SOLAR COOLING SYSTEM OF A CAR

By

NADIYA BINTI JAALAM

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
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CERTIFICATION OF APPROVAL

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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.

Nadiya binti Jaalam

ABSTRACT

This report is based on the 'Solar Cooling System' project that has been implemented. The report will give an overview to all the processes and constructions of project work. The main objective of this project is to provide cooling in the car by using solar power.

Hot day and high temperature will give uncomfortable situation to most people, especially when they get into their car after parking for several hours in open space. The person could not even hold the steering or sit comfortably on the seat because the things are already heat up. They also feel hot when they open the window during the car moving for saving the fuel or the air conditioning is not functioning. In order to reduce the high temperature, this project will utilize the solar (photovoltaic) energy as a source to the cooling system in a car. The solar (photovoltaic) energy will charge the battery instead of activating the system. The battery will be used as a back up when solar energy is not sufficient and generates other electronic devices in the car. A thermistor that contains in control unit will be used to sense the temperature difference. When the temperature has reached to the temperature that has been set, the cooling system will turn on in order to reduce the temperature inside the car and suck the hot air out. The research and design stage will be complete during the first semester and construction stage will be done during the second semester. The analysis of cooling system to the real application will also be carried out to fulfill the design requirement instead of improving it.

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Symbol	Meaning	Units
A	area	m^2
A_c	cross-sectional area	m^2
A_s	surface area	m^2
A_n	constant depending on value of n	
b	outer radius of a disc	m
$Bi = hL/k$	Biot number	
B_n	constant depending on value of n	
c	velocity of electromagnetic radiation	m/s
C	specific heat (of a solid)	J/kgK
$C = \dot{m}C_p$	heat capacity rate of a heat exchanger fluid	W/K
C_p	specific heat at constant pressure	J/kg K
C_s	empirical constant in pool boiling	
D	diameter	m
$D_h = 4A_c/P$	hydraulic diameter	m
e	specific internal energy	J/kg
e	mean roughness height	m
E	energy	J
E	emissive power	W/m^2
E_b	black body emissive power	W/m^2
E_λ	spectral emissive power at wavelength λ	W/m^3
$E_c = U^2/C_p\Delta T$	Eckert number	
f	friction factor	
F	heat exchanger temperature ratio	
F_y	radiation view factor	

Symbol	Meaning	Units
$F_o = \alpha t/L^2$	Fourier number	
F(Re)	impinging jet parameter	
F_x, F_y, F_z	body forces per unit volume	N/m^3
g	acceleration due to gravity	m/s^2
G	irradiation	W/m^2
G_s	solar irradiation	W/m^2
G(r/D,H/D)	impinging jet parameter	
H	Planck's constant	Js
$h = q / \Delta T$	heat transfer coefficient	W/m^2K
h_c, h_b	convective and boiling heat transfer coefficient	W/m^2K
h_f	enthalpy of a saturated liquid	J/kg
h_{fg}	latent heat vaporisation	J/kg
h_g	enthalpy of a saturated vapour	J/kg
H	enthalpy flow rate	W/m
H	height	m
i	specific enthalpy	J/kg
I	current	A
I	radiation intensity	W/m^2sr
J	radiosity	W/m^2
$Ja = C_p(T_{sat}-T_w)/h_{fg}$	Jakob number	
k	thermal conductivity	W/mK
k	Boltzmann constant, $1.3806x10^{-23}$	J/K
k_c, k_e	contraction and expansion loss coefficient	
L	thickness, length, characteristic length scale	m
L_c	flow boiling parameter	

Symbol	Meaning	Units
$L_{h,\ entry}$	hydrodynamic entry length	m
$L_{L,entry}$	thermal entry length	m
$m = (hP/kA_c)^{1/2}$	fin parameter	m^{-1}
M	mass	kg
M_a	mass of air	kg
$NTU = UA/C_{min}$	number of heat transfer units	
$Nu_{av} = h_{av}L/k$	average Nusselt number	
nu	frequency	
p	pressure	Pa
P	wetted perimeter	m
P	heat exchanger temperature ratio	
$P_r = \mu C_p$	Prandtl number	
P*	flow boiling parameter	
q	heat flux	W/m^2
q_{av}	average heat flux	W/m^2
q_b	heat flux due to black body radiation	W/m^2
q_c, q_b	convective and boiling heat fluxes	W/m^2
q'_g	internal heat generation term	W/m^3
q_s	surface heat flux	W/m^2
q_{solar}	heat flux due to radiation	W/m^2
q^*	flow boiling parameter	
Q	heat quantity	W
Q_a	heat quantity of air	W
r	radial coordinate	m
r_{crit}	critical insulation of radius	m
r_i , r_o	inner and outer radius	m

