing	80
To copy from library box	20
Diodes	80
Heat Control Circuit	500
Current source circuits	40
Total	920

1.7 Project Layout:

Our project composed of seven chapters and here a general description of the contents of each chapter.

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

Chapter two: is the theoretical background, includes packaging, thermal characteristic of the diode, effect of the temperature on the semiconductors, sense the junction temperature without calibration and temperature sensors.

Chapter three: is the hardware design includes: regulated heat plate design and current source.

Chapter four: is Measuring strategy, presents Calibration process, Calibration procedures and expected error of calibration.

Chapter five: Measurements; include calibration results of tested power diodes, and determining junction temperature of a power diode at specific load current.

Chapter six: Applications, presents diode as temperature sensor, diode demo circuit, junction temperature while in operation and Direct-reading thermometer.

Chapter seven: Conclusions and future work; which presents project conclusions, recommendations and future work.

Chapter Two

Theoretical Background

2. Theoretical background

This chapter presents some concepts about the effects of temperature on Semiconductor device, Thermal Resistance, Diode and its Thermal Characteristics and Thermal response of diode junction. The chapter also presents Packaging, Sense junction temperatures without calibration and Temperature sensor.

2.1 Packaging

Electronic packaging is generally defined as the combination of engineering and manufacturing technologies required to convert an electronic circuit into manufactured assembly. In Packaging of power electronic devices there is an additional consideration that a power semiconductor chip can be much larger and dissipates much higher power level than a chip of a signal IC.

The role of packaging is to: connect a die to the external circuit; provide a way to remove the heat generated by the device; protect the die from the external environment (moisture, dust).

Many of the reliability issues of power device are either related to excessive temperature of fatigue due to thermal cycling. Research is currently carried out on the following topics: improve the cooling performance, improve the resistance to thermal cycling by closely matching the Coefficient of thermal expansion of the packaging to that of the silicon and increase the maximum operating temperature of the packaging material.

Researchs is also ongoing on electrical issues such as reducing the parasitic inductance of packaging. This inductance limits the operating frequency as it generates losses in the devices during commutation.

Low-voltage MOSFETs are also limited by the parasitic resistance of the packages, as their intrinsic on-state resistance can be as low as one or two milliohms.

There are mainly three packaging concepts in power electronics: Discrete devices, Power modules and Disc cells (or Hockey pack) figure 2.1, the most important criteria in selecting the packaging type power class of the device.

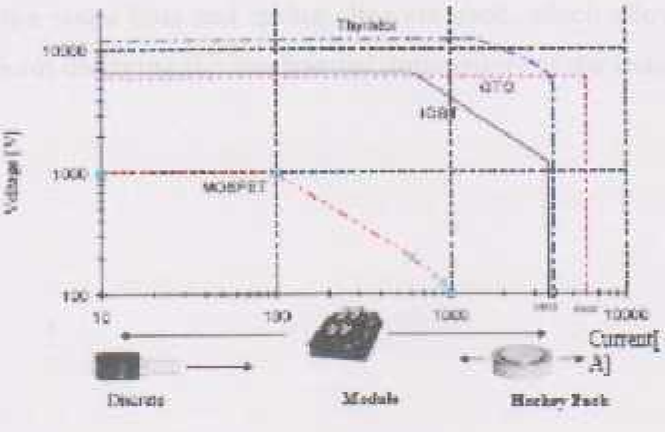


figure 2.1 :Packaging types

Discrete devices are the primary packaging form in power electronics and were presented at the begin of the sixties of the last century . The most important representative of the discrete devices is the TO-family members (TO220, TO247 etc.) which are widely used in low and middle power applications like DC/DC and AC/DC converters.

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. (see Figure 2.2).

Classic TO cases exhibit screw holes for screwing the devices to the heat sink, where a thermal pad between the bottom side of the device and the heat sink provides the necessary electrical isolation and represents the thermal coupling. However; an advanced version abandons the screw hole and spring clips are used, which allows the integration of larger chips without changing the mechanical dimensions of the case.

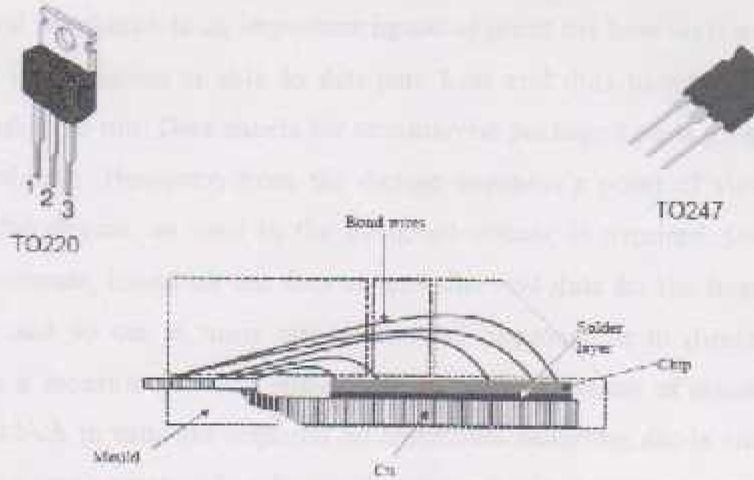


Figure 2.2: To-cases structure

2.2 The effect of temperature on semiconductor device and thermal resistance

The power consumed by semiconductor devices is converted into heat; this generated heat causes a rise in temperature of semiconductor devices. Semiconductor devices will operate normally as long as the temperature does not exceed an upper limit which on this temperature the device stops operating normally and becomes damaged.

Thermal effects are indispensable when using the semiconductor for high power application or using it under the high operating temperature. The concept of thermal resistance is used when considering heat dissipation.

Thermal resistance is an important figure of merit for how well a diode package and heat-sink combination is able to dissipate heat and thus to what power level the device may safely be run. Data sheets for commercial packaged parts give typical values for the general case. However, from the design engineer's point of view, the thermal resistance of the device, as used in the designed circuit, is required. One option is to calculate an estimate, based on the data sheet value and data for the heat sink used the thermal paste and so on. A more straightforward approach is to directly measure it, although such a measurement has previously required a means of measuring junction temperature, which in turn has required an additional sampling diode and a calibration procedure using some means of uniformly elevating the device's temperature to a known value.

The first step in thermal resistance measurements requires careful consideration of how the junction temperature will be determined. While there are several methods available: infra-red, liquid crystal, electrical parameter only the Electrical Test Method (ETM) is truly practical for most device manufacturers and users as described in chapter one. This method relies on the fact that a temperature sensitive electrical parameter can be found for the device that provides a direct correlation to the device junction temperature. Unlike other methods, the ETM does not require any special modification to the device and can be performed on the device in its final form by making electrical connection to its leads. The simplest and most common parameter used for temperature sensing within a device is the junction voltage across a diode forward-biased with a low value of current. This voltage will usually vary linearly with temperature over a range suitable for making thermal resistance measurements and is very repeatable.

In power devices thermal resistance between junction and a reference point ($R_{th\text{-}ref}$) is usually given and can be calculated according to Equation 2.1. The selection of a usable reference temperature depends on the packaging concept of the device.

$$R_{th} = \frac{T_j - T_0}{P_d} \qquad \text{Eq. (2.1)}$$

Where: T_j= junction temperature; T_0= Temperature at reference point; P_d= heat flow rate between point junction and the reference point. However; there are important considerations that have to be aware when using R_{th} (K/W) to specify the maximum operating conditions of a system:

a) Equation 2.1 does not consider the non-linearity in the thermal systems especially the nonlinear dependency of thermal parameters of the different layers on temperature. Therefore, the measured R_{th} depends on junction temperature and thus indirectly on the dissipated power Pd and load current.

b) The calculated power P_d in equation 2.1 is not the real power dissipated within the chip. Despite these limitations, thermal resistance is still considered as an important measurable parameter of the capability of a device to dissipate the heat energy generated within the chip and has been developed over the years as an aid to the manufacturer and user for calculating the junction temperature of the operating device [5].

2.3 Diode and its Thermal Characteristics:

The main reason semiconductor materials are so useful is that the behavior of a semiconductors can be easily manipulated by the addition of impurities, known as doping. Semiconductor conductivity can be controlled by introduction of an electric field, by exposure to light, and even pressure and heat; thus, semiconductors can make excellent sensors. Current conduction in a semiconductor occurs via mobile or "free" electrons and holes (collectively known as charge carriers). Doping a semiconductor such as silicon with a small amount of impurity atoms, such as phosphorus or boron, greatly increases the number of free electrons or holes within the semiconductor. When a doped semiconductor contains excess holes it is called "p-type", and when it contains excess free electrons it is known as "n-type". The semiconductor material used in devices is doped under highly controlled conditions in a fabrication facility, to precisely control the location and concentration of p- and n-type doping regions. The junctions which form where n-type and p-type semiconductors join together are called p-n junctions.

The p-n junction diode is a device made from a p-n junction. At the junction of a p-type and an n-type semiconductor there forms a region called the depletion region which blocks current conduction from the n-type region to the p-type region, but allows current to conduct from the p-type region to the n-type region. Thus when the device is forward biased, with the p-side at higher electric potential, the diode conducts current easily; but the current is very small when the diode is reverse biased.

2.3.1 Thermal response of diode junction:

When diode is in operation, heat generated within its junction. The rate of heat generation is a function of power (P). Heat is transmitted from the junction to the case, case to heat sink, and then heat sink to ambient, or if no heat sink, heat dissipated from the case to ambient. The junction temperature (Tj) will rise until equilibrium is reached when the rate of heat generation is equal to the rate of heat dissipation. How fast and how high Tj rises depending on the conducting medium.

Generally, the characteristics of the conducting medium are defined in terms of thermal resistance (Rth) using an electrical analogy where the temperature is equivalent to the voltage, power to current, and Rth to resistance, the junction temperature rises ΔTj relative to the case would be the product of the power (P) and thermal resistance junction to the case :

$$\Delta Tj = P \times Rth \qquad \text{Eq (2.2)}$$

There are times when a diode would fail during operation even through its Tj is seemingly below the maximum rating based on the DC or average power dissipation. It's very possible that some time during operation when transient surge occurs, the excess heat associated with the surge may not dissipate fast enough from the junction to the case, thus causing Tj to rise beyond the critical limit. Another possible scenario would be if the diode current is in the form of repetitive pulses.

The Shockley ideal diode equation is the I-V characteristic of an ideal diode in either forward or reverse bias (or no bias). It is derived with the assumption that the only processes giving rise to current in the diode are drift (due to electrical field), diffusion, and thermal recombination-generation. It also assumes that the recombination-generation (R-G) current in the depletion region is insignificant. This means that the Shockley equation doesn't account for the processes involved in reverse breakdown and photon-assisted R-G. Additionally, it doesn't describe the "leveling off" of the I-V curve at high forward bias due to internal resistance, nor does it explain the practical deviation from the ideal at very low forward bias due to R-G current in the depletion region.

$$V_T = \frac{KT}{e} \qquad \text{Eq (2.3)}$$

Where: e is the magnitude of charge on an electron, k is Boltzmann's constant, T is the absolute temperature of the p-n junction [7].

2.4 Sense junction temperatures without calibration

Diodes can be used as low-cost temperature sensors. Sensing temperature with a silicon junction often exploits the fact that the forward voltage drop has a temperature coefficient of −2.2 mV/°C. The problem with this method is that the actual junction voltage at a given temperature is subject to wide variation, requiring a calibration whenever different devices are used. Manual calibration can be tedious and also involves accuracy-degrading potentiometers.

Sensing junction temperature without calibration relies on the predictability of junction voltage variation at two currents over temperature, described by the familiar:

$$V = \frac{KT}{q} \ln (I1/I2) \qquad \text{Eq (2.4)}$$

Rearranging to yield T, assuming a 10:1 ratio for I1/I2, and assuming 8.7248^{5} for K/q, this simplifies to a good approximation for most common diodes.

$$T = \frac{V}{(K/q)\ln(I1/I2)} = \frac{V}{0.0002} \qquad \text{Eq (2.5)}$$

This result is in degrees Kelvin; simply subtract 273 to convert the result to degrees Celsius. As an idea of the amplitudes involved, a 10:1 current ratio will yield a 59.6-mV difference between the junction drop at high current and low current, at 25°C, with a temperature coefficient of +200 µV/°C.

