SOLAR COOLING SYSTEM IN CAR

By

WAN NORAKMAL BT WAN MOHAMAD

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

SOLAR COOLING SYSTEM IN CAR

by

Wan Norakmal bt Wan Mohamad

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

Dr Taj Mohammad Baloch
Senior Lecturer
Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
31750 Tronoh
Perak Darul Ridzuan, MALAYSIA

Dr Taj Mohamad Baloch,
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Wan Norakmal bt Wan Mohamad

ABSTRACT

The purpose of this project is to design cooling system by implementing thermoelectric cooler (Peltier) to be applied in a car. This report consists of 3 major chapters which are Introduction, Literature review and Methodology. In average, people park their car at open parking space which exposed directly to sun. This situation will yield an uncomfortable situation and damage certain device in a car. Also, the readily available air conditioning system nowadays uses fuel which is frequently exposed to price hike. These lead to high maintenance cost of the car itself. These problems can be solved by developing a reliable Cooling System. As Malaysia adapts a sunny climate, it is very convenient to utilize Solar Power for Cooling System in Car. The main objective of the project is to design a system which implements a thermoelectric cooler, and eventually to construct prototype of Cooling System in a car. In order to accomplish that, many studies on Solar Cell, Thermal Cooling System, Thermoelectric Cooler and Battery Storage is done. To ensure the smoothness of this project. Methods, tools and software that are going to be used are determined in Methodology. Due to time constrain, the project will be implemented by stages where by stage 1(first semester) is Literature review , research , data gathering and calculations and stage 2 (second semester) is Design ,testing , prototype , installation and analysis.

ACKNOWLEDGEMENTS

I would like to thank Allah S.W.T. for giving me the opportunity to do this final year project and because of his mercies, I am successfully completed the project. Also, I would like to express my appreciation to University Technology of PETRONAS for providing the facilities and technical expertise to implement the project.

My appreciation is extended to my supervisor, Dr Taj Mohamad Baloch for the numerous hour of spending his time to assist in my project. His suggestions for this project are very valuable. Also, I would like to thank Dr Balbir Singh and Ms Siti Hawa bt Hj Tahir for their assistance during the development of the project. Without their contributions this volume may not have come to fruition.

Special thanks go to my family and friends for their endless moral support during the development of the project. There are others to thank; namely those with whom I did not have the pleasure of interacting personally, but whose contribution are extremely valuable, nevertheless.

TABLE OF CONTENTS

LIST OF TABLES viii
LIST OF FIGURES ix
LIST OF ABBREVIATIONS x

CHAPTER 1: INTRIDUCTION
1.1 Background of Study 1
1.2 Problem Statement 2
1.3 Objective and Scope of Study 2

CHAPTER 2 LITERATURE REVIEW AND THEORY
2.1 Photovoltaic 4
2.2 Solar Radiation in Malaysia 6
2.3 Thermoelectric Module(Peltier) 8
2.4 Cooling Load 9
2.5 Cooling System: Air to Air System 11
2.6 Heat Transfer 12

CHAPTER 3 METHODOLOGY 14

CHAPTER 4 ANALYSIS AND RESULT
4.1 Operation of the Cooling System 17
4.2 Solar Radiation 18
4.3 Photovoltaic System 20
4.4 Cooling Load Calculation 22
4.5 Analysis on Peltier 27
4.6 Temperature Controller Circuit 29
4.7 Temperature Display Circuit 30
4.8 Construction of Prototype 32

CHAPTER 5 DISCUSSION....36

CHAPTER 6 CONCLUSION AND RECOMMENDATION....38

REFERENCES....39

APPENDICES....40

APPENDIX A – Gantt Chart

APPENDIX B – 1. Table of Peak Solar Heat Gain through Ordinary Glass

2. Table of Shading Coefficient for Glass

APPENDIX C - Datasheet of Photovoltaic Panel

APPENDIX D - Hourly Global Radiation Data

APPENDIX E – Datasheet:-

1.LM358

2.LM308

3.LM335

4.ICL7107

LIST OF TABLES

Table 1 Summary on Result 19
Table 2 Specifications of PV 20
Table 3 The Voltage and Current consumption when Heatsink and Fan are used 28

LIST OF FIGURES

Figure1 Diagram of Photovoltaic Panel 5
Figure 2 Photovoltaic cells,Modules,Panels and Array 5
Figure 3 Photovoltaic System Components 6
Figure 4 Mean Solar Radiation in Malaysia 7
Figure 5 Schematic of Thermoelectric Cooler (Peltier) 8
Figure 6 Heat Flow Diagram 10
Figure 7 Air to Air System 11
Figure 8 Heat Transfer from surrounding into the Car 12
Figure 9 Flow Chart of Methodology 15
Figure 10 Designated Cooling System 16
Figure 11 Photovoltaic System 20
Figure 12 Schematic of Battery Charger 21
Figure 13 Interior Measurement of PERODUA KANCIL 23
Figure 14 Peltier Module 27
Figure 15 Schematic of Temperature Controller 29
Figure 16 Schematic of Temperature Sensor 30
Figure 17 Schematic of Temperature Display 30
Figure 18 The case for Peltier Module 33
Figure 19 3 Peltier Modules sandwiched between heat sink and fan 33
Figure 20 Peltier Modules in the case 34
Figure 21 Peltier Module placed under the seat(back of the car) 34
Figure 22 The blowing and sucking fan are placed in front of the car 34
Figure 23 Prototype (car) which cooling system is modeled 35

LIST OF ABBREVIATIONS

Symbol	Meaning	Units
A	Area	m^2
CLTD	Cooling Load Temperature Difference	
DC	Direct Current	
EWB	Engineering Work Bench	
ft	feet	ft
GLF	Glass Load Factor	K
I_{max}	Maximum Current	A
K	Kelvin	K
kW	Kilowatt	kW
MJm^{-2}	Mean Joule per meter square	MJm^{-2}
^oC	Degree Celsius	^oC
P	Power	W
PV	Photovoltaic	
Q	Cooling Load	
SC	Shading Coefficient	
SHGF	Solar Heat Gain Factor	
TEC	Thermoelectric Cooler	
U	Heat Transfer Coefficient	W/m^2K
V	Voltage	v
Ω	Ohm	Ω

CHAPTER 1
INTRODUCTION

Associated with the Electrical and Electronics Engineering technological development, the world is now moving towards nanotechnology applications. Such application leads to research in thermoelectric one of which can be used as cooler in the car compartment, where the thermoelectric will be solar powered .The project innovation is to design a Cooling System utilizing thermoelectric cooler to be implemented in a car.

1.1 Background of Study

The sun is a source of practically unlimited energy, most of which is wasted but nevertheless provides with millions kilowatt of power to be utilized by human being. Nowadays, solar power has become one of the energy for human life. The use of solar power is also very clean and environmental friendly and only requires little maintenance as it has no rotational part. Photovoltaic panel is the example of the sun energy which produces electricity directly from the sun.

Thermoelectric coolers are solid state heat pumps used in applications where temperature stabilization, temperature cycling, or cooling below ambient are required. There are many products which use thermoelectric coolers, including CCD cameras (charge coupled device), laser diodes, microprocessors, blood analyzers and portable picnic coolers. Thermoelectrics modules are based on the Peltier Effect, discovered in 1834, by which DC current applied across two dissimilar materials causes a temperature differential.

1.2 Problem Statement

With the rapid growth of Malaysia's economy, car becomes a necessity rather than a symbol of luxury. With Malaysia's climate, car owners have to live with overheated compartments if they park their car under the sun. The problem with overheating is that it can damage several equipments in the car. Even if the car is running, the air condition system in the car uses fuel as the main energy drive. The price hike of fuel is a burden to the car owner because apart of the air condition system, the engine of the car also depends on the fuel as the main energy drive. Both of these problems lead to waste of money and high maintenance of the car itself.

1.3 Objective and Scope of Study

The objectives of this project are:

a) To study and design a cooling system that utilize the Solar Energy

b) To study the implementation of Thermoelectric Module in the Cooling System

c) To construct a prototype of cooling system in a car

The scopes of study of the project are

a) The solar cell operation and its system

b) Analysis on thermal cooling system on real application

c) Cooling Load Analysis

d) Thermoelectric Cooler (TEC)

e) Battery Storage

f) Circuit design and assemblage

g) Prototype design and construction

CHAPTER 2

LITERATURE REVIEW AND THEORY

The cooling system will consists of PV, battery as power and storage, battery charger to prevent overcharging , a temperature controller including temperature sensor for temperature difference measurement, thermoelectric cooler (TEC), and temperature display to provide monitoring. The PV panel will collect the solar energy and convert it to electrical energy – the direct current (DC). The DC current will straight away energize the cooling system in the car. Whilst energizing the circuit, the PV will also charge the battery and stores the excess energy in the battery. The electrical energy in the battery is used to energize the controlling unit if the PV power produced is not sufficient.

2.1 Photovoltaic

Photovoltaics (PV) are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads.

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.(refer to Figure 1).[1]

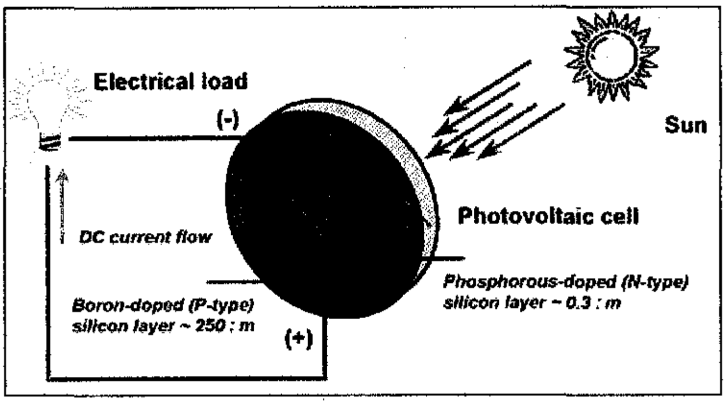


Figure 1: Diagram of Photovoltaic Cell [1]

Photovoltaic cells are connected electrically in series or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building block of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

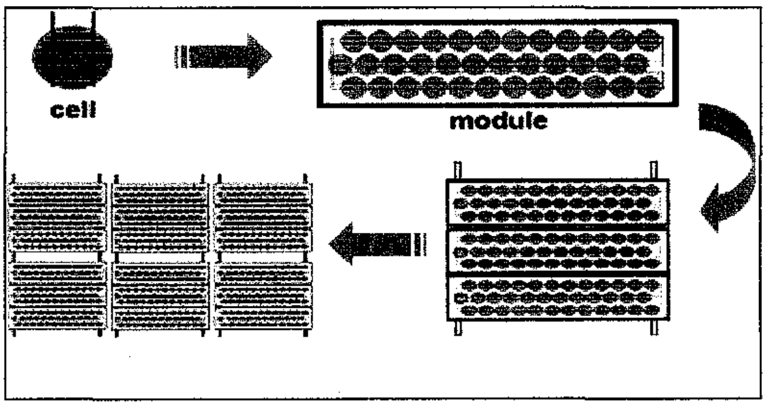


Figure 2: Photovoltaic cells, modules, panels and arrays [1]

PV systems are like any other electrical power generating systems but the equipment used is different than that used for conventional electromechanical generating systems.

However, the principles of operation and interfacing with other electrical systems remain the same. Although a PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.

Depending on the functional and operational requirements of the system, the specific components required, a DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and sometimes the specified electrical load (appliances). In addition, an assortment of balance of system (BOS) hardware, including wiring, overcurrent, surge protection and disconnect devices, and other power processing equipment. Figure 3 show a basic diagram of a photovoltaic system and the relationship of individual components.

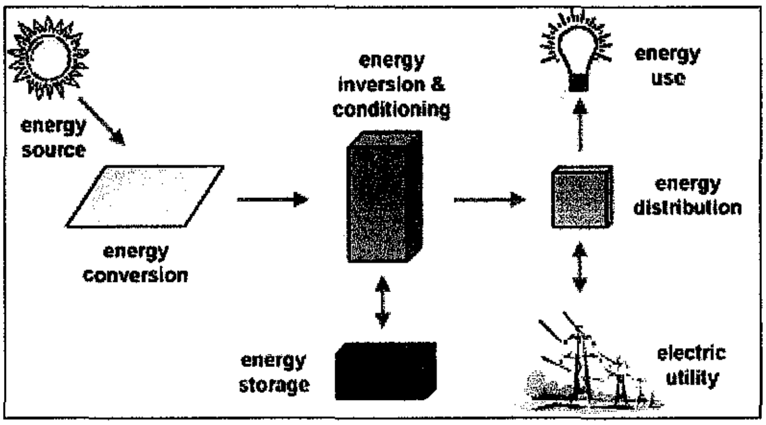


Figure 3: Photovoltaic System Components.[1]

2.2 Solar Radiation in Malaysia

Solar radiation originates from the sun, which can be taken as a sphere of intensely hot gaseous matter. Solar radiation is the electromagnetic radiation emitted by the sun, where most of the radiation is in the broadband solar radiation wavelength region of 280 nm to 4000 nm.[2]

In general, the second decade of March 2006 shows that the country recorded normal solar radiation. Meanwhile, central Pahang and western Sarawak recorded much above normal of solar radiation. In terms of solar radiation amount as shown in Figure 5, most parts of the Peninsular Malaysia and Sabah recorded solar radiation amount of 20-24MJm^{-2}, whereas other parts of the country recorded the amount of 16-18 MJm^{-2}. South Perak, northwest Pahang, and most parts of Selangor, Negeri Sembilan, Malacca and Sarawak had lower solar radiation between 16.5 and 19 MJm^{-2} per day. On the other hand, most parts of Kedah, Perlis, Penang, Terengganu and northeast Pahang had higher solar radiation between 24 and 24.6MJm^{-2}per day. [3]

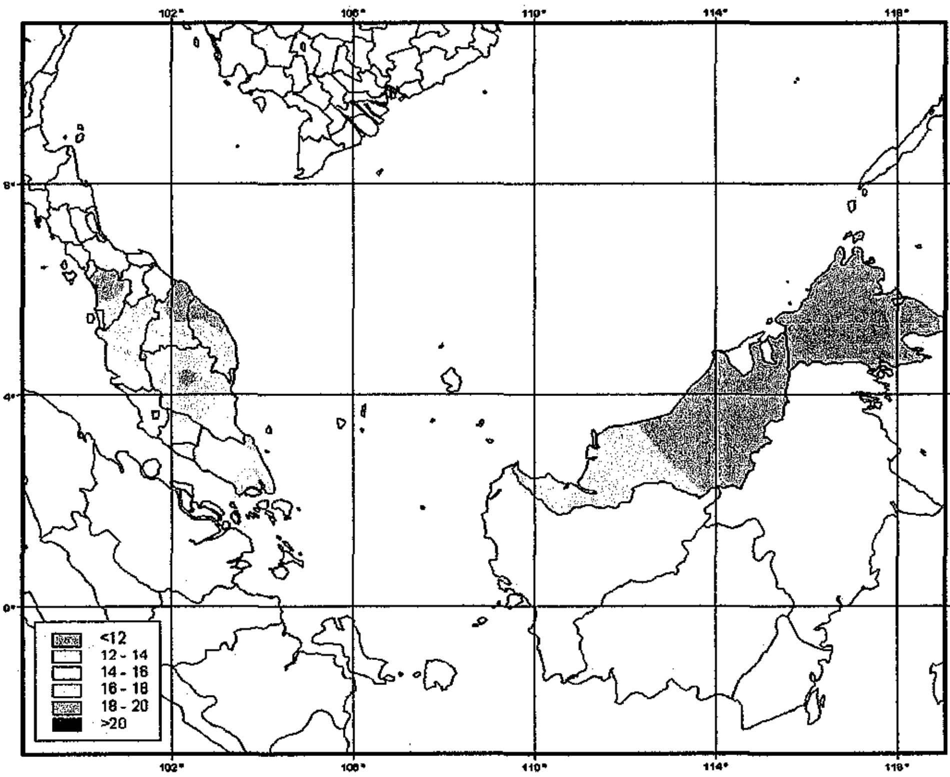


Figure 4: Mean Daily Solar Radiation (MJm$^{-2)}$ [3]

2.3 Thermoelectric Module

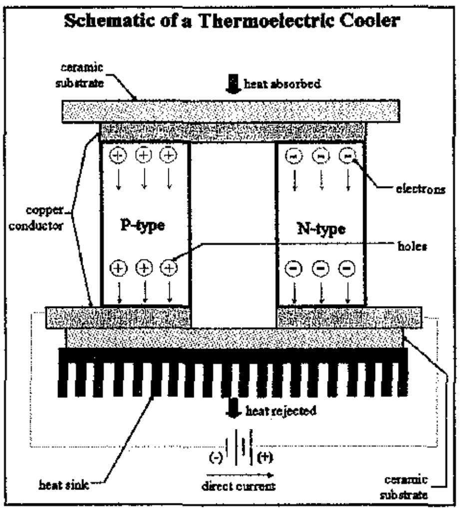


Figure 5: Schematic of Thermoelectric Cooler [4]

Thermoelectric modules or as known as Peltier modules (from now on will be refer as Peltier) are solid-state heat pumps that operate on the Peltier effect (The phenomenon whereby the passage of an electrical current through a junction consisting of two dissimilar metals result in a cooling effect). A thermoelectric module consists of an array of p- and n-type semiconductor elements heavily doped with electrical carriers. The array of elements is soldered so that it is electrically connected in series and thermally connected in parallel. This array is then affixed to two ceramic substrates, one on each side of the elements As electrons flow through one pair of n- and p- type elements (often referred to as a "couple") within the thermoelectric module: Electrons can travel freely in the copper conductors but not so freely in the semiconductor. As the electrons leave the copper and enter the hot-side of the p-type, they must fill a "hole" in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process. Essentially the holes in the p-type are moving from the cold side to the hot side. Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are bumped back to a higher energy level and absorb heat in the process.

Next, the electrons move freely through the copper until they reach the cold side of the n-type semiconductor. When the electrons move into the n-type, they must bump up an energy level in order to move through the semiconductor. Heat is absorbed when this occurs. Finally, when the electrons leave the hot-side of the n-type, they can move freely in the copper. They drop down to a lower energy level and release heat in the process.[4]

In summary, heat is always absorbed at the cold side of the n- and p- type elements. The electrical charge carriers (holes in the p-type; electrons in the n-type) always travel from the cold side to the hot side, and heat is always released at the hot side of thermoelectric element. The heat pumping capacity of a module is proportional to the current and is dependent on the element geometry, number of couples, and material properties.

2.4 Cooling Load

The air inside a car receives heat from number of sources from surrounding. If the temperature and humidity are to be maintained at a comfortable level, this heat must be removed. The amount of heat that must be removed is called Cooling Load. The Cooling Load is defined as the rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. In this context, the energy means the Quantity of Heat that need to be removed in the car in order to maintain the temperature inside the car per designed value.

The amount of heat that must be removed (cooling load) is not always equal to the amount of heat received at given time. This difference is a result of the heat storage and time lag effects. Of the total amount of heat entering the car at instant, only a portion of it heats the car air immediately .The other part heats the car mass – the roof, walls, floors, and furnishings. This is the heat storage effect. Only at a later time does the stored heat portion contribute to heating the car air. This is the time lag effect, as shown in figure below. [5]

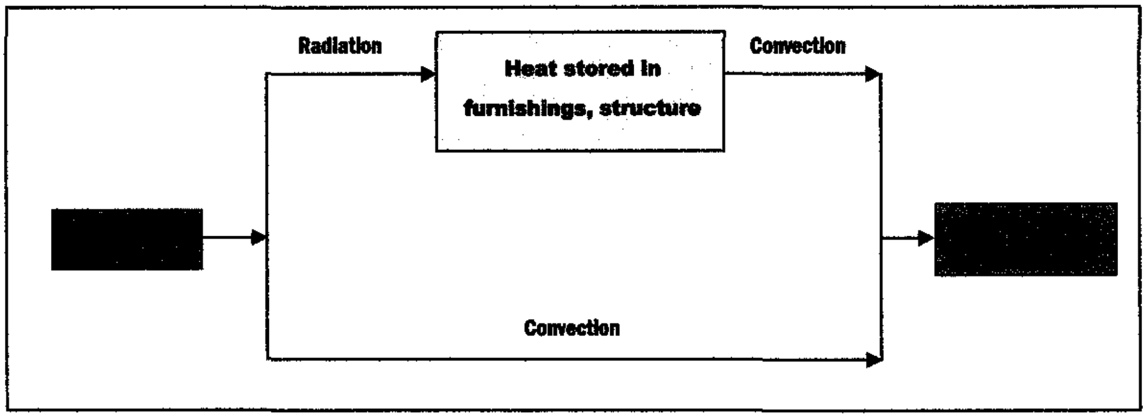


Figure 6: Heat flow diagram showing Heat Gain, Heat Storage and Cooling Load [5]

2.5 Cooling System: Air to Air system (AA)

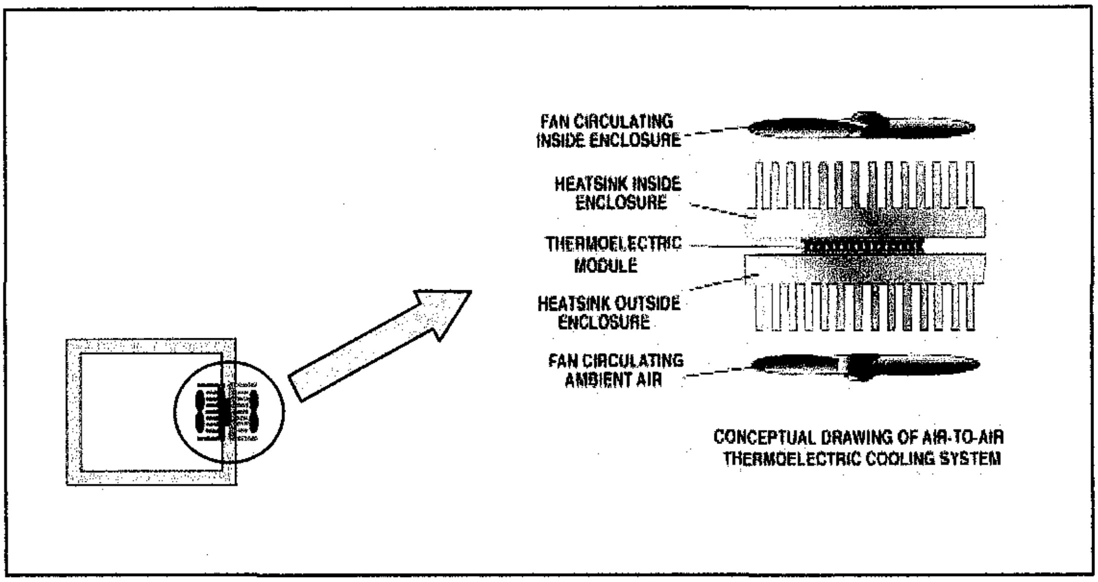


Figure 7: Conceptual Design of Cooling System

In this project, the cooling system that will be used is AA. Generally the basis of this cooling system is, air in an enclosure is cooled and the heat is dispersed to the surrounding air.

Figure 7 is a typical thermoelectric system designed to cool air in an enclosure .Here the challenge is to 'gather' heat from the inside of the box, pump it to a heat exchanger on the outside of the box, and release the collected heat into the ambient air. Usually, this is done by employing two heat sink/fan combinations in conjunction with one or more Peltier device.

The smaller of the heat sinks is used on the inside of the enclosure; cooled to a temperature below that of the air in the box, the sink picks up heat as the air circulates between the fins. In the simplest case, the Peltier device is mounted between this 'cold side' sink and a larger sink on the 'hot side' of the system. As direct current passes through the thermoelectric device, it actively pumps heat from the cold side sink to the one on the hot side. The fan on the hot side then circulates ambient air between the sink's fins to absorb some of the collected heat. Note that the heat dissipated on the hot side not only includes what is pumped from the box, but also the heat produced within the Peltier device itself (V x I). [4]

2.6: Heat Transfer

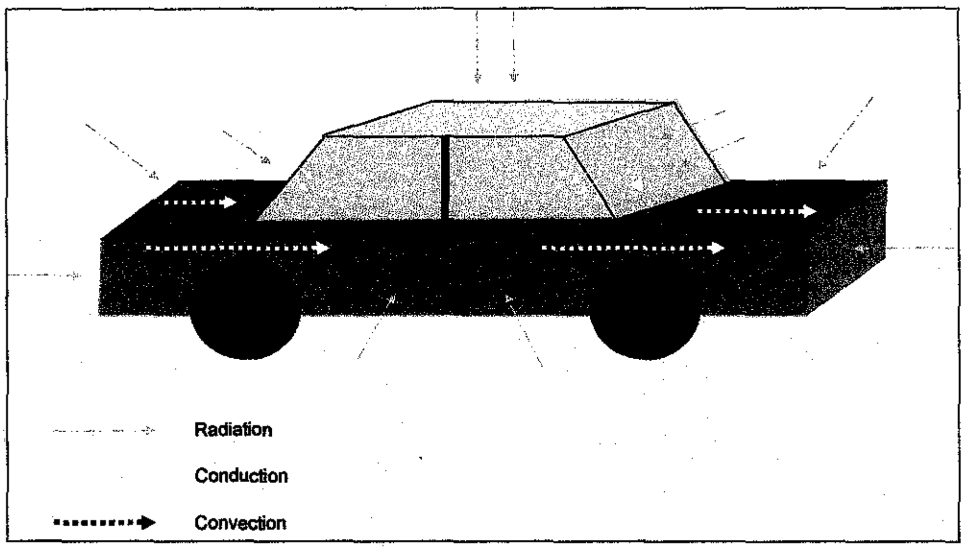


Figure 8: Heat transfer from surrounding into the car

Heat load inside the car is of a passive heat load, which is parasitic in nature and may consist of radiation, convection and conduction. The radiation from the sun heats the air of the atmosphere .Heat gained by conduction or radiation from the sun is moved about the planet by convection. Convection is heat transfer by the movement of mass from one place to another. It can take place only in liquids and gases. Radiation is the only way heat is transferred that can move through the relative emptiness of space. All other forms of heat transfer require motion of molecules like air or water to move heat.

The heat transfer in the car is initialized by Radiation from the sun. Then, the heat is transferred through conduction from the metal part (chassis) to the interior of the car, namely insulator at the roof, insulator at the door, seat and dashboard of the car. The heat transferred to the interior is then transferred through convection to the car compartment. Over certain period, the heat will accumulate and temperature inside the car will rise.

CHAPTER 3
METHODOLOGY

This project will be implemented in duration of 2 semesters. The project will be implemented by stages as listed below:

First semester: Literature review / research / data gathering / calculations

Second semester: Design / testing / prototype / installation / analysis

3.1 Literature review and research

Literature review and research will be done by seeking information through books, internet and journals. The stage provides important and useful knowledge for design stage.

3.2 Data Gathering

All the relevant information obtained from research for this project are gathered and revised.

3.3 Sizing and Calculation

The determination of component sizes, number of component used and amount of parameter of supply and load will be calculated during this stage.

3.4 Design

The design software (EWB) will be used to ensure the efficiency and accuracy of the design.

3.5 Testing, Prototype and Installation

This is the stage where prototype will be developed. The testing is done to ensure the devices function well. After that, prototype will be developed and installed.