Symbol	Meaning	Units
R	radial dimension	m
R	electrical resistance	Ω
R	heat exchanger temperature ratio	
R	characteristic gas constant	J/kgK
R	residual	
Ra = Gr.Pr	Rayleigh number	
Ra*	alternative Rayleigh number	
$Re_D = \rho U_b D/\mu$	Reynolds number based on diameter D	
$Re_x = \rho U_\infty x/\mu$	local Reynolds number	
R_f	heat exchanger fouling resistance	m^2K/W
s	gap distance	m
s	specific entropy	J/kgK
S	entropy	J/K
S_c	solar constant	W/m^2
t	time	s
t	thickness	m
T	temperature	K
T_b	bulk mean temperature	K
T_{ref}	reference temperature	K
u,v,w	velocity in x ,y and z direction	m/s
U	overall heat transfer coefficient	W/m^2K
V	voltage	V
V	volume	m^3
W	width	m
W	work	J

Symbol	Meaning	Units
x	vapour quality	
x_0	start of thermal boundary layer	m
$X = x / L$	dimensionless coordinate	
$Y = y / L$	dimensionless coordinate	
α	thermal diffusivity	m^2/s
α	absorptivity	
α_s	solar absorptivity	
$\beta = 1 / \rho(\delta\rho/\delta T)_p$	volume expansion coefficient	K^{-1}
Γ	mass flow rate per unit area	
kg/m^2s		
δ	film thickness	m
δ	velocity boundary layer thickness	m
δ_T	thermal boundary layer thickness	m
ΔT_{lm}	logarithmic mean temperature difference	K
ε	emissivity	
η	efficiency	
θ	temperature difference	
θ	weighting parameter	
κ	mixing length constant	
$\lambda = A_s/mC$	lumped mass conduction parameter	m^2K/J
λ	wavelength	
μ	Dynamic viscosity	kg/ms
v	kinematic viscosity	m^2/s
ρ	density	kg/m^3
ρ	reflectivity	
σ	Stefan – Boltzmann constant, $56.7x10^{-9}$	W/m^2K^4
σ	Surface tension	N/m

σ	area ratio	
σ	normal stress	
$\tau = \alpha\tau / L^2$	dimensionless time	N/m^2
τ	shear stress	
τ	time	s
τ	transmissivity	
Φ	dissipation function	s^{-2}
Φ	flow boiling parameter	
ω	solid angle	sr
Ω	numerical acceleration parameter	
Ω	rotational speed	rad/s

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The sun, is a source of practically unlimited energy, most of which is wasted but nevertheless provides with millions of kilowatts of power, to keep warm, and grows all the food. Nowadays solar power has become one of the energy for human life. The demands for solar power are increasing and still continue.

Solar power is used in two primary forms, which are **thermal solar**, where the heat of the sun is used to heat water or another working fluid, which drives turbines or other machinery to create electricity; and **photovoltaic**, where electricity is produced directly from the sun with no moving parts. Photovoltaic panel is the example which produces electricity directly from the sun.

Photovoltaic power is one of the most promising renewable energy sources in the world. It's totally non-polluting, safe, has no moving parts to break down, and does not require much maintenance.

On top of it, photovoltaic power has been used in many applications for daily usage. For example it has been used for lighting, to run electronic devices and others. As in this project, it will be utilized to energize the cooling system in a car.

The cooling system in a car will provide a comfortable condition for the passenger in a car and decrease the high temperature. It is energy free, cheap and cost saving because the system will straight away use the photovoltaic power.

The solar cooling system of a car project is more on conceptual design of electronic circuit to provide cooling energized by photovoltaic power. In the first semester, research and design are implemented. The circuit assemblage, construction of the prototype and circuit installation in the prototype will be completed in second semester.

1.2 Problem Statement

People park their cars at the open space which are exposed to the sunlight. From the study that has been done, it is shown that the temperature inside the car will reach until 40°C and above. The high temperature inside the car will make an uncomfortable condition to the passengers whenever they get into their car. Because of that, the person feels uncomfortably to sit in the car even hold the steering of the car. Usually the temperature inside the car is higher than the temperature outside the car because the car is fully sealed. The car will absorb the heat and the heat will accumulate. Although there is an air conditioner, it will only cool inside the car after a few minutes after it was turned on. In order to overcome these problems, this project will design a temperature controller circuit that will be used to cool down or reduce the temperature inside the car to normal room temperature.

Instead of that the system also can be used during the car moving. For energy saving, the passenger will turn off the air conditioner and open the car window. As the temperature has reached to the certain amount of temperature that has been set, the system will turn on. This will provide more cooling inside the car for the benefit of the passenger. If the cooling is already sufficient, and the temperature already drops from its set point, the system will automatically off. The passenger also can always turn off the system manually if the cooling is not needed.