You can stimulate a junction to yield this information by toggling it between two currents, as the circuits described here do. Then you simply measure the dV between the two current values and use the above equation to describe the temperature of the junction. This small signal represents a slight challenge when amplifying, since you are trying to observe a tiny signal (the tempco) contained in a larger signal (the dV/I), riding on top of a big imprecise diode drop with a comparatively huge tempco (0.4 to 0.7 V, −2,2 mV/°C). These constraints favor a means of stimulation that allows ac coupling the dV/I voltage to an amplifying circuit. These variations, available supply voltage, and the dynamic range of the device (ADC) that this circuit will feed dictate the maximum allowable gain of the amplifier.

The basic approach for junction temperature sensing with hardware monitor IC such as the LM80. The general purpose output of the LM80 is used as a control line for a circuit which continuously supplies 10 µA of current to the measurement junction when the control line is low.

To make a measurement, the control line is momentarily taken high, supplying an additional 90 mA to the junction for a total of 100 mA. The amplifier/conditioner circuit is designed to extract and amplify the difference between the low-current and high-current junction voltages. This voltage then is sensed by one of the analog inputs of the LM80.

The National LM80 Personal Computer Hardware Monitor IC. The LM80 is simply an analog-to-digital converter, converting the voltage to digital form. Once in a computer, the actual temperature is simply a matter of software calculation. The LM80 provides a 0- to 2.56-V full-scale range with 10-mV LSB (least significant bit) [4]

2.5 Temperature sensors

There are several ready-made temperature-to-voltage sensors available, which provide all three steps in one very small package. All that needs to be done is to connect a power source (like a 9-volt battery) and a voltmeter (like a Digital Multimeter, also known as a DMM or DVM). They generate 0.01 volts (10 mV) for every degree F (LM34) or degree C (LM35), so a temperature of 75 degrees would read 0.75 volts on the meter. The sensor itself can be mounted in a rigid tube and sealed to protect it from liquids, forming a temperature probe, or can be left at the end of the wires, allowing flexible sensor placement. Sensors such as the LM34 or LM35 are top choices for this kind of application.

The main problem with the LM34/35 is that the most accurate versions are also the most expensive (up to $30 for the "A" grade). Less-accurate grades are available reasonably priced, but they can be off by as much as four degrees Fahrenheit ("D" grade).

However, for general-purpose use, they are excellent and very simple to use devices. We use the semiconductor temperature sensor which converts the temperature to voltage which will be the negative feedback of the system to the comparator, LM35 integrated circuit will used because it has more reliability then the other sensors.

Chapter Three

Required Hardware Design

3. Required Hardware Design

This chapter presents practical system for control and power circuits for regulated heat plate, also practical circuit of current source.

3.1 Heat Plate

This part of the chapter present the design of the regulated heat plate, with high accuracy and reliability, which is use to get different values of the temperature to set the power diode temperature to desired value for the calibration, figures 3.1, 3.2 show the control and the heater circuits.

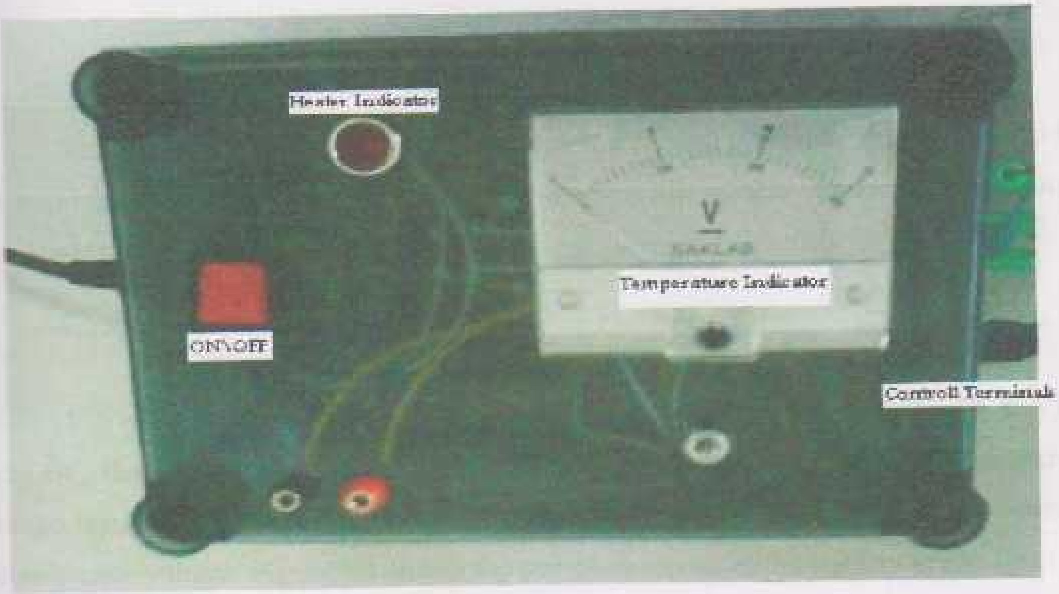


Figure 3.1: Heater control circuit

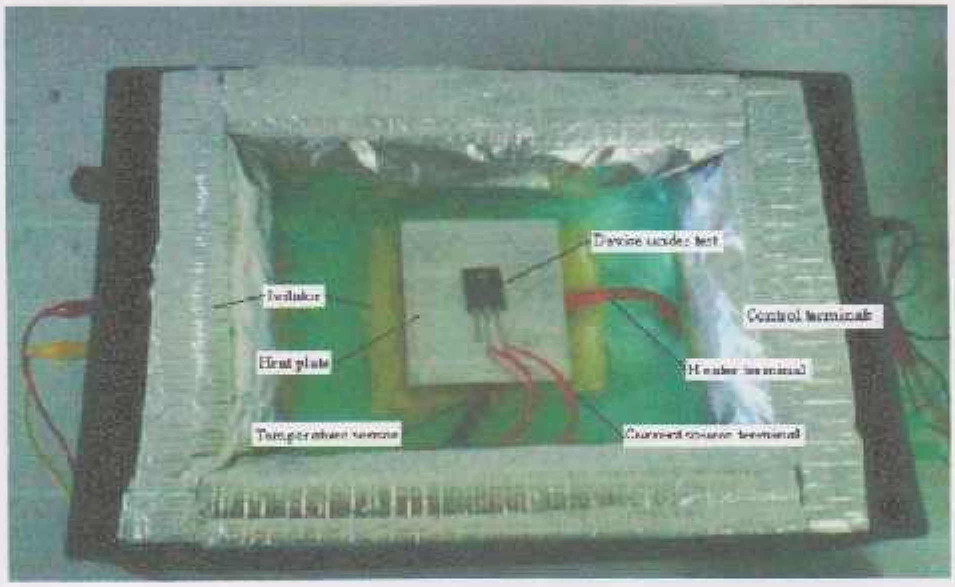


Figure 3.2: Regulated heat plate

The general block diagram of the closed loop control system for the heater used in the regulated heat plate shown in the figure 3.3 where this system contains the following components:

1. Vref: this block consist of two parts: regulated power supply from -15 to +15 volts DC, that is built using center tap transformer, bridge rectifier positive and negative voltage regulators (LM7815, LM7915). The second part is the potentiometer to control the reference voltage. Figure 3.4 shows the complete circuit of the power supply.

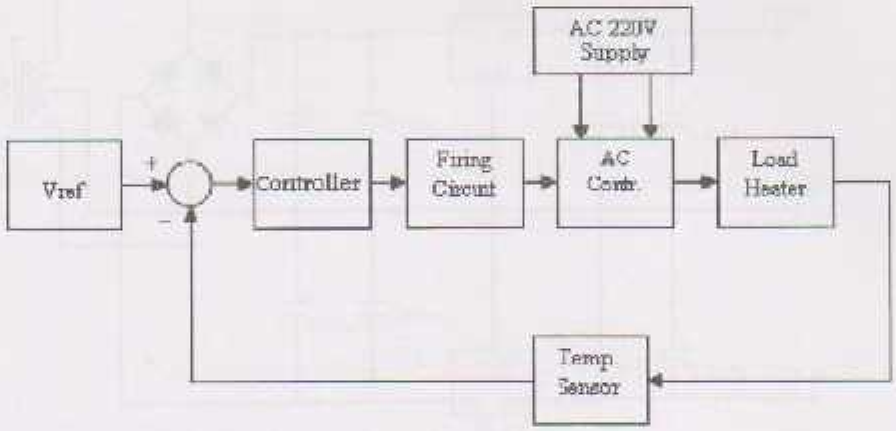


Figure 3.3: overall heater block diagram

2. Comparator (LM741): to compare the reference voltage with the feedback signal from the temperature sensor

3. Controller (LM741): As P-controller to amplify the comparator signal with gain equal to 10.

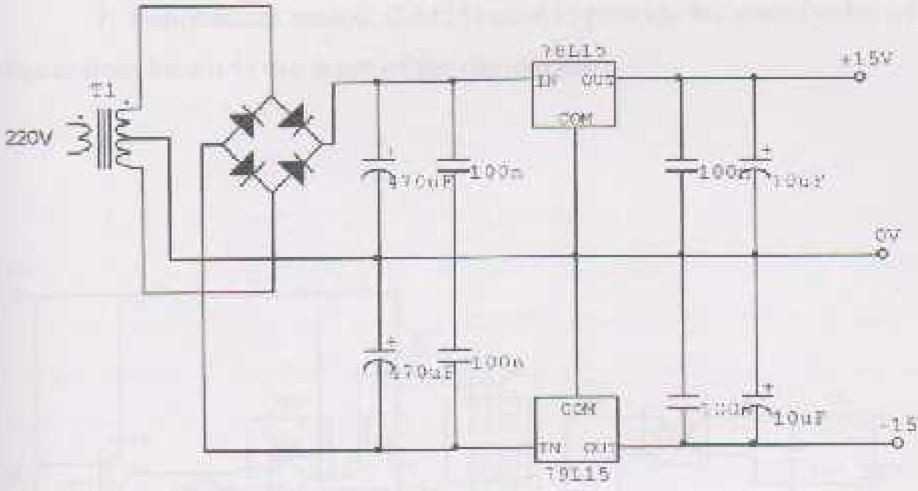


Figure 3.4: Power supply circuit

4. Firing circuit: using the timer NE555 to generate pulses to drive the opt coupler MOC4031 which fire the triac and isolate the control and the power circuits. [3].

5. AC voltage controller: with phase control using a triac (BT139), to control with the input voltage of the heater which control output temperature of the heater.

6. Heater: An electrical heater (ST220V70W7-1) that gives the heat to the aluminum plate which the diode placed on; according the input voltage the amount of heat changes and gives the desired temperature value. The heater system isolated from the ambient by thermal isolator, to reserve the set value of temperature.

7. Temperature sensor: (LM35) used to provide the actual value of feedback signal from heater to the input of the comparator.

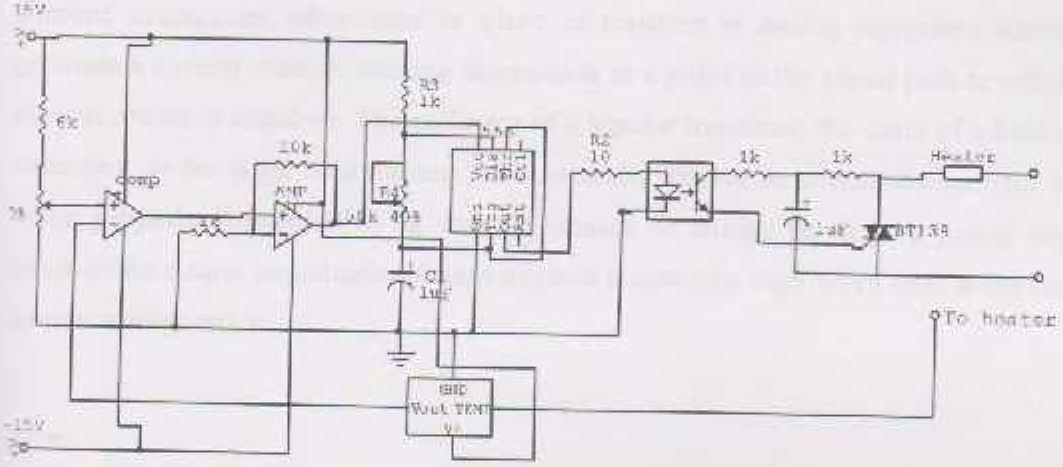


Figure 3.5: AC voltage controller with firing circuit.