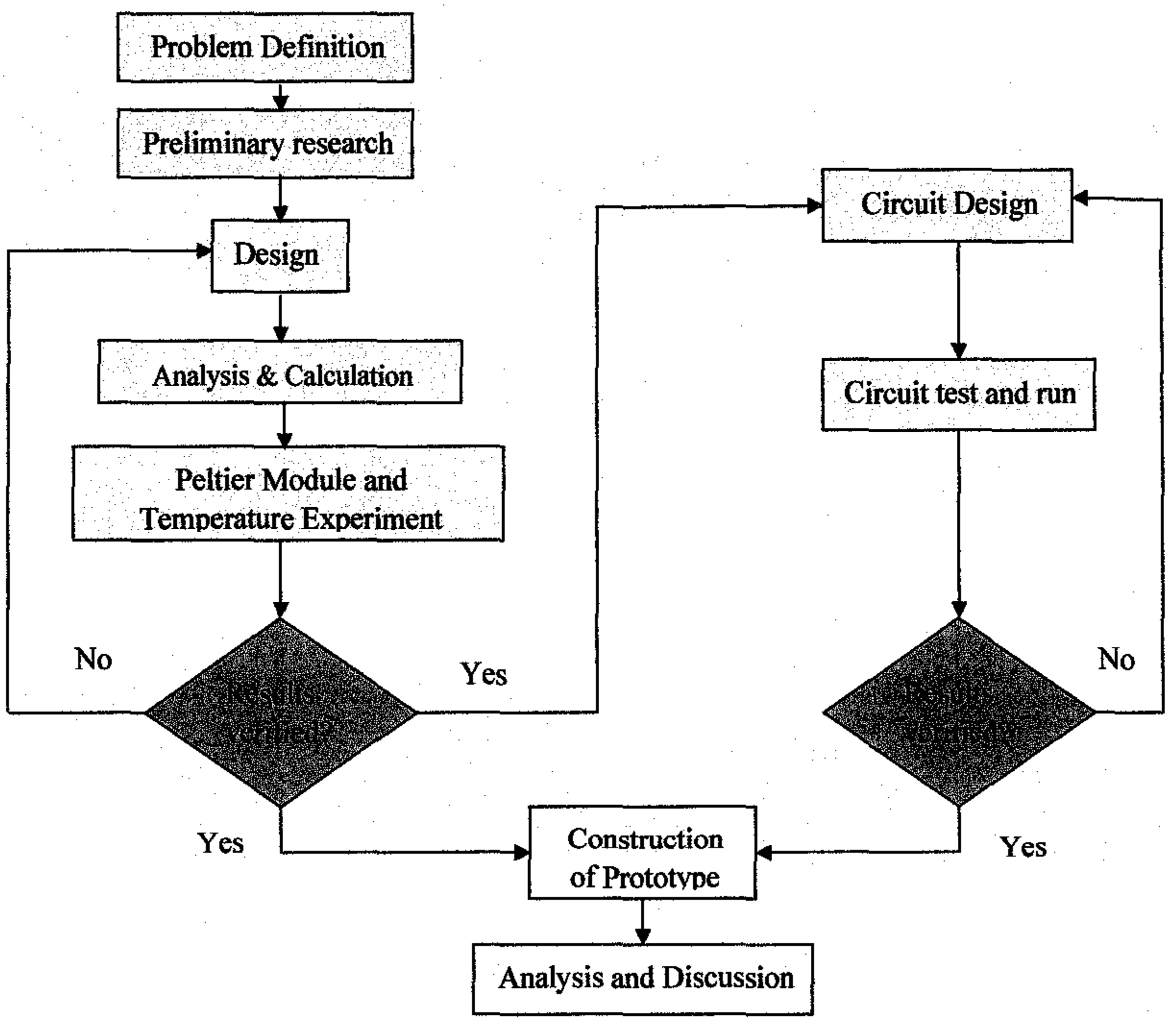


Figure 9: Flow Chart of Methodology

CHAPTER 4
ANALYSIS & RESULTS

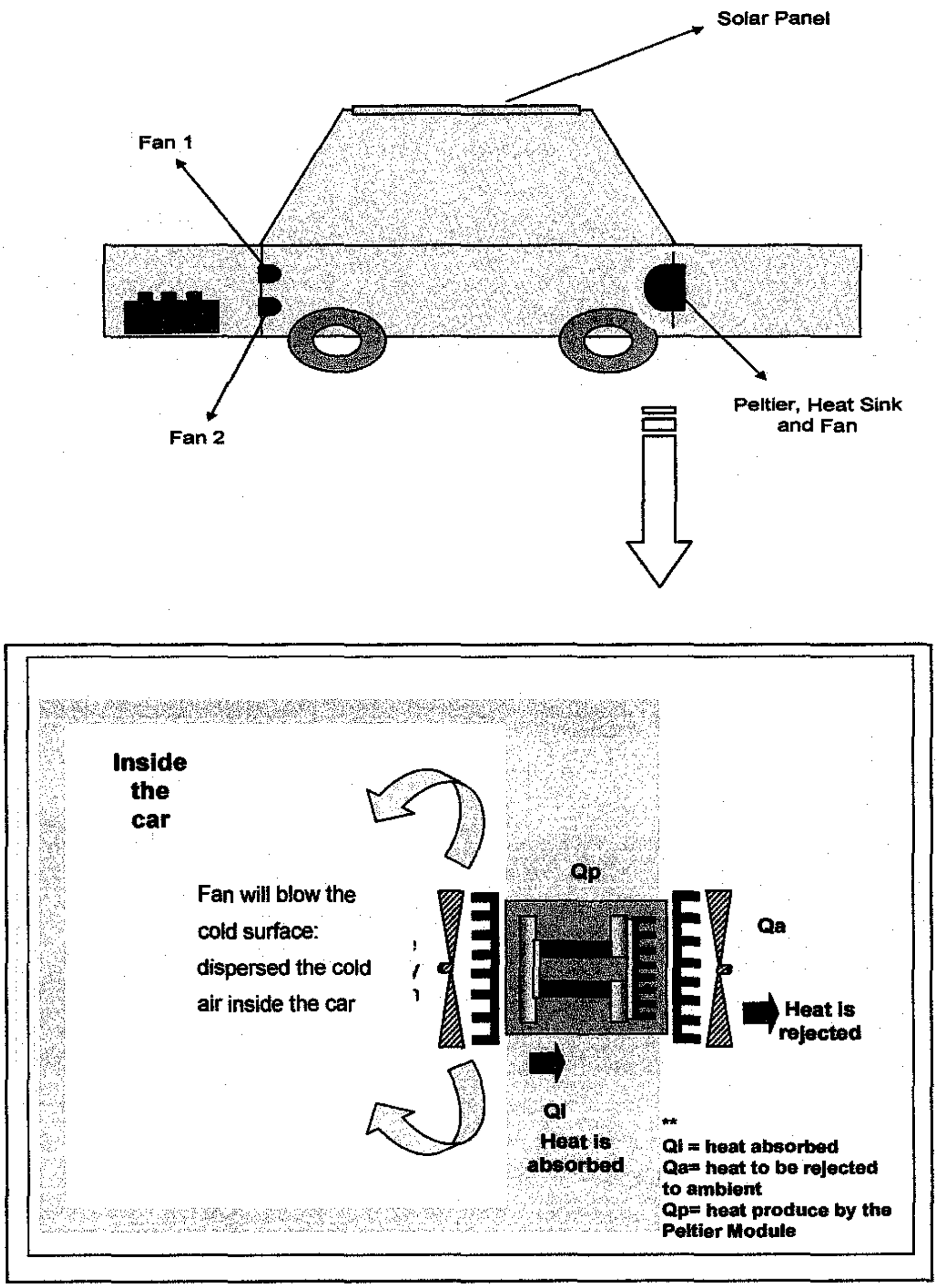


Figure 10: Designated Cooling System in a Car

4.1 Operation of the Cooling System

The above figure shows the placement of the main components of the Cooling System. The Cooling System is equipped with Temperature Controller Circuit, which function is to turn ON the Cooling System whenever the temperature inside the car reaches up to 26°C and above. The cooling system will turned OFF whenever the temperature inside the car fall below 26°C.Thus, the circuit will regulate the temperature inside the car at 26°C.

Battery Charger Circuit has been included in the Cooling System to prevent overcharge to the Battery from Photovoltaic Panel. Whenever, the battery reaches 11v (undercharge) the circuit will disconnect the load from the battery and the load will directly connected to the Photovoltaic Panel. At the same time, the Photovoltaic Panel will charge the battery until it reaches 12.5v (overcharge).After the battery reaches 12.5v, it will disconnect from the Photovoltaic Panel (stop charging) and the load will reconnect to the battery.

Observation on the efficiency of the Cooling System is done by providing the Temperature Display Circuit (thermometer) into the system. The circuit will monitor, sample and display the temperature using Seven Segment Display. The increment and decrement of the temperature (before and after the cooling system is turned ON) inside the car can be observed

4.2 Solar Radiation

The purpose of this analysis is to ensure the solar radiation in Malaysia is sufficient to be use as energy .This analysis is very important because the cooling system designed is to be solar powered. For the analysis, data of Global radiation in Ipoh (refer to appendix d) and datasheet of 80watt PV panel from SHARP (refer to appendix c) is used. The data provided (global radiation) is daily hourly global solar radiation, in MJ/m^2.

The relationship between energy and solar radiation is given below:

$$1000 w/m^2 \approx 3.6\ MJ/m^2 \quad [6]$$

$$1 w/m^2 \approx (3.6/1000)\ MJ/m^2$$

The information to calculate the efficiency of the PV is provided in the datasheet (refer to appendix c)

Efficiency, $\eta = P_{max} / [(1000)\ w/m2 \times (h \times w)]$

where;

P_{max} = Maximum power produced by PV panel (w)

h = height of PV panel
w = width of PV panel
} h x w (area of PV)

$\eta = 123 / 1058.538 = 12.39\ \%$

Assume the efficiency is constant,

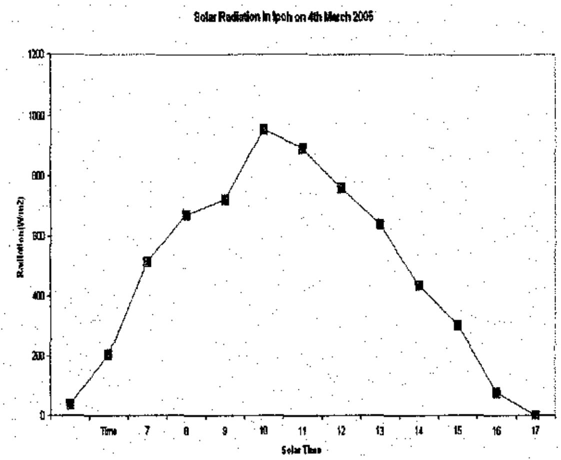
$$\eta = P_{out} / P_{in}$$

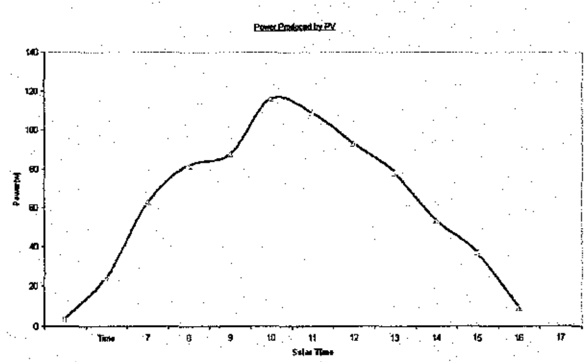
$$P_{out} = P_{in} \times \eta$$

The table and figures below show the result of the analysis. The total solar radiation produced per day is 22.33 MJ/m^2 (taken on 4th March 2005) which is enough to use as energy· At 1200 hour, the solar radiation produced is maximum i.e 116.2937w. Thus, the power produced by the panel is also maximum at 1200 hour. At 700 hour, the solar radiation produced is minimum i.e 36.11111111w and the power produced is 4.407635w. During this time, the solar energy is not sufficient to drive the cooling system. To overcome the problem, the cooling system is provided with battery storage as backup to the system.

Table 1: Summary on the result

Time	MJ/m2	W/m2	Pout
7	0.13	36.11111111	4.407635
8	0.73	202.7777778	24.75056
9	1.85	513.8888889	62.72403
10	2.41	669.4444444	81.71076
11	2.59	719.4444444	87.81364
12	3.43	952.7777778	116.2937
13	3.21	891.6666667	108.8347
14	2.74	761.1111111	92.89938
15	2.3	638.8888889	77.98123
16	1.57	436.1111111	53.23066
17	1.09	302.7777778	36.95632
18	0.28	77.77777778	9.493367
TOTAL	22.33		





4.3 Photovoltaic System

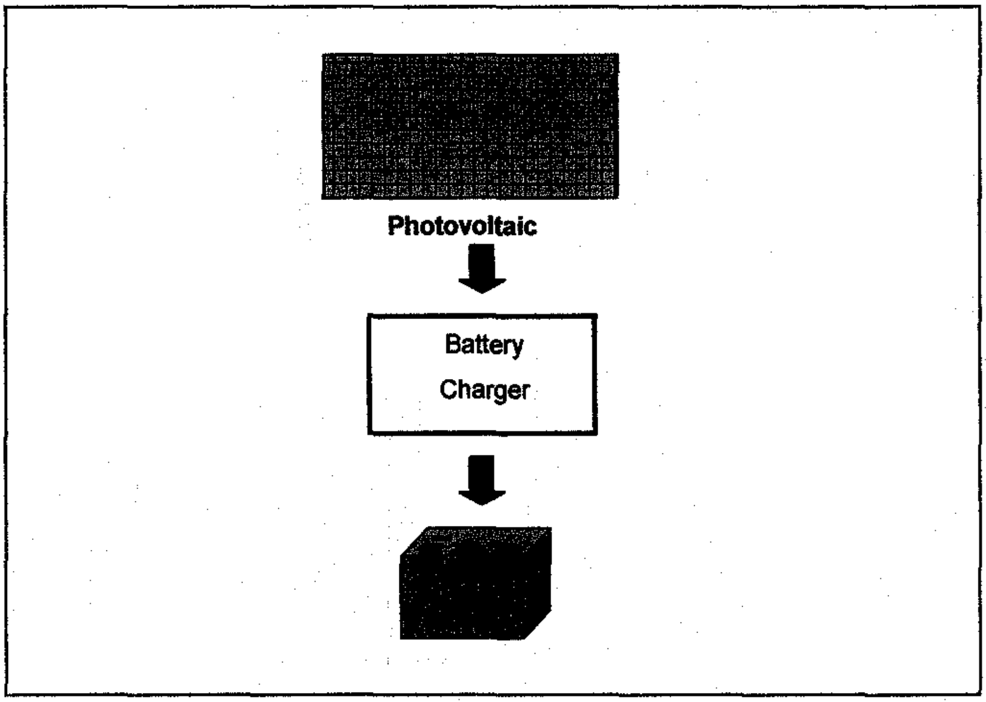


Figure 11: Photovoltaic System

A photovoltaic system consists of 3 major subsystems – photovoltaic, battery charger and storage battery.

4.3.1 Photovoltaic

The specifications of PV to be use in the system are as following: -

Table 2 : Specification of PV

Maximum Voltage (v)	Maximum Current (A)
17.3	4.63

The cooling system needs at least 27v for operation. Thus, photovoltaic system must include a Boost Converter to increase the voltage supply. Note that the Boost Converter will not be covered extensively by the author, as it is not in the scope of the study for this project.

4.3.2 Battery Storage

Battery that will be used is Rechargeable Sealed Lead Acid type which suitable for the storage for Photovoltaic [6].The PV panel usually connected diode to prevent the PV discharging through battery system. The battery will produce a reverse flow of current to the solar panel when used as stand alone especially at night. This flow will drain power from batteries and damage it .Thus, diode is used to stop the reverse current. This protection is included in the Battery Charger Circuit.

4.3.3 Battery Charger Circuit [7]

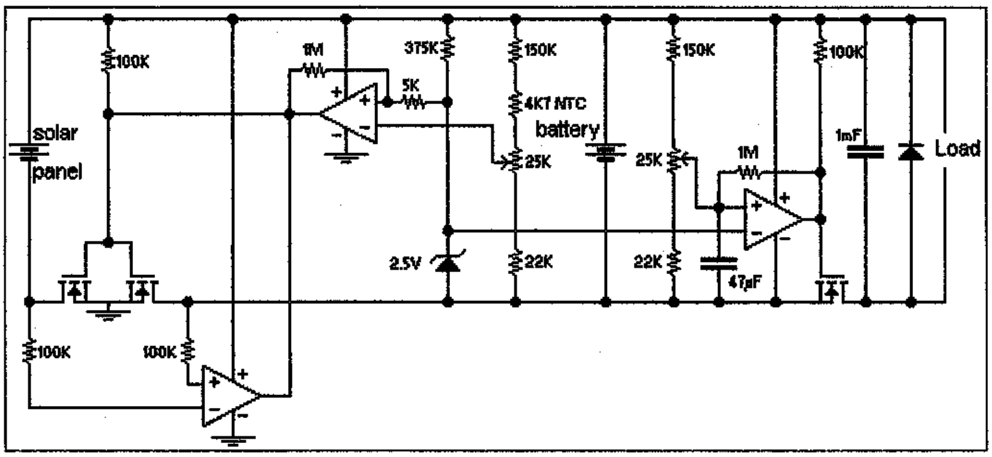


Figure 12: Schematic of Battery Charger

This circuit is intended for charging lead-acid batteries with a solar panel. The customary diode that prevents the battery from discharging through the solar panel has been replaced by a FET-comparator combination. The charger will stop charging once a pre-set voltage (temperature compensated) has been reached, and recommence charging when the voltage has dropped off sufficiently. The load is disconnected when the battery voltage drops below 11V and reconnected when it gets back to 12.5V [7].

4.4 Cooling Load Calculation

The Cooling Load is defined as the rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. In this context, the energy means the Quantity of Heat that need to be removed in the car in order to maintain the temperature inside the car per designed value. The analysis need to be done to the system so it can be applied to the real application. The main objectives of this analysis are to calculate the capacity of heat to be removed and power that needed by a car to energize the cooling system.

The method used to calculate the heat load is acquired through the 2001 American Society of Heating, Refrigerating, and Air-Conditioning Engineers(ASHRAE) fundamentals Handbook. Some assumptions were made during calculation, when selecting the coefficient values to be used. As there are no specific procedures for calculating the heat load in a vehicle, coefficient used are mostly set for the worse circumstance. The author will use the specifications of 850EX PERODUA Kancil as case study.

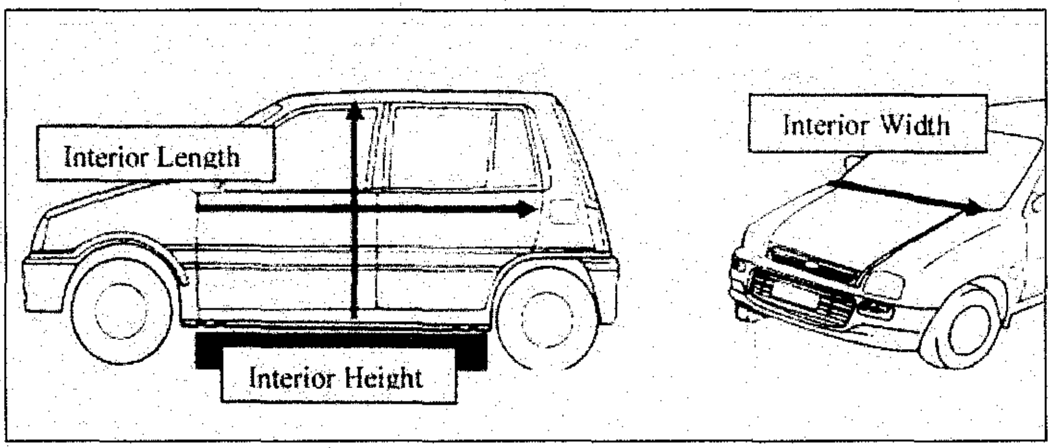
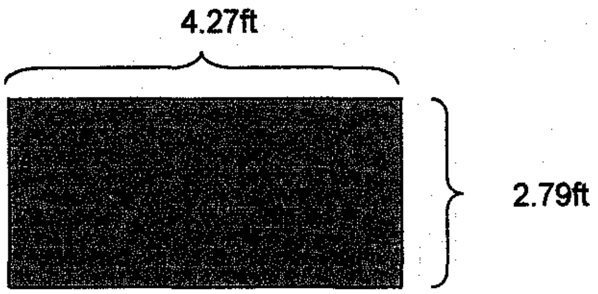


Figure 13: The Interior measurement of PERODUA Kancil

Roof



Q $= U \times A \times CLTD_c$ [6]

Where;

Q = Cooling Load for roof, BTU/hr

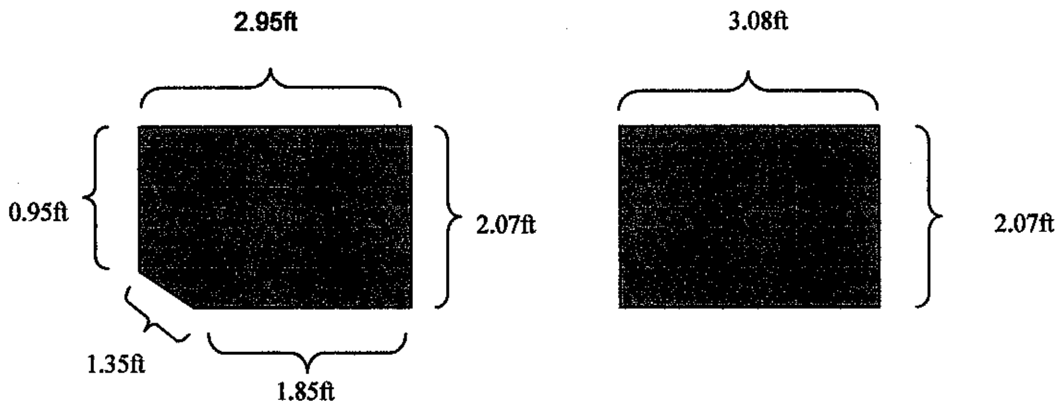
U = overall heat transfer coefficient, BTU/hr-ft^2-F

A = area of roof, ft^2

$CLTD_c =$ corrected cooling load temperature difference, F

Q = 0.213 x 11.91 x 84.9 = 215.38 btu/hr = **63.11w**

Door



Front Door

$$Q = U \times A \times CLTD_c$$

$$= 0.213 \times 6.376 \times 85.5 \times 2$$

$= 234.24$ btu/hr $=$ **68.04w**

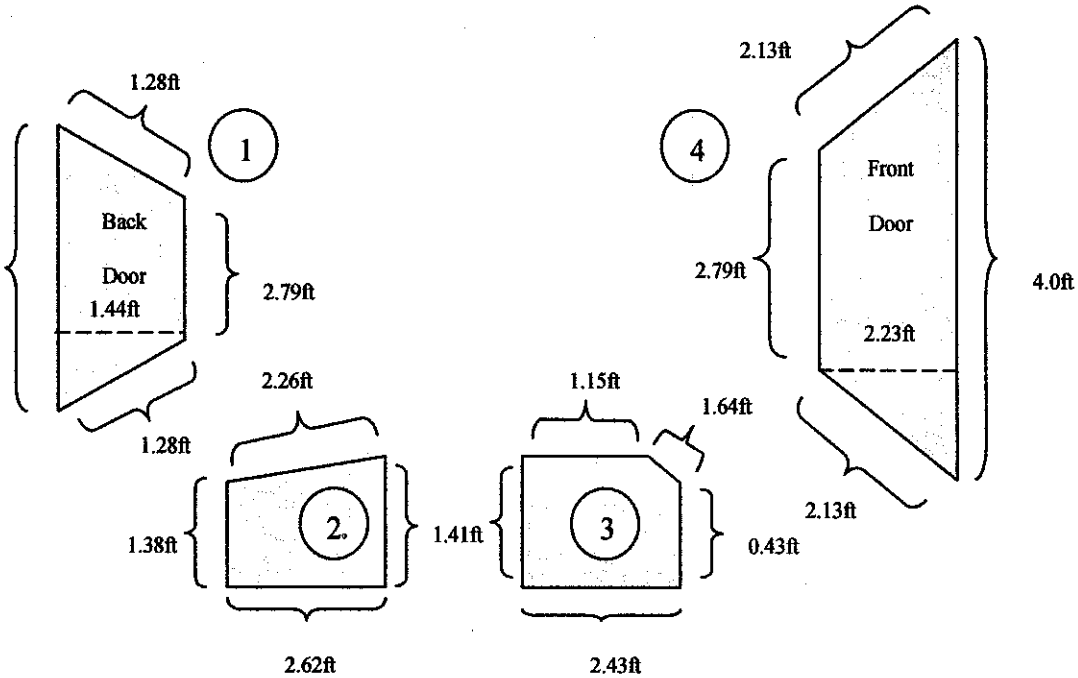
Back Door

$$Q = U \times A \times CLTD_c$$

$$= 0.213 \times 5.4 \times 85.5 \times 2$$

$= 196.68$ btu/hr $=$ **57.63w**

Window (glass)



$$Q = \text{SHGF x A x CLF [6]}$$

Where;

Q = Solar radiation cooling load for glass

SHGF = maximum solar heat gain factor, Btu/hr-ft^2

A = area, ft^2

CLF = Cooling Load Factor for Glass

The maximum solar heat gain factor (SHGF) is the maximum solar heat gain through single clear glass taken in June, facing west at 1400 solar time. [6]

Q1 = 210 x 5.2 x 0.53 = 578.76 btu/hr = **169.58w**

Q2 = 210 x 8.92 x 0.53 = 992.79btu/hr = 290.89w x **2** = **581.78w**

Q3 = 210 x 3.35 x 0.53 = 372.86btu/hr = 109.25w x **2** = **218.5w**

Q4 = 210 x 3.44 x 0.53 = 765.74 btu/hr = 224.36w x **2** = 448.73w

Total Cooling Load = 63.11w + 68.04w + 57.63w + 169.58w + 581.78w + 218.5w + 448.73w

= **1607.37w**

The Cooling System will start to cool down the car when the temperature inside the car reaches 26^0c. From a study, the maximum temperature recorded in the car while parked in sunlight is 48^0C.

$\Delta T = (48-26) = 22^0C$

$$\Delta T = 1 - \frac{\text{heat load}}{P_{max}} \times \text{maximum temperature difference}$$

$22 = 1 - 1607.37/P_{max} \times 68^0C$

Thus, Maximum Cooling Power, P_{max} = 2376.1122watt

4.5 Peltier

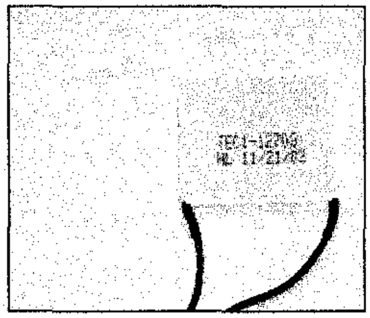


Figure 14: Peltier Modules

Specification

Voltage(max) : 15.4v   Current(max) :4.5A   Power(max) :40w

Several tests have been conducted to ensure the Peltier Modules will operate efficiently. The first test was done to observe and recognize the side that will produced heat, while the other side will be cold.

The second test was conducted to determine the minimum and maximum voltage the Peltier Modules can withstand. It is found out that the Peltier starts to react at 1.0v .As the voltage increases, the hot side will get hotter and the cold side gets cooler. However, at 6.0v both sides start to get warm. As a result, the amount of voltage that it can receive to operate successfully was 5.5v. Nevertheless, the voltage supply can be increased by using heat sink and fan .The table below shows the Voltage and Current Consumption when the Peltier modules is embedded with fan and heat sink. It is found out that; the Peltier device can withstand a maximum of 15.0v voltage when fan and heat sink are used.