1.3 Objectives

The objectives of this project are:

- To study and design a cooling system that utilize the solar energy
- To study the battery operation in photovoltaic operation
- To construct a prototype of cooling system in a car by using solar
- To come out with a design which is energy saving and cost effective

1.4 Scope of Study

Due to constrain in time frame allocated and to ensure this project will be successfully done; the scope of study for this project will be limited within the following area:

- The photovoltaic system and its operation
- Battery operation in photovoltaic operation(storage)
- Circuit design and its assemblage
- Prototype design and construction
- Analysis on cooling system to the real application

CHAPTER 2

LITERATURE AND THEORETICAL REVIEW

2.1 The Photovoltaic System

The solar cooling system of a car will consist of solar photovoltaic (PV) panel, battery as power storage, a control unit which consists of calibration and output circuit, and the output which are the fan and temperature display. The solar photovoltaic (PV) panel will collect the solar energy and convert it to electrical energy - the direct current (DC). The amount of conversion is depends on the intensity of sunlight. This means that, if the day is brighter, the more electrical energy will be produced. The dc current will straight away energize the cooling system in the car. Instead of energizing the circuit, the photovoltaic power also charges 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 photovoltaic power is not sufficient and also use to generate other electronic devices in the car. Generally the photovoltaic system consists of a number of subsystems which shown in Figure 1:

1) The solar panel with sun tracking system
2) Batteries (power storage)
3) Control unit, including temperature sensor for temperature difference measurement
4) The output which provide cooling and monitoring, which are the fan and temperature display.

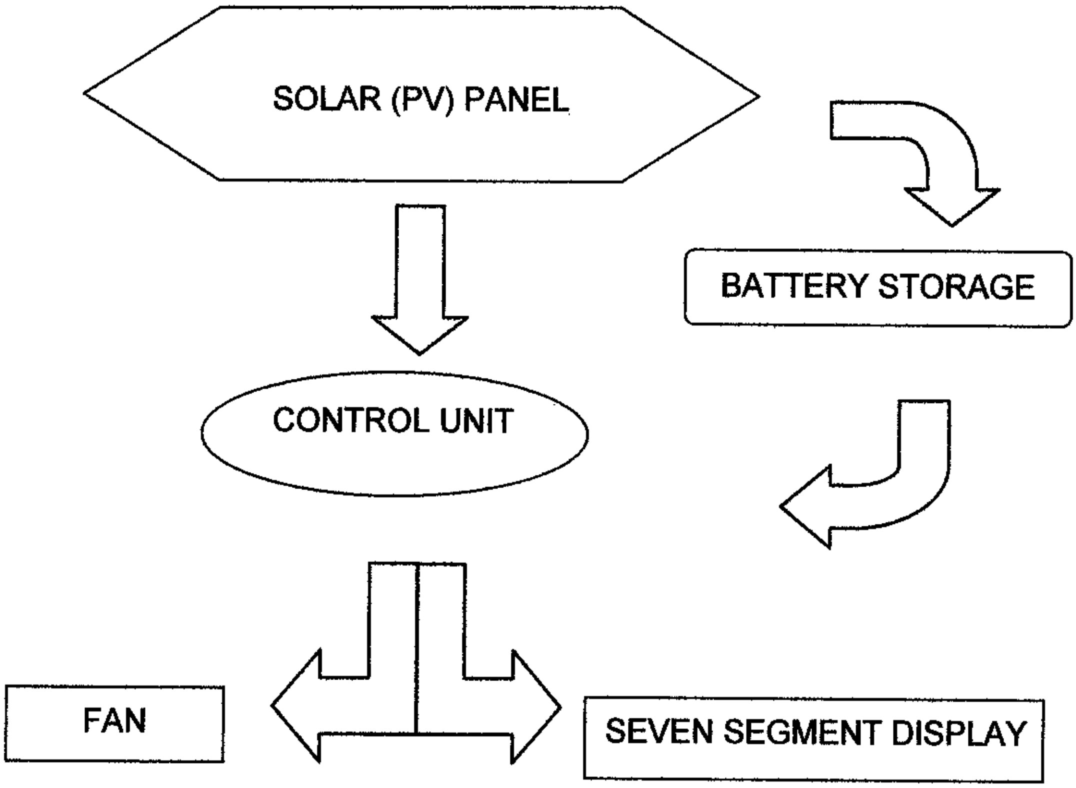


Figure 1 : Cooling System Flow Chart

2.2 Solar Photovoltaic (PV) Panel

A Solar Photovoltaic (PV) is the most benign method of power generation today. The PV produces absolutely no emission and uses the unlimited resource of the free sunshine as its fuel. Since sunshine is available everywhere whenever there is a sun, the PV applications have no boundary. The PV system also has no moving part. Thus the operation of a PV system is very quiet, clean and requires almost no maintenance. Today, most PV modules are guaranteed to last between 20 to 30 years. Solar Photovoltaic (PV) is made of semiconductor material, most commonly silicon. Solar Photovoltaic (PV) Panel works on the principle of the photovoltaic effect. The photovoltaic effect is the conversion of sunlight (photon) directly into electricity. This occurs when the PV cell is exposed to the light (photon) and struck by the sunlight (photon). The electrical charges are generated and this can be conducted away by electrical conductor as direct current (d.c.). The 'freeing' silicon electrons to travel from the PV cell, through electronic circuitry, to a load. Then they return to the PV cell, where the silicon recaptures the electron and the process is repeated. The effect of photovoltaic is shown in figure 2.