Also rockwool material is used as small room around the heat plate; to make excellent and reliable insulator for the system and to reduce the error. See Appendix .C.

This method is more effective than other methods for the diodes breakdown voltage of less than 5.6 V, the compensating diode is usually not required because the breakdown mechanism is not as temperature dependent as it is in breakdown diodes above this voltage [7].

7. Temperature sensor: (LM35) used to provide the actual value of feedback signal from heater to the input of the comparator.

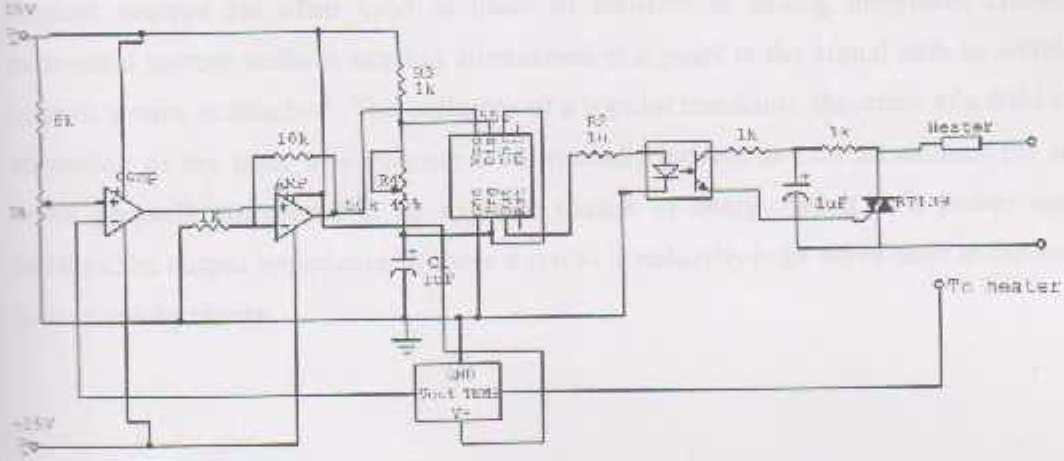


Figure 3.5: AC voltage controller with firing circuit.

Also rockwool material is used as small room around the heat plate; to make excellent and reliable insulator for the system and to reduce the error. See Appendix .C.

This method is more effective than other methods for the diodes breakdown voltage of less than 5.6 V, the compensating diode is usually not required because the breakdown mechanism is not as temperature dependent as it is in breakdown diodes above this voltage [7].

3.2 Current Source

Active current sources have many important applications in electronic circuits. Current sources are often used in place of resistors in analog integrated circuits to generate a current without causing attenuation at a point in the signal path to which the current source is attached. The collector of a bipolar transistor, the drain of a field effect transistor, or the plate of a vacuum tube naturally behave as current sources (or sinks) when properly connected to an external source of energy (such as a power supply) because the output impedance of these devices is naturally high when used in the current source configuration.

A JFET can be made to act as a current source by tying its gate to its source. The current then flowing is the I_{DSS} of the FET. These can be purchased with this connection already made and in this case the devices are called current regulator diodes. An enhancement mode N channel MOSFET can be used in the circuits listed below.

The circuit of current source that we will use is as the following figure 3.6.

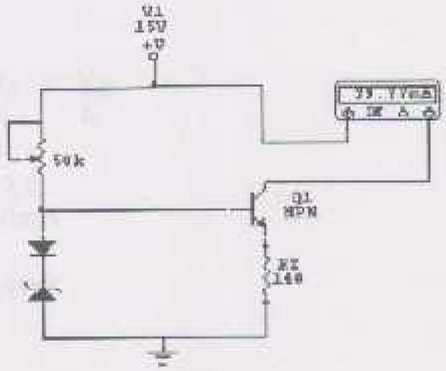


Figure 3.6: Current source circuit.

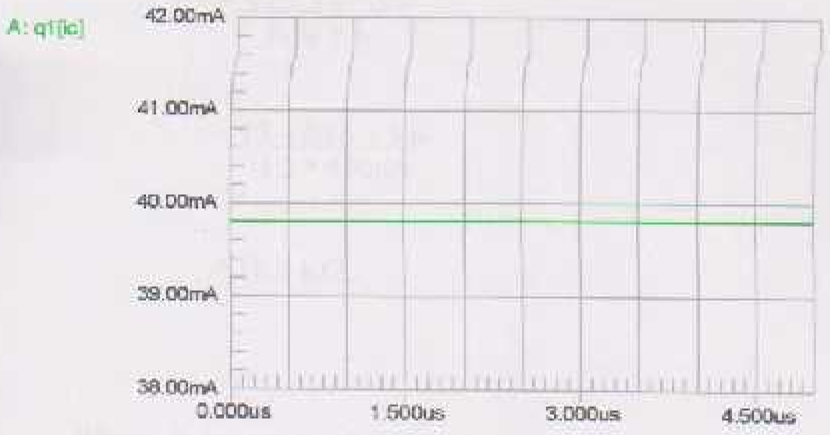


Figure 3.7: Simulation result for the current source circuit

This circuit including a standard diode D (of the same semiconductor material as the transistor) in series with the zener diode as shown in Figure(3.6) The diode drop (V_D) tracks the V_{BE} changes due to temperature and thus suppresses temperature dependence of the CCS.

Resistance R_2 is now calculated as

$$R_2 = \frac{V_Z}{I_{R2}} = \frac{V_Z}{I_C}$$

$$= \frac{5.6}{40\text{mA}}$$

$$= 140\Omega.$$

$$R1 = \frac{V_S - V_D - V_Z}{K\ I_B + I_Z}$$

$$= \frac{15 - 0.65 - 5.6}{1.2 * 400\mu A}$$

$$= 18.2\ K\Omega.$$

Where: Iz is very small (ignore).

$$I_B = I_C / B_F.$$
$$= 40mA / 100$$
$$= 400\ \mu A.$$

Chapter Four

Measuring Strategy

4. Measuring strategy

This chapter presents how the $V_f - T_j$ relationship for the power diode can be obtained, which called the calibration operation. And we show the other hardware that we use in the calibration operation and in the project. Such as current source and regulated heat plate and its design.

4.1 Calibration

Means; how to obtain the relation of junction temperature with related to the forward voltage across the power diode; which used to determine the junction temperature by measuring the forward voltage that varied within the temperature.

This step is necessary to derive the linear equation which describes the relation Tj as function of V_f at low sense current; the calibration will be done to the device one time or more times to get the specific relation $T_j = f(V_f)$ of this device at low sense current. By defining a specific value of V_f its easy to know the junction temperature directly from the curve or the equation. We can make calibration for other power devices at the same method.

The importance of selecting the small sense current:

1. To prevent an extra heating from the load current.
2. This current must be enough to make the diode forward biased.
3. To reduce the consumed power in the application of using a diode as sensor.
4. To have linear characteristics between forward voltage and junction temperature.

The hardware used in calibration was: device under testing: in our project we select a power diode for the simplicity.

Current source: we use an adjustable current source from 20 to 120 mA provide 1/1000 of the rated current of the power device (power diode).
We must note that the constant current through the sensor diode, generating a voltage which changes only with temperature.

Regulated heat plate: it's an adjustable temperature isolated heater used to provide many temperature values to the diode, for calibration operation see chapter 3.

Other devices will be the measuring devices:

- Sensitive Multimeter to measure the adjustable sense current to the desired value and the forward voltage of the diode.
- Thermometer to measuring the temperature of the heat plate or the diode junction.

4.2 Calibration procedures

The first step; in the calibration process is to select the value of the sense current. It must be large; enough to establish conduction in the body of the junction. At the same time, it must be low enough to allow the neglecting of the generated self-heating. In this work, sense currents amounted 1/1000 of the nominal load current of the sensed device. The next step; is the gradually adiabatic heating of the device till thermal equilibrium at each step is reached. Subsequently voltage versus temperature data pairs at fixed sense current is measured. The waiting period till a thermal equilibrium is established depends on the thermal capacity of the devices and the thermal resistance between the device and the environmental medium. However, these two parameters are usually unknown prior calibration, therefore reaching of the thermal equilibrium is determined when no more changes of the sensitive parameter for sufficient long time was detected.

Actually two calibration points are sufficient to establish a straight line as shown in figure 1.1. However, extension of the number of the data pairs and the range of the calibration temperature at which the device will be later stressed increases the accuracy. Also averaging of the sensed TSEP of different samples of the same type decreases the random error related to the manufacturing distribution. The calibration processes in this work are executed by using of temperature regulated heat plate where devices are mounted and gradually heated (see Figure 4.1). The first calibration data pair is usually obtained at room temperature where the last pair is obtained at the nominal T_j,max that will be reached in the cycling tests.

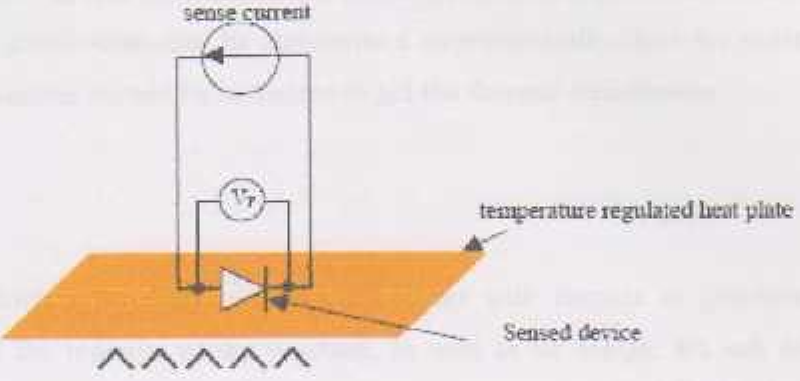


Figure 4.1: Calibration process

To avoid the inclusion of the voltage dropped at the current leading wires, it is important to measure the voltage across the device at the points where the current actually enters and leaves the die (Kelvin method).

The calibration which already done is practical for determining the junction temperature for a specific power device In the case at the junction is in operation state .That immediately after the device that contains the P-N junction diode should be turned off the calibration should applied to the specific P-N junction power diode. Then to measure the P-N junction temperature that relate the forward voltage.

Also calibration can be used to measure the temperature of many different applications that affected with heat, in other word as temperature sensor. That the temperature of P-N junction is equal to the temperature of the application somewhere.

An important consideration in the calibration operation is: the initial point is commonly measured at 25 °C, and then the device under test (DUT) is allowed to reach thermal equilibrium. A dwell time can be determined experimentally. But for most packages, a soak of 10 minutes should be sufficient to get the thermal equilibrium.

The point at which a junction becomes nonlinear with respect to junction temperature depends on the material of the junction, as well as its design. It's safe to assume linearity for most materials in normal operating environments up to 80° to 100°C. Nonlinearity can be determined experimentally by measuring the voltage at higher and higher ambient temperatures until there are a deviation from linearity. This relationship is nearly linear for most devices. It can be expressed mathematically as mentioned in chapter 1. [4,5,6] .

4.3 Expected Error of Calibration

One vitally important aspect of device calibration is the determination of accuracy and the typical error bounds for the temperature measurement. These errors branch from three sources:

1. **Random errors associated with TSEP measurement**: These random errors are those associated with making the electrical measurement. Proper shielding and grounding, instrument calibration, and an adequately sensitive TSEP will reduce these errors.

2. **Systematic errors in device calibration procedures**: Device calibration data is comprised of the TSP voltage and the corresponding temperature of the semiconductor. This semiconductor temperature is typically measured with an external contact sensor on the outside surface of a packaged semiconductor device figure 3.2. Depending on the time-temperature history of the device, the outside surface temperature may not be equal to the internal temperature of the semiconductor. This situation introduces a systematic error into the device calibration data.