4.4.1 Test Result

Min voltage - 1.0 v (start to function)

Max voltage - 6.0 v (both side getting hot)

Table 3 : The Voltage and Current Consumption when Heat Sink and Fan are used

Voltage (v)	Current(A)
1.0	0.120
2.0	0.240
3.0	0.410
4.0	0.600
5.0	0.730
6.0	0.820
7.0	1.180
8.0	1.350
9.0	1.500
10.0	1.670
11.0	1.800
12.0	2.050
13.0	2.270
14.0	2.380
15.0	2.570

4.6 Temperature Controller Circuit

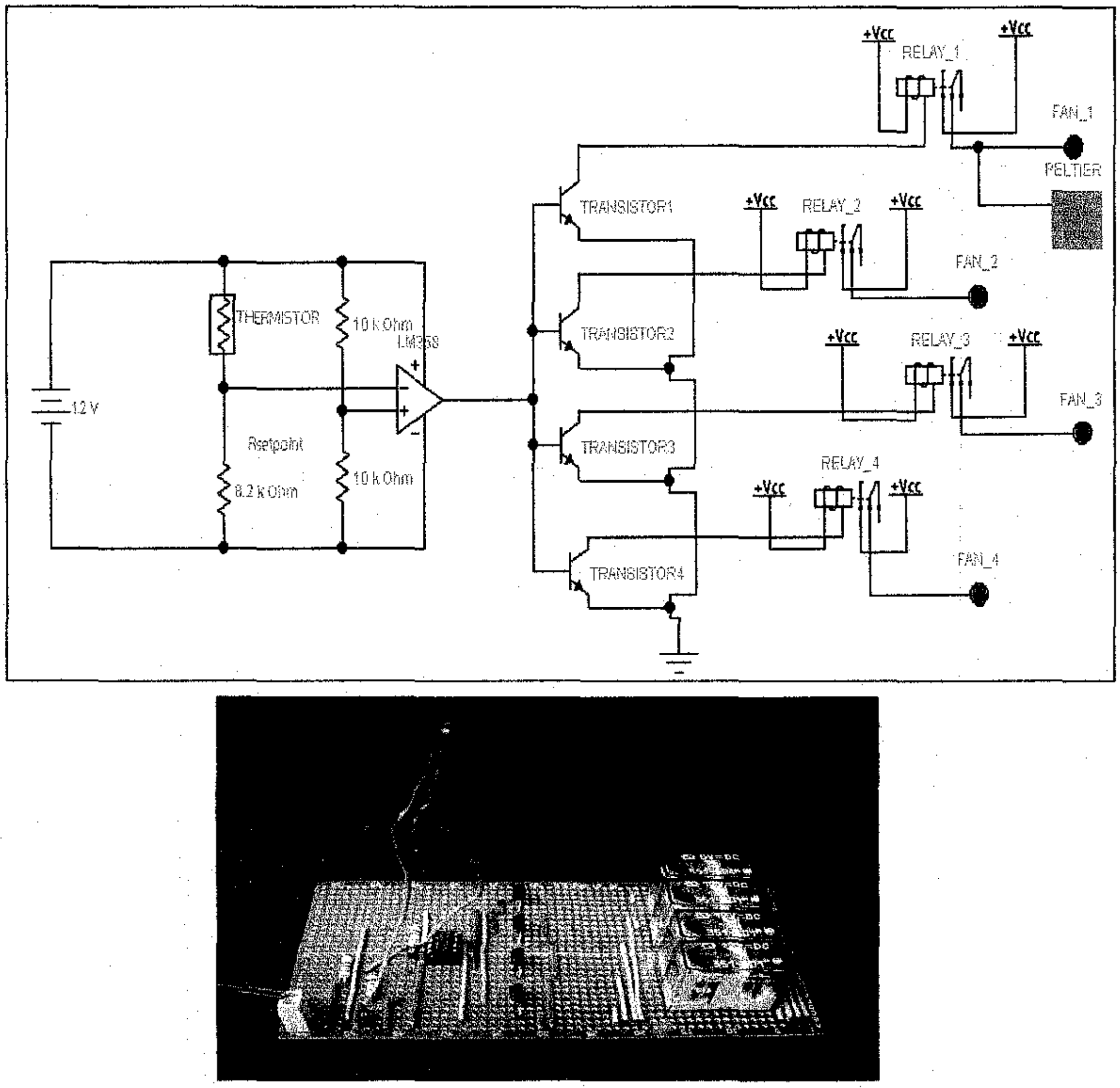
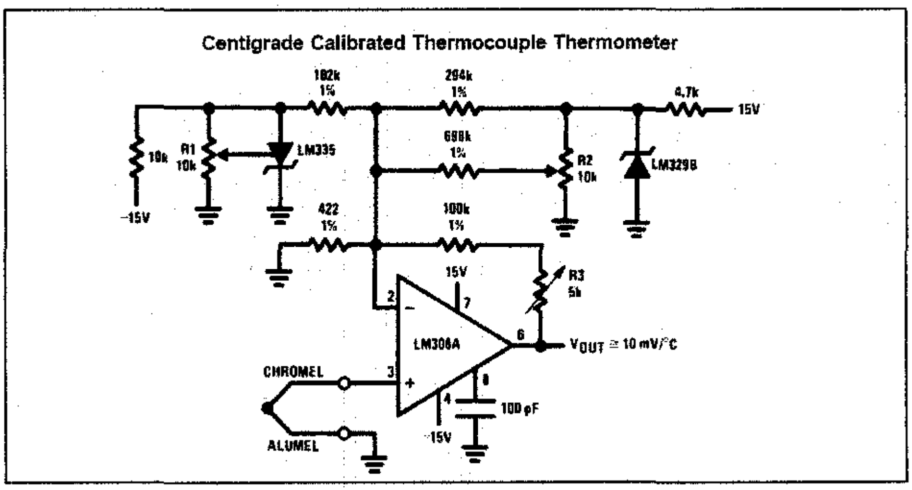


Figure 15: Temperature Controller Schematic

In the circuit, Thermistor is used as the Temperature sensor. Thermistor is a semiconductor device that has a negative coefficient of resistance with temperature - i.e., as the temperature raises the resistance gets less. The value of $R_{setpoint}$ is found out through experiment as follows: The circuit is constructed, and calibrated (set Thermistor temperature at 25°C). At this point, the value of the $R_{setpoint}$ is 10kΩ [6].

Heat is applied at the Thermistor and the value of $R_{setpoint}$ is continuously changed until the value of $R_{setpoint}$ which will trigger the comparator output to produced high output at 26 °C is found. Through the analysis, it is found out that the $R_{setpoint}$ is equal to 8.2kΩ to trigger the output (high) at 26 °C.

4.7 Temperature Display Circuit



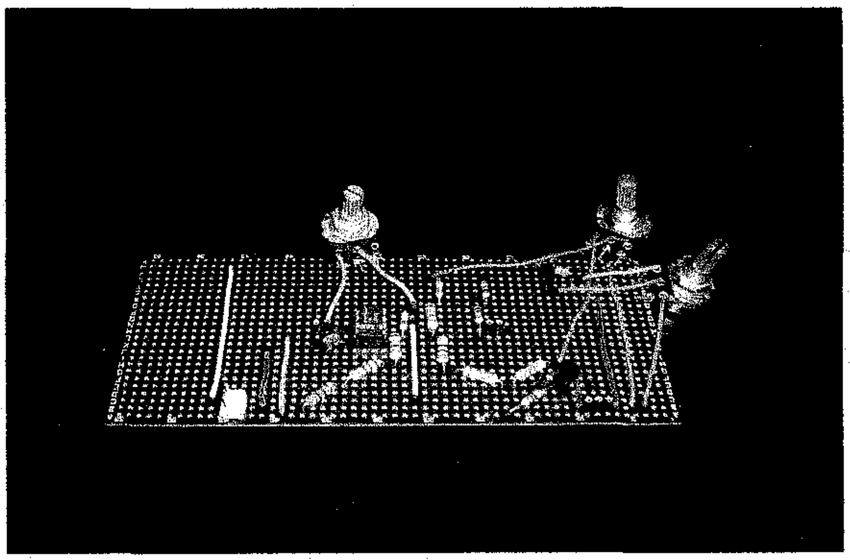


Figure 16: Temperature Sensor Schematic

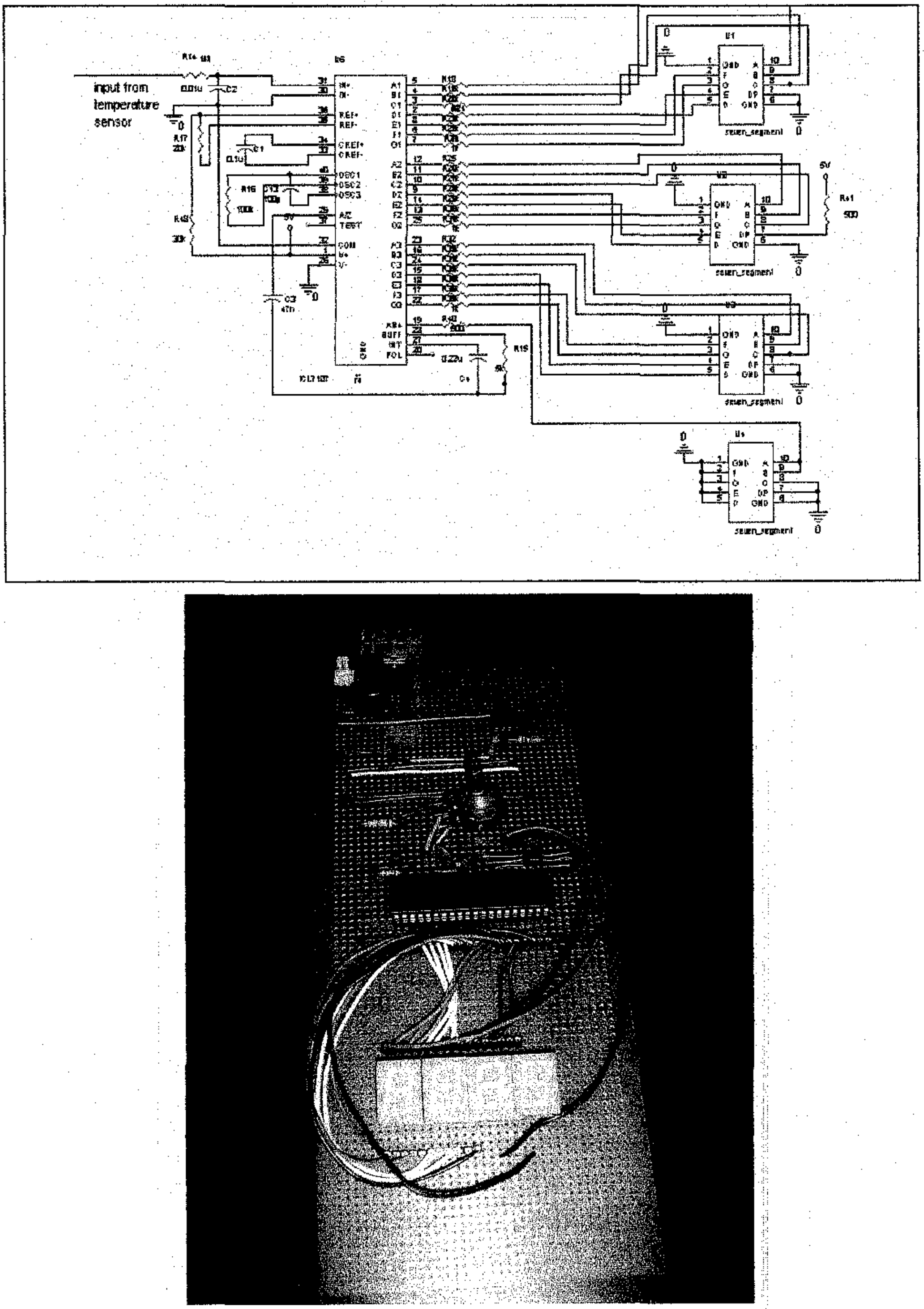


Figure 17: Temperature Display Schematic

The above circuit is used to monitor the temperature inside the car. The circuit design includes precision centigrade temperature sensor and a digital to analog converter to display the temperature with seven segment displayers. Thermistor and LM335 have been used for temperature sensing. The ICL7107 analog to digital converter which directly drives Seven Segment Display is also used.

The temperature sensing circuit gives 10mv output voltage per centigrade. This becomes the input voltage to the converter .The operation of the temperature display circuit is described in two stages. During the first stage where for a given period the input voltage, and the output of the integrator at the end of this period, there is a voltage which is directly proportional to the input voltage. At the end of the preset period the integrator is fed with an internal reference voltage and the output of the circuit is gradually reduced until it reaches the level of the zero reference voltage. This second phase is known as the negative slope period and its duration depends on the output of the integrator in the first period. As the duration of the first operation is fixed and the length of the second phase is variable it is possible to compare the two and this way the input voltage is in fact compared to the internal reference voltage and the result is coded and is send to the display.[7]

4.8 Construction of Prototype

The construction of the prototype will focus mainly on the temperature controller circuit and the temperature display circuit. The author did not concentrate on the power supply part because of the cost constrain to purchase the PV. Also, the author cannot demonstrate the function of the battery charger since the PV is not available. Thus, for the prototype the supply of the cooling system will be provided by the DC power supply.

4.8.1 Peltier module

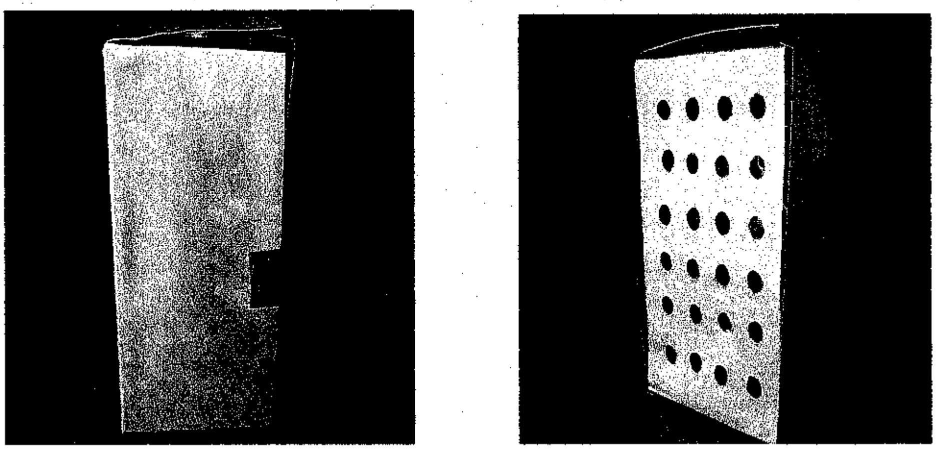


Figure 18: The case for Peltier Module

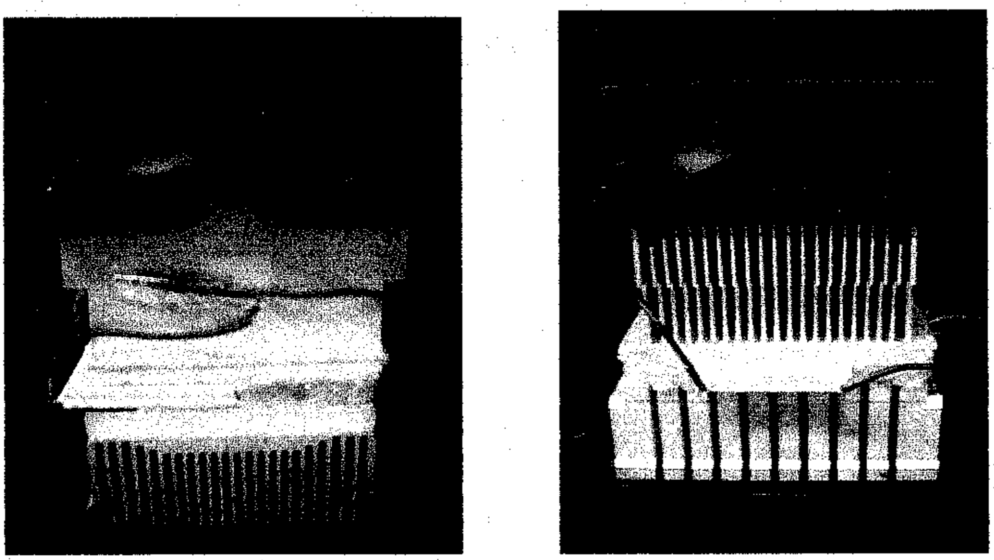


Figure 19: 3 Peltier Module are sandwiched between heat sink and fan

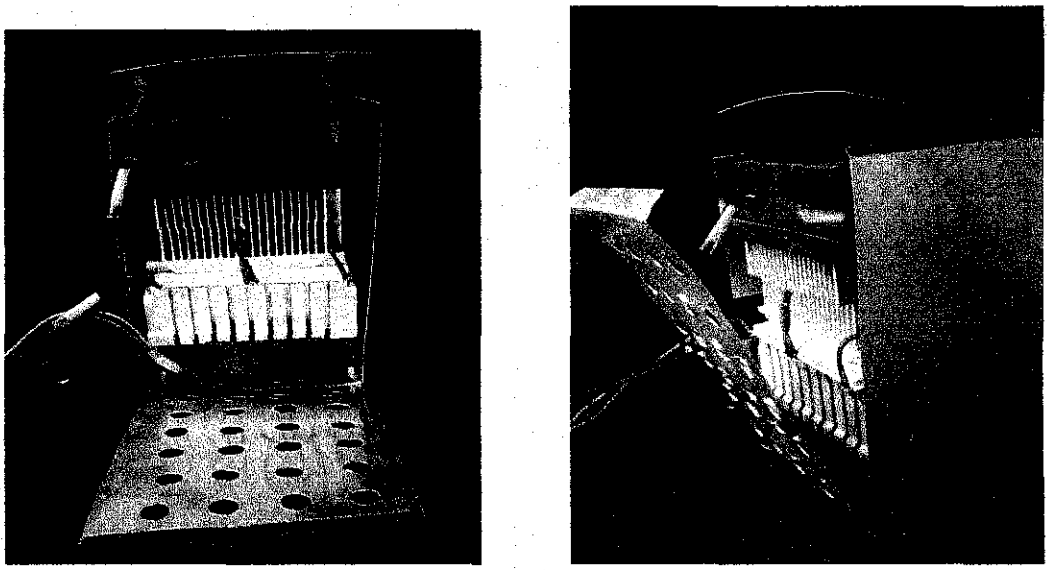


Figure 20: Peltier Module in the case

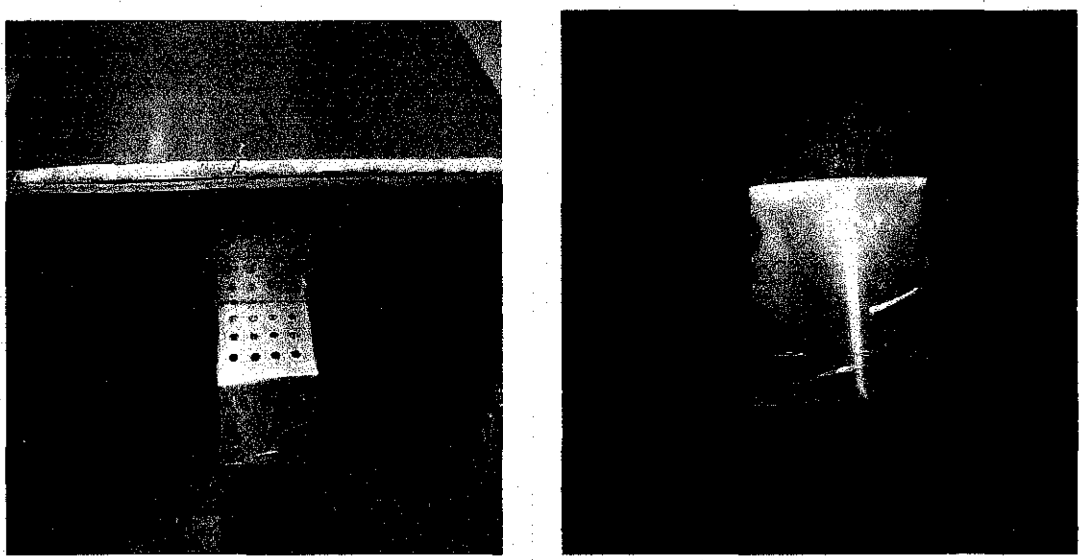


Figure 21: The Peltier module is placed under the passenger seat (back of the car)

4.8.2 Fan

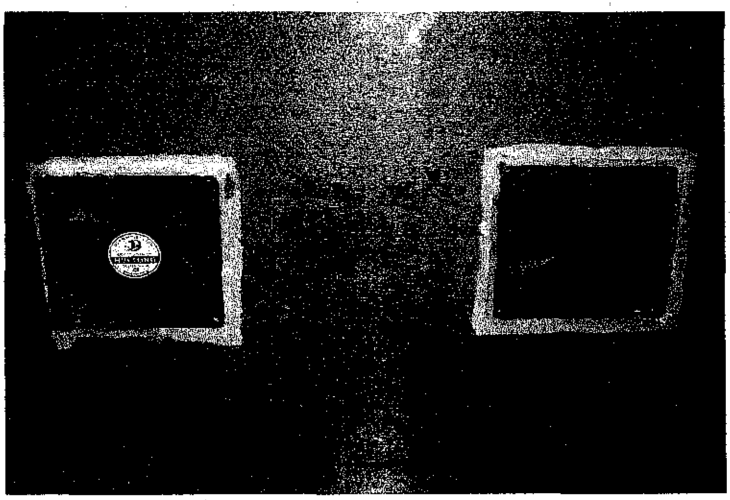


Figure 22: The blowing fan and sucking fan are placed in front part of the car

4.8.3 Model

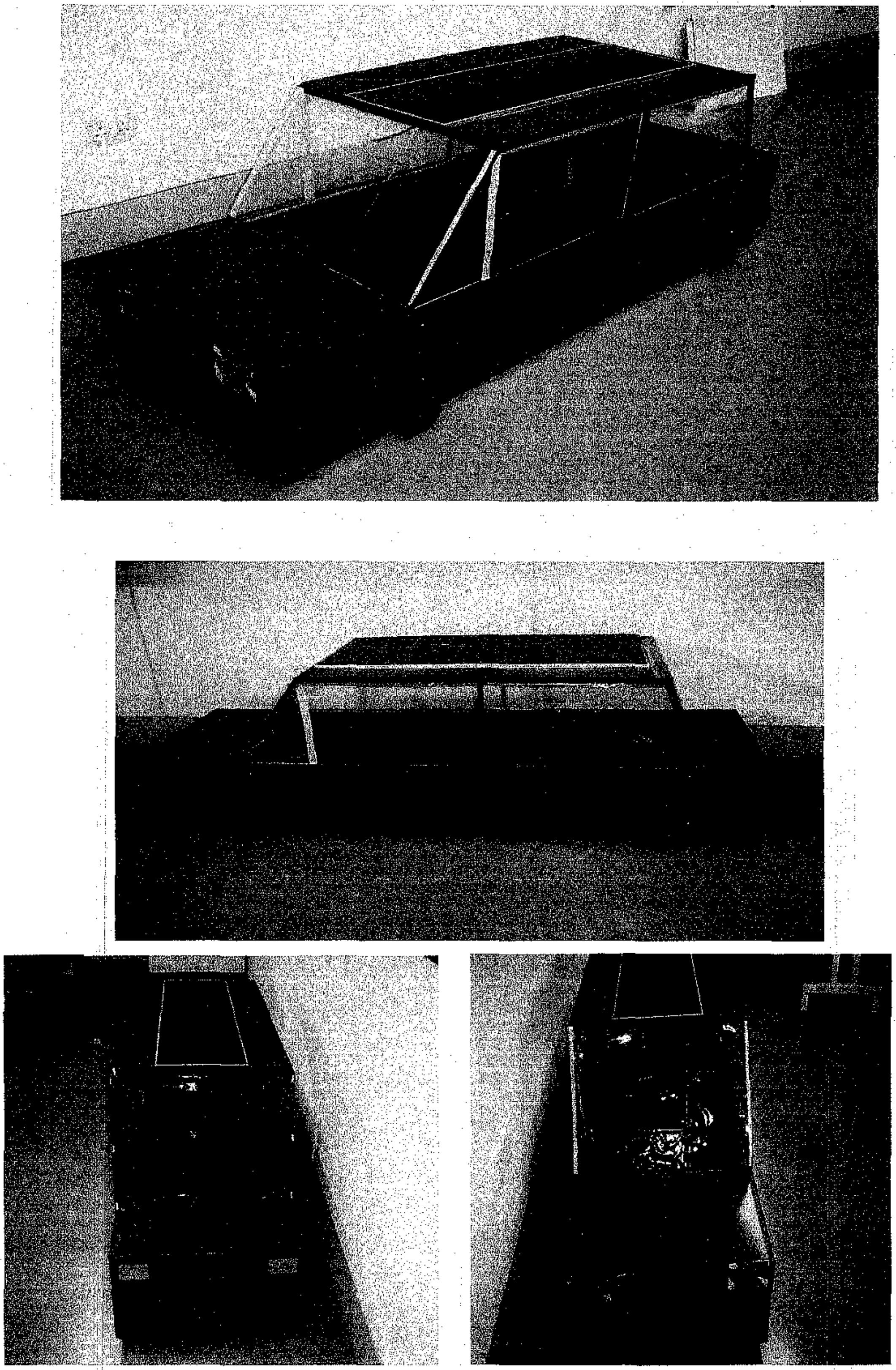


Figure 23: Prototype (car) which cooling system is modeled

CHAPTER 5
DISCUSSION

From the Cooling Load Analysis. It can be concluded that to regulate the temperature in side the car at 26 °C, the maximum cooling load needed is approximately 2. 4kw. Car is a fixed size, the same volume of air enters the room must also exit the room. Theoretically Qi = Qa (refer to Figure 10). But, the value of Qp must be taken into consideration when sizing the outside fan and heat sink because not only they have to reject the heat inside the car, but also the heat produced by the Peltier device itself. Thus, Qa becomes Qi + Qp.

Based on the value of power obtain in the Cooling Load Analysis. The specifications needed for Peltier Module is determined. The author decided that the temperature inside the car to be maintained is 26°C.The value of the temperature and coefficient for this analysis are chosen based on the value to design Air Conditioning System in Malaysia provided by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).The Peltier module specifications is Max delta = 68°C and Max power = 40watt. The author had done a thorough research on cost and performance of Peltier module provided by the various vendors. It is decided to purchase the Peltier Module of specifications Max delta temperature = 68 °C and Max power = 40watt provided by Pacific Supercool Ltd. Hence, the cooling system will need at least 60 Peltier modules to regulate the temperature inside the car at 26°C.

This is definitely not the cost effective design. Thus, to overcome this problem the author added an additional fan at the front part of the car (refer to figure 22).2 fans are added which are blowing fan and sucking fan. Blowing fan is used to blow the air into the car and the other fan will suck the hot air out. This operation is used as ventilation and provided additional cooling in the car. The fans will activate simultaneously as Peltier modules .By providing the additional fans, the cooling load in the car is reduced.

When the temperature inside the car reaches 26°C.The 4 fans and Peltier embedded in the Cooling system are supposed to turn ON. But, only Peltier and 3 fan able to turn ON. One fan cannot be turned ON, this scenario happened because of Peltier draws a high current which result in large voltage drop. From the analysis, the 12v supply used to turn ON the Peltier module and 4 fans dropped to 8.0v and the current draws by the Peltier is 1.94 A. The voltage is insufficient to turn ON all the fans. To overcome the problem, the author uses 3 Peltier instead of 1. The 3 Peltier is connected serially. By using this connection, the large voltage drop is reduced. The 12v supply dropped to 5.6v and the serially connected Peltier draws 0.80A.The voltage is now sufficient to turn ON all the fan and Peltier.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

As for conclusions, the project is successfully done within the timeframe. The cooling system has been designed and a working prototype is also constructed.

Overall, based upon studies, experiments and model constructed, this project successfully shows that thermoelectric technology provides various cooling approach, but limited for small scale application. It is not favorable for large scale due to high current drainage and high power consumption with limited solar power, where power usage is considered expensive.

It is recommended that the project is enhanced by providing a tracking method for the PV so that the usage of the PV can be optimized. Also, advance research is recommended to be done to overcome the high current drainage of the Peltier module so that the application of the module can be enhanced and widen.

REFERENCE

1. www.fsec.ucf.edu/pvt
2. Balbir Singh, M.S.(2004). 'A Study of An Optimum Parabolic Trough Design For Possible Power Generation in Malaysia'. PhD Thesis, Universiti Sains Malaysia.
3. www.kjc.gov.my/english /publication/10ab-1.htm
4. www.tetech.com/assys/plate.html
5. Edward G.Pita.(2002) 'Air Conditioning Principles and Systems, An Energy Approach' ,New Jersey, Prentice Hall
6. H P Grag and J Prakash,(1997) 'Solar Energy,Fundamentals and Applications',Delhi ,Tata McGraw Hill
7. www.electronics-lab.com
8. Thermistor datasheet
9. Intersil Datasheet for LM335(issued November 2000), ICL7107(issued December 2005),LM 358(issued October 2005),,LM 308A(issued December 1994)
10. Mohamad Faizul B Mohamad Aziz,(2005), 'Final Year Project Report , Vehicle Compartments Environmental Control Systems Using Solar Powered Thermoelectrics' ,Universiti Teknologi Petronas.
11. Nadya Jaalam, (2004) 'Final Year Project Report, Solar Cooling System', Universiti Teknologi Petronas.