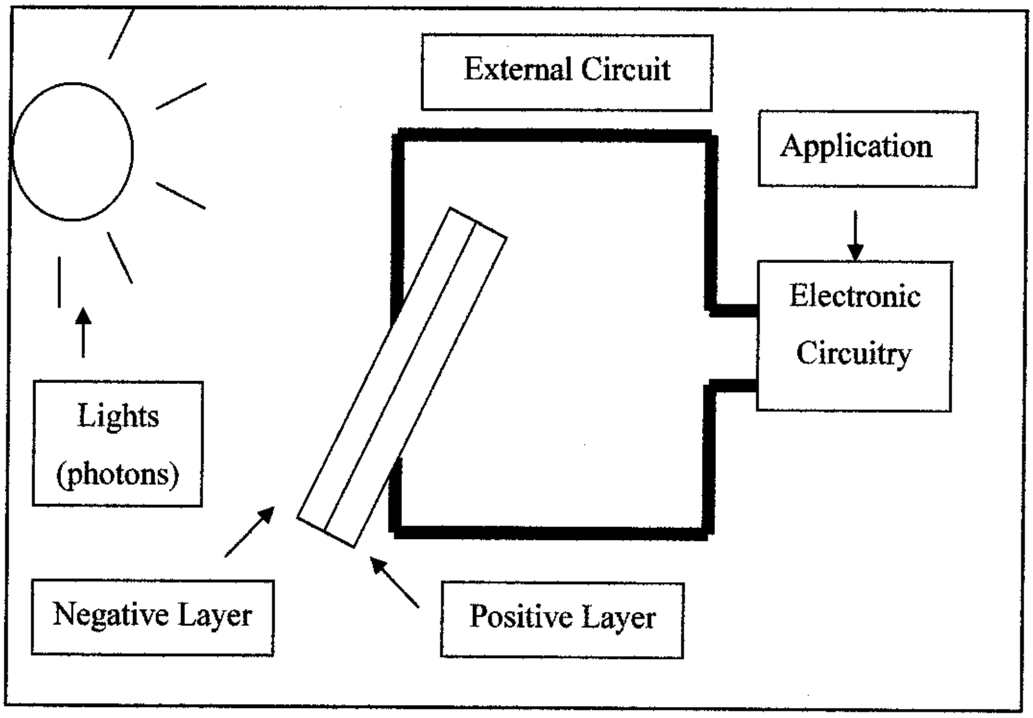


Figure 2 : Principle of Operation

2.2.1 Solar Photovoltaic Theory

A solar PV module is made up of several solar cells. Each solar cell consists of two type semiconductors, which are P type and N type.

(*blue – electron; red- electron holes)

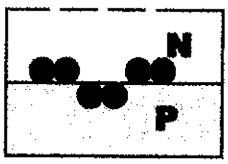


Figure 3 : Sun strikes the semiconductor

The operation starts when sunlight strikes the semiconductors, pairs of electrons (-) and electron holes (+) are produced.

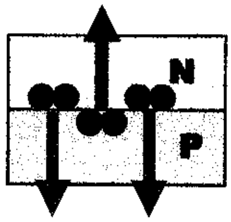


Figure 4 : Electrons and electron holes attracted to P and N semiconductor

The electrons (-) are attracted to the N type semiconductor and the electron holes (+) are attracted to the P type semiconductor. Because the contact surface between the N type and P type semiconductor are one way route, once they are attracted to the semiconductor they cannot return.

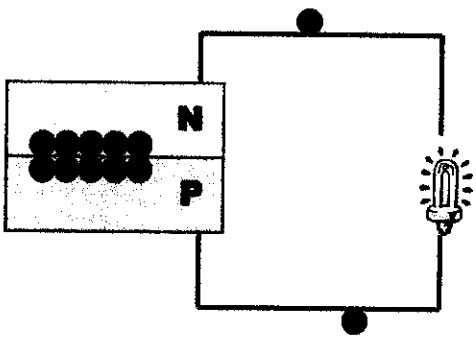


Figure 5 : Electrons overflow

When the N type semiconductor has become filled with electrons (-), they overflow into the conductor and move towards the P type semiconductor, causing a current to flow and the energy in the solar radiation is converted into electrical energy in the circuit.

The **efficiency of photovoltaic conversion** is limited by the relationships between the photon energies and the energy gap in the semiconductor. Photons in the ultra-violet and visible regions of the solar spectrum have energies greater than the energy gap, so only part of their energy is converted into electrical energy by the creation of electron-hole pairs. The excess energy is dissipated as heat. Photons in the near infra-red with wavelengths 0.7 μm to 1.1 μm have energies only slightly greater than the energy gap, so most of their energy is converted into electricity. Near infra-red photons with wavelengths greater than 1.13 μm have energies less than the energy gap and cannot produce electron-hole pairs, so they cannot contribute to the electrical energy output of the solar cell. Taking these facts into consideration it is found that an upper limit to the efficiency of a silicon solar cell is 45%. However, recombination of electrons and holes before they are completely separated reduces the attainable efficiency still further to about 20%.