3. **Accuracy of data representation**: These errors are associated with the formulation of the calibrating equation as a representation of the TSEP data. A calibration based on two data points will not reveal a non-linear TSEP characteristic, or provide the accuracy enhancement of data averaging over a range of temperature data. [9].

Chapter Five

Forward Voltage and Temperature Measurements

5. Forward Voltage and Temperature Measurements

In this chapter the taken data will be recorded and analyzed. This data is taken for four samples of power diodes two diodes (MBR4045) with rated current 40 amperes,45 volts and two diodes (SBD3040) with rated current 30 amperes, 40 volts, the data will be junction temperature with respect to the forward voltage at different values for each diode. The reason of taking two diodes of the same type and specifications is to obtaining more accurate curve.

5.1 Calibration measurements

The practical calibration as mentioned in chapter 4 applied on any power diode, done by applying forward constant current source with 1/1000 of the nominal current of the power diode, changing the junction temperature using the regulated heat plate and taking the forward voltages by digital voltmeter for different temperature values.

Figure 5.1 Practical calibration measurements.

5.1.1 Power diode MBR4045 calibration:

As mention, two samples of MBR4045 power diode are taken to calibrate and conclude to junction temperature relate to forward voltage curve and its equation. Where sense current applied to the diode is equal to 40mA. See Appendix .B.

A) First sample. Table 5.1 shows the first sample of MBR4045 power diode calibration results. The curve and equation of the linear line can be obtained using excel program. see figure 5.2.

Table 5.1: first sample of MBR4045 T_J, V_f measurements.

T_J(°C)	V_f(mV)
27.7	385
40.5	358
69.4	298
90.4	255

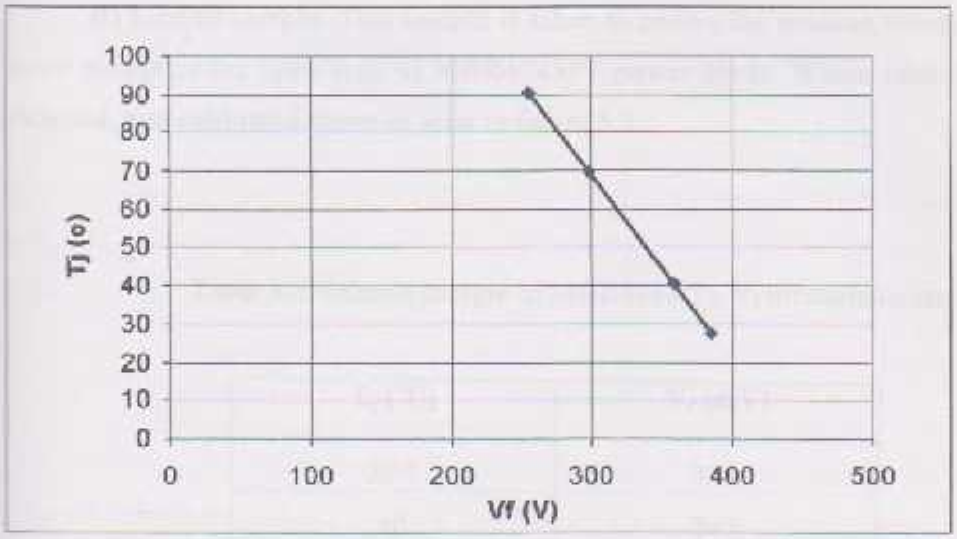


Figure 5.2: First sample of MBR4045 calibration curve.

The curve equation:

$$T_j = -0.4824 \times V_f + 213.29 \qquad \text{Eq(5.1)}$$

Where: T_j in Celsius.

: V_f in mV

Suppose that if this diode in operation, then directly applying the sense current of 40mA only, and taking the forward voltage (as example $V_f = 250\text{mV}$). From equation 5.1,

$$T_j = 92.69^{\circ}\text{C}.$$

B) Second sample. This sample is taken to ensure the measurements and calibrated curve results of the same type of MBR4045PT power diode. Where table 5.2 shows data obtained, and calibrated curve as seen in figure 5.3.

Table 5.2: Second sample of MBR4045 T_J, V_f measurements.

T_j (°C)	V_f (mV)
23.7	375
40	343
69.4	285
90.4	244

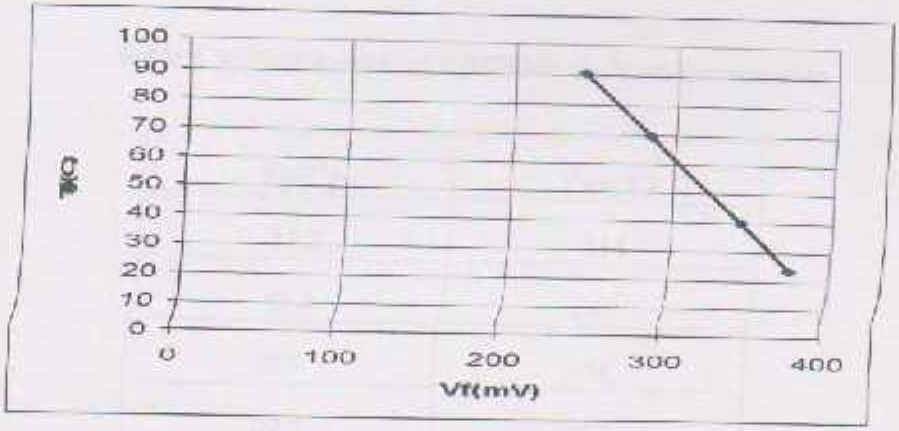


Figure 5.3: Second sample of MBR4045 calibration curve.

The curve equation:

$$T_j = -0.5088 \times V_f + 214.5 \qquad \text{Eq(5.2)}$$

If the forward voltage is equal to 250mV then Tj = 87.3°C.

5.1.2 Power diode SBD3040 calibration:

Also two samples of another power diode with 30A, 40V (SBD3040P) placed on the same condition of calibration, except sense current is equal to 30mA. To ensure that every power diode have calibrated linear curve different from another one.

A) First sample. Table 5.3 and figure 5.4 illustrates calibrated data (junction temperature with respect to forward voltage of power diode) and the linear line of that results data.

Table 5.3: First sample of SBD3040 T_J, V_f measurements.

T_j(°C)	V_f(mV)
22.2	314
45.4	269
79.7	204
99.2	167

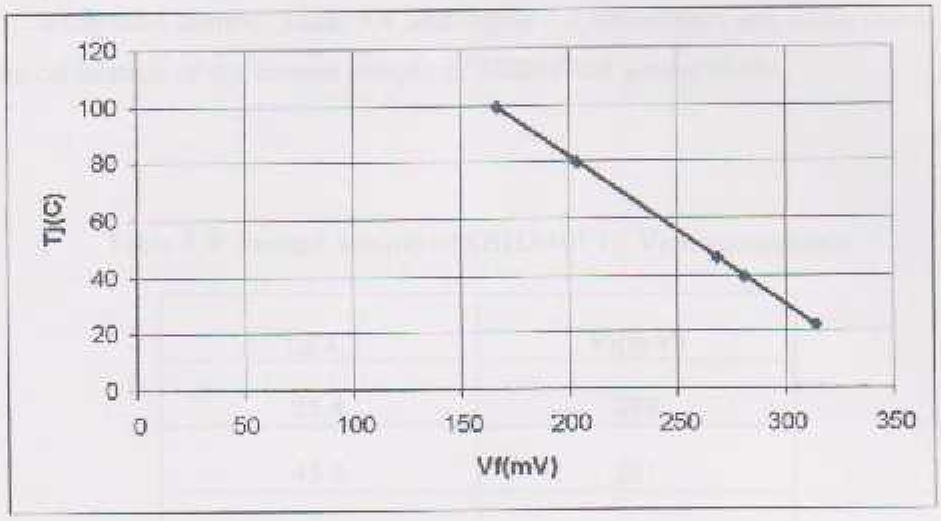


Figure 5.4: First sample of SBD3040 calibration curve.

The curve equation is:

$$T_j = -0.5242 \times V_f + 186.66 \qquad \text{Eq(5.3)}$$

If the forward voltage is equal to 250mV then

$$T_j = 55.61^\circ C$$

B) Second sample. Table 5.4, and figure 5.5 shows data and linear curve obtained from the calibration of the second sample of SBD3040P power diode.

Table 5.4: Second sample of SBD3040 T_J, V_f measurements

T_J(°C)	V_f(mV)
25.4	299
45.3	261
79.7	195
99.2	158

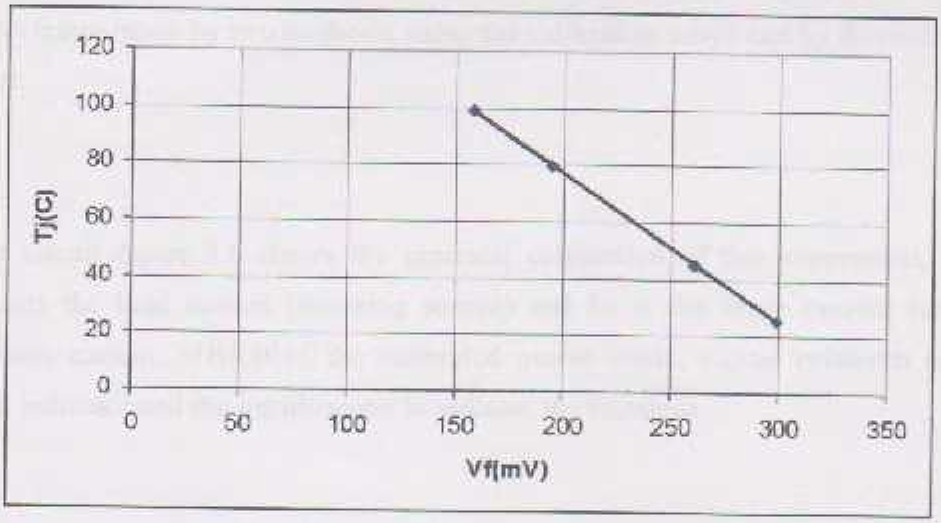


Figure 5.5: Second sample of SBD3040 calibration curve.

The curve equation is:

$$T_j = -0.523 \times V_f + 181.78 \qquad \text{Eq(5.4)}$$

So if the forward voltage measured (Vf) equal to 250mV. Then

$$T_j = 51.03.$$

5.2 Junction temperature at specific load current.

This experiment as one of practical application of this project that show the junction temperature by two methods: using the calibration curve and by thermal resistance concept.

The circuit figure 5.6 shows the practical connection of this experiment, where I_{S2} represents the load current (stressing source) and I_{S1} is the sense current same as the calibration current, MBR4045 the calibrated power diode, digital voltmeter as forward voltage indicator and the oscilloscope to indicate the transient.

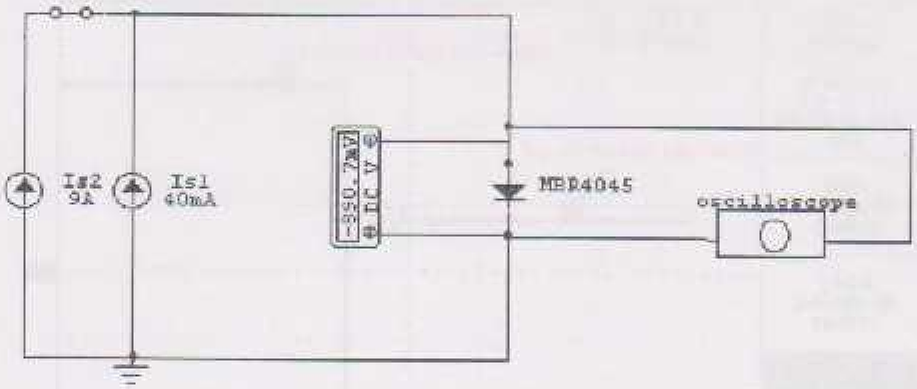


Figure 5.6: junction temperature at specific load current.