APPENDICES

APPENDIX A – Gantt Chart

APPENDIX B – 1. Table of Peak Solar Heat Gain through Ordinary Glass

2. Table of Shading Coefficient for Glass

APPENDIX C - Datasheet of Photovoltaic Panel

APPENDIX D - Hourly Global Radiation Data

APPENDIX E – Datasheet:-

1.LM358

2.LM308

3.LM335

4.ICL7107

APPENDIX A
GANTT CHART

Gantt chart for Final Year Project I, Semester July 2005

No	Detail/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Problem Definition														
2	Research and Analysis														
3	Logbook (weekly report)			x	x	x	x	x	x	x	x	x			
4	Submission of Progress Report 1				x										
5	Design Calculation & Research														
6	Submission of Progress Report 2								x						
7	Material gathering, Circuit design														
8	Submission of Draft Report												x		
9	Submission of Interim Report													x	
10	Oral Presentation														x

Gantt chart for Final Year Project II, Semester June 2006

No	Detail/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Resource Gathering														
2	Experiment and Analysis														
3	Logbook (weekly report)			x	x	x	x	x	x	x	x	x			
4	Submission of Progress Report 1				x										
5	Circuit assemblage and prototype construction														
6	Submission of Progress Report 2								x						
7	Submission of Final Draft												x		
8	Submission of Technical Report													x	
9	Oral Presentation														x
10	Final report (hard cover)														x

X milestone

Process

APPENDIX B

1.TABLE OF PEAK SOLAR HEAT GAIN THROUGH ORDINARY GLASS

2. TABLE OF SHADING COEFFICIENTS FOR GLASS

'or Malaysia 3°- 4° latitude, use 0° latitude values

TABLE —PEAK SOLAR HEAT GAIN THRU ORDINARY GLASS*

Btu/(hr)(sq ft)

NORTH LAT.	MONTH	EXPOSURE NORTH LATITUDE									MONTH	SOUTH LAT.
		N	NE	E	SE	S	SW	W	NW	Horiz		
0°	June	59	156	147	42	14	42	147	155	225	Dec	0°
	July & May	48	153	152	52	14	52	152	153	233	Nov & Jan	
	Aug & April	25	141	163	79	14	79	163	141	245	Oct & Feb	
	Sept & March	10	118	167	118	14	118	167	118	252	Sept & March	
	Oct & Feb	10	79	163	141	36	141	163	79	245	Aug & April	
	Nov & Jan	10	52	152	153	67	153	152	52	233	July & May	
	Dec	10	42	147	156	82	156	147	42	226	June	
10°	June	40	153	155	55	14	55	155	153	243	Dec	10°
	July & May	30	148	158	65	14	65	158	148	247	Nov & Jan	
	Aug & April	13	130	163	94	14	94	163	130	250	Oct & Feb	
	Sept & March	10	103	164	127	28	127	164	103	247	Sept & March	
	Oct & Feb	10	66	155	149	73	149	155	66	230	Aug & April	
	Nov & Jan	9	37	143	161	106	101	143	37	210	July & May	
	Dec	9	21	137	163	130	163	137	73	202	June	

Table 5: Peak Solar Heat Gain through Ordinary Glass

TABLE 6.7 SHADING COEFFICIENTS FOR GLASS WITHOUT OR WITH INTERIOR SHADING DEVICES

Type of Glazing	Nominal Thickness, in (Each light)	Without Shading	With Interior Shading: Venetian Blinds Medium	Venetian Blinds Light	Roller Shades Opaque Dark	Roller Shades Opaque Light	Roller Shades Translucent Light
Single glass							
Clear	¼	0.94	0.74	0.67	0.81	0.39	0.44
Heat absorbing	¼	0.69	0.57	0.53	0.45	0.30	0.36
Double glass							
Clear	¼	0.81	0.62	0.58	0.71	0.35	0.40
Heat absorbing	¼	0.55	0.39	0.36	0.40	0.22	0.30

Note: Venetian blinds are assumed set at a 45° position. Adapted with permission from the *1993 ASHRAE Handbook—Fundamentals.*

Table 6: Shading Coefficients for Glass

APPENDIX C

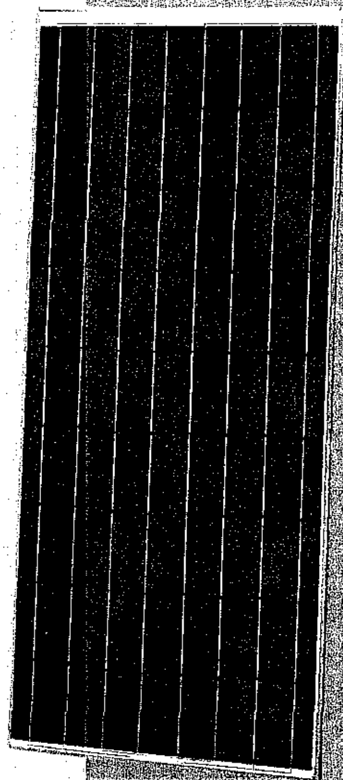
DATASHEET OF SOLAR PANEL

SHARP

MULTI-PURPOSE MODULE **NE-80EJEA**

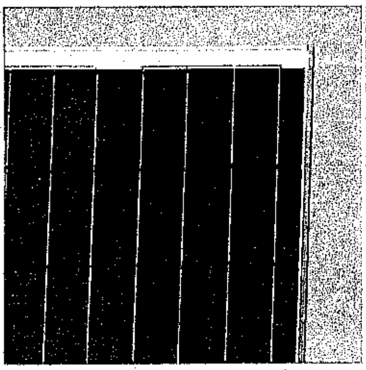
80 WATT

POWERFUL PERFORMANCE. SHARP RELIABILITY.

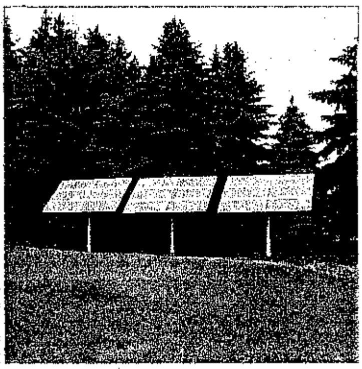


POLY-CRYSTALLINE SILICON PHOTOVOLTAIC MODULE WITH 80W MAXIMUM POWER

Sharp's NE-80EJEA photovoltaic modules offer industry-leading performance, durability, and reliability for a variety of electrical power requirements. Using breakthrough technology perfected by Sharp's 45 years of research and development, these modules incorporate an advanced surface texturing process to increase light absorption and improve efficiency. Common applications include cabins, solar power stations, pumps, beacons, and lighting equipment. Designed to withstand rigorous weather conditions, a junction box is also provided for easy electrical connections in the field, making Sharp's NE-80EJEA modules the perfect combination of advanced technology and reliability.



Solder-coated grid results in high fill factor performance under low light conditions.



Sharp multi-purpose modules offer industry-leading performance for a variety of applications.

FEATURES

- High-power module (80W) using 125mm square poly-crystalline silicon solar cells with 12.40% module conversion efficiency
- Sharp's advanced surface texturing process increases light absorption and efficiency while providing a more subdued, "natural" look
- Bypass diodes minimize the power drop caused by shade
- Water white, tempered glass, EVA laminate, plus aluminum frame for extended outdoor use
- Junction box for easy electrical connections in the field
- Nominal 12VDC output for battery charging applications
- UL Listings: UL 1703 cUL
- Sharp modules are manufactured in ISO 9001 certified facilities
- 25-year limited warranty on power output (see dealer for details)

MULTI-PURPOSE MODULE

80 WATT

ELECTRICAL CHARACTERISTICS

Cell	Poly-crystalline silicon
No. of Cells and Connections	36 in series
Open Circuit Voltage (Voc)	21.6V
Maximum Power Voltage (Vpm)	17.3V
Short Circuit Current (Isc)	5.16A
Maximum Power Current (Ipm)	4.63A
Maximum Power (Pmax)*	80W (+10% / -5%)
Module Efficiency (ηm)	12.40%
Maximum System Voltage	600VDC
Series Fuse Rating	10A
Type of Output Terminal	Junction Box

* (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

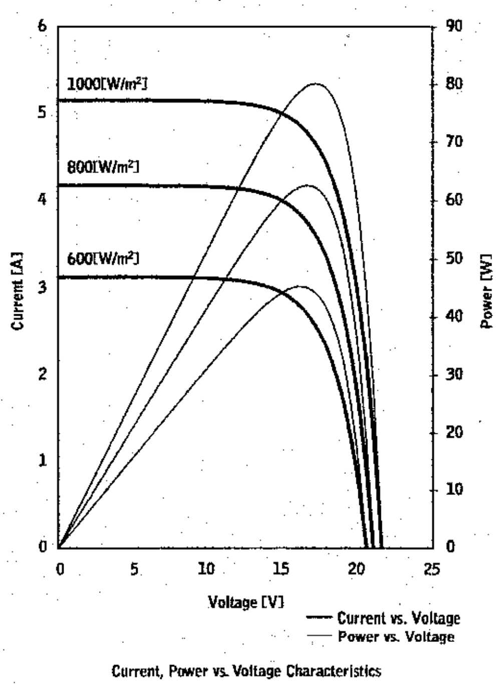
MECHANICAL CHARACTERISTICS

Dimensions (H x W x D)	47.28" x 20.14" x 1.81" 1200mm x 512mm x 46mm
Weight	20.94lbs / 9.5kg
Packing Configuration	1 pc per carton
Size of Carton	53.15" x 27.56" x 2.95" 1350mm x 700mm x 75mm
Loading Capacity (20 ft container)	242 pcs (242 cartons)
Loading Capacity (48 ft container)	506 pcs (506 cartons)

ABSOLUTE MAXIMUM RATINGS

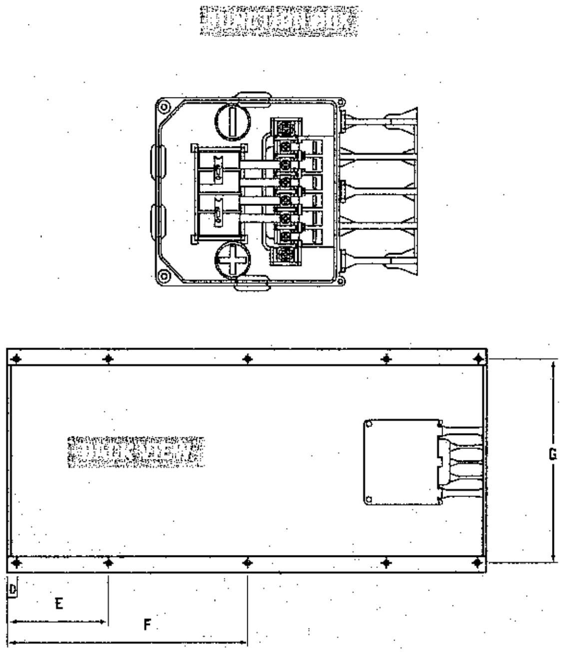
Operating Temperature	-40 to +194°F / -40 to +90°C
Storage Temperature	-40 to +194°F / -40 to +90°C

IV CURVES



Current, Power vs. Voltage Characteristics

DIMENSIONS



D	E	F	G
.99"/25.1mm	9.84"/250.0mm	23.62"/600.0mm	18.9"/480.0mm

Design and specifications are subject to change without notice.

RM 1596.00

In the absence of confirmation by product manuals, Sharp takes no responsibility for any defects that may occur in equipment using any Sharp devices.
Contact Sharp to obtain the latest product manuals before using any Sharp device.

SHARP

Sharp Electronics Corporation • 5901 Bolsa Avenue, Huntington Beach, CA 92647
Tel:1-800-SOLAR-06 • E-mail: sharpsolar@sharpusa.com • www.sharpusa.com/solar

Cover photo: Solar installation by Hudson Valley Clean Energy, Rhinebeck NY SSD-80-805

APPENDIX D

HOURLY GLOBAL RADIATION DATA

Station : IPOH
Lat : 4° 34' N Long : 101° 06' E
Ht. Above M.S.L. : 40.1 m Unit : MJm^{-2}

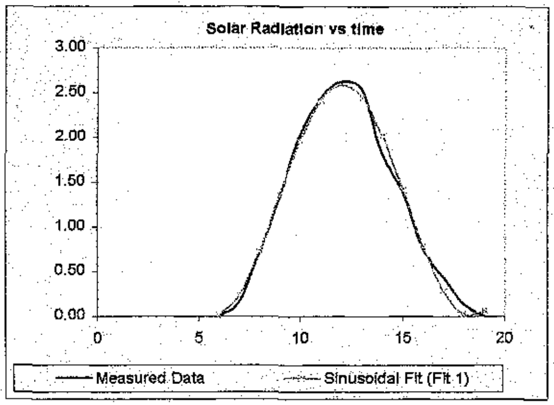
Records of Hourly Global Radiation
Simulated Data for Aug 2005

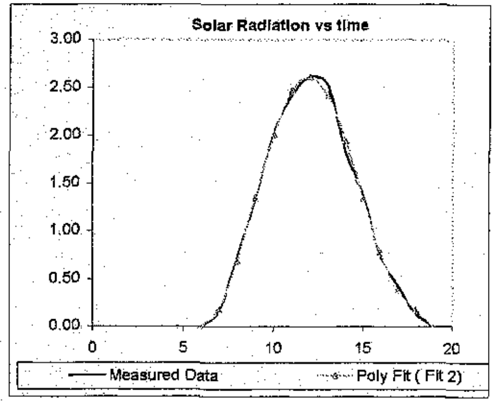
day	Time in Hours														Daily Total MJm^{-2}
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	0.00	0.21	0.87	1.63	2.33	2.90	3.00	3.18	2.80	2.15	1.03	0.59	0.18	0.00	20.87
2	0.00	0.19	0.67	1.62	2.02	2.14	2.94	2.17	2.26	2.28	2.13	0.79	0.07	0.00	19.28
3	0.00	0.03	0.46	1.00	1.08	0.92	1.31	1.53	1.36	1.62	0.92	0.51	0.10	0.00	10.84
4	0.00	0.13	0.73	1.85	2.41	2.59	3.43	3.21	2.74	2.30	1.57	1.09	0.28	0.00	22.33
5	0.00	0.13	0.81	1.58	0.91	1.63	1.99	2.20	2.12	1.13	0.79	0.47	0.27	0.00	14.03
6	0.00	0.15	0.64	1.34	1.38	1.65	1.93	1.75	2.14	1.79	1.11	0.64	0.18	0.00	14.70
7	0.00	0.13	0.43	0.73	1.35	1.69	2.30	1.83	2.07	1.71	1.29	0.56	0.18	0.00	14.27
8	0.00	0.13	0.62	1.02	1.35	2.08	2.01	2.17	2.01	1.80	1.26	1.05	0.16	0.00	15.66
9	0.00	0.16	0.60	1.03	1.99	2.19	3.00	2.54	1.18	1.09	0.16	0.12	0.11	0.00	14.17
10	0.00	0.06	0.69	1.32	2.18	2.74	3.10	3.08	2.91	1.16	0.21	0.03	0.03	0.00	17.51
11	0.00	0.17	0.71	1.06	1.93	2.77	3.04	3.19	2.92	1.15	0.96	0.36	0.03	0.00	18.29
12	0.00	0.15	0.69	1.30	2.28	2.79	3.10	2.85	0.85	0.54	0.08	0.03	0.00	0.00	14.66
13	0.00	0.32	1.16	1.74	2.41	2.81	1.15	1.77	0.30	0.10	0.05	0.13	0.11	0.00	12.05
14	0.00	0.16	0.90	1.55	2.35	2.93	3.38	2.54	0.91	2.24	0.77	0.03	0.00	0.00	17.76
15	0.00	0.07	0.60	1.08	1.58	2.99	2.29	2.55	0.95	0.29	0.39	0.18	0.02	0.00	12.99
16	0.00	0.12	0.50	1.19	2.37	3.11	3.60	2.39	1.10	0.50	0.13	0.16	0.14	0.00	15.31
17	0.00	0.33	0.97	0.77	2.17	3.14	2.04	2.43	1.38	2.31	1.03	0.28	0.05	0.00	16.90
18	0.00	0.18	0.71	1.20	2.17	2.22	2.54	2.89	2.60	1.86	1.42	0.58	0.18	0.00	18.55
19	0.00	0.30	0.97	1.64	2.50	3.04	2.49	2.17	2.20	2.08	1.14	0.61	0.21	0.00	19.35
20	0.00	0.16	0.67	1.11	2.04	2.32	2.56	3.50	2.75	2.56	1.84	1.09	0.27	0.00	20.87
21	0.00	0.08	0.44	1.21	2.27	2.70	3.34	3.25	2.90	2.57	0.48	0.58	0.31	0.00	20.13
22	0.00	0.17	0.94	1.67	2.45	2.94	3.26	3.29	3.11	0.85	0.07	0.05	0.11	0.00	18.91
23	0.00	0.05	0.51	0.60	0.42	0.38	1.01	0.88	0.34	0.26	0.21	0.11	0.03	0.00	4.80
24	0.00	0.27	1.08	1.88	2.67	2.82	3.15	3.43	2.09	0.53	0.46	0.36	0.20	0.00	18.94
25	0.00	0.14	0.77	1.71	2.35	3.04	2.91	2.93	2.28	1.94	0.90	0.53	0.11	0.00	19.61
26	0.00	0.15	0.57	0.81	2.39	2.62	2.95	3.25	2.74	1.57	0.41	0.35	0.09	0.00	17.90
27	0.00	0.11	0.67	1.64	2.43	2.81	2.76	3.29	0.21	0.22	0.25	0.10	0.04	0.00	14.53
28	0.00	0.19	0.88	1.79	2.55	3.09	2.78	2.27	2.18	1.80	0.73	0.49	0.13	0.00	18.88
29	0.00	0.16	0.69	1.58	2.16	1.53	2.68	1.14	0.36	0.67	0.81	0.48	0.15	0.00	12.41
30	0.00	0.13	0.65	1.64	2.49	1.76	1.77	2.28	0.75	0.36	0.55	0.38	0.10	0.00	12.86
31	0.00	0.17	0.62	0.87	1.89	2.78	3.37	2.57	2.11	1.37	0.29	0.53	0.32	0.00	16.89
Monthly Total	0.00	4.90	22.22	41.16	62.87	75.12	81.18	78.52	56.62	42.80	23.44	13.26	4.16	0.00	506.25
Monthly Mean	0.00	0.16	0.72	1.33	2.03	2.42	2.62	2.53	1.83	1.38	0.76	0.43	0.13	0.00	16.33

Curve Fitting Analysis

1	Fit 1:	Sinusoidal Fit						$y= a+(b*\cos(cx+d))$
	a =	1.2931						
	b =	1.2888						Standard Error: 0.099
	c =	0.4994						Correlation Coefficient: 0.996
	d =	0.2681						
2	Fit 2 :	Polynomial Fit						$y= a+bx+cx^2+dx^3+ex^4+fx^5+gx^6+hx^7+ix^8+jx^9+kx^{10}+lx^{11}$
	a =	-18.548	d =	0.73536	h=	0		
	b =	15.725	e =	-0.0555	I=	0		
	c =	-4.9246	f=	0.00204	j=	0		Standard Error: 0.075
			g=	#######	k=	0		Correlation Coefficient: 0.998
					l=	0		

	MJm⁻²		
Time	Average	Fit 1	Fit 2
6	0.00	0.01	0.00
7	0.16	0.25	0.18
8	0.72	0.73	0.68
9	1.33	1.36	1.36
10	2.03	1.97	2.01
11	2.42	2.41	2.47
12	2.62	2.56	2.61
13	2.53	2.44	2.42
14	1.83	2.01	1.95
15	1.38	1.41	1.35
16	0.76	0.79	0.78
17	0.43	0.28	0.37
18	0.13	0.02	0.17
19	0.00	0.07	-0.01





APPENDIX E

DATASHEET:-

1.LM358

2.LM308

3.LM335

4.ICL7107

$^{1}/_{2}$ Digit, LCD/LED Display, A/D :onverters

he Intersil ICL7106 and ICL7107 are high performance, low ower, $3^{1}/_{2}$ digit A/D converters. Included are seven egment decoders, display drivers, a reference, and a clock. he ICL7106 is designed to interface with a liquid crystal isplay (LCD) and includes a multiplexed backplane drive; ie ICL7107 will directly drive an instrument size light mitting diode (LED) display.

he ICL7106 and ICL7107 bring together a combination of igh accuracy, versatility, and true economy. It features auto-ero to less than 10μV, zero drift of less than 1μV/°C, input ias current of 10pA (Max), and rollover error of less than ne count. True differential inputs and reference are useful in ll systems, but give the designer an uncommon advantage /hen measuring load cells, strain gauges and other bridge /pe transducers. Finally, the true economy of single power upply operation (ICL7106), enables a high performance anel meter to be built with the addition of only 10 passive omponents and a display.

Features

- Guaranteed Zero Reading for 0V Input on All Scales
- True Polarity at Zero for Precise Null Detection
- 1pA Typical Input Current
- True Differential Input and Reference, Direct Display Drive
  - LCD ICL7106, LED ICL7107
- Low Noise - Less Than $15\mu V_{P-P}$
- On Chip Clock and Reference
- Low Power Dissipation - Typically Less Than 10mW
- No Additional Active Circuits Required
- Enhanced Display Stability
- Pb-Free Plus Anneal Available (RoHS Compliant)

)rdering Information

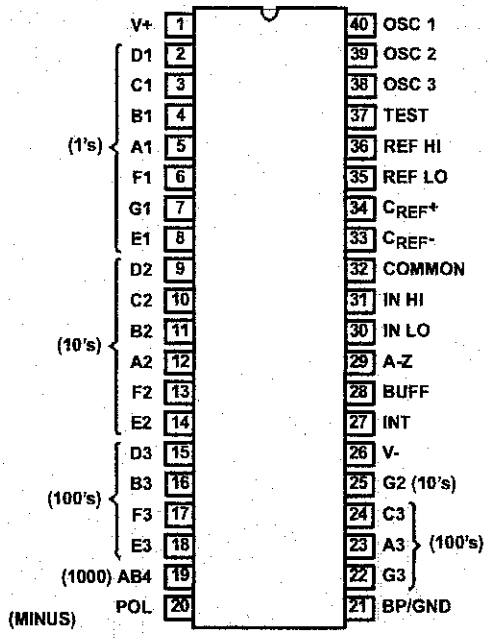
PART NO.	PART MARKING	TEMP. RANGE (°C)	PACKAGE	PKG. DWG. #
CL7106CPL	ICL7106CPL	0 to 70	40 Ld PDIP	E40.6
CL7106CPLZ (Note 2)	ICL7106CPLZ	0 to 70	40 Ld PDIP(Pb-free) (Note 3)	E40.6
CL7106CM44	ICL7106CM44	0 to 70	44 Ld MQFP	Q44.10x10
CL7106CM44Z (Note 2)	ICL7106CM44Z	0 to 70	44 Ld MQFP (Pb-free)	Q44.10x10
CL7106CM44ZT (Note 2)	ICL7106CM44Z	0 to 70	44 Ld MQFP Tape and Reel (Pb-free)	Q44.10x10
CL7107CPL	ICL7107CPL	0 to 70	40 Ld PDIP	E40.6
CL7107CPLZ (Note 2)	ICL7107CPLZ	0 to 70	40 Ld PDIP(Pb-free) (Note 3)	E40.6
CL7107RCPL	ICL7107RCPL	0 to 70	40 Ld PDIP (Note 1)	E40.6
CL7107RCPLZ (Note 2)	ICL7107RCPLZ	0 to 70	40 Ld PDIP (Pb-free) (Notes 1, 3)	E40.6
CL7107SCPL	ICL7107SCPL	0 to 70	40 Ld PDIP (Notes 1, 3)	E40.6
CL7107SCPLZ (Note 2)	ICL7107SCPLZ	0 to 70	40 Ld PDIP (Pb-free) (Notes 1, 3)	E40.6
CL7107CM44	ICL7107CM44	0 to 70	44 Ld MQFP	Q44.10x10
CL7107CM44T	ICL7107CM44	0 to 70	44 Ld MQFP Tape and Reel	Q44.10x10
CL7107CM44Z (Note 2)	ICL7107CM44Z	0 to 70	44 Ld MQFP (Pb-free)	Q44.10x10
CL7107CM44ZT (Note 2)	ICL7107CM44Z	0 to 70	44 Ld MQFP Tape and Reel (Pb-free)	Q44.10x10

IOTES:

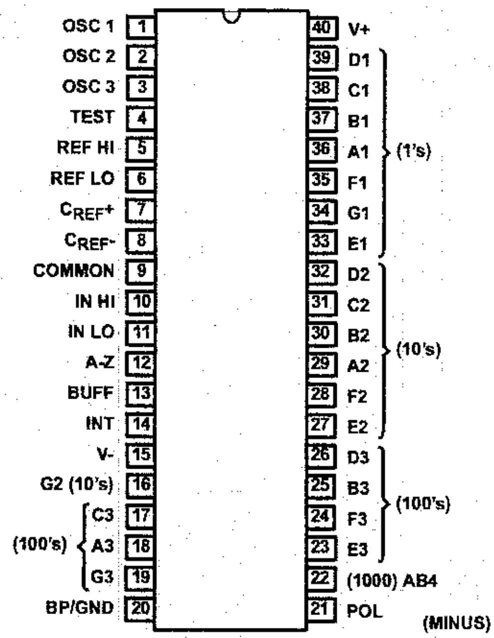
1. "R" indicates device with reversed leads for mounting to PC board underside. "S" indicates enhanced stability.
2. Intersil Pb-free plus anneal products employ special Pb-free material sets; molding compounds/die attach materials and 100% matte tin plate termination finish, which are RoHS compliant and compatible with both SnPb and Pb-free soldering operations. Intersil Pb-free products are MSL classified at Pb-free peak reflow temperatures that meet or exceed the Pb-free requirements of IPC/JEDEC J STD-020.
3. Pb-free PDIPs can be used for through hole wave solder processing only. They are not intended for use in Reflow solder processing applications.

Pinouts

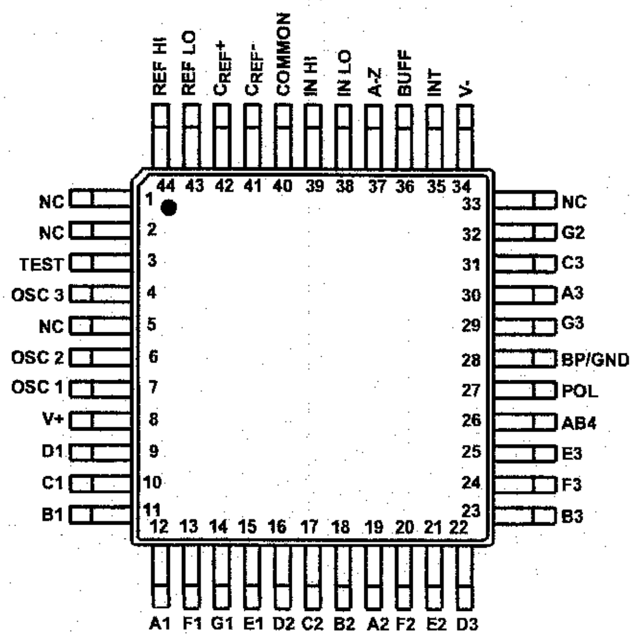
ICL7106, ICL7107 (PDIP)
TOP VIEW



ICL7107R (PDIP)
TOP VIEW



ICL7106, ICL7107 (MQFP)
TOP VIEW



bsolute Maximum Ratings

upply Voltage
- ICL7106, V+ to V- 15V
- ICL7107, V+ to GND 6V
- ICL7107, V- to GND . . . . -9V

nalog Input Voltage (Either Input) (Note 1) . . . . . . V+ to V-
eference Input Voltage (Either Input) . . . . . . V+ to V-
lock Input
- ICL7106 . . . . TEST to V+
- ICL7107 . . . . GND to V+

perating Conditions

emperature Range . . . . 0^oC to 70^oC

Thermal Information

Thermal Resistance (Typical, Note 2) θ_{JA} ($^oC/W$)
- PDIP Package 50
- MQFP Package 75

Maximum Junction Temperature . . . . 150^oC
Maximum Storage Temperature Range . . . . -65^oC to 150^oC
Maximum Lead Temperature (Soldering 10s) . . . . 300^oC
(MQFP - Lead Tips Only)

NOTE: Pb-free PDIPs can be used for through hole wave solder processing only. They are not intended for use in Reflow solder processing applications.

AUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the evice at these or any other conditions above those indicated in the operational sections of this specification is not implied.

IOTES:

1. Input voltages may exceed the supply voltages provided the input current is limited to ±100μA. 0.000100
2. θ_{JA} is measured with the component mounted on a low effective thermal conductivity test board in free air. See Tech Brief TB379 for details.

lectrical Specifications (Note 3)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
SYSTEM PERFORMANCE					
Zero Input Reading	V_{IN} = 0.0V, Full Scale = 200mV	-000.0	±000.0	+000.0	Digital Reading
Stability (Last Digit) (ICL7106S, ICL7107S Only)	Fixed Input Voltage (Note 6)	-000.0	±000.0	+000.0	Digital Reading
Ratiometric Reading	V_{IN} = V_{REF}, V_{REF} = 100mV	999	999/1000	1000	Digital Reading
Rollover Error	$-V_{IN} = +V_{IN} \cong$ 200mV Difference in Reading for Equal Positive and Negative Inputs Near Full Scale	-	±0.2	±1	Counts
Linearity	Full Scale = 200mV or Full Scale = 2V Maximum Deviation from Best Straight Line Fit (Note 5)	-	±0.2	±1	Counts
Common Mode Rejection Ratio	V_{CM} = 1V, V_{IN} = 0V, Full Scale = 200mV (Note 5)	-	50	-	μV/V
Noise	V_{IN} = 0V, Full Scale = 200mV (Peak-To-Peak Value Not Exceeded 95% of Time)	-	15	-	μV
Leakage Current Input	V_{IN} = 0 (Note 5)	-	1	10	pA
Zero Reading Drift	V_{IN} = 0, 0^oC To 70^oC (Note 5)	-	0.2	1	μV/^oC
Scale Factor Temperature Coefficient	V_{IN} = 199mV, 0^oC To 70^oC, (Ext. Ref. 0ppm/×^oC) (Note 5)	-	1	5	ppm/^oC
End Power Supply Character V+ Supply Current	V_{IN} = 0 (Does Not Include LED Current for ICL7107)	-	1.0	1.8	mA
End Power Supply Character V- Supply Current	ICL7107 Only	-	0.6	1.8	mA
COMMON Pin Analog Common Voltage	25kΩ Between Common and Positive Supply (With Respect to + Supply)	2.4	3.0	3.2	V
Temperature Coefficient of Analog Common	25kΩ Between Common and Positive Supply (With Respect to + Supply)	-	80	-	ppm/^oC
DISPLAY DRIVER ICL7106 ONLY					
Peak-To-Peak Segment Drive Voltage Peak-To-Peak Backplane Drive Voltage	V+ = to V- = 9V (Note 4)	4	5.5	6	V

V = 5.49V
I = 0.001mA
R = V/I = 5.49/1mA =

Electrical Specifications (Note 3) (Continued)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
DISPLAY DRIVER ICL7107 ONLY					
Segment Sinking Current	V+ = 5V, Segment Voltage = 3V				
Except Pins AB4 and POL		5	8	-	mA
Pin AB4 Only		10	16	-	mA
Pin POL Only		4	7	-	mA

NOTES:

3. Unless otherwise noted, specifications apply to both the ICL7106 and ICL7107 at $T_A = 25^oC$, $f_{CLOCK} = 48kHz$. ICL7106 is tested in the circuit of Figure 1. ICL7107 is tested in the circuit of Figure 2.
4. Back plane drive is in phase with segment drive for "off" segment, 180 degrees out of phase for "on" segment. Frequency is 20 times conversion rate. Average DC component is less than 50mV.
5. Not tested, guaranteed by design.
6. Sample Tested.