2.2.2 Solar Cell Materials

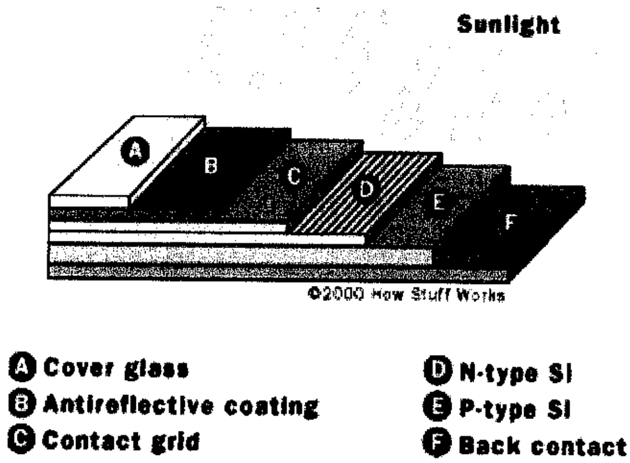


Figure 6 : Basic structure of a generic silicon PV cell

Semiconductors behave partly as insulators and partly as conductors. Atoms in a semiconductor easily lose one of their electrons, allowing another from a nearby atom to replace it. Semiconductors are significant because the flow of electrons can be controlled. Germanium, copper oxide, and silicon are all materials, which can be used to create semiconductors. Over 95% of the solar cells formed globally are made up of the semiconductor, Silicon. Silicon cells are about 10 cm x 10 cm until recently. A clear **anti-reflection film** shields the cell and reduces reflective loss on the cell surface. The usable voltage from solar cells depends on the semiconductor material. The semi-conductor silicon creates amounts equal to about a 0.5 Volt.

The conductivity of a semiconductor is clearly affected by slight amounts of impurity. There are a numerous materials suitable for producing these semi-conducting layers, and each has its benefits and drawbacks. There is no one ideal material for all types of cells and applications. Solar cells have an electrical contact to collect electrons from the semiconductor. It then moves the electrons to the external load, and then they transfer to the **back of the contact-layer** to complete the electrical circuit. On top of the complete cell is typically a **glass cover** to seal the cell and to keep the weather out, and an **anti reflective coating** to keep the cell from reflecting the light back away from the cell. A typical solar cell consists of a cover glass, an anti-reflective layer, a front contact to allow the electrons to enter a circuit, p-layer, n-layer, and then the semiconductor.

2.2.3 Solar Radiation

Solar Radiation in Malaysia

A heavy rainfall, constantly high temperature and relative humidity characterize the Malaysian climate. Much of the precipitation occurs as thunderstorms and the normal pattern is one of heavy falls within a short period. Generally, chances of rain falling in the afternoon or early evening are high compared with that in the morning. The country experiences more than 170 rainy days; however, an area may have a greater number of rainy days and yet receive a lesser amount of rain in a year than another area with smaller number of rainy days but receiving its rain in heavy spells. Ambient temperature remains uniformly high over the country throughout the year. Average ambient temperatures are between 26.0 to 32.0 °C. Most locations have a relative humidity of 80 – 88%, rising to nearly 90 % in the highland areas, and never falling below 60%.

The monthly average daily solar radiation in Malaysia is 4000 - 5000 Whr/m^2, with the monthly average daily sunshine duration ranging from 4 hr to 8 hr (Sopian and Othman, 1992). It is also estimated that the total solar energy received in a year is 16 times the Malaysian annual conventional energy requirement.

Most places in Malaysia recorded normal solar radiation except the highland areas of east Perak & southwest Kelantan and Perlis had slightly below normal solar radiation, where as northeast Sarawak had slightly above normal solar radiation. In Figure 7 shown below, most places in Peninsular Malaysia recorded solar radiation ranging from 14 to 20 MJm^{-2} per day whereas the whole Sabah & Sarawak recorded 16 MJm^{-2} to 23

MJm^{-2} per day. The lowest solar radiation is between 11 MJm^{-2} to 14 MJm^{-2} per day was recorded over the highland areas of southeast Perak, northwest Pahang & southwest Kelantan. However, the highest daily solar radiation of between 22 and 23 MJm^{-2} was recorded over most parts of Sabah.