The two currents will be applied to the diode at the same time, that I_{S1} heat effect is neglected, after enough time of applying I_{S2} to rise the junction temperature to specific value; then S1 will opened and the forward voltage taken, at this time store oscilloscope must stopped to note the transient changes while S1 opened; the oscilloscope will show the output will be as figure 5.7.

Part one: Determining the junction temperature using the calibration equation:

Measured forward voltage: $V_F = 300\text{mV}$

Calculated junction temperature using equation 5.1.

$$T_j = -0.4824 \times 300 + 213.29$$

$$= 68.57^{\circ}\text{C}.$$

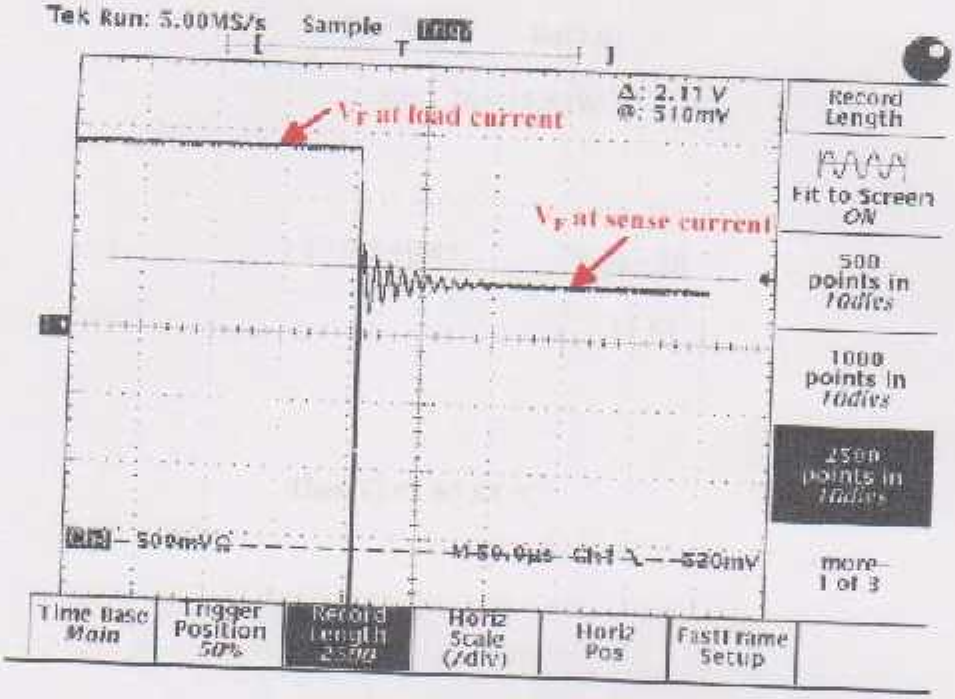


Figure 5.7: typical switching process and the correspondent voltage levels observed during thermal measurements of a power diode

Part tow: using thermal resistance concepts, junction temperature can be obtained as equation 5.5.

$$R_{thcj} + R_{thch} + R_{thhamp} = \frac{T_j - T_0}{P_d} \qquad Eq(5.5)$$

Where: R_{thcj} : thermal resistance between junction and case.

R_{thch}: thermal resistance between case and heatsink.

R_{thhamp}: thermal resistance between heatsink to ampient

$$Pd = V_f \times I_f \qquad Eq(5.6)$$

$$= 9 \times 1.76 = 15.84W$$

$$1.2 + 0.2 + 0.85 = \frac{T_j - 30}{15.84}$$

Then $T_j = 65.64$ °C.

$$\text{So the error is equal} = \frac{68.57 - 65.64}{65.64} = 4\%$$

Chapter Six

Applications

6. Applications

This chapter describes two main applications: using power diode as temperature sensor and define power diode temperature when it is in operation. Besides that it presents electronic thermometer description and diode demo circuit.

6.1 Overview

Semiconductor junctions have many verity applications from the millions of transistors used in ICs to the large-area compound junctions that make high-brightness LEDs possible power electronics so we must know the failure reasons; they have a in importance of failure due to an increasing in heat can all suffer early failure due to increased heat. This becomes an even larger issue when feature size shrinks and current requirements expand. Even normal operation can create heat buildup, raising the junction temperature. Such elevated temperatures may increase the amount of defects within the junction, decreasing performance and shortening lifespan.

Another method is to place a temperature sensor very close to the semiconductor junction and measure the sensor output signal. As the heat flows to the outside area, it would raise the temperature of the area and the sensor. Although a straightforward process, there are physical limitations due to the finite size of the sensor. In many cases, the sensor itself would be larger than the junction to be measured. It would add a large thermal mass to the system, as well as additional error to the measurement, thus degrading measurement accuracy. So this technique hardly helps most applications [4].

6.2.1 Diode as temperature sensor:

In this part of chapter we will show the usage of power diode calibration curve and equation to measure the temperature.

After making the calibration for a specific power diode, we can use the calibration curve produced to identify the forward voltage across the diode corresponding temperature of many practical applications, especially when the diode has better efforts in this side like:

1. When the other sensors is not practical to measure it.
2. Using the diode will be more accurate than other temperature sensor.
3. Low cost.
4. Excellent long term stability.
5. High sensitivity over limited temperature range (-55C to 150C)
6. Low power consumption.
7. The measuring circuit is simple.

A better solution is to employ the junction itself as a temperature sensor. With most materials, there's a strong correlation between the forward voltage drop of a junction and the temperature of that junction. Voltage differences on the order of 1 to 2 mV commonly indicate a 1°C change in junction temperature. This measured voltage is the V_{f1} at T_{J1} (25 °C).

The disadvantages of using a diode as temperature sensor:

1. Every device needs calibration process.

2. The produced curve actually not completely linear and we consider it as linear relation; so that causes a small error in measuring.

3. In this application we need an amplifier or sensitive measuring device to know the small changes in the forward voltage.

Temperature monitoring and control is a fundamental necessity of brewing. There are many kinds of thermometers available in practical measuring of the temperature. Each has advantages and disadvantages in their use. Mercury or alcohol thermometers can be very accurate but are prone to breakage if mishandled and usually must be read from the side, which make them impractical for checking temperatures deep inside a container. Dial thermometers offer good performance and accuracy, but often the dial scales are small and hard to read. Larger dial thermometers can be expensive and harder to find.

Electronic thermometers offer a direct numerical readout and use a remote sensing probe like diode, which allows one to easily read temperatures in difficult-to-reach areas. They can be home-built at low cost and rival or exceed the best dial thermometers in accuracy. Perhaps their best feature is that they provide a "front end" for electronic temperature controllers and other devices.

6.2.2 Electronic temperature sensors overview

There are many ways to sense temperature using electronic components. Thermistors are resistors whose resistance changes with temperature. They are relatively inexpensive and are useful in certain control applications, but they don't have a "linear" response to temperature, so accurate conversion of a thermostat's resistance to direct temperature readout is difficult for the hobbyist circuit builder. Thermocouples are little electrical "generators" whose voltage changes predictably with temperature, although again, they require special processing of their output to determine temperature.

Perhaps the best electronic sensor for our applications is a piece of silicon available in the form of a diode. A diode is an inexpensive electronic component designed to allow current to flow through it in one direction, but which blocks current attempting to flow in the opposite direction. Picture a diode as an electronic like in hydraulic science "check valve" allowing electrons (instead of fluid) to flow in one direction only. As current flows in the diode, a voltage builds across it. For a given diode, this voltage depends on two things: the amount of current flowing through it, and the diode's temperature. If we can establish a fixed and known current, we can assume that any changes in the diode voltage are due only to changes in temperature.

The change in the diode's voltage in response to temperature changes is very linear, so we've solved a big problem there. There are a couple of other problems though that will require addressing before we can use a diode in a direct-reading thermometer. First, most of the voltage cross the diode must be "subtracted" to leave only the part which changes proportionally to the temperature units we are interested in (normally degrees F or C). This "offset" voltage is roughly 0.5 to 0.7 volts. Next, the voltage change in response to temperature change is very small; about 1.22 thousandths of a volt (1.22 mV) per degree Fahrenheit (or 2.2 mV/deg C). Finally, the voltage drops as temperature rises, and rises as temperature drops. So in order to use a diode in a direct-reading thermometer, we must:

(1) Subtract the amount of voltage required to "leave" only the part that changes with temperature,

(2) Amplify or "scale" the remaining voltage change to match the desired readout in degrees.

(3) "Invert" or "reverse" the direction of change so that the voltage rises with rising temperature and vice-versa. Normally we would do these three things so that 10 millivolts of voltage equals one degree of temperature. This relationship allows direct temperature readout on a digital voltmeter while keeping the voltage levels reasonable.

6.2.3 Diode Demo Circuit

The simplest diode thermometer circuit is shown below. While not very practical, it does demonstrate the diode's accurate response to temperature. Actually, it can be used along with a sheet of graph paper, so you can measure the voltage and look up the temperature on the chart. Label your graph paper from 0C to 100C on the temperature scale, and 0.400 volts to 0.700 volts on the voltage scale.

In order to have the diode voltage respond only to temperature, we must fix the current at a constant unchanging level. The selected current a constant current, the exact value of the current is not almost important it better to be 1/1000 of the nominal value of diode current, and only the fact that it doesn't change.

Astute readers may wonder how we can maintain a constant current through the diode this way, when the diode voltage is changing with temperature. However, the slight change in current due to the change in diode voltage translates to a *very* small additional change in the diode voltage, so the error is negligible.

After you've wired the circuit, prepare a glass of ice water and a coffee mug with near-boiling water. Also get out your favorite, most accurate thermometer as a reference. Tie the sensor to the reference thermometer with a twisty and dunk them into the ice water. Allow them to settle for a few minutes to equilibrate with the surrounding temperature. With the thermometer and sensor still immersed, read the temperature from the reference thermometer and the voltage from the DVM. Write these numbers down. Now repeat using the hot water. You now have two data points. Mark them on the graph paper and carefully draw a straight line between them. Now you can simply read the voltage from the DVM, check the chart, and determine the temperature with great accuracy.

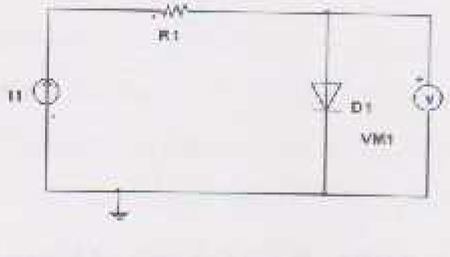


Figure (6.1) diode demo circuit

You can build a thermometer circuit using simple parts like a diode, small current source and measuring device. In addition, it's easy to add on to these circuits to create a complete temperature-control application in addition to a simple thermometer. A little skill in soldering is all that's needed.

Building a Probe: Let's start by building a temperature sensor probe using a diode. In actuality, we'll use a power diode, in TO- package. which has the leads all coming out from one side, so the "body" can be fully exposed to liquid on one end while the leads are protected and out of the way at the other end. Just be sure that the leads are fully protected from contact with liquid but leave the body exposed for fastest response to temperature.

Another thing to keep in mind is that every individual diode has its own particular voltage-versus-temperature characteristic. This means that if you should ever replace a probe, you must recalibrate your thermometer to "match" it to the new sensor. But as long as you always use the same sensor with the same circuit, you shouldn't need to recalibrate, although periodic checks are a good idea.

6.2.4 Direct-Reading Thermometer

To be truly practical, it would be nice to have the DVM read out directly in degrees rather than having to carry a chart around! However, if we equated one volt with one degree, boiling water at 212 degrees would require us to generate 212 volts, which would be difficult as well as dangerous! If we equate one degree to a more reasonable one *hundredth* of a volt (10 mV), the "digits" will be right; we'll just have to "ignore" the decimal point. A temperature of 145 degrees would then read 1.45 volts; 34 degrees would read 0.34V. This "scale factor" (10 mV per degree) is the industry standard for temperature sensors.

In order to do this, we must solve the three "problems" discussed earlier: we must subtract a large fixed voltage, invert the *direction* of change of the remaining voltage, and scale its rate of change. The thermometer will maintain its accuracy as long as the diode current doesn't change. The voltage regulator will maintain a constant output voltage as long as the source voltage is above about seven volts [8].