Typical Applications and Test Circuits

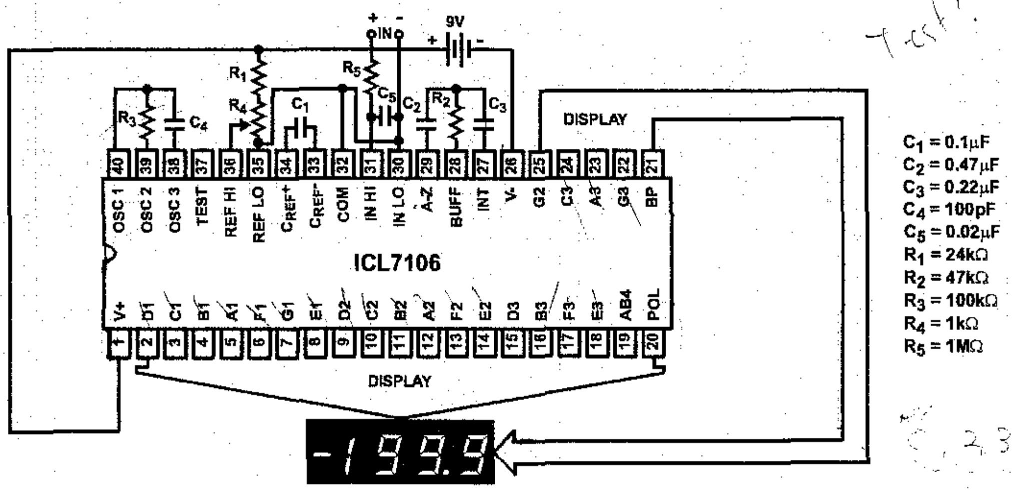


FIGURE 1. ICL7106 TEST CIRCUIT AND TYPICAL APPLICATION WITH LCD DISPLAY COMPONENTS SELECTED FOR 200mV FULL SCALE

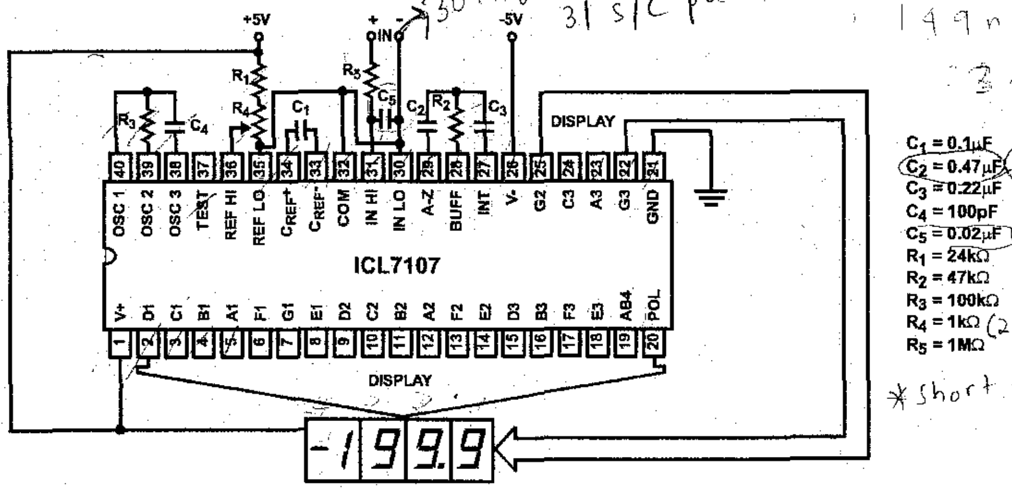


FIGURE 2. ICL7107 TEST CIRCUIT AND TYPICAL APPLICATION WITH LED DISPLAY COMPONENTS SELECTED FOR 200mV FULL SCALE

Design Information Summary Sheet

OSCILLATOR FREQUENCY

$f_{OSC} = 0.45/RC$
$C_{OSC} > 50pF$; $R_{OSC} > 50k\Omega$
f_{OSC} (Typ) = 48kHz

OSCILLATOR PERIOD

$t_{OSC} = RC/0.45$

INTEGRATION CLOCK FREQUENCY

$f_{CLOCK} = f_{OSC}/4$

INTEGRATION PERIOD

$t_{INT} = 1000 \times (4/f_{OSC})$

60/50Hz REJECTION CRITERION

t_{INT}/t_{60Hz} or t_{INT}/t_{60Hz} = Integer

OPTIMUM INTEGRATION CURRENT

$I_{INT} = 4\mu A$

FULL SCALE ANALOG INPUT VOLTAGE

V_{INFS} (Typ) = 200mV or 2V

INTEGRATE RESISTOR

$$R_{INT} = \frac{V_{INFS}}{I_{INT}}$$

INTEGRATE CAPACITOR

$$C_{INT} = \frac{(t_{INT})(I_{INT})}{V_{INT}}$$

INTEGRATOR OUTPUT VOLTAGE SWING

$$V_{INT} = \frac{(t_{INT})(I_{INT})}{C_{INT}}$$

V_{INT} MAXIMUM SWING:

$(V- + 0.5V) < V_{INT} < (V+ - 0.5V)$, V_{INT} (Typ) = 2V

- **DISPLAY COUNT**

  $$COUNT = 1000 \times \frac{V_{IN}}{V_{REF}}$$

- **CONVERSION CYCLE**

  $t_{CYC} = t_{CLOCK} \times 4000$
  $t_{CYC} = t_{OSC} \times 16{,}000$
  when f_{OSC} = 48kHz; t_{CYC} = 333ms

- **COMMON MODE INPUT VOLTAGE**

  $(V- + 1V) < V_{IN} < (V+ - 0.5V)$

- **AUTO-ZERO CAPACITOR**

  $0.01\mu F < C_{AZ} < 1\mu F$

- **REFERENCE CAPACITOR**

  $0.1\mu F < C_{REF} < 1\mu F$

- **V_{COM}**

  Biased between Vi and V-.

- **$V_{COM} \cong V+ - 2.8V$**

  Regulation lost when V+ to V- < ≅6.8V
  If V_{COM} is externally pulled down to (V+ to V-)/2, the V_{COM} circuit will turn off.

- **ICL7106 POWER SUPPLY: SINGLE 9V**

  V+ - V- = 9V
  Digital supply is generated internally
  $V_{GND} \cong V+ - 4.5V$

- **ICL7106 DISPLAY: LCD**

  Type: Direct drive with digital logic supply amplitude.

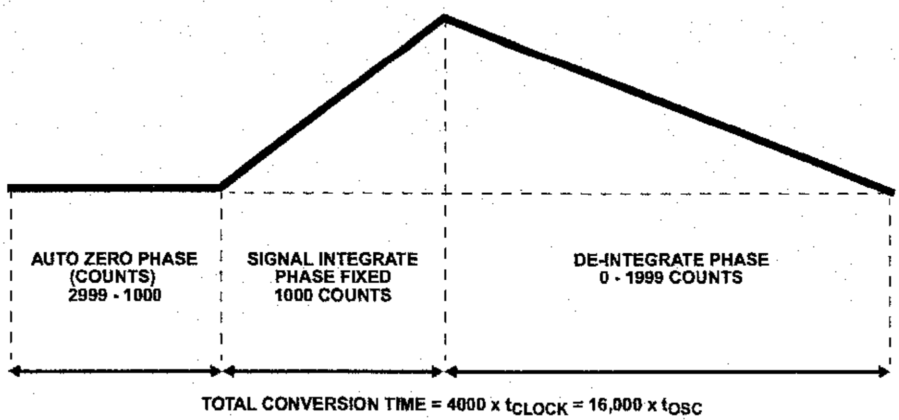
- **ICL7107 POWER SUPPLY: DUAL ±5.0V**

  V+ = +5V to GND
  V- = -5V to GND
  Digital Logic and LED driver supply V+ to GND

- **ICL7107 DISPLAY: LED**

  Type: Non-Multiplexed Common Anode

Typical Integrator Amplifier Output Waveform (INT Pin)



)etailed Description

\nalog Section

:igure 3 shows the Analog Section for the ICL7106 and CL7107. Each measurement cycle is divided into three ıhases. They are (1) auto-zero (A-Z), (2) signal integrate INT) and (3) de-integrate (DE).

\uto-Zero Phase

)uring auto-zero three things happen. First, input high and low ıre disconnected from the pins and internally shorted to analog ;OMMON. Second, the reference capacitor is charged to the eference voltage. Third, a feedback loop is closed around the ystem to charge the auto-zero capacitor C_{AZ} to compensate ɔr offset voltages in the buffer amplifier, integrator, and omparator. Since the comparator is included in the loop, the A- : accuracy is limited only by the noise of the system. In any ase, the offset referred to the input is less than 10μV.

;ignal Integrate Phase

)uring signal integrate, the auto-zero loop is opened, the ıternal short is removed, and the internal input high and low ıre connected to the external pins. The converter then ıtegrates the differential voltage between IN HI and IN LO for a xed time. This differential voltage can be within a wide ommon mode range: up to 1V from either supply. If, on the ıther hand, the input signal has no return with respect to the onverter power supply, IN LO can be tied to analog COMMON ɔ establish the correct common mode voltage. At the end of ıis phase, the polarity of the integrated signal is determined.

)e-Integrate Phase

'he final phase is de-integrate, or reference integrate. Input ɔw is internally connected to analog COMMON and input ıigh is connected across the previously charged reference apacitor. Circuitry within the chip ensures that the capacitor vill be connected with the correct polarity to cause the ıtegrator output to return to zero. The time required for the output to return to zero is proportional to the input signal. Specifically the digital reading displayed is:

$$\text{DISPLAY COUNT} = 1000\left(\frac{V_{IN}}{V_{REF}}\right).$$

Differential Input

The input can accept differential voltages anywhere within the common mode range of the input amplifier, or specifically from 0.5V below the positive supply to 1V above the negative supply. In this range, the system has a CMRR of 86dB typical. However, care must be exercised to assure the integrator output does not saturate. A worst case condition would be a large positive common mode voltage with a near full scale negative differential input voltage. The negative input signal drives the integrator positive when most of its swing has been used up by the positive common mode voltage. For these critical applications the integrator output swing can be reduced to less than the recommended 2V full scale swing with little loss of accuracy. The integrator output can swing to within 0.3V of either supply without loss of linearity.

Differential Reference

The reference voltage can be generated anywhere within the power supply voltage of the converter. The main source of common mode error is a roll-over voltage caused by the reference capacitor losing or gaining charge to stray capacity on its nodes. If there is a large common mode voltage, the reference capacitor can gain charge (increase voltage) when called up to de-integrate a positive signal but lose charge (decrease voltage) when called up to de-integrate a negative input signal. This difference in reference for positive or negative input voltage will give a roll-over error. However, by selecting the reference capacitor such that it is large enough in comparison to the stray capacitance, this error can be held to less than 0.5 count worst case. (See Component Value Selection.)

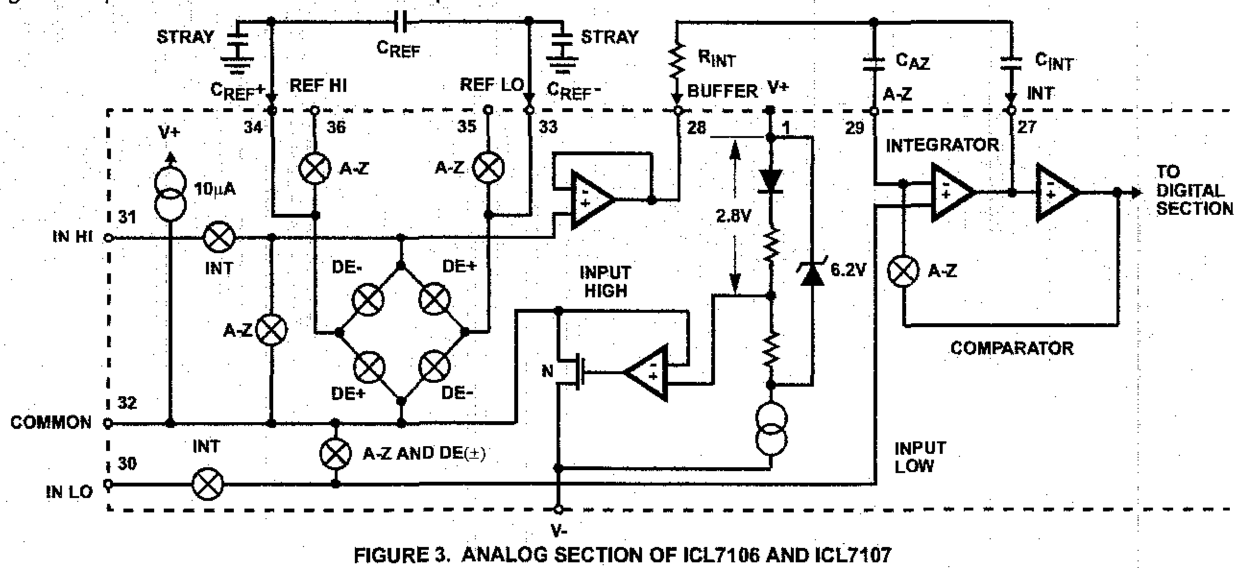


FIGURE 3. ANALOG SECTION OF ICL7106 AND ICL7107

ılog COMMON

pin is included primarily to set the common mode ıge for battery operation (ICL7106) or for any system re the input signals are floating with respect to the power ɔly. The COMMON pin sets a voltage that is ·oximately 2.8V more negative than the positive supply. is selected to give a minimum end-of-life battery voltage ɔout 6V. However, analog COMMON has some of the ɔutes of a reference voltage. When the total supply ıge is large enough to cause the zener to regulate (>7V), COMMON voltage will have a low voltage coefficient)1%/V), low output impedance (≅15Ω), and a ɔerature coefficient typically less than 80ppm/×°C.

limitations of the on chip reference should also be gnized, however. With the ICL7107, the internal heating h results from the LED drivers can cause some adation in performance. Due to their higher thermal ;tance, plastic parts are poorer in this respect than mic. The combination of reference Temperature fficient (TC), internal chip dissipation, and package nal resistance can increase noise near full scale from / to 80µV$_{P-P}$. Also the linearity in going from a high pation count such as 1000 (20 segments on) to a low pation count such as 1111(8 segments on) can suffer by unt or more. Devices with a positive TC reference may ire several counts to pull out of an over-range condition. is because over-range is a low dissipation mode, with the least significant digits blanked. Similarly, units with a ıtive TC may cycle between over-range and a non-over- e count as the die alternately heats and cools. All these lems are of course eliminated if an external reference is l.

ICL7106, with its negligible dissipation, suffers from of these problems. In either case, an external reference easily be added, as shown in Figure 4.

og COMMON is also used as the input low return during -zero and de-integrate. If IN LO is different from analog MMON, a common mode voltage exists in the system is taken care of by the excellent CMRR of the converter. ever, in some applications IN LO will be set at a fixed vn voltage (power supply common for instance). In this cation, analog COMMON should be tied to the same ;, thus removing the common mode voltage from the erter. The same holds true for the reference voltage. If ence can be conveniently tied to analog COMMON, it ld be since this removes the common mode voltage the reference system.

in the IC, analog COMMON is tied to an N-Channel FET can sink approximately 30mA of current to hold the ge 2.8V below the positive supply (when a load is trying ıll the common line positive). However, there is only \ of source current, so COMMON may easily be tied to a negative voltage thus overriding the internal reference.

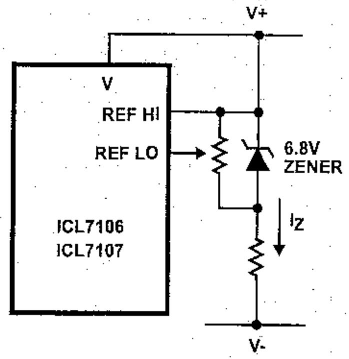


FIGURE 4A.

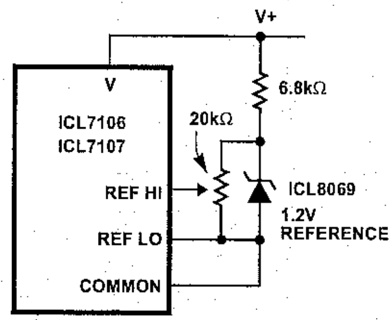


FIGURE 4B.

FIGURE 4. USING AN EXTERNAL REFERENCE

TEST

The TEST pin serves two functions. On the ICL7106 it is coupled to the internally generated digital supply through a 500Ω resistor. Thus it can be used as the negative supply for externally generated segment drivers such as decimal points or any other presentation the user may want to include on the LCD display. Figures 5 and 6 show such an application. No more than a 1mA load should be applied.

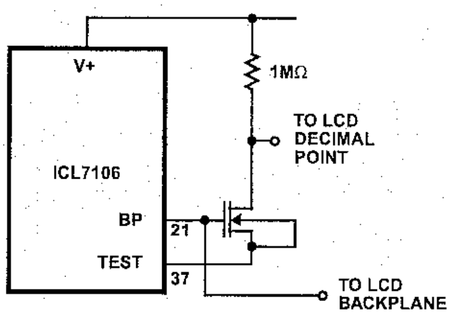
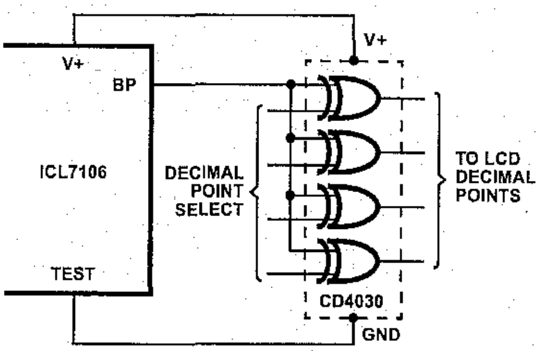


FIGURE 5. SIMPLE INVERTER FOR FIXED DECIMAL POINT

The second function is a "lamp test". When TEST is pulled high (to V+) all segments will be turned on and the display should read "1888". The TEST pin will sink about 15mA under these conditions.

CAUTION: In the lamp test mode, the segments have a constant DC voltage (no square-wave). This may burn the LCD display if maintained for extended periods.



JRE 6. EXCLUSIVE 'OR' GATE FOR DECIMAL POINT DRIVE

jital Section

res 7 and 8 show the digital section for the ICL7106 and '107, respectively. In the ICL7106, an internal digital nd is generated from a 6V Zener diode and a large ıannel source follower. This supply is made stiff to absorb the relative large capacitive currents when the back plane (BP) voltage is switched. The BP frequency is the clock frequency divided by 800. For three readings/sec., this is a 60Hz square wave with a nominal amplitude of 5V. The segments are driven at the same frequency and amplitude and are in phase with BP when OFF, but out of phase when ON. In all cases negligible DC voltage exists across the segments.

Figure 8 is the Digital Section of the ICL7107. It is identical to the ICL7106 except that the regulated supply and back plane drive have been eliminated and the segment drive has been increased from 2mA to 8mA, typical for instrument size common anode LED displays. Since the 1000 output (pin 19) must sink current from two LED segments, it has twice the drive capability or 16mA.

In both devices, the polarity indication is "on" for negative analog inputs. If IN LO and IN HI are reversed, this indication can be reversed also, if desired.

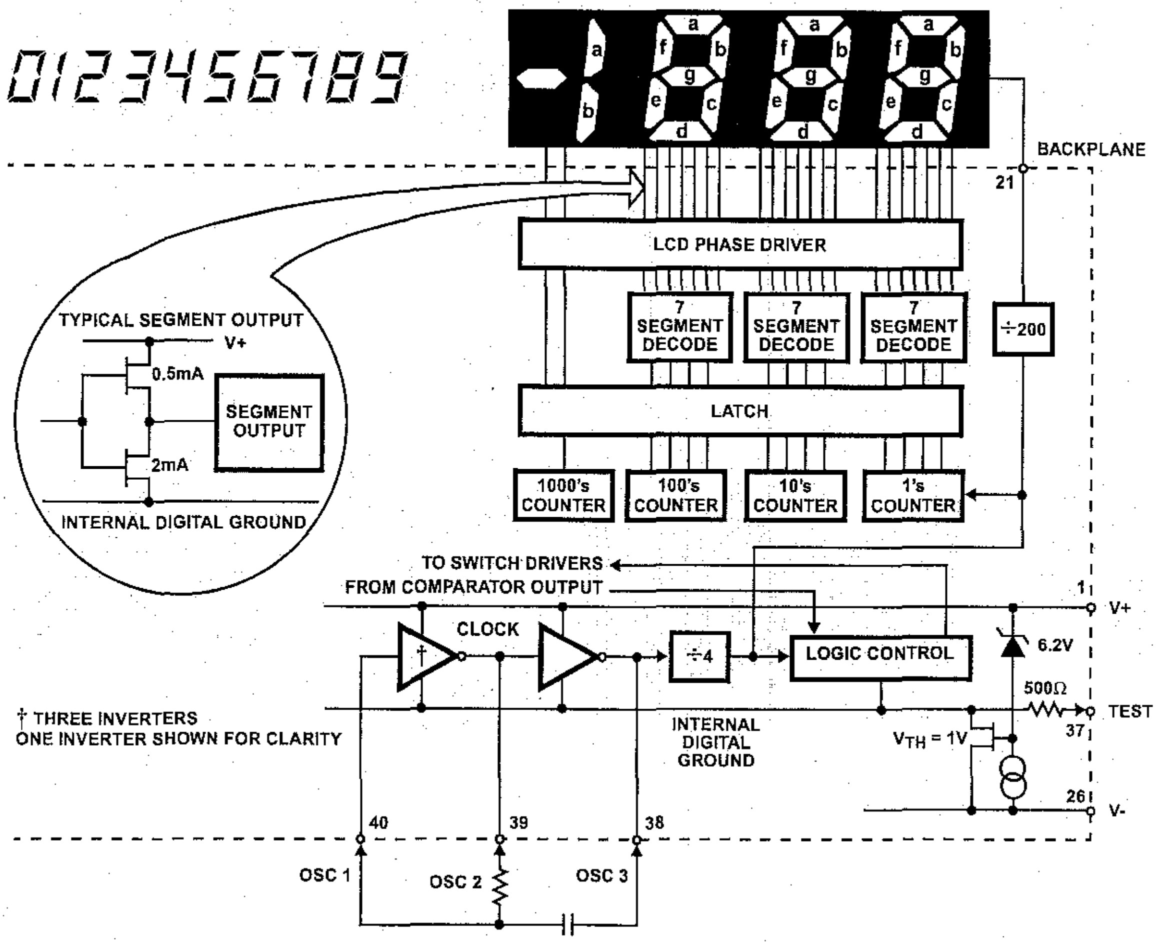


FIGURE 7. ICL7106 DIGITAL SECTION

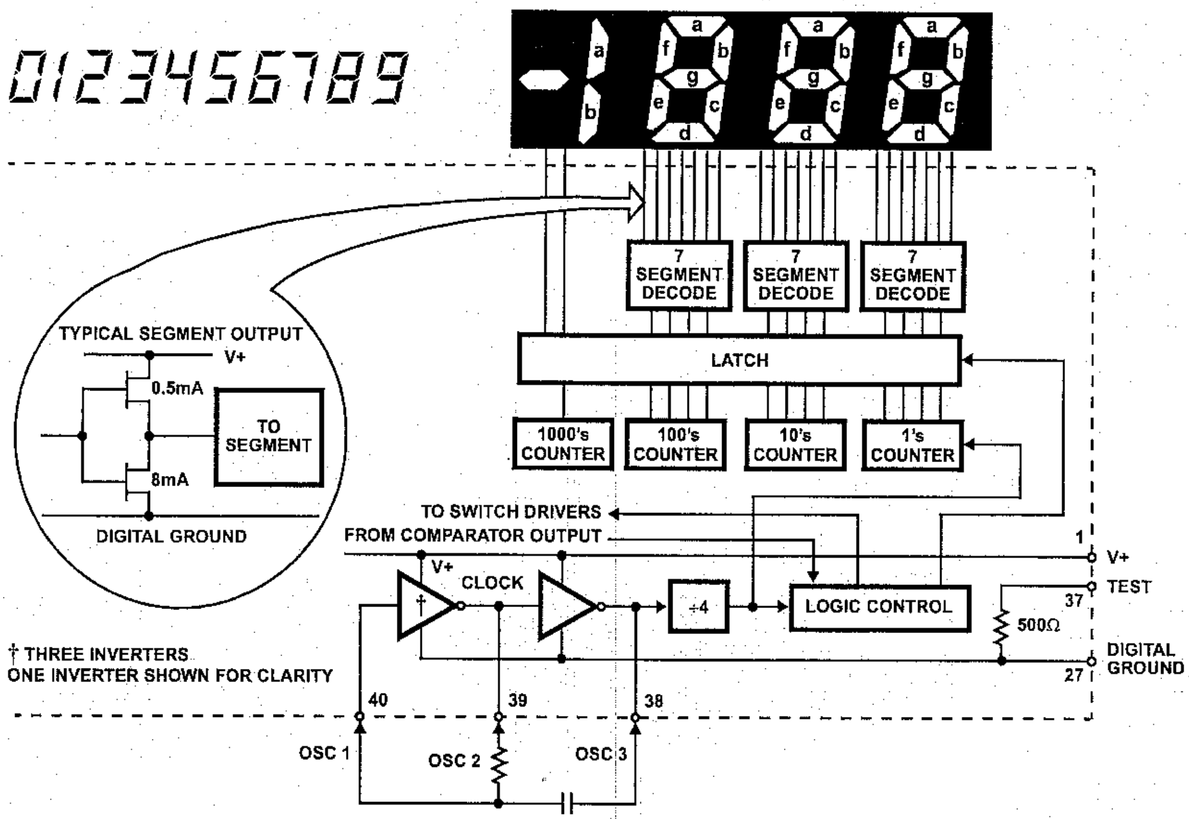


FIGURE 8. ICL7107 DIGITAL SECTION

tem Timing

re 9 shows the clocking arrangement used in the '106 and ICL7107. Two basic clocking arrangements be used:

-igure 9A. An external oscillator connected to pin 40.

-igure 9B. An R-C oscillator using all three pins.

oscillator frequency is divided by four before it clocks the ıde counters. It is then further divided to form the three 'ert-cycle phases. These are signal integrate (1000 ıts), reference de-integrate (0 to 2000 counts) and -zero (1000 to 3000 counts). For signals less than full ∍, auto-zero gets the unused portion of reference ıtegrate. This makes a complete measure cycle of 4,000 ıts (16,000 clock pulses) independent of input voltage. hree readings/second, an oscillator frequency of 48kHz d be used.

chieve maximum rejection of 60Hz pickup, the signal ırate cycle should be a multiple of 60Hz. Oscillator ıencies of 240kHz, 120kHz, 80kHz, 60kHz, 48kHz, ız, $33^1/_3$kHz, etc. should be selected. For 50Hz ction, Oscillator frequencies of 200kHz, 100kHz, ₃kHz, 50kHz, 40kHz, etc. would be suitable. Note that ız (2.5 readings/second) will reject both 50Hz and 60Hz ı 400Hz and 440Hz).