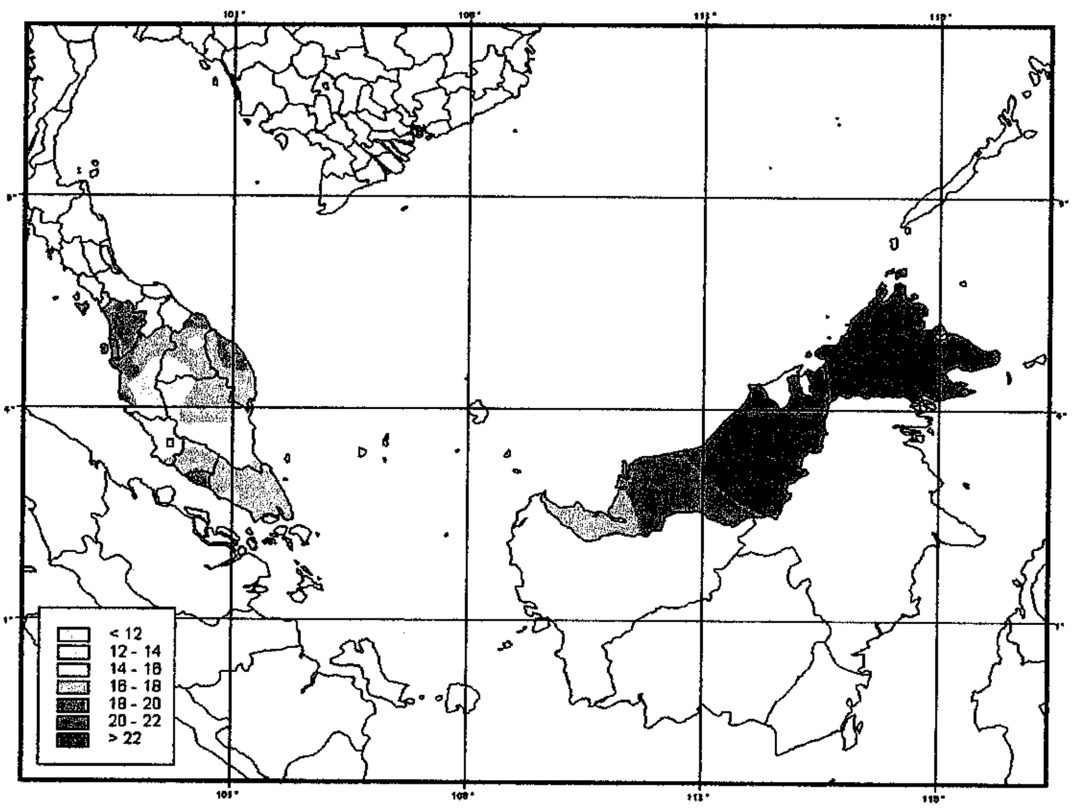


Figure 7 : Mean Daily Solar Radiation(MJm^{-2})

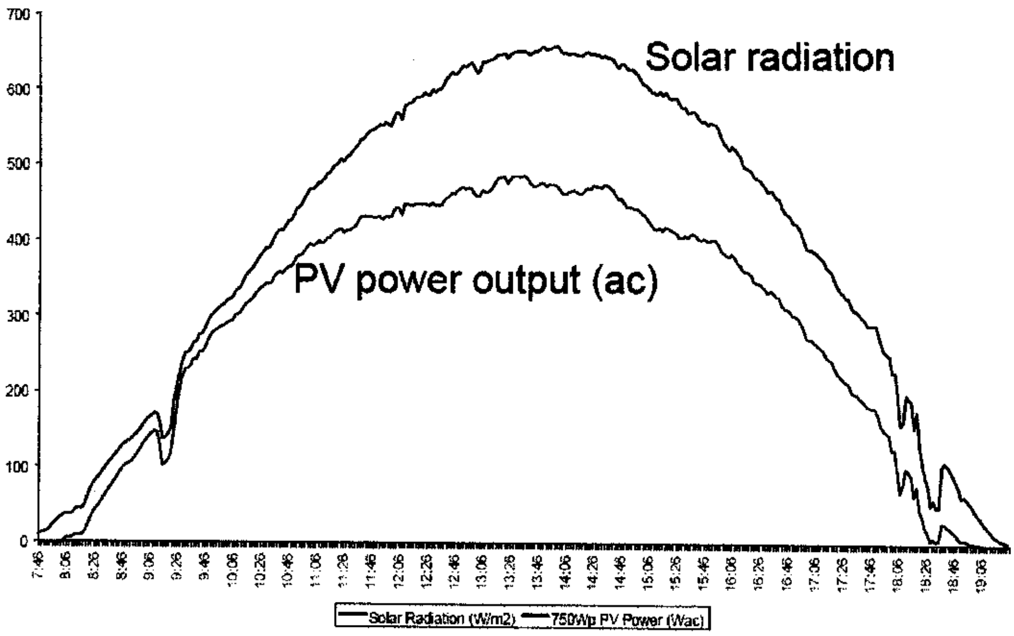
Ideally, the orientation of a photovoltaic panel must face south towards the equator, but Malaysia being close to the equator offers an advantage for innovative architectural ecstatic and sensible design with varieties of orientations and shading considerations. Table 1 shows the estimates for the annual energy yield from photovoltaic installations located at the various locations. A solar photovoltaic installation in Malaysia would produce energy of about 900 – 1400 kWh/kWp per year depending on the locations. Areas located at the northern and middle part of the Peninsular and the coastal part of Sabah and Sarawak would yield higher performance. An installation in Kuala Lumpur would yield around 1100 kWh/kWp per year (Alamsyah *et al*, 2004).