6.3 PN- junction temperature while in operation

The important consideration in systems design is the temperature of the pn-junction of the devices or diodes when the needs of design or monitor a normally operation of the diode like rectifiers, inverters which self heating due to the load current or the around environment, because the diode temperature has upper limit that when it reaches to causes diode failure due to disconnecting of the bond weirs which connect the pn-junction and the pines the value of the temperature may used as a feedback to the control system to remove the cause of the temperature – the load- automatically.

An accurate temperature-measurement method for semiconductor devices is needed to prevent critically high temperatures. One technique is a simple junction-temperature measurement that can be performed using the calibrated curve. Results of this measurement can be used to monitor operating conditions for a given device. The ideal way to measure junction temperature is to monitor the device temperature as close as possible to the heat source. Current flowing through a semiconductor junction produces heat, which then flows through the junction material to the outside world.

Another importance of measuring the temperature of the junction that the datasheets gives the maximum absolute temperature of the junction itself, so knowing the temperature of the junction very useful as feedback to the control circuit to reserve normally operation conditions to the real time application like rectifiers.

Once the junction reaches thermal equilibrium, a short-duration current (1/1000 of power diode rated current) is sourced into the device under test DUT. After turn off the device which has the power diode and that delivering a larger amount of power that may skew the results by heating the junction.

Many times, the junction-under-test is a silicon or compound diode. For these device types, a good starting point for experimentation is 1 ms of sourced current at a few milliamps of drive current. If you're unsure, the self-heating of the junction also can be determined experimentally by using a source capable of very short pulses (less than 1 ms). You can then experiment by varying pulse widths and comparing the voltages of each pulse duration. Voltage differences on the order of 1 to 2 mV commonly indicate a 1 °C change in junction temperature. This measured voltage is the V_{F1} at T_{J1} (25 °C).

When the diode used as switching device in normal operation, it will heated due to the load current or the surrounding environment this case failure, so we must monitor the junction temperature continuously to get an overview of its thermal behavior. The most significant method is to use the junction itself to determining its temperature.

The block diagram of this application shown in figure (6.2)

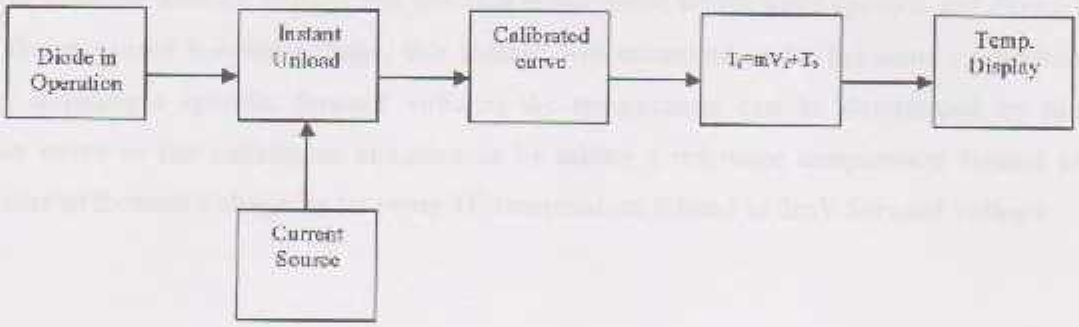


Figure (6.2) Block diagram of In Operation diode to determine T_j

Instant unload:

Turn off the heat cause -load- of the diode to applying the current source and satisfy the calibration condition, which the specific diode calibrated to get the forward voltage related to the temperature of the junction, then specifying the junction temperature.

Current Source

First we must wait a littlie time to ensure that the diode restore its natural conduction properties see sec(5.2), then applying the constant current source with small and constant calibrated current value to get forward voltage that compatible to calibration curve.

Calibrated carve

The resulting of calibrating curve from the calibration process which gives the linear relation between the forward voltage and junction temperature which has a specific and defined value of the measured forward voltage, this voltage will measured under the same calibration curve, by defining a specific forward voltage; the temperature can be determined by the calibration curve or the calibration equation or by taking a reference temperature related to known value of forward voltage by let every 1C temperature related to 2mV forward voltage.

Chapter Seven

Conclusions and Future work

7. Conclusions and Future work

This chapter presents the project conclusions; it also practical application of the results as will as presents suggestions and future work and.

7.1 Conclusions

There are two general methods to measure the junction temperature there are: direct (infrared camera, liquid crystal) and indirect (temperature sensitive electrical parameter) methods, and the direct methods have disadvantage over than indirect that the device must be opened or coated with suitable surface that results to destruct the device; so indirect method the is more practical , accurate and nondestructive.

The PN junction temperature of the power diode has linear inversely proportional to its forward voltage under low constant sense current. The current must be small enough to causes the power diode to conduct and to avoid its self heating. If the sense current has large values, the calibration curve will be not linear.

Every 2mV forward voltage of power diode approximately has 1°C junction temperature in calibrated curve obtained. That means there is a 2mV difference between specific temperature point (Tj) and (Tj+1) temperature.

When a specific temperature of a heater heats power diode; we must wait for about 20 minutes before measure the forward voltage in order to the equilibrium condition that case temperature is equal to the junction temperature.

Every power diode device have calibrated linear line curve (between forward voltage and temperature) differ from another one. So maybe some error happened in the same type of power diode due to manufacturing company, doping process and calibration operation.

Using power diode as a sensor is better than other temperature sensors; since it is more accurate, high sensitivity and low power consumption.

7.2 Recommendations and Future work:

Calibration process can be done for any power diode such as MBR4045PT power diode to obtain the linear line curve and calibrated curve between forward voltage and junction temperature where every power diode have different curve from the other.

Also calibration can be done for any power device - IGPT, MOSFET...-to have it's a specific calibrated curve, except that most power devices need to simple triggering circuit.

The lifetime of the power device measured by the number of the cycles which the device live, that the number of cycles determined using the power cycle test, Power cycling test can be obtained by designing a system; heating and cooling between two limited temperatures. Where heating done by loading current, and cooling done by cooling system as fan. This process done thousands times which needs a complete automatic heating-cooling system to determine the number of cycles which give the device life time.

The main reason of monitoring the temperature of power device is to protect it from the higher temperatures, to achieve this protection a feedback system can be built to return the forward voltage after unloading the device and applying a constant current source to a control circuit that removes the heat reason on the power device or drive a cooling system to return the temperature into its normal limit.

References:

1. Michel Nicolaidis, Yerant Zorian, Technology and Industrial Arts, 1998, page 85.

2. Raghbir Singh Khandpur, Biomedical Instrumentation, page 94.

3. www.Littlefuse.com , Application notes.

4. www.eleedsign.com , Articles

5. Dr. Raed Amro, Power cycling capability of advanced packaging and interconnection

technologies at high temperature swings, 2006, pages 58-64

6. Department of Defense USA, Test Methods Standard Semiconductor Devices, 1995, page 348.

7. www.eng.wikipedia.org , current sources.

8. Ken Sekwartz, Electronic Thermometers For Brewers, 1999.

9. Dr. John W. Sofia, Electrical Temperature Measurement Using Semiconductors, Analysis Tech.

10. Jason Chonko, Use Forward Voltage Drop To Measure Junction Temperature

, 2005

11. Tony R Kuphaldt, Pn-Junction as Temperature Sensor, FEEE.

12. 4 Evaldo M. Miranda, John A. Cleary and Elizabeth A. Lillis, Method And a Measuring Circuit for Determining Temperature From a PN Junction Temperature Sensor.

Appendix .A

Appendix. A:

Symbols and Constant

A.1 Symbols:

AC: Alternating Current.

ADC: Analog to Digital Converter.

CSS: Current Controller Source.

DC: Direct current.

DMM: Digital Multimeter.

DVM: Digital Voltmeter.

DUT: Device Under Test.

ETM: Electrical Test Method.

IC: Integrated Circuit.

I_d: Diode current.

I_s: Diode saturation current.

LED: Light Emitting Diode.

LSB: Least Significant Bit.

P_D: Heat flow rate between point junction and reference point

R_{th}: Thermal resistance.

$R_{th,JC}$: thermal resistance between the junction and the case.

$R_{th,ch}$: thermal resistance between the case and the heat sink.

$R_{th,hamb}$: thermal resistance between the heat sink and the ambient.

T_0: Temperature at reference point.

T_J: PN-junction temperature.

TSEP: Temperature Sensitive Electrical Parameter.

V_F: Forward voltage.

$V_{GE,th}$: gate emitter threshold voltage.

V_{ref}: Reference voltage.

V_t: Thermal voltage.

V_Z: Zener voltage.

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

Appendix .B

Datasheet

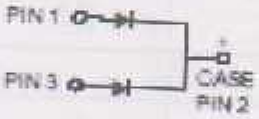
B.1 MBR4035PT - MBR4060PT

Features

- Low power loss, high efficiency.
- High surge capacity.
- For use in low voltage, high frequency
- inverters, free wheeling, and polarity protection applications.
- Metal silicon junction, majority carrier conduction.
- High current capacity, low forward voltage drop.
- Guard ring for over voltage protection.

Packaging

TO-3P/TO-247AD



Absolute Maximum Ratings

Symbol	Parameter	Value				Units
		4035PT	4045PT	4050PT	4060PT	
V_{RRM}	Maximum Repetitive Reverse Voltage	35	45	50	60	V
$I_{F(AV)}$	Average Rectified Forward Current .375 " lead length @ T_A = 125°C	40				A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	400				A
T_{stg}	Storage Temperature Range	-65 to +175				°C
T_J	Operating Junction Temperature	-65 to +150				°C

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JL}$	Thermal Resistance, Junction to Lead	1.2	°C/W

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Device				Units
		4035PT	4045PT	4050PT	4060PT	
V_F	Forward Voltage I_F = 20 A, T_C = 25°C I_F = 20 A, T_C = 125°C I_F = 40 A, T_C = 25°C I_F = 40 A, T_C = 125°C	0.70 0.60 0.80 0.75		0.72 0.62 - -		V V V V
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 125°C	1.0 100				mA mA
I_{RRM}	Peak Repetitive Reverse Surge Current 2.0 us Pulse Width, f = 1.0 KHz	2.0		1.0		A

B.2 SBD3040P

Description:	Center-Tapped Schottky Doubler.
V(RRM)(V) Rep.Pk.Rev Voltage:	40.
I(RM) Max.(A) Reverse Current:	10m.
V(R) (V)(Test Condition):	40.
I(RM) Max.(A) Pk. Rev. Current:	100m.
Temp. (°C) (Test Condition):	100.
I(FSM) Max.(A) Pk.Fwd.Sur.Cur:	300.
V(FM) Max.(V) Forward Voltage:	550m.
I(FM) (A) (Test Condition):	15.
I(O) Max.(A) Output Current:	30.
Temp (°C) (Test Condition) :	100.
Semiconductor Material :	Silicon.
Package Body Material:	Plastic.
Package :	TO-247.