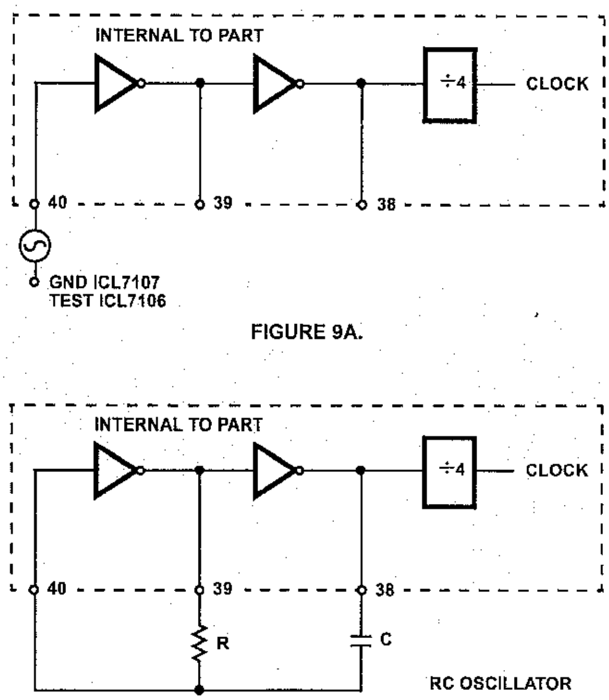


FIGURE 9A.

FIGURE 9B.

FIGURE 9. CLOCK CIRCUITS

mponent Value Selection

ɪgrating Resistor

ı the buffer amplifier and the integrator have a class A ıut stage with 100µA of quiescent current. They can ɔly 4µA of drive current with negligible nonlinearity. The ɟrating resistor should be large enough to remain in this linear region over the input voltage range, but small ɹgh that undue leakage requirements are not placed on ᴾC board. For 2V full scale, 470kΩ is near optimum and larly a 47kΩ for a 200mV scale.

ɪgrating Capacitor

integrating capacitor should be selected to give the imum voltage swing that ensures tolerance buildup will saturate the integrator swing (approximately. 0.3V from ɜr supply). In the ICL7106 or the ICL7107, when the og COMMON is used as a reference, a nominal +2V full- ɜ integrator swing is fine.(For the ICL7107 with +5V ɔlies and analog COMMON tied to supply ground, a V to +4V swing is nominal. For three readings/second Hz clock) nominal values for C_{INT} are 0.22µF and µF, respectively. Of course, if different oscillator ɹencies are used, these values should be changed in rse proportion to maintain the same output swing.

ıdditional requirement of the integrating capacitor is that ɹst have a low dielectric absorption to prevent roll-over ·s. While other types of capacitors are adequate for this ication, polypropylene capacitors give undetectable ·s at reasonable cost.

o-Zero Capacitor

size of the auto-zero capacitor has some influence on ıoise of the system. For 200mV full scale where noise is important, a 0.47µF capacitor is recommended. On the cale, a 0.047µF capacitor increases the speed of very from overload and is adequate for noise on this ɜ.

ɜrence Capacitor

1µF capacitor gives good results in most applications. ever, where a large common mode voltage exists (i.e., ⅃EF LO pin is not at analog COMMON) and a 200mV ɜ is used, a larger value is required to prevent roll-over . Generally 1µF will hold the roll-over error to 0.5 count is instance.

·illator Components

ıll ranges of frequency a 100kΩ resistor is recommended :he capacitor is selected from the equation:

$\frac{).45}{RC}$ For 48kHz Clock (3 Readings/sec),

100pF.

Reference Voltage

The analog input required to generate full scale output (2000 counts) is: $V_{IN} = 2V_{REF}$. Thus, for the 200mV and 2V scale, V_{REF} should equal 100mV and 1V, respectively. However, in many applications where the A/D is connected to a transducer, there will exist a scale factor other than unity between the input voltage and the digital reading. For instance, in a weighing system, the designer might like to have a full scale reading when the voltage from the transducer is 0.662V. Instead of dividing the input down to 200mV, the designer should use the input voltage directly and select V_{REF} = 0.341V. Suitable values for integrating resistor and capacitor would be 120kΩ and 0.22µF. This makes the system slightly quieter and also avoids a divider network on the input. The ICL7107 with ±5V supplies can accept input signals up to ±4V. Another advantage of this system occurs when a digital reading of zero is desired for $V_{IN} \neq 0$. Temperature and weighing systems with a variable fare are examples. This offset reading can be conveniently generated by connecting the voltage transducer between IN HI and COMMON and the variable (or fixed) offset voltage between COMMON and IN LO.

ICL7107 Power Supplies

The ICL7107 is designed to work from ±5V supplies. However, if a negative supply is not available, it can be generated from the clock output with 2 diodes, 2 capacitors, and an inexpensive IC. Figure 10 shows this application. See ICL7660 data sheet for an alternative.

In fact, in selected applications no negative supply is required. The conditions to use a single +5V supply are:

1. The input signal can be referenced to the center of the common mode range of the converter.
2. The signal is less than ±1.5V.
3. An external reference is used.

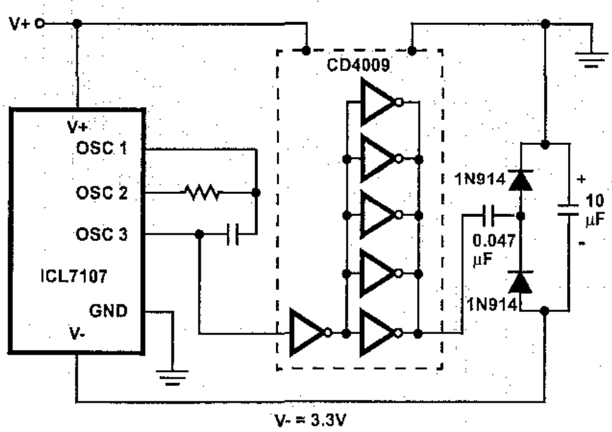


FIGURE 10. GENERATING NEGATIVE SUPPLY FROM +5V

ɔical Applications

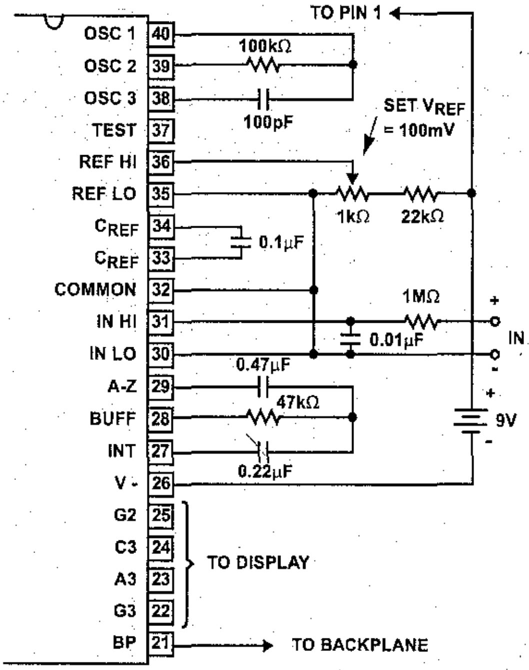
ICL7106 and ICL7107 may be used in a wide variety of ·igurations. The circuits which follow show some of the ɜibilities, and serve to illustrate the exceptional versatility ıese A/D converters.

following application notes contain very useful ·mation on understanding and applying this part and are ·lable from Intersil Corporation.

Application Notes

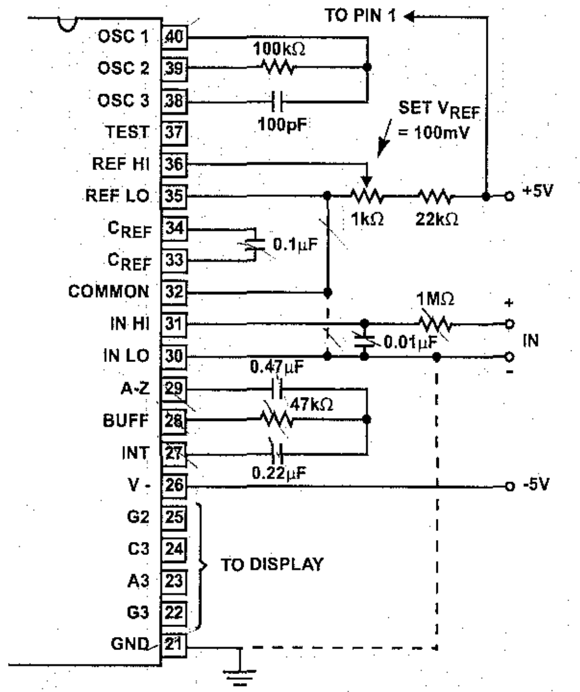
NOTE #	DESCRIPTION
AN016	"Selecting A/D Converters"
AN017	"The Integrating A/D Converter"
AN018	"Do's and Don'ts of Applying A/D Converters"
AN023	"Low Cost Digital Panel Meter Designs"
AN032	"Understanding the Auto-Zero and Common Mode Performance of the ICL7136/7/9 Family"
AN046	"Building a Battery-Operated Auto Ranging DVM with the ICL7106"
AN052	"Tips for Using Single Chip $3^1/_2$ Digit A/D Converters"
AN9609	"Overcoming Common Mode Range Issues When Using Intersil Integrating Converters"

ɔical Applications



ɜs shown are for 200mV full scale, 3 readings/sec., floating ly voltage (9V battery).

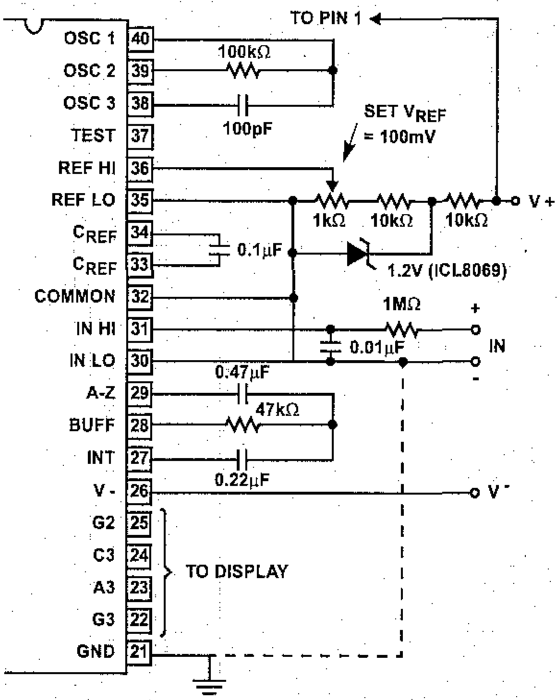
GURE 11. ICL7106 USING THE INTERNAL REFERENCE



Values shown are for 200mV full scale, 3 readings/sec. IN LO may be tied to either COMMON for inputs floating with respect to supplies, or GND for single ended inputs. (See discussion under Analog COMMON).

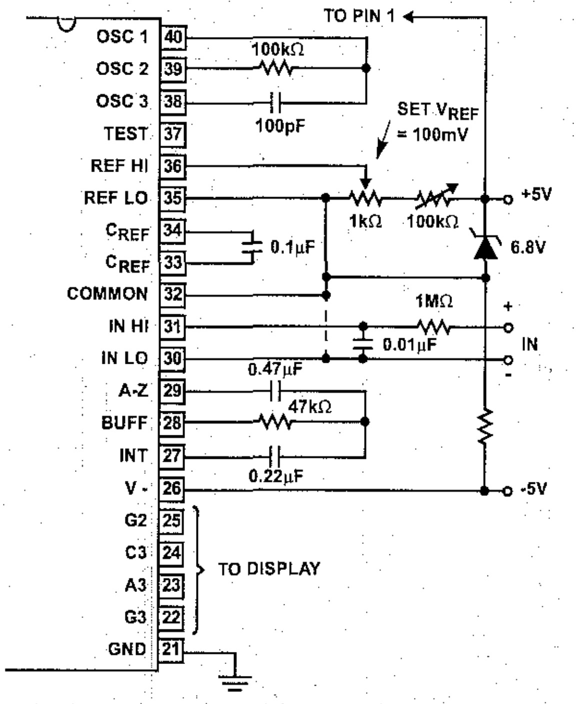
FIGURE 12. ICL7107 USING THE INTERNAL REFERENCE

ɔical Applications (Continued)



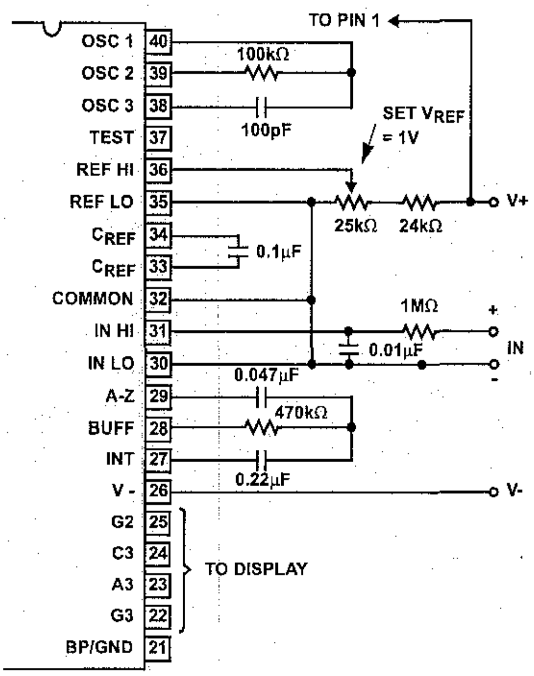
ⅽ is tied to supply COMMON establishing the correct common mode ɡe. If COMMON is not shorted to GND, the input voltage may float ʳespect to the power supply and COMMON acts as a pre-regulator ɪe reference. If COMMON is shorted to GND, the input is single d (referred to supply GND) and the pre-regulator is overridden.

ɜURE 13. ICL7107 WITH AN EXTERNAL BAND-GAP REFERENCE (1.2V TYPE)

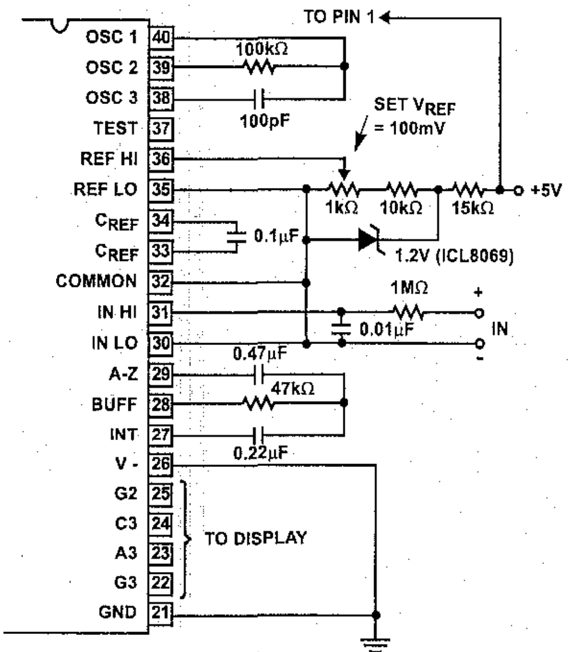


Since low TC zeners have breakdown voltages ~ 6.8V, diode must be placed across the total supply (10V). As in the case of Figure 12, IN LO may be tied to either COMMON or GND.

FIGURE 14. ICL7107 WITH ZENER DIODE REFERENCE



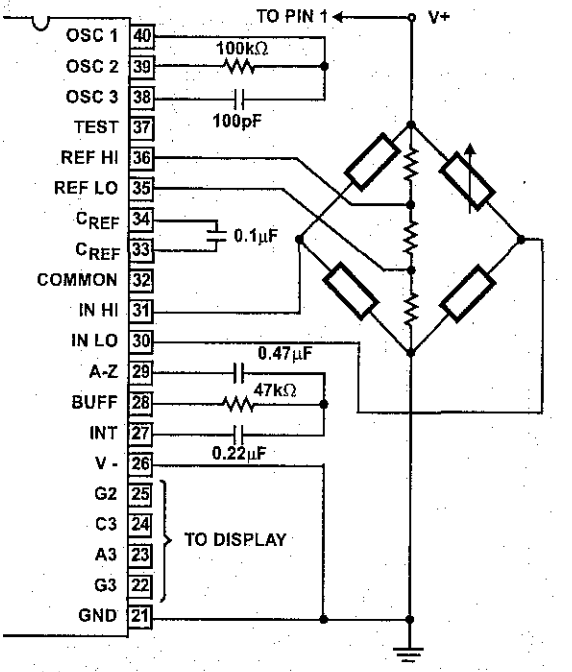
ɜURE 15. ICL7106 AND ICL7107: RECOMMENDED COMPONENT VALUES FOR 2V FULL SCALE



An external reference must be used in this application, since the voltage between V+ and V- is insufficient for correct operation of the internal reference.

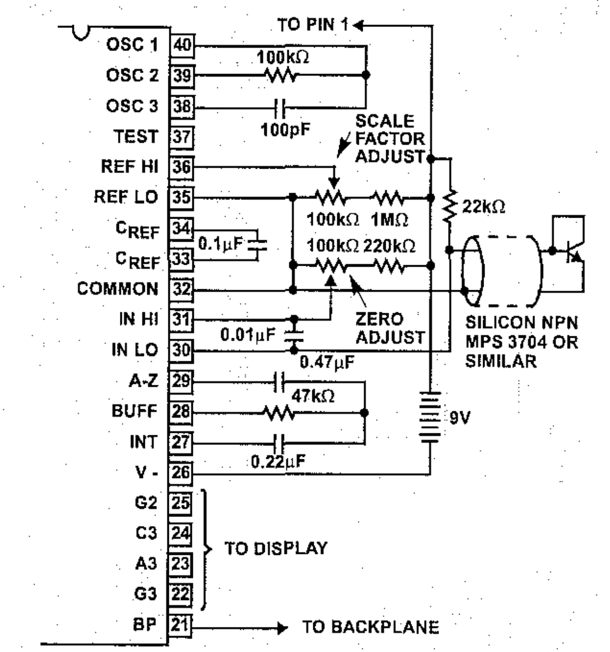
FIGURE 16. ICL7107 OPERATED FROM SINGLE +5V

ɔical Applications (Continued)



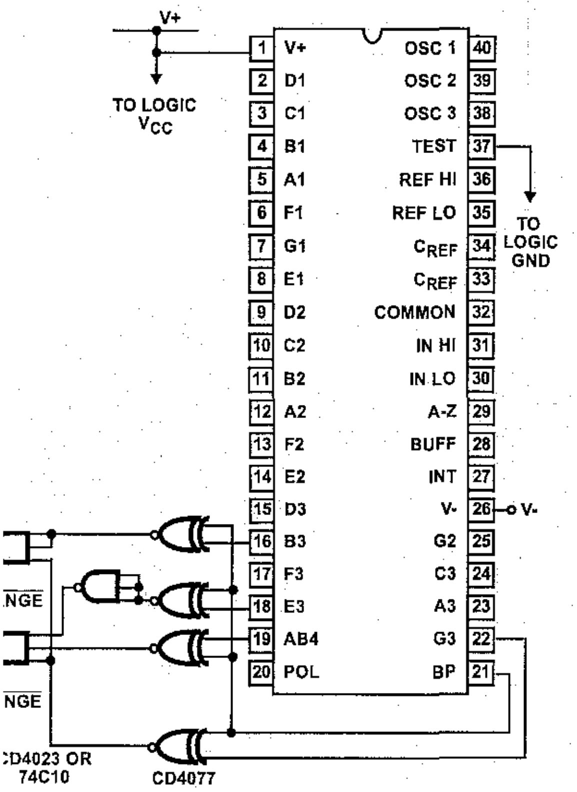
resistor values within the bridge are determined by the desired itivity.

ɜURE 17. ICL7107 MEASUREING RATIOMETRIC VALUES OF QUAD LOAD CELL



A silicon diode-connected transistor has a temperature coefficient of about -2mV/°C. Calibration is achieved by placing the sensing transistor in ice water and adjusting the zeroing potentiometer for a 000.0 reading. The sensor should then be placed in boiling water and the scale-factor potentiometer adjusted for a 100.0 reading.

FIGURE 18. ICL7106 USED AS A DIGITAL CENTIGRADE THERMOMETER



ɿURE 19. CIRCUIT FOR DEVELOPING UNDERRANGE AND OVERRANGE SIGNAL FROM ICL7106 OUTPUTS

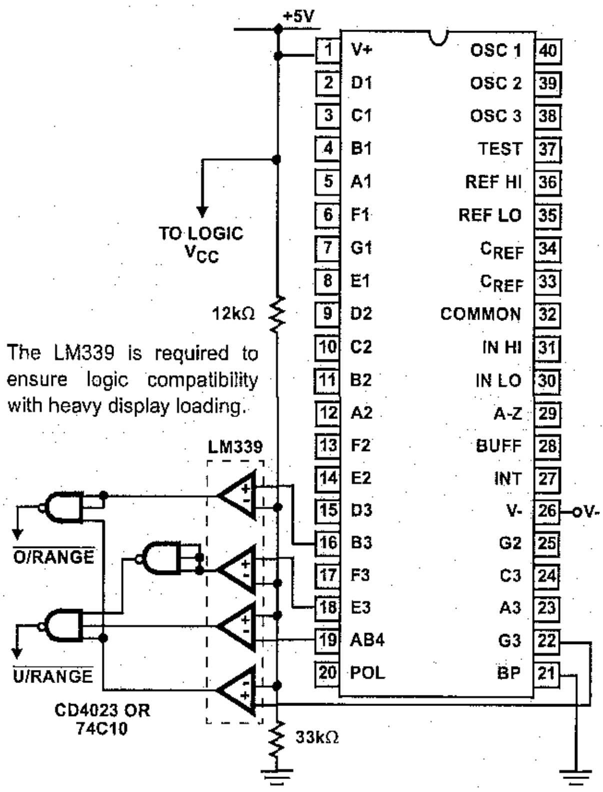
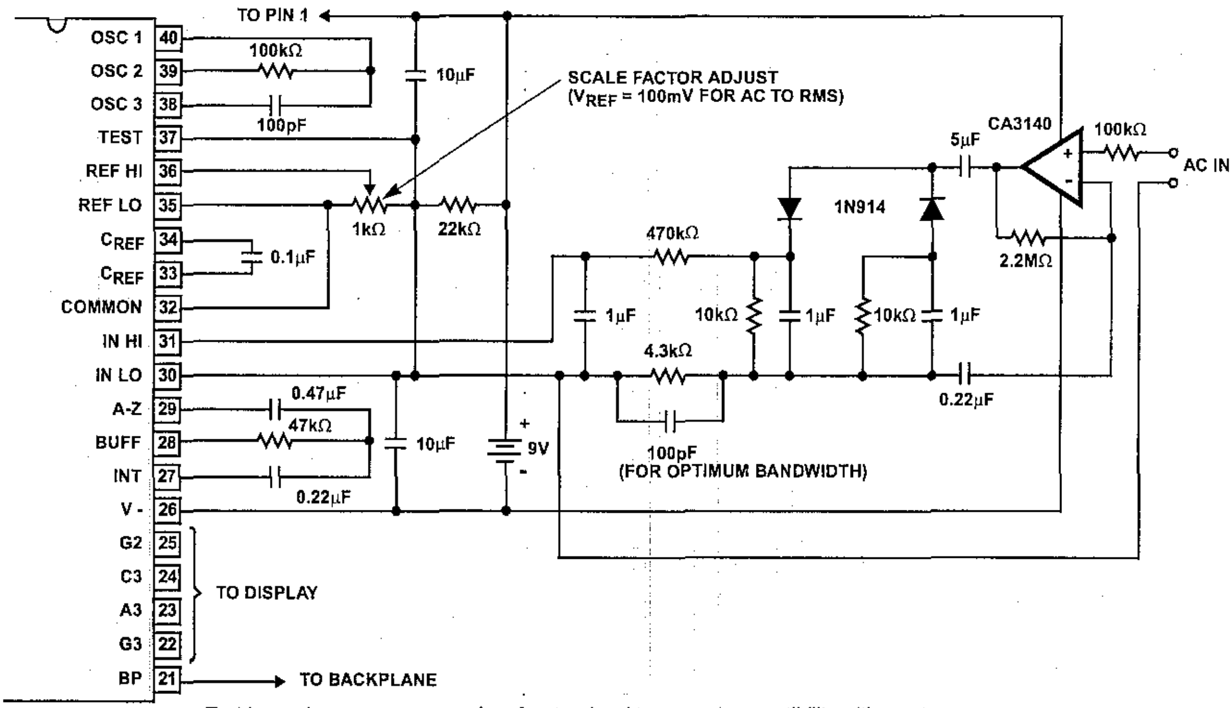


FIGURE 20. CIRCUIT FOR DEVELOPING UNDERRANGE AND OVERRANGE SIGNALS FROM ICL7107 OUTPUT

pical Applications (Continued)



Test is used as a common-mode reference level to ensure compatibility with most op amps.

FIGURE 21. AC TO DC CONVERTER WITH ICL7106

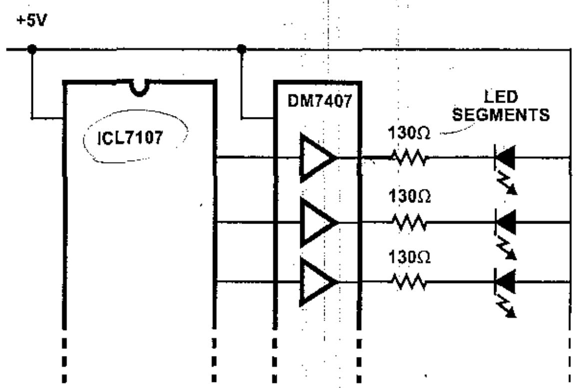
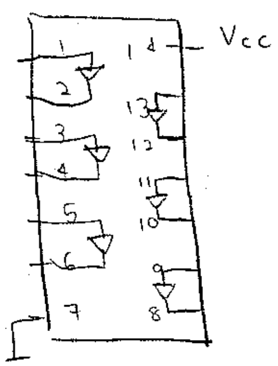
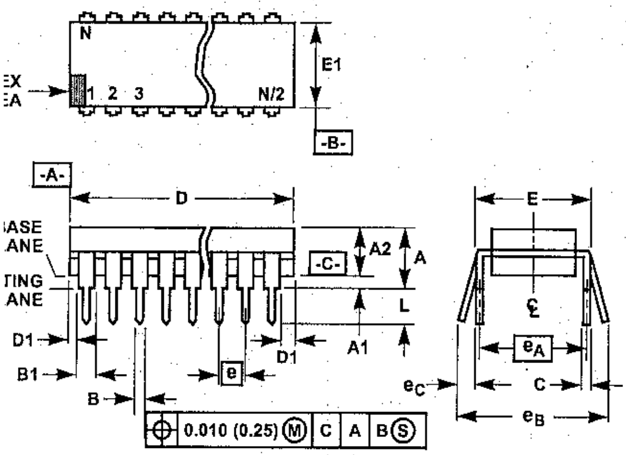


FIGURE 22. DISPLAY BUFFERING FOR INCREASED DRIVE CURRENT



'al-In-Line Plastic Packages (PDIP)



'ES:

Controlling Dimensions: INCH. In case of conflict between English and Metric dimensions, the inch dimensions control.

Dimensioning and tolerancing per ANSI Y14.5M-1982.

Symbols are defined in the "MO Series Symbol List" in Section 2.2 of Publication No. 95.

Dimensions A, A1 and L are measured with the package seated in JEDEC seating plane gauge GS-3.

D, D1, and E1 dimensions do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.010 inch (0.25mm).

E and e_A are measured with the leads constrained to be perpendicular to datum -C-.

e_B and e_C are measured at the lead tips with the leads unconstrained. e_C must be zero or greater.

B1 maximum dimensions do not include dambar protrusions. Dambar protrusions shall not exceed 0.010 inch (0.25mm).

N is the maximum number of terminal positions.

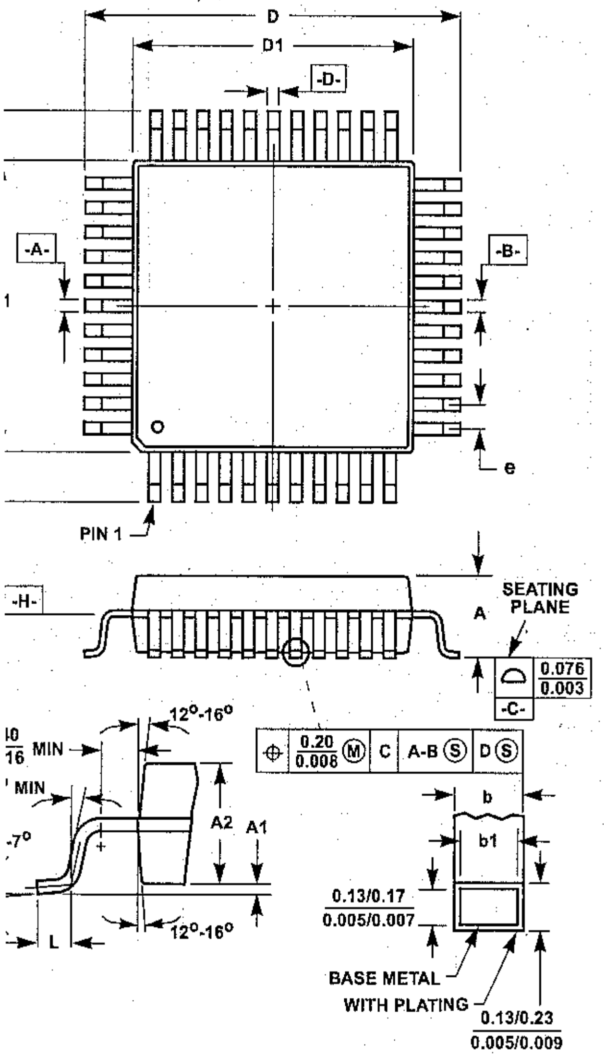
Corner leads (1, N, N/2 and N/2 + 1) for E8.3, E16.3, E18.3, E28.3, E42.6 will have a B1 dimension of 0.030 - 0.045 inch (0.76 - 1.14mm).