Locations	Penang	Ipoh	Johore Baru	Kuala Lumpur	Kota Baru
Energy yield	1286	1253	1171	1132	1229
Locations	Kota Kinabalu	Kuala Trengganu	Kuching	Bandar Baru Bangi	Kuantan
Energy yield	1369	1235	1157	1072	1154

Table 1 : Estimates of Annual Energy Yield for Various Locations in Malaysia

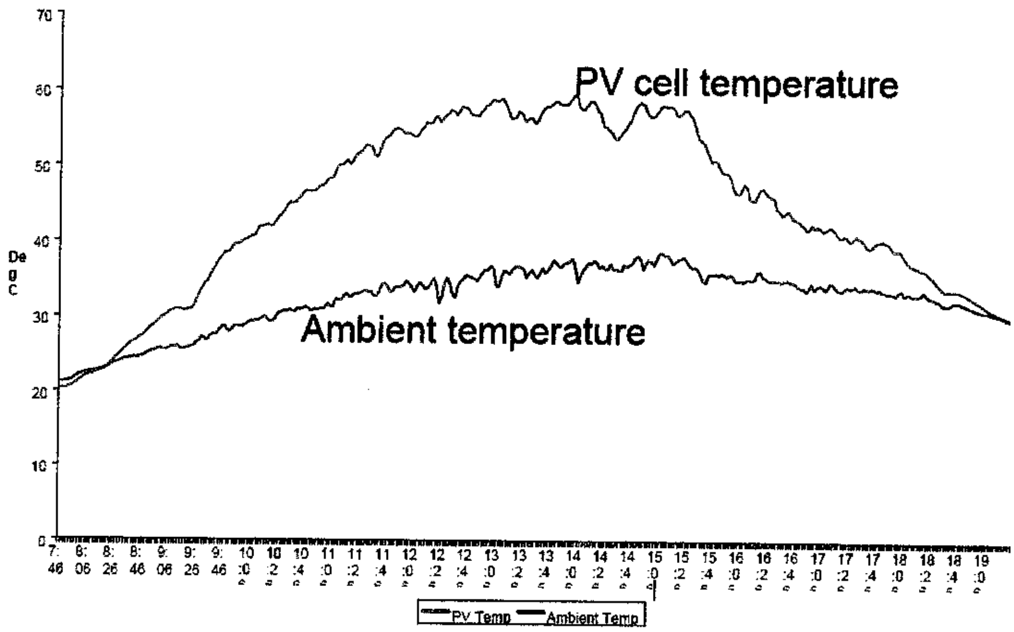
Solar Radiation Characteristic

A PV module would generate d.c. electricity whenever it is exposed to direct sunshine. The amount of power generated is proportional to the intensity of the solar radiation, but it could be affected by ambient temperature. A $100W_p$ solar PV module would produce $100W_{d.c.}$ power at Standard Test Condition (STC), i.e. at direct exposure to $1000W/m^2$ of solar radiation with air mass of 1.5AM and the PV cell temperature is at 25°C. However, this ideal condition is difficult to achieve. In tropical climate country such as in Malaysia, the maximum solar radiation is typically between $800W/m^2$ to $1000W/m^2$, but the ambient temperature could be as high as 40°C at noon, resulting in a 60°C PV cell temperature. Hence, the $100W_p$ PV would only produce a maximum of $80W_{d.c.}$ power at times. Graphs below show the relationship between solar radiation and PV power output (AC) versus time and PV cell temperature with ambient temperature versus time.



Solar Radiation ↑, Ipv ↑, Ppv↑

Figure 8 : Graphs for Solar Radiation and PV power output (AC) versus time



1°C ↑, 0.4%ηpv ↓

Figure 9 : Graphs for PV cell temperature and Ambient temperature versus time

2.2.4 Solar Panel Construction

The most important material for solar panel production is silicon. At the time being it is almost the only material used for solar cell mass production. As the most often used semiconductor material it has some important advantages:

- In nature it can be easily found in large quantities. Silicon oxide forms 1/3 of the Earth's crust.
- It is not poisonous, and it is environment friendly, its waste does not represent any problems.
- It can be easily melted, handled, and it is fairly easy formed into mono-crystalline form.
- Its electrical properties with endurance of 125°C allow the use of silicon semiconductor devices even in the most harsh environment and applications.