B.3 LM35 (Precision Centigrade Temperature Sensors)

General Description

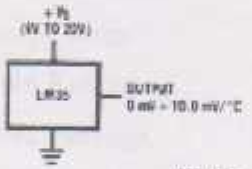
The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant 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



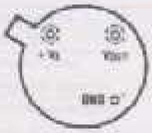
Basic Centigrade Temperature Sensor
(+2°C to +150°C)

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

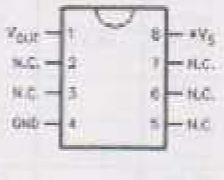
Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

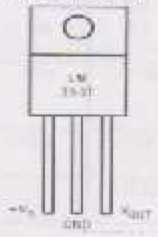


SO-8
Small Outline Molded Package



TO-92
Plastic Package

TO-220
Plastic Package*

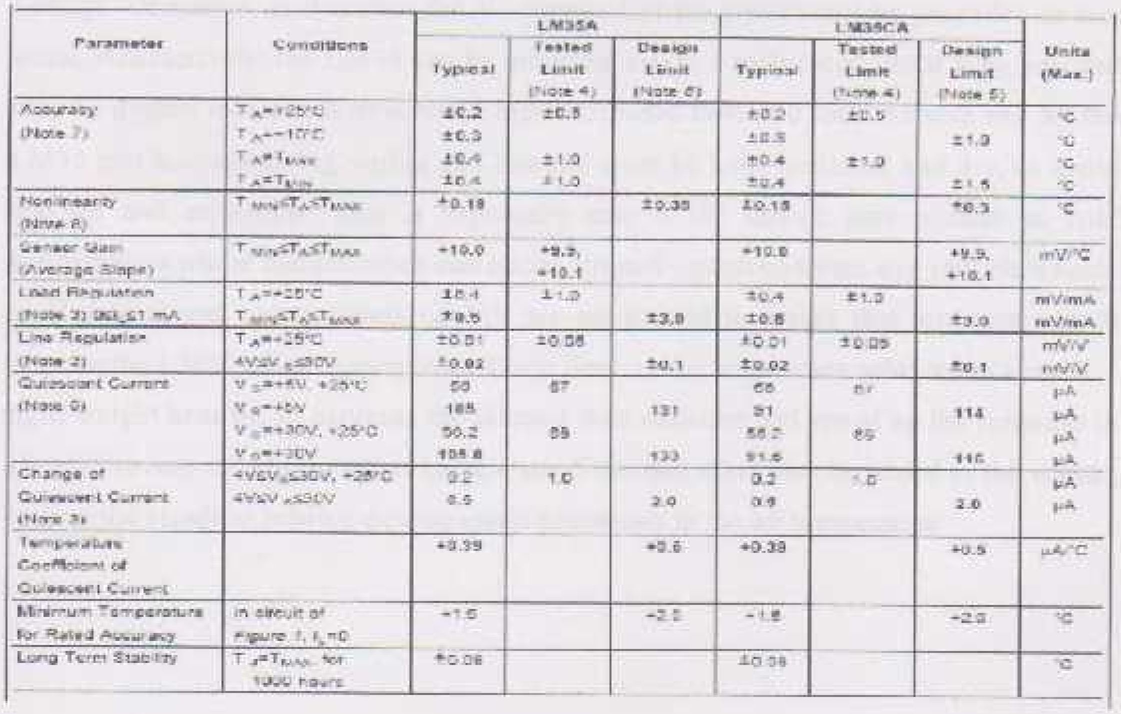


Absolute Maximum Ratings

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) $0\le I_L\le 1$ 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.

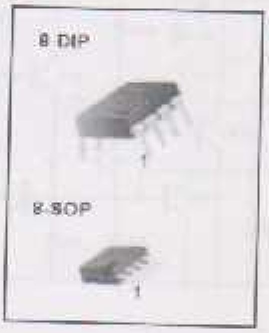
B.4 LM741 (Single Operational Amplifier)

Features

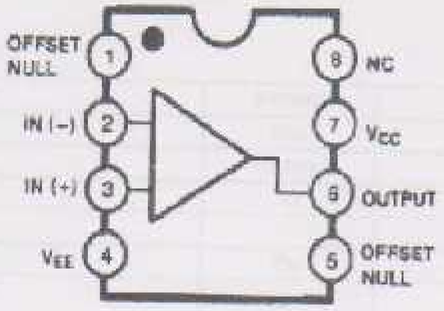
- Short circuit protection
- Excellent temperature stability
- Internal frequency compensation
- High Input voltage range
- Null of offset

Description

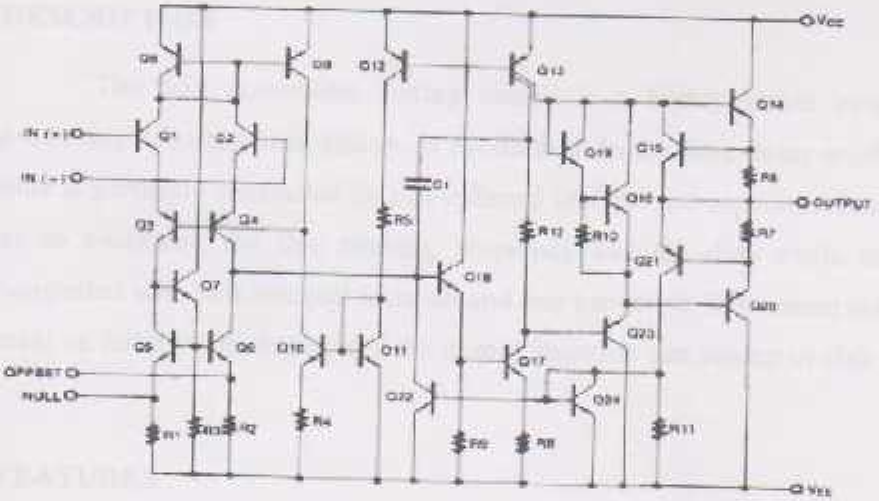
The LM741 series are general purpose operational amplifiers.It is intended for a wide range of analog applications.The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback application.



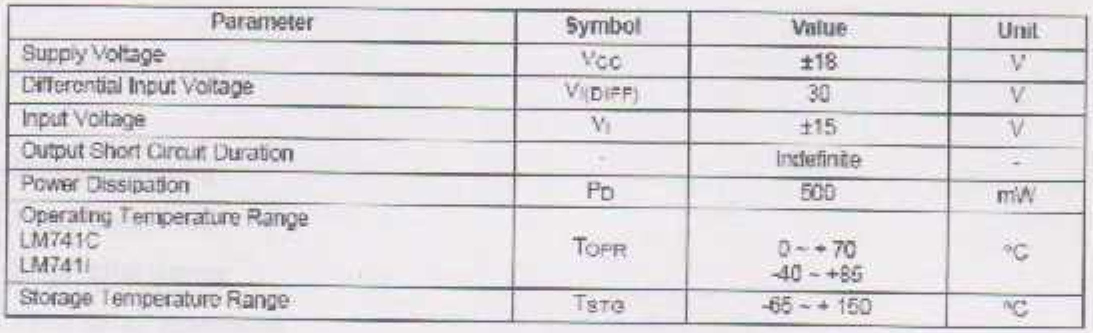
Internal Block Diagram



Schematic Diagram



Absolute Maximum Ratings (TA = 25°C)



Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	±18	V
Differential Input Voltage	$V_{I(DIFF)}$	30	V
Input Voltage	V_I	±15	V
Output Short Circuit Duration	-	Indefinite	-
Power Dissipation	P_D	500	mW
Operating Temperature Range LM741C LM741I	T_{OPR}	0 ~ + 70 -40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ + 150	°C

B.5 Timer (NE/SA/SE555/SE555C)

DESCRIPTION

The 555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200 mA.

FEATURES

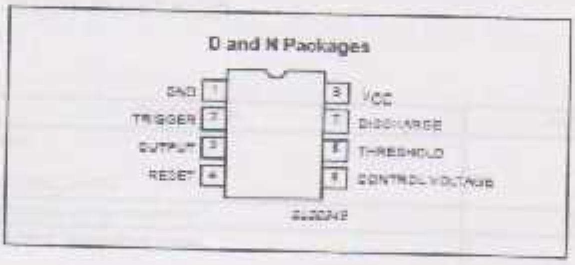
- Turn-off time less than 2 □s.
- Max. Operating frequency greater than 500 kHz.
- Timing from microseconds to hours.
- Operates in both a stable and mono stable modes.
- High output current.

- Adjustable duty cycle.
- TTL compatible.
- Temperature stability of 0.005% per □C.

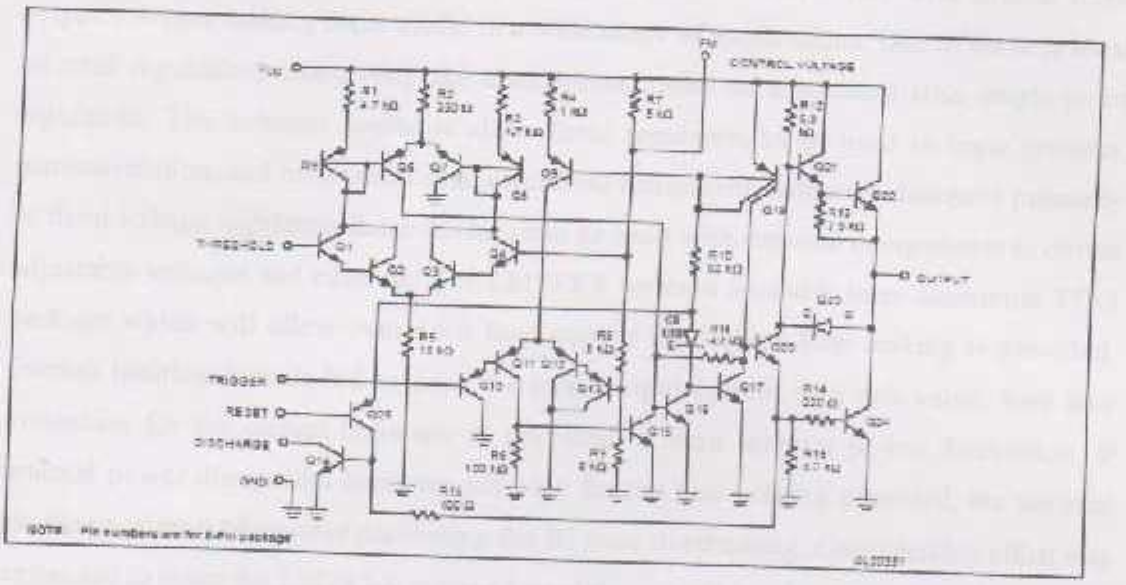
APPLICATIONS

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation

PIN CONFIGURATION



EQUIVALENT SCHEMATIC



NOTE: Pin numbers are for 8-Pin package

ABSOLUTE MAXIMUM RATINGS

SYMBOL	PARAMETER	RATING	UNIT
V_{CC}	Supply voltage SE555 NE555, SE555C, SA555	 +18 +16	 V V
P_D	Maximum allowable power dissipation[1]	600	mW
T_{amb}	Operating ambient temperature range NE555 SA555 SE555, SE555C	 0 to +70 −40 to +85 −55 to +125	 °C °C °C
T_{stg}	Storage temperature range	−65 to +150	°C
T_{SOLD}	Lead soldering temperature (10 sec max)	+230	°C

B.6 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

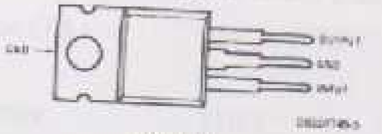
- Output current in excess of 1A.
- Internal thermal overload protection.
- No external components required.
- Output transistor safe area protection.
- Internal short circuit current limit.
- Available in the aluminum TO-3 package.

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

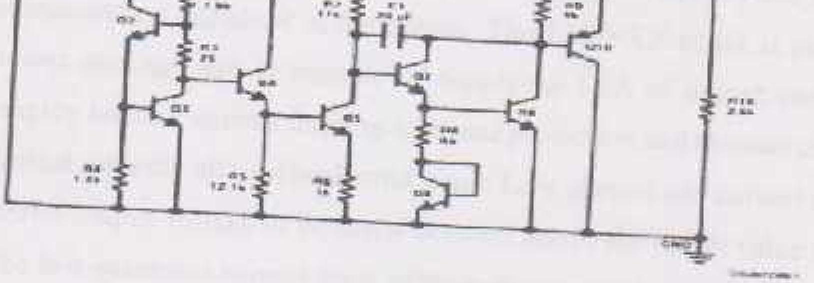
Connection Diagrams

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.

B.7 LM79XX Series (3-Terminal Negative Regulators)

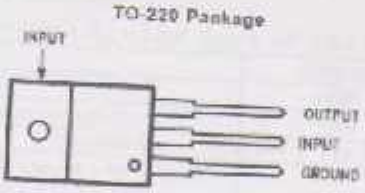
General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of −5V, −12V, and −15V. These devices need only one external component—a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current. These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions. Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode. For applications requiring other voltages, see LM137 datasheet.