E40.6 (JEDEC MS-011-AC ISSUE B)
40 LEAD DUAL-IN-LINE PLASTIC PACKAGE

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN	MAX	MIN	MAX	
A	-	0.250	-	6.35	4
A1	0.015	-	0.39	-	4
A2	0.125	0.195	3.18	4.95	-
B	0.014	0.022	0.356	0.558	-
B1	0.030	0.070	0.77	1.77	8
C	0.008	0.015	0.204	0.381	-
D	1.980	2.095	50.3	53.2	5
D1	0.005	-	0.13	-	5
E	0.600	0.625	15.24	15.87	6
E1	0.485	0.580	12.32	14.73	5
e	0.100 BSC		2.54 BSC		-
e_A	0.600 BSC		15.24 BSC		6
e_B	-	0.700	-	17.78	7
L	0.115	0.200	2.93	5.08	4
N	40		40		9

Rev. 0 12/93

ɪtric Plastic Quad Flatpack Packages (MQFP)



Q44.10x10 (JEDEC MS-022AB ISSUE B)
44 LEAD METRIC PLASTIC QUAD FLATPACK PACKAGE

SYMBOL	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	NOTES
A	-	0.096	-	2.45	-
A1	0.004	0.010	0.10	0.25	-
A2	0.077	0.083	1.95	2.10	-
b	0.012	0.018	0.30	0.45	6
b1	0.012	0.016	0.30	0.40	-
D	0.515	0.524	13.08	13.32	3
D1	0.389	0.399	9.88	10.12	4, 5
E	0.516	0.523	13.10	13.30	3
E1	0.390	0.398	9.90	10.10	4, 5
L	0.029	0.040	0.73	1.03	-
N	44		44		7
e	0.032 BSC		0.80 BSC		-

Rev. 2 4/99

NOTES:

1. Controlling dimension: MILLIMETER. Converted inch dimensions are not necessarily exact.
2. All dimensions and tolerances per ANSI Y14.5M-1982.
3. Dimensions D and E to be determined at seating plane -C-.
4. Dimensions D1 and E1 to be determined at datum plane -H-.
5. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25mm (0.010 inch) per side.
6. Dimension b does not include dambar protrusion. Allowable dambar protrusion shall be 0.08mm (0.003 inch) total.
7. "N" is the number of terminal positions.

National Semiconductor

October 2005

LM158/LM258/LM358/LM2904
Low Power Dual Operational Amplifiers

General Description

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

The LM358 and LM2904 are available in a chip sized package (8-Bump micro SMD) using National's micro SMD package technology.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

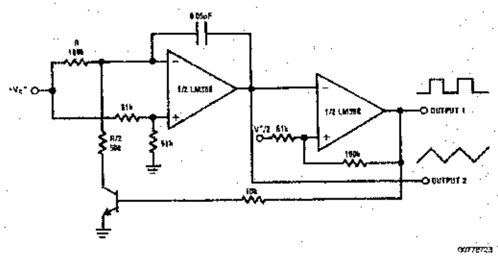
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Available in 8-Bump micro SMD chip sized package, (See AN-1112)
- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
  - — Single supply: 3V to 32V
  - — or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 µA)—essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing

Voltage Controlled Oscillator (VCO)



 DS007787

Absolute Maximum Ratings (Note 9)

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

	LM158/LM258/LM358 LM158A/LM258A/LM358A	LM2904
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	−0.3V to +32V	−0.3V to +26V
Power Dissipation (Note 1)		
Molded DIP	830 mW	830 mW
Metal Can	550 mW	
Small Outline Package (M)	530 mW	530 mW
micro SMD	435mW	
Output Short-Circuit to GND (One Amplifier) (Note 2)		
$V^+ \le 15V$ and $T_A = 25°C$	Continuous	Continuous
Input Current ($V_{IN} < -0.3V$) (Note 3)	50 mA	50 mA
Operating Temperature Range		
LM358	0°C to +70°C	−40°C to +85°C
LM258	−25°C to +85°C	
LM158	−55°C to +125°C	
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C
Lead Temperature, DIP (Soldering, 10 seconds)	260°C	260°C
Lead Temperature, Metal Can (Soldering, 10 seconds)	300°C	300°C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260°C	260°C
Small Outline Package		
Vapor Phase (60 seconds)	215°C	215°C
Infrared (15 seconds)	220°C	220°C
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.		
ESD Tolerance (Note 10)	250V	250V

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5), $T_A = 25°C$		1	2		2	3		2	5	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$, $V_{CM} = 0V$, (Note 6)		20	50		45	100		45	150	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		2	10		5	30		3	30	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps										
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5), $T_A = 25°C$		2	7		2	7	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$, $V_{CM} = 0V$, (Note 6)		45	250		45	250	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		5	50		5	50	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps							
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25°C$, $R_L \geq 2\ k\Omega$, (For $V_O = 1V$ to 11V)	50	100		25	100		50	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, $V_{CM} = 0V$ to $V^+-1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2904, $V^+ = 5V$ to 26V), $T_A = 25°C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), (Note 8)		−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25°C$, $V_O = 2V$	10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25°C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		12	50		μA
Short Circuit to Ground		$T_A = 25°C$, (Note 2), $V^+ = 15V$		40	60		40	60		40	60	mA
Input Offset Voltage		(Note 5)			4			5			7	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7	15		7	20		7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			30			75			100	nA
Input Offset Current Drift		$R_S = 0\Omega$		10	200		10	300		10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	200		40	300	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, (Note 7) (LM2904, $V^+ = 26V$)	0		V^+-2	0		V^+-2	0		V^+-2	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = +15V$ ($V_O = 1V$ to 11V) $R_L \geq 2\ k\Omega$	25			15			25			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$), $R_L = 2\ k\Omega$	26			26			26			V
		$V^+ = +30V$ (LM2904, $V^+ = 26V$), $R_L = 10\ k\Omega$	27	28		27	28		27	28		V
	V_{OL}	$V^+ = 5V$, $R_L = 10\ k\Omega$		5	20		5	20		5	20	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$	10	20		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$	10	15		5	8		5	8		mA

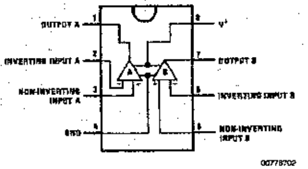
Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25°C$, $R_L \geq 2\ k\Omega$, (For $V_O = 1V$ to 11V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, $V_{CM} = 0V$ to $V^+-1.5V$	65	85		50	70		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2904, $V^+ = 5V$ to 26V), $T_A = 25°C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), (Note 8)		−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25°C$, $V_O = 2V$	10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25°C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		μA
Short Circuit to Ground		$T_A = 25°C$, (Note 2), $V^+ = 15V$		40	60		40	60	mA
Input Offset Voltage		(Note 5)			9			10	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7			7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			150		45	200	nA
Input Offset Current Drift		$R_S = 0\Omega$		10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	500		40	500	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, (Note 7) (LM2904, $V^+ = 26V$)	0		V^+-2	0		V^+-2	V

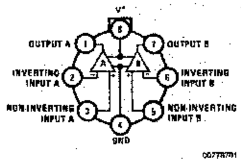
Connection Diagrams

DIP/SO Package



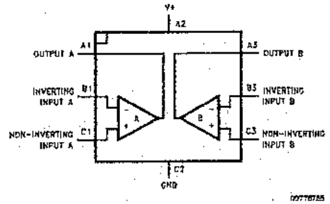
Top View

Metal Can Package



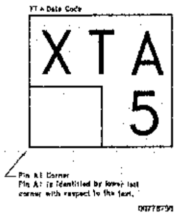
Top View

8-Bump micro SMD



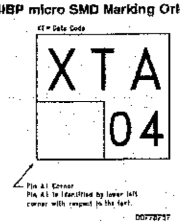
Top View
(Bump Side Down)

LM358BP micro SMD Marking Orientation



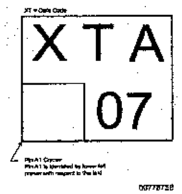
Top View

LM2904IBP micro SMD Marking Orientation



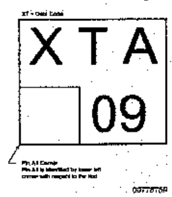
Top View

LM358TP micro SMD Marking Orientation



Top View

LM2904ITP micro SMD Marking Orientation



Top View

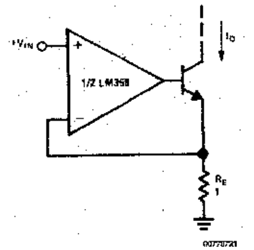
Ordering Information

Package	Temperature Range				NSC Drawing
	−55°C to 125°C	−25°C to 85°C	0°C to 70°C	−40°C to 85°C	
SO-8			LM358AM LM358AMX LM358M LM358MX	LM2904M LM2904MX	M08A
8-Pin Molded DIP			LM358AN LM358N	LM2904N	N08E
8-Pin Ceramic DIP	LM158AJ/883(Note 11) LM158J/883(Note 11) LM158J LM158AJLQML(Note 12) LM158AJQMLV(Note 12)				J08A
TO-5, 8-Pin Metal Can	LM158AH/883(Note 11) LM158H/883(Note 11) LM158AH LM158H LM158AHLQML(Note 12) LM158AHLQMLV(Note 12)	LM258H	LM358H		H08C
8-Bump micro SMD			LM358BP LM358BPX	LM2904IBP LM2904IBPX	BPA08AAB 0.85 mm Thick
8-Bump micro SMD Lead Free			LM358TP LM358TPX	LM2904ITP LM2904ITPX	TPA08AAA 0.50 mm Thick
14-Pin Ceramic SOIC	LM158AWG/883				WG10A

Note 11: LM158 is available per SMD #5962-8771001
LM158A is available per SMD #5962-8771002
Note 12: See STD Mil DWG 5962L87710 for Radiation Tolerant Devices

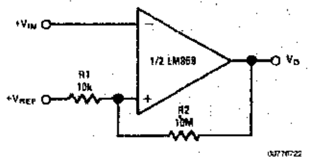
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

High Compliance Current Sink

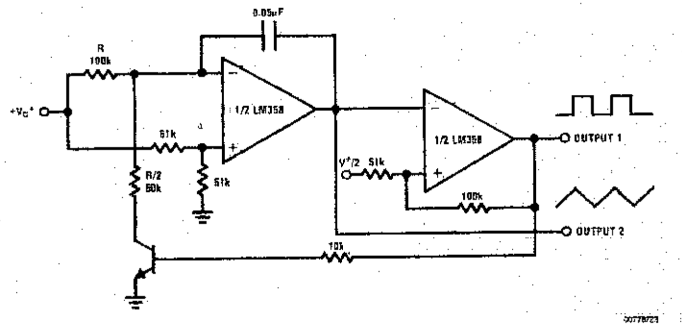


I_O = 1 amp/volt V_{IN}
(Increase R_E for I_O small)

Comparator with Hysteresis



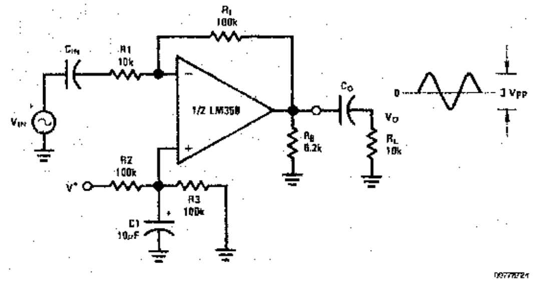
Voltage Controlled Oscillator (VCO)



*WIDE CONTROL VOLTAGE RANGE: 0 $V_{DC} \leq V_C \leq 2\ (V^+ - 1.5V_{DC})$

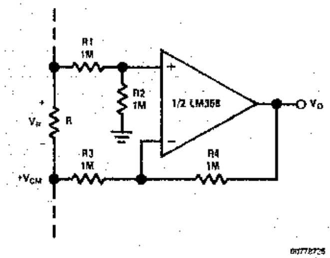
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

AC Coupled Inverting Amplifier



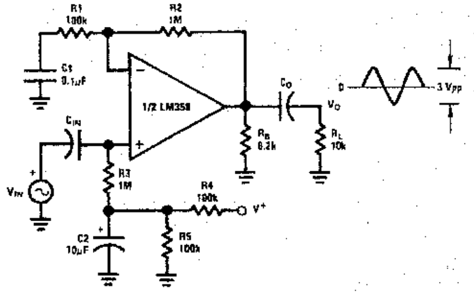
$A_V = \frac{R_f}{R1}$ (As shown, A_V = 10)

Ground Referencing a Differential Input Signal



Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

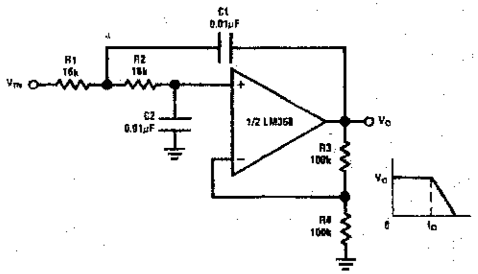
AC Coupled Non-Inverting Amplifier



$A_V = 1 + \frac{R2}{R1}$

$A_V = 11$ (As Shown)

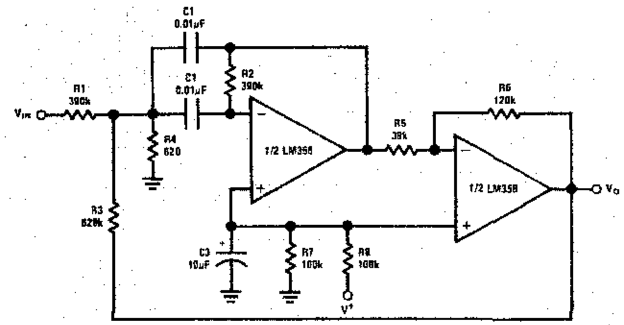
DC Coupled Low-Pass RC Active Filter



$f_O = 1$ kHz
$Q = 1$
$A_V = 2$

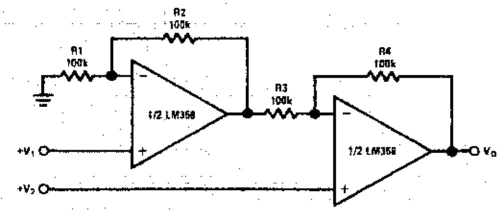
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Bandpass Active Filter



$f_o = 1$ kHz
$Q = 25$

High Input Z, DC Differential Amplifier

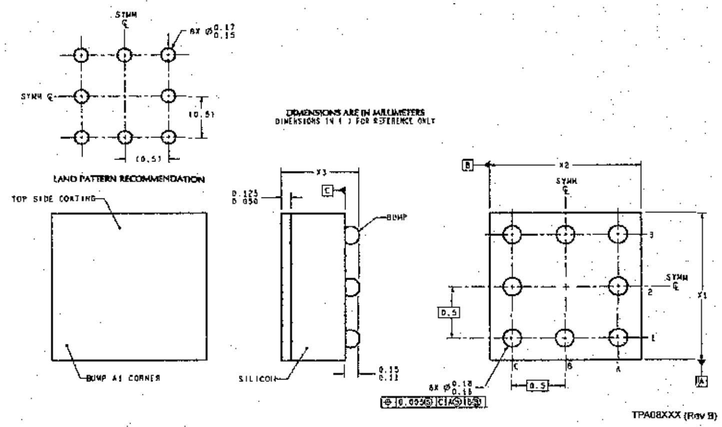


For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3}(V_2 - V_1)$

As Shown: $V_O = 2(V_2 - V_1)$

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING.
2. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.
3. PIN A1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.
4. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.
5. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD Lead Free
NS Package Number TPA08AAA
X_1 = 1.285 X_2 = 1.285 X_3 = 0.500

National Semiconductor Americas Customer Support Center
Email: new.feedback@nsc.com
Tel: 1-800-272-9959

National Semiconductor Europe Customer Support Center
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Support Center
Email: ap.support@nsc.com

National Semiconductor Japan Customer Support Center
Fax: 81-3-5639-7507
Email: jpn.feedback@nsc.com
Tel: 81-3-5639-7560

www.national.com

National Semiconductor

December 1994

LM108/LM208/LM308 Operational Amplifiers

General Description

The LM108 series are precision operational amplifiers having specifications a factor of ten better than FET amplifiers over a −55°C to +125°C temperature range.

The devices operate with supply voltages from ±2V to ±20V and have sufficient supply rejection to use unregulated supplies. Although the circuit is interchangeable with and uses the same compensation as the LM101A, an alternate compensation scheme can be used to make it particularly insensitive to power supply noise and to make supply bypass capacitors unnecessary.

The low current error of the LM108 series makes possible many designs that are not practical with conventional amplifiers. In fact, it operates from 10 MΩ source resistances, introducing less error than devices like the 709 with 10 kΩ sources. Integrators with drifts less than 500 μV/sec and analog time delays in excess of one hour can be made using capacitors no larger than 1 μF.

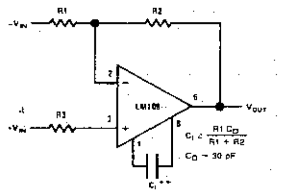
The LM108 is guaranteed from −55°C to +125°C, the LM208 from −25°C to +85°C, and the LM308 from 0°C to +70°C.

Features

- Maximum input bias current of 3.0 nA over temperature
- Offset current less than 400 pA over temperature
- Supply current of only 300 μA, even in saturation
- Guaranteed drift characteristics

Compensation Circuits

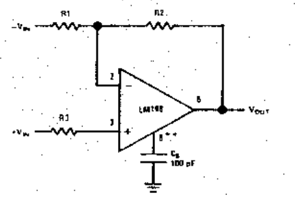
Standard Compensation Circuit



TL/H/7756-1

**Bandwidth and slew rate are proportional to $1/C_f$

Alternate* Frequency Compensation

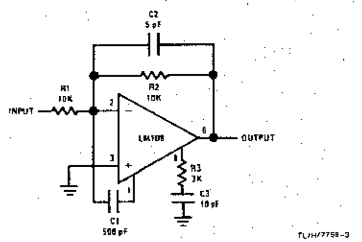


TL/H/7756-2

*Improves rejection of power supply noise by a factor of ten.

**Bandwidth and slew rate are proportional to $1/C_S$

Feedforward Compensation



TL/H/7756-3

RRD-B30M115/Printed in U. S. A.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 5)

	LM108/LM208	LM308
Supply Voltage	±20V	±18V
Power Dissipation (Note 1)	500 mW	500 mW
Differential Input Current (Note 2)	±10 mA	±10 mA
Input Voltage (Note 3)	±15V	±15V
Output Short-Circuit Duration	Continuous	Continuous
Operating Temperature Range (LM108)	−55°C to +125°C	0°C to +70°C
(LM208)	−25°C to +85°C	
Storage Temperature Range	−65°C to +150°C	65°C to +150°C
Lead Temperature (Soldering, 10 sec)		
DIP	260°C	260°C
H Package Lead Temp (Soldering 10 seconds)	300°C	300°C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260°C	
Small Outline Package		
Vapor Phase (60 seconds)	215°C	
Infrared (15 seconds)	220°C	
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.		
ESD Tolerance (Note 6)	2000V	

Electrical Characteristics (Note 4)

Parameter	Condition	LM108/LM208			LM308			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$		0.7	2.0		2.0	7.5	mV
Input Offset Current	$T_A = 25°C$		0.05	0.2		0.2	1	nA
Input Bias Current	$T_A = 25°C$		0.8	2.0		1.5	7	nA
Input Resistance	$T_A = 25°C$	30	70		10	40		MΩ
Supply Current	$T_A = 25°C$		0.3	0.6		0.3	0.8	mA
Large Signal Voltage Gain	$T_A = 25°C$, $V_S = \pm15V$ $V_{OUT} = \pm10V$, $R_L \geq 10\ k\Omega$	50	300		25	300		V/mV
Input Offset Voltage				3.0			10	mV
Average Temperature Coefficient of Input Offset Voltage			3.0	15		6.0	30	μV/°C
Input Offset Current				0.4			1.5	nA
Average Temperature Coefficient of Input Offset Current			0.5	2.5		2.0	10	pA/°C
Input Bias Current				3.0			10	nA
Supply Current	$T_A = +125°C$		0.15	0.4				mA
Large Signal Voltage Gain	$V_S = \pm15V$, $V_{OUT} = \pm10V$ $R_L \geq 10\ k\Omega$	25			15			V/mV
Output Voltage Swing	$V_S = \pm15V$, $R_L = 10\ k\Omega$	±13	±14		±13	±14		V

Electrical Characteristics (Note 4) (Continued)

Parameter	Condition	LM108/LM208			LM308			Units
		Min	Typ	Max	Min	Typ	Max	
Input Voltage Range	$V_S = \pm 15V$	±13.5			±14			V
Common Mode Rejection Ratio		85	100		80	100		dB
Supply Voltage Rejection Ratio		80	96		80	96		dB

Note 1: The maximum junction temperature of the LM108 is 150°C, for the LM208, 100°C and for the LM308, 85°C. For operating at elevated temperatures, devices in the H08 package must be derated based on a thermal resistance of 160°C/W, junction to ambient, or 20°C/W, junction to case. The thermal resistance of the dual-in-line package is 100°C/W, junction to ambient.

Note 2: The inputs are shunted with back-to-back diodes for overvoltage protection. Therefore, excessive current will flow if a differential input voltage in excess of 1V is applied between the inputs unless some limiting resistance is used.

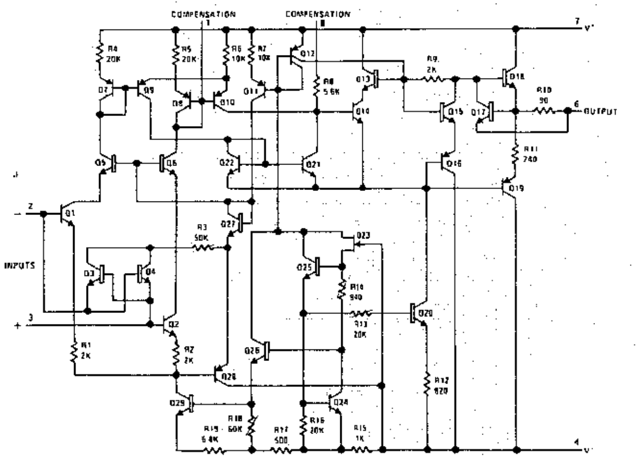
Note 3: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 4: These specifications apply for $\pm 5V \le V_S \le \pm 20V$ and $-55°C \le T_A \le +125°C$, unless otherwise specified. With the LM208, however, all temperature specifications are limited to $-25°C \le T_A \le 85°C$, and for the LM308 they are limited to $0°C \le T_A \le 70°C$.

Note 5: Refer to RETS108X for LM108 military specifications and RETs 108AX for LM108A military specifications.

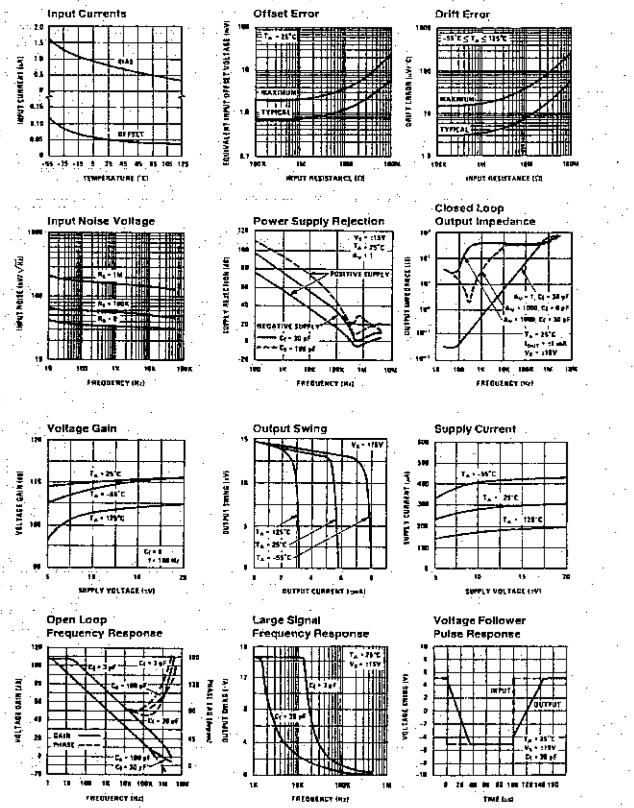
Note 6: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram



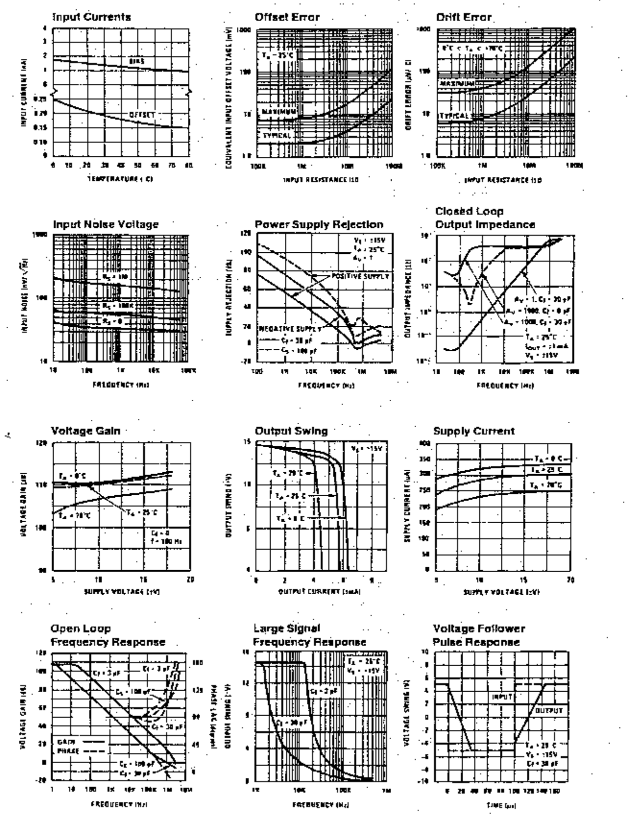
TL/H/7758-8

Typical Performance Characteristics LM108/LM208



TL/H/7758-6

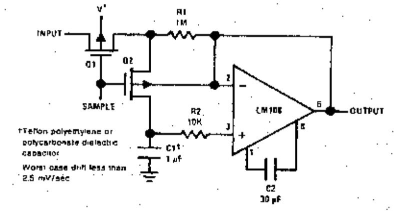
Typical Performance Characteristics LM308



TL/H/7758-7

Typical Applications

Sample and Hold

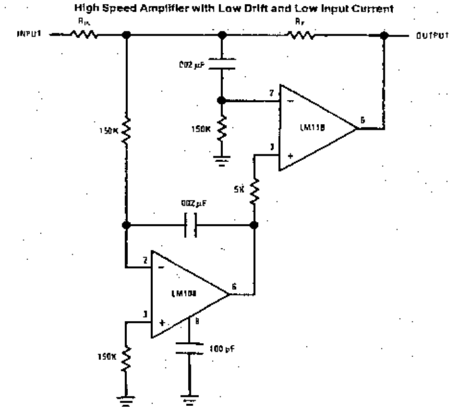


†Teflon polyethylene or polycarbonate dielectric capacitor

Worst case drift less than 2.5 mV/sec

TL/H/7758-4

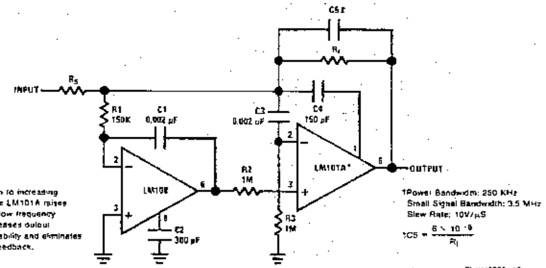
High Speed Amplifier with Low Drift and Low Input Current



TL/H/7758-5

Typical Applications (Continued)

Fast† Summing Amplifier



*In addition to increasing speed, the LM101A raises high and low frequency gain, increases output drive capability and eliminates thermal feedback.

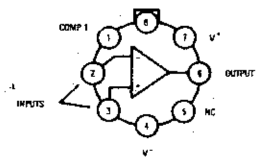
†Power Bandwidth: 250 kHz
Small Signal Bandwidth: 3.5 MHz
Slew Rate: 10V/µs

$‡C5 = \frac{6 \times 10^{-8}}{R_f}$

TL/H/7758–12

Connection Diagrams

Metal Can Package



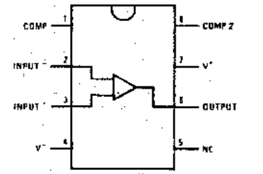
TL/H/7758–13

*Package is connected to Pin 4 (V−)

**Unused pin (no internal connection) to allow for input anti-leakage guard ring on printed circuit board layout.

Order Number LM108H, LM108H/883, LM308AH or LM308H
See NS Package Number H08C

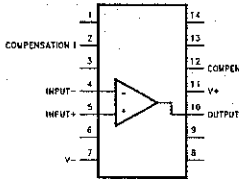
Dual-In-Line Package



TL/H/7758–15

Top View

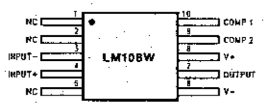
Order Number LM108J-8/883, LM308M or LM308N
See NS Package Number J08A, M08A or N08E



TL/H/7758–16

Top View

Order Number LM108J/883
See NS Package Number J14A

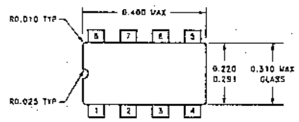


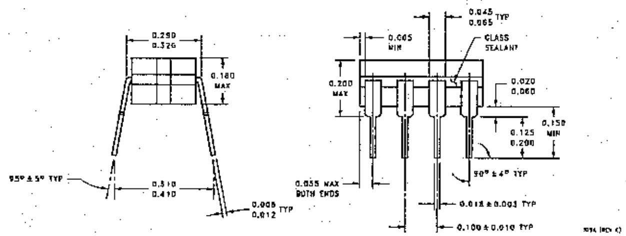
TL/H/7758–17

Order Number LM108W/883
See NS Package Number W10A

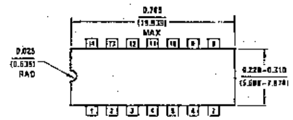
‡Also available per JM38510/10104

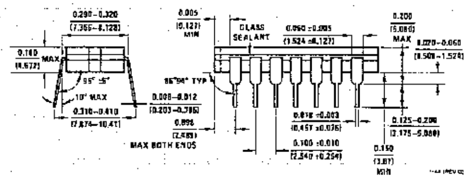
Physical Dimensions inches (millimeters)





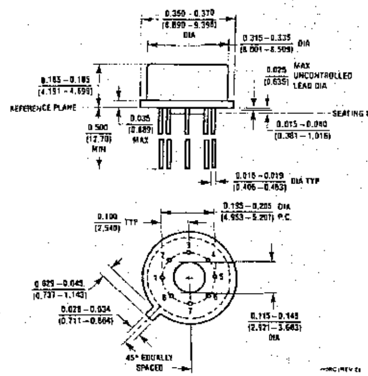
Ceramic Dual-In-Line Package (J)
Order Number LM108J/883
NS Package Number J08A



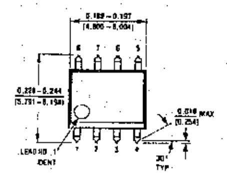


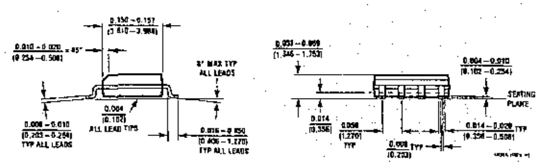
Ceramic Dual-In-Line Package (J)
Order Number LM108/883
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)



Metal Can Package (H)
Order Number LM108H, LM108H/883 or LM308H
NS Package Number H08C

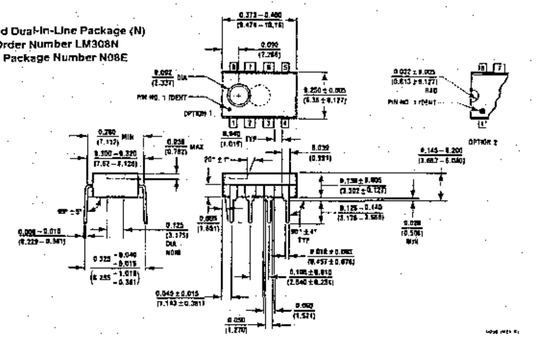




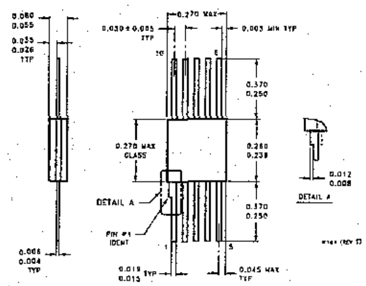
S.O. Package (M)
Order Number LM308M
NS Package Number M08A

Physical Dimensions inches (millimeters) (Continued)

Molded Dual-In-Line Package (N)
Order Number LM308N
NS Package Number N08E



Ceramic Flatpack Package (W)
Order Number LM108AW/883 or LM108W/883
NS Package Number W10A



National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408

National Semiconductor

November 2000

LM135/LM235/LM335, LM135A/LM235A/LM335A Precision Temperature Sensors

General Description

The LM135 series are precision, easily-calibrated, integrated circuit temperature sensors. Operating as a 2-terminal zener, the LM135 has a breakdown voltage directly proportional to absolute temperature at +10 mV/°K. With less than 1Ω dynamic impedance the device operates over a current range of 400 µA to 5 mA with virtually no change in performance. When calibrated at 25°C the LM135 has typically less than 1°C error over a 100°C temperature range. Unlike other sensors the LM135 has a linear output.

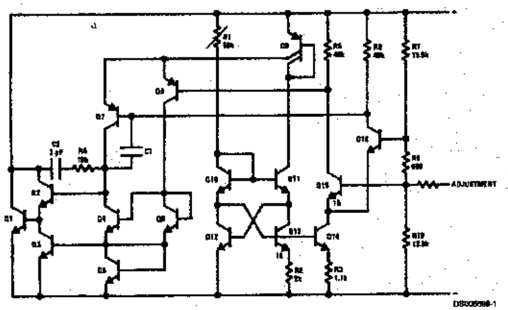
Applications for the LM135 include almost any type of temperature sensing over a −55°C to +150°C temperature range. The low impedance and linear output make interfacing to readout or control circuitry especially easy.

The LM135 operates over a −55°C to +150°C temperature range while the LM235 operates over a −40°C to +125°C temperature range. The LM335 operates from −40°C to +100°C. The LM135/LM235/LM335 are available packaged in hermetic TO-46 transistor packages while the LM335 is also available in plastic TO-92 packages.

Features

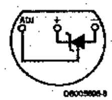
- Directly calibrated in °Kelvin
- 1°C initial accuracy available
- Operates from 400 µA to 5 mA
- Less than 1Ω dynamic impedance
- Easily calibrated
- Wide operating temperature range
- 200°C overrange
- Low cost

Schematic Diagram



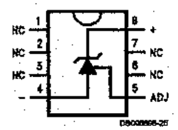
Connection Diagrams

TO-92
Plastic Package



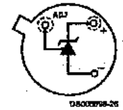
Bottom View
Order Number LM335Z
or LM335AZ
See NS Package
Number Z03A

SO-8
Surface Mount Package



Order Number LM335M
See NS Package
Number M08A

TO-46
Metal Can Package*



*Case is connected to negative pin

Bottom View
Order Number LM135H,
LM135H-MIL, LM235H,
LM335H, LM135AH,
LM235AH or LM335AH
See NS Package
Number H03H

Absolute Maximum Ratings (Note 4)

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

Reverse Current	15 mA
Forward Current	10 mA
Storage Temperature	
TO-46 Package	−60°C to +180°C
TO-92 Package	−60°C to +150°C
SO-8 Package	−65°C to +150°C

Specified Operating Temp. Range

	Continuous	Intermittent (Note 2)
LM135, LM135A	−55°C to +150°C	150°C to 200°C
LM235, LM235A	−40°C to +125°C	125°C to 150°C
LM335, LM335A	−40°C to +100°C	100°C to 125°C

Lead Temp. (Soldering, 10 seconds)	
TO-92 Package:	260°C
TO-46 Package:	300°C
SO-8 Package:	300°C
Vapor Phase (60 seconds):	215°C
Infrared (15 seconds):	220°C

Temperature Accuracy (Note 1)

LM135/LM235, LM135A/LM235A

Parameter	Conditions	LM135A/LM235A			LM135/LM235			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$T_C = 25°C$, $I_R = 1$ mA	2.97	2.98	2.99	2.95	2.98	3.01	V
Uncalibrated Temperature Error	$T_C = 25°C$, $I_R = 1$ mA		0.5	1		1	3	°C
Uncalibrated Temperature Error	$T_{MIN} \le T_C \le T_{MAX}$, $I_R = 1$ mA		1.3	2.7		2	5	°C
Temperature Error with 25°C Calibration	$T_{MIN} \le T_C \le T_{MAX}$, $I_R = 1$ mA		0.3	1		0.5	1.5	°C
Calibrated Error at Extended Temperatures	$T_C = T_{MAX}$ (Intermittent)		2			2		°C
Non-Linearity	$I_R = 1$ mA		0.3	0.5		0.3	1	°C

Temperature Accuracy (Note 1)

LM335, LM335A

Parameter	Conditions	LM335A			LM335			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage	$T_C = 25°C$, $I_R = 1$ mA	2.95	2.98	3.01	2.92	2.98	3.04	V
Uncalibrated Temperature Error	$T_C = 25°C$, $I_R = 1$ mA		1	3		2	6	°C
Uncalibrated Temperature Error	$T_{MIN} \le T_C \le T_{MAX}$, $I_R = 1$ mA		2	5		4	9	°C
Temperature Error with 25°C Calibration	$T_{MIN} \le T_C \le T_{MAX}$, $I_R = 1$ mA		0.5	1		1	2	°C
Calibrated Error at Extended Temperatures	$T_C = T_{MAX}$ (Intermittent)		2			2		°C
Non-Linearity	$I_R = 1$ mA		0.3	1.5		0.3	1.5	°C

Electrical Characteristics (Note 1)

Parameter	Conditions	LM135/LM235 LM135A/LM235A			LM335 LM335A			Units
		Min	Typ	Max	Min	Typ	Max	
Operating Output Voltage Change with Current	400 μA≤I_R≤5 mA At Constant Temperature		2.5	10		3	14	mV
Dynamic Impedance	I_R=1 mA		0.5			0.6		Ω
Output Voltage Temperature Coefficient			+10			+10		mV/°C
Time Constant	Still Air		80			80		sec
	100 ft/Min Air		10			10		sec
	Stirred Oil		1			1		sec
Time Stability	T_C=125°C		0.2			0.2		°C/khr

Electrical Characteristics (Note 1) (Continued)

Note 1: Accuracy measurements are made in a well-stirred oil bath. For other conditions, self heating must be considered.

Note 2: Continuous operation at these temperatures for 10,000 hours for H package and 5,000 hours for Z package may decrease life expectancy of the device.

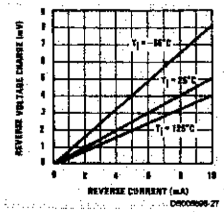
Note 3:

Thermal Resistance	TO-92	TO-46	SO-8
θ_{JA} (junction to ambient)	202°C/W	400°C/W	165°C/W
θ_{JC} (junction to case)	170°C/W	N/A	N/A

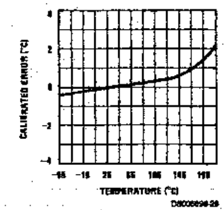
Note 4: Refer to RETS135H for military specifications.

Typical Performance Characteristics

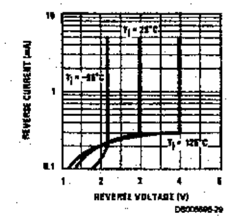
Reverse Voltage Change



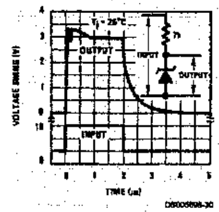
Calibrated Error



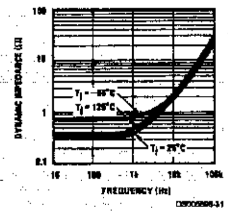
Reverse Characteristics



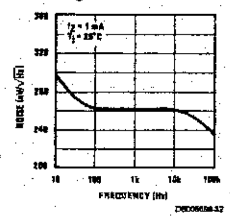
Response Time



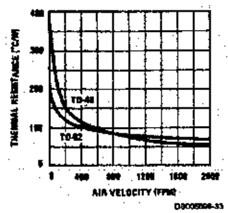
Dynamic Impedance



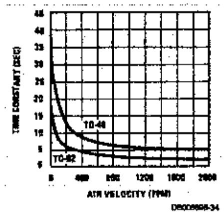
Noise Voltage



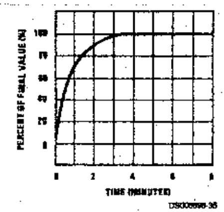
Thermal Resistance Junction to Air



Thermal Time Constant

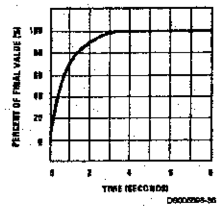


Thermal Response in Still Air

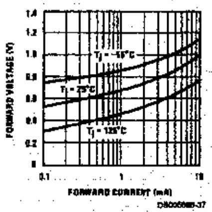


Typical Performance Characteristics (Continued)

Thermal Response in Stirred Oil Bath



Forward Characteristics



Application Hints

CALIBRATING THE LM135

Included on the LM135 chip is an easy method of calibrating the device for higher accuracies. A pot connected across the LM135 with the arm tied to the adjustment terminal allows a 1-point calibration of the sensor that corrects for inaccuracy over the full temperature range.

This single point calibration works because the output of the LM135 is proportional to absolute temperature with the extrapolated output of sensor going to 0V output at 0°K (−273.15°C). Errors in output voltage versus temperature are only slope (or scale factor) errors so a slope calibration at one temperature corrects at all temperatures.

The output of the device (calibrated or uncalibrated) can be expressed as:

$$V_{OUT_T} = V_{OUT_{T_o}} \times \frac{T}{T_o}$$

where T is the unknown temperature and T_o is a reference temperature, both expressed in degrees Kelvin. By calibrating the output to read correctly at one temperature the output at all temperatures is correct. Nominally the output is calibrated at 10 mV/°K.

To insure good sensing accuracy several precautions must be taken. Like any temperature sensing device, self heating can reduce accuracy. The LM135 should be operated at the lowest current suitable for the application. Sufficient current, of course, must be available to drive both the sensor and the calibration pot at the maximum operating temperature as well as any external loads.

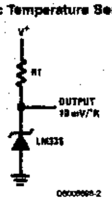
If the sensor is used in an ambient where the thermal resistance is constant, self heating errors can be calibrated out. This is possible if the device is run with a temperature stable current. Heating will then be proportional to zener voltage and therefore temperature. This makes the self heating error proportional to absolute temperature the same as scale factor errors.

WATERPROOFING SENSORS

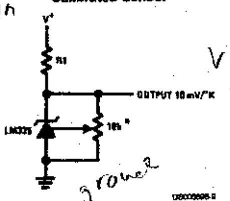
Meltable inner core heat shrinkable tubing such as manufactured by Raychem can be used to make low-cost waterproof sensors. The LM335 is inserted into the tubing about ½" from the end and the tubing heated above the melting point of the core. The unfilled ½" end melts and provides a seal over the device.

Typical Applications

Basic Temperature Sensor

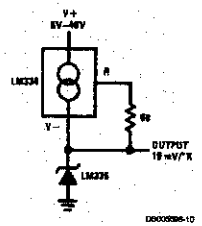


Calibrated Sensor



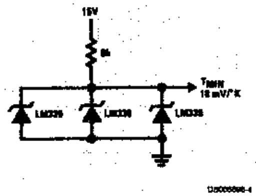
*Calibrate for 2.982V at 25°C

Wide Operating Supply

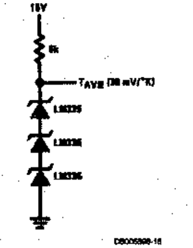


Typical Applications (Continued)

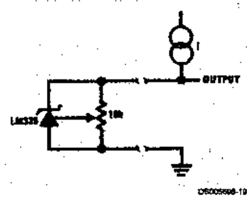
Minimum Temperature Sensing



Average Temperature Sensing



Remote Temperature Sensing

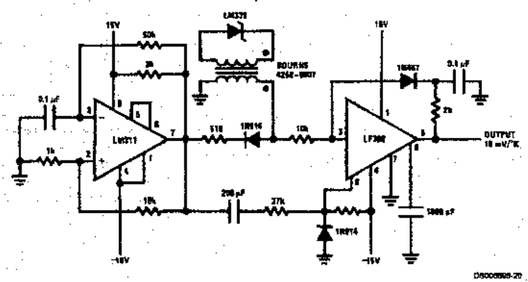


Wire length for 1°C error due to wire drop

AWG	I_R = 1 mA FEET	I_R = 0.5 mA* FEET
14	4000	8000
16	2500	5000
18	1600	3200
20	1000	2000
22	625	1250
24	400	800

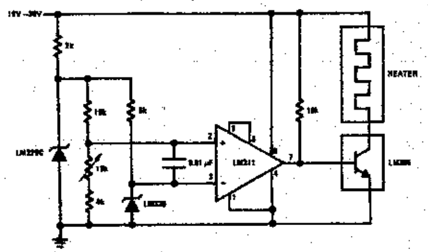
*For I_R = 0.5 mA, the trim pot must be deleted.

Isolated Temperature Sensor



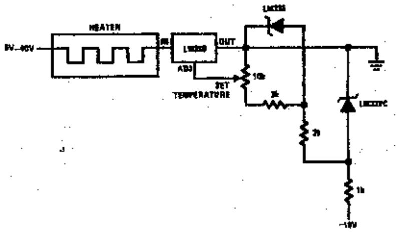
Typical Applications (Continued)

Simple Temperature Controller



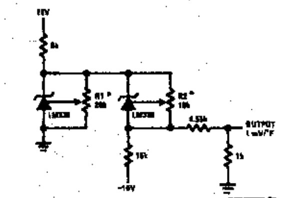
DS005698-8

Simple Temperature Control



DS005698-21

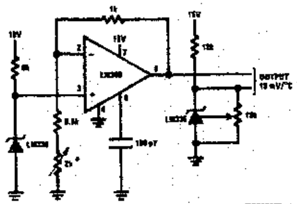
Ground Referred Fahrenheit Thermometer



DS005698-22

*Adjust R2 for 2.554V across LM336.
Adjust R1 for correct output.

Centigrade Thermometer

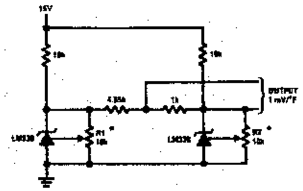


DS005698-23

*Adjust for 2.7315V at output of LM308

Typical Applications (Continued)

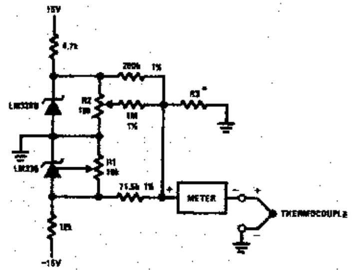
Fahrenheit Thermometer



DS005698-24

*To calibrate adjust R2 for 2.554V across LM336.
Adjust R1 for correct output.

THERMOCOUPLE COLD JUNCTION COMPENSATION
Compensation for Grounded Thermocouple



DS005698-6

*Select R3 for proper thermocouple type

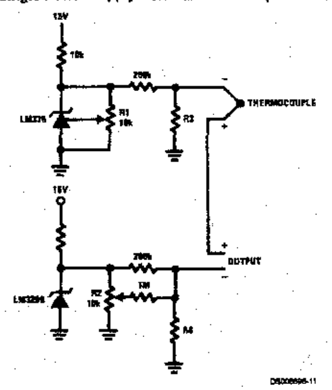
THERMO-COUPLE	R3 (±1%)	SEEBECK COEFFICIENT
J	377Ω	52.3 µV/°C
T	308Ω	42.8 µV/°C
K	293Ω	40.8 µV/°C
S	45.8Ω	6.4 µV/°C

Adjustments: Compensates for both sensor and resistor tolerances
1. Short LM329B
2. Adjust R1 for Seebeck Coefficient times ambient temperature (in degrees K) across R3.
3. Short LM335 and adjust R2 for voltage across R3 corresponding to thermocouple type

J	14.32 mV	K	11.17 mV
T	11.79 mV	S	1.768 mV

Typical Applications (Continued)

Single Power Supply Cold Junction Compensation



*Select R3 and R4 for thermocouple type

THERMO-COUPLE	R3	R4	SEEBECK COEFFICIENT
J	1.05K	385Ω	52.3 μV/°C
T	856Ω	315Ω	42.8 μV/°C
K	816Ω	300Ω	40.8 μV/°C
S	128Ω	46.3Ω	6.4 μV/°C

Adjustments:

1. Adjust R1 for the voltage across R3 equal to the Seebeck Coefficient times ambient temperature in degrees Kelvin.
2. Adjust R2 for voltage across R4 corresponding to thermocouple

J	14.32 mV
T	11.79 mV
K	11.17 mV
S	1.768 mV

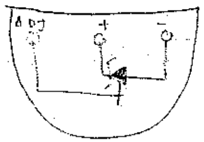
A = 1 + (100k + R3) / 422

245.7 = 1 + (100k + R3) / 422

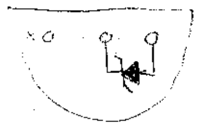
103.685k = 422 + 100k + R3

3.263k = R3

LM335



LM329

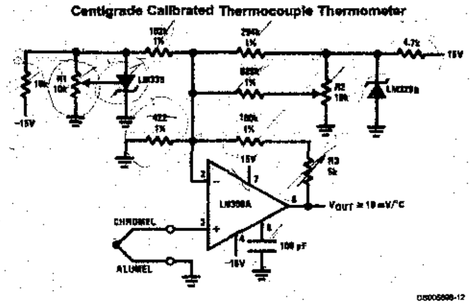


LM135/LM235/LM335, LM135A/LM235A/LM335A

Typical Applications (Continued)

A = 42

Centigrade Calibrated Thermocouple Thermometer

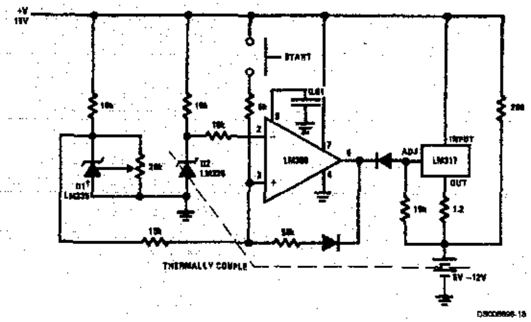


Terminate thermocouple reference junction in close proximity to LM335.

Adjustments:

1. Apply signal in place of thermocouple and adjust R3 for a gain of 245.7.
2. Short non-inverting input of LM308A and output of LM329B to ground.
3. Adjust R1 so that V_{OUT} = 2.982V @ 25°C.
4. Remove short across LM329B and adjust R2 so that V_{OUT} = 246 mV @ 25°C.
5. Remove short across thermocouple.

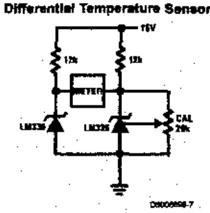
Fast Charger for Nickel-Cadmium Batteries



†Adjust D1 to 50 mV greater V_Z than D2.

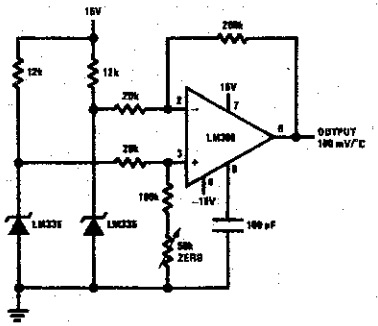
Charge terminates on 5°C temperature rise. Couple D2 to battery.

Differential Temperature Sensor

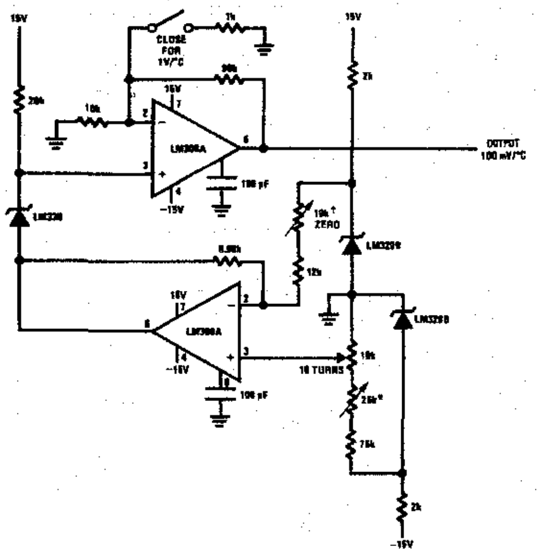


Typical Applications (Continued)

Differential Temperature Sensor



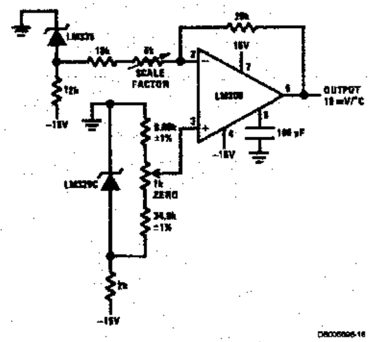
Variable Offset Thermometer



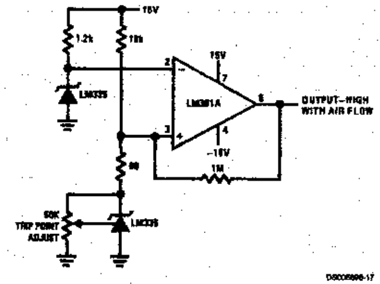
†Adjust for zero with sensor at 0°C and 10T pot set at 0°C
*Adjust for zero output with 10T pot set at 100°C and sensor at 100°C
Output reads difference between temperature and dial setting of 10T pot

Typical Applications (Continued)

Ground Referred Centigrade Thermometer



Air Flow Detector*



*Self heating is used to detect air flow

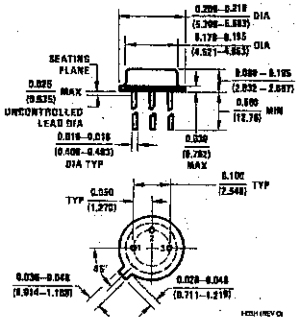
Definition of Terms

Operating Output Voltage: The voltage appearing across the positive and negative terminals of the device at specified conditions of operating temperature and current.

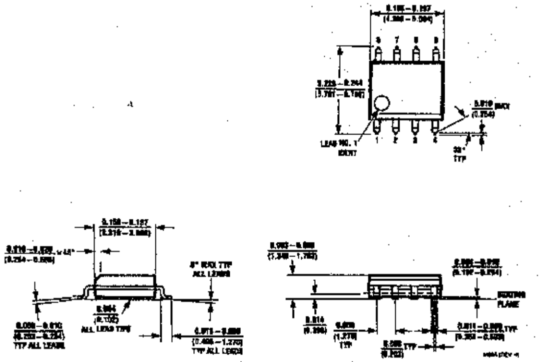
Uncalibrated Temperature Error: The error between the operating output voltage at 10 mV/°K and case temperature at specified conditions of current and case temperature.

Calibrated Temperature Error: The error between operating output voltage and case temperature at 10 mV/°K over a temperature range at a specified operating current with the 25°C error adjusted to zero.

Physical Dimensions inches (millimeters) unless otherwise noted

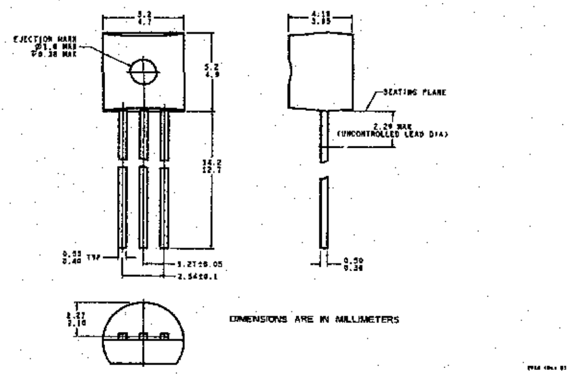


Metal Can Package (H)
Order Number LM135H, LM235H, LM335H, LM135AH, LM235AH or LM335AH
NS Package Number H03H



8-Lead Molded Small Outline Package (M)
Order Number LM335M
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Plastic Package
Order Number LM335Z or LM335AZ
NS Package Z03A

National Semiconductor Corporation
Americas
Tel: 1-800-272-9959
Fax: 1-800-737-7018
Email: support@nsc.com
www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507