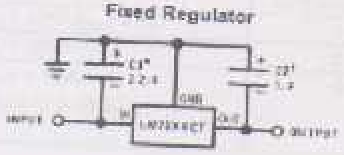
Features

- Thermal, short circuit and safe area protection.
- High ripple rejection.
- 1.5A output current.
- 4% tolerance on preset output voltage.

Connection Diagrams

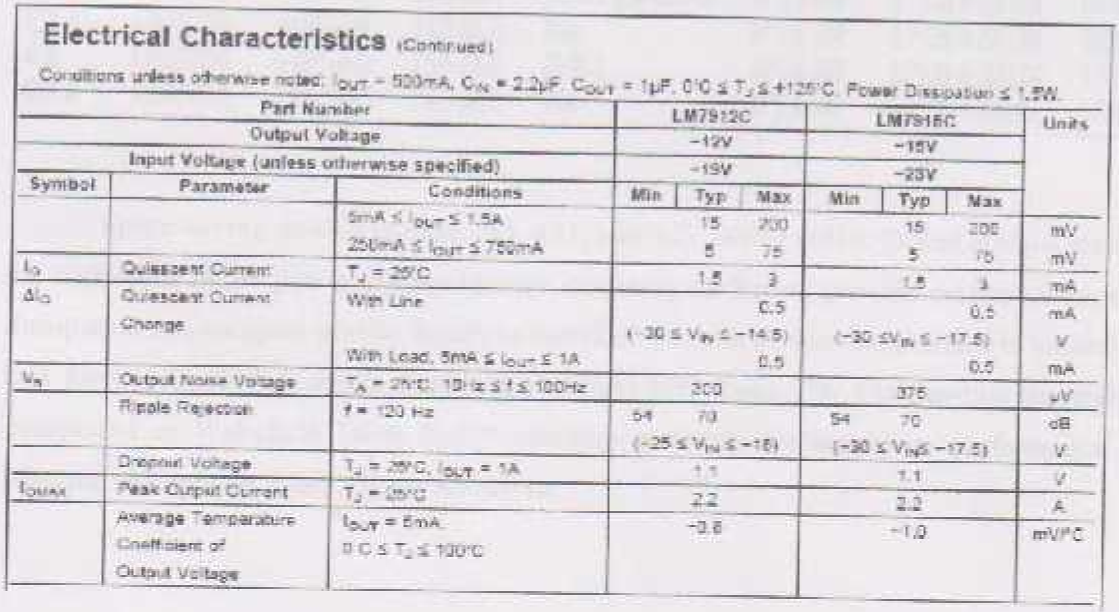


Typical Applications



Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted. Required for stability. For value given, capacitor must be solid tantalum. 25μF aluminum electrolytic may be substituted. Values given may be increased without limit. For output capacitance in excess of 100μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

Electrical Characteristics



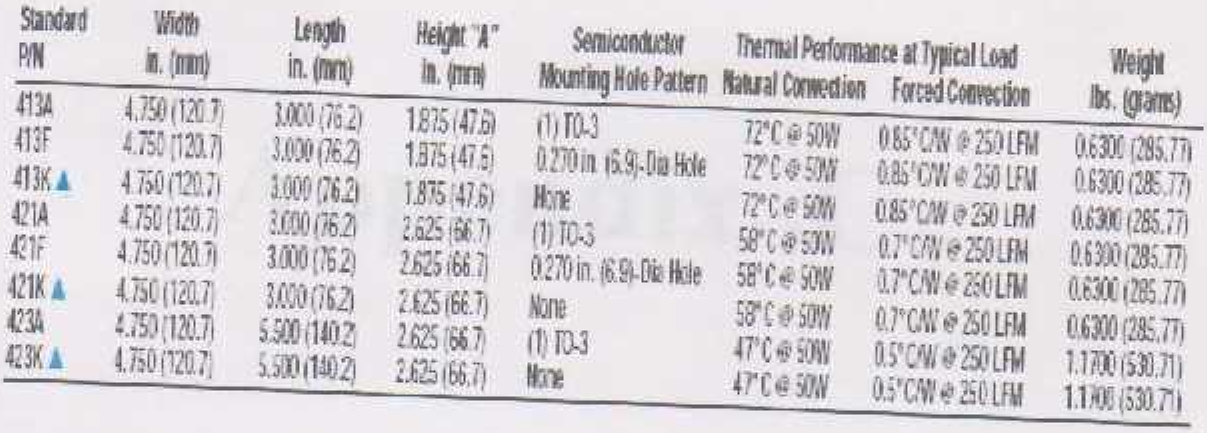
Electrical Characteristics (Continued)

Conditions unless otherwise noted: I_{OUT} = 500mA, C_{IN} = 2.2μF, C_{OUT} = 1μF, 0°C ≤ T_J ≤ +125°C, Power Dissipation ≤ 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	
		5mA ≤ I_{OUT} ≤ 1.5A		15	200		15	200	mV
		250mA ≤ I_{OUT} ≤ 750mA		5	75		5	75	mV
I_Q	Quiescent Current	T_J = 25°C		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Line			0.5			0.5	mA
			(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)			V
		With Load, 5mA ≤ I_{OUT} ≤ 1A			0.5			0.5	mA
V_N	Output Noise Voltage	T_A = 25°C, 10Hz ≤ f ≤ 100Hz		200			375		μV
	Ripple Rejection	f = 120 Hz	54	70		54	70		dB
			(−25 ≤ V_{IN} ≤ −15)			(−30 ≤ V_{IN} ≤ −17.5)			V
	Dropout Voltage	T_J = 25°C, I_{OUT} = 1A		1.1			1.1		V
I_{PEAK}	Peak Output Current	T_J = 25°C		2.2			2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5mA 0°C ≤ T_J ≤ 100°C		−0.8			−1.0		mV/°C

B.8 413/421/423 SERIES HEATSINK (Low-Height Double-Surface Heat Sinks for TO Case Styles and Diodes)

Nominal Dimensions and specifications



Standard P/N	Width in. (mm)	Length in. (mm)	Height "A" in. (mm)	Semiconductor Mounting Hole Pattern	Thermal Performance at Typical Load Natural Convection	Thermal Performance at Typical Load Forced Convection	Weight lbs. (grams)
413A	4.750 (120.7)	3.000 (76.2)	1.875 (47.6)	(1) TO-3	72°C @ 50W	0.85°C/W @ 250 LFM	0.6300 (285.77)
413F	4.750 (120.7)	3.000 (76.2)	1.875 (47.6)	0.270 in. (6.9)-Dia Hole	72°C @ 50W	0.85°C/W @ 250 LFM	0.6300 (285.77)
413K ▲	4.750 (120.7)	3.000 (76.2)	1.875 (47.6)	None	72°C @ 50W	0.85°C/W @ 250 LFM	0.6300 (285.77)
421A	4.750 (120.7)	3.000 (76.2)	2.625 (66.7)	(1) TO-3	58°C @ 50W	0.7°C/W @ 250 LFM	0.6300 (285.77)
421F	4.750 (120.7)	3.000 (76.2)	2.625 (66.7)	0.270 in. (6.9)-Dia Hole	58°C @ 50W	0.7°C/W @ 250 LFM	0.6300 (285.77)
421K ▲	4.750 (120.7)	3.000 (76.2)	2.625 (66.7)	None	58°C @ 50W	0.7°C/W @ 250 LFM	0.6300 (285.77)
423A	4.750 (120.7)	5.500 (140.2)	2.625 (66.7)	(1) TO-3	47°C @ 50W	0.5°C/W @ 250 LFM	1.1700 (530.71)
423K ▲	4.750 (120.7)	5.500 (140.2)	2.625 (66.7)	None	47°C @ 50W	0.5°C/W @ 250 LFM	1.1700 (530.71)

Space-saving double surface 413, 421, and 423 Series utilize finned surface area on both sides of the power semiconductor mounting surface to provide maximum heat dissipation in a compact profile. Ready to install on popular power components in natural and forced convection applications. Apply Wakefield Type 126 silicone-free thermal compound or Wakefield Delta Pad™ interface materials for maximum performance. Material: Aluminum Alloy, Black Anodized.

Appendix .C

Appendix .C

Mineral wool

Mineral wool, means fibres made from minerals or metal oxides, be they synthetic or natural. In industry use, MMMF (man-made-mineral-fibres) generally refer to synthetic materials. This includes fibreglass, ceramic fibres and also rockwool, also known as stone wool, and rock wool. Mineral wool is an inorganic substance used for insulation and filtering. A common mistake is to believe that fibreglass and ceramic fibres are NOT mineral wools, but they are by virtue of their consisting of minerals or metal oxides.

1. Manufacture of stone wool

Stone wool is a furnace product of molten stone, at a temperature of about 1600 °C, through which is blown a stream of air or steam. More high tech production techniques are based on spinning molten rock (lava) on high speed spinning wheels (compare with candy floss) The final product is a mass of fine, intertwined fibres with a typical diameter of 6 to 10 micrometres. Mineral wool may contain a binder, often phenol formaldehyde resin, and an oil to reduce dusting and making it water repellent (hydrophobic).

2. Usage

The fibres themselves are excellent conductors of heat, but they package air so well, that when pressed into rolls and sheets, rockwool makes for an excellent and reliable insulator. Batts, sheets and roll made of rockwool are a poor conductor of heat and sound. Fire resistive properties for mineral wools is given here in ascending order, from lowest to highest:

1. fibreglass,
2. stone wool,
3. ceramic fibres.

No conventional building materials, including mineral wool are immune to the effects of fire of sufficient duration or intensity. However, each of the aforementioned three wools make common components in passive fire protection systems, such as in spray fireproofing, stud cavities in drywall assemblies required to have a fire-resistance rating, packing materials in firestops and more.

Mineral wools are unattractive to rodents but will provide a structure for bacterial growth if allowed to become wet. Other uses are in resin bonded panels, growth medium in hydroponics, filler in compounds for gaskets, brake pads, in plastics in the automotive industry and as a filtering medium

3. Use in hydroponics

Mineral wool is used for its ability to hold large quantities of water and at the same time maintain a high percentage of air as well. This aids root growth and nutrient uptake. The fibrous nature of mineral wool also provides a good mechanical structure to hold the plant stable. Mineral wool has a high pH, which is unsuitable to plant growth. This requires correcting or **conditioning**. Conditioned mineral wool has a long, stable pH.

4. Safety of material

Precautions need to be taken when handling a fibre product as it can be absorbed into the body by inhalation. It can also irritate the eyes, skin and respiratory tract. Prolonged exposure could lead to long term effects and it is considered a possible carcinogen to humans. This effect may depend upon the fibre diameter and length, chemical composition and persistence within the body.

High bio soluble fibres (HT-fibres) are produced that do not cause damage to the human cell. IARC (the International Agency for Research on Cancer) has reviewed the carcinogenicity of man made mineral fibres in October 2002. These newer biosoluble materials have been tested for carcinogenicity and most are found to be non-carcinogenic, or to cause tumours in experimental animals only under very restricted conditions of exposure. The IARC Monographs working group concluded that only the more biopersistent materials remain classified by IARC as possible human carcinogens (Group 2B). These include refractory ceramic fibres, which are used industrially as insulation in high-temperature environments such as blast furnaces, and certain special-purpose glass wools not used as insulating materials. In contrast, the more commonly used vitreous fibre wools including insulation glass wool, rock (stone) wool and slag wool are considered not classifiable as to carcinogenicity to humans (Group 3).

The EU risk and safety phrases associated with this material in general are:

- R38 – Irritating to the skin
- R39 – Danger of very serious irreversible effects
- R40 – Possible risk of irreversible effects
- S36/37 – Wear suitable protective clothing and gloves.

All European produced rock (stone)wool and glass wool is bio soluble and R39 and R40 do not apply. For these products only the risk phrase R38 remains. This irritation to the skin however is not a chemical irritation but only a temporal mechanical irritation, comparable with exposure of the skin to straw, grass or hay.

Controversy exists over these rulings, as the majority of test results upon which they are based have typically been provided by the industry that makes the fibres. Test results that contravene such results were deemed inadmissible to IARC as submission by whistleblowers are not sanctioned by the party paying for the tests. Still by following common sense and industrial guidelines to prevent breathing of the fibres, it is possible to reduce the likelihood of pathology