The solar panel must go through certain process before it can be used. A figure 10 show how the solar silicon is made into a solar energy module or solar panel is made:

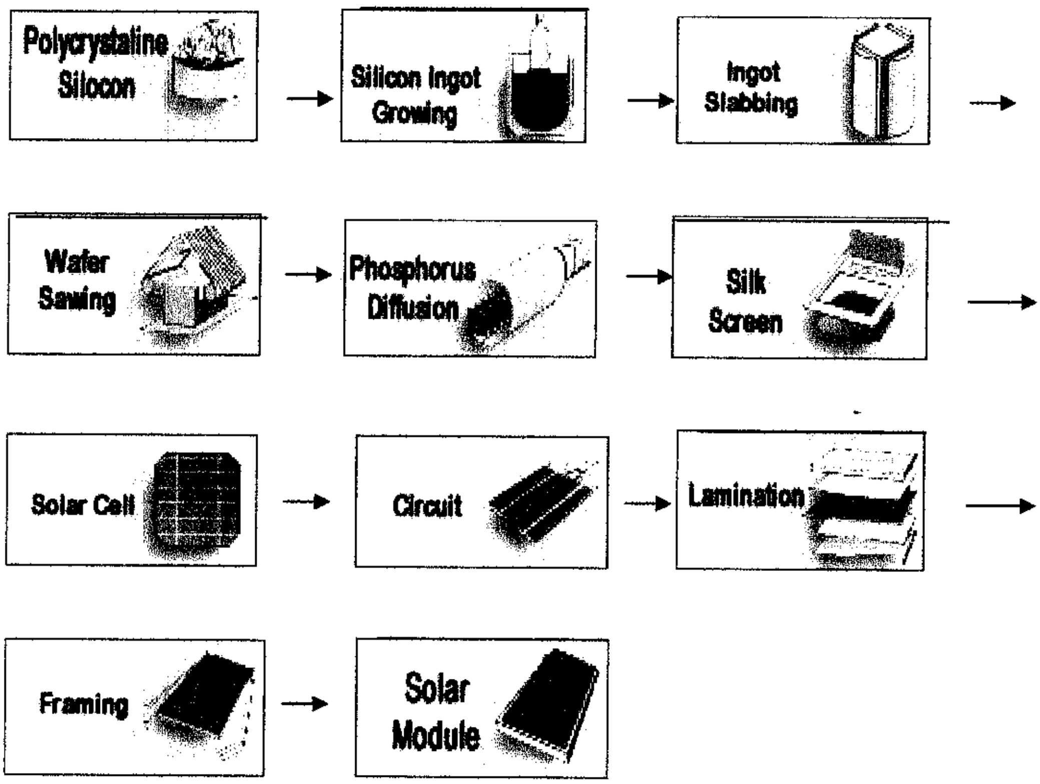
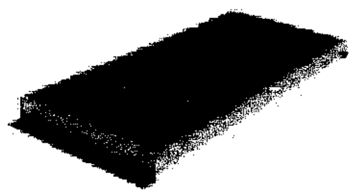


Figure 10 : Solar Panel Construction

2.2.5 Solar Cells, Solar Panel and Solar Array

A solar panel or solar module consists of many solar cells. Solar cells capture the sun's energy and change it to electricity. Inside a solar panel, each cell contains silicon, an element found in sand that absorbs sunlight. The energy in this absorbed light produces a small electrical current. Metal grids around the solar cells direct the currents into wires that lead to the power controls. The solar cells are then combined to be solar panel. One or more solar panels will produce solar array which convert sunlight into clean solar electricity. PV is short for Photovoltaics, which means electricity from light. The solar panels need to be located facing the sun and avoiding shade for best results to generate DC power.

Cell



Panel

Array

Figure 11 : Solar cell, modules, panel and array

2.2.6 *Types of Solar (PV) Cell*

There are more than four types of solar cells that normally used today. The different types of solar cells are because of on how the silicones are made into cells. These are the general types of solar (PV) cells:

1. **Monocrystalline Silicon Cells:**

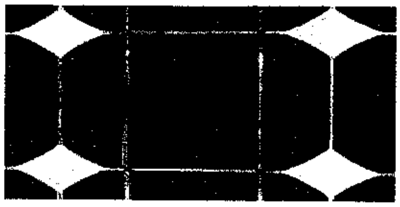


Figure 12 : Monocrystalline Silicone Cell

Made using cells saw-cut from a single cylindrical crystal of silicon, this is the most efficient of the photovoltaic (PV) technologies. The principle advantage of monocrystalline cells are their high efficiencies, typically around 15%, although the manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

2. **Multicrystalline Silicon Cells**

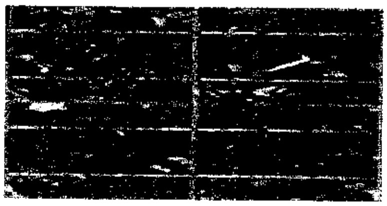


Figure 13 : Multicrystalline Silicon Cell

It is made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon; these ingots are then saw-cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones, due to the simpler manufacturing process. However, they tend to be slightly less efficient, with average efficiencies of around 12%., creating a granular texture.

3. **Thick-film Silicon**

Figure 14 : Thick-film Silicon

Another multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, this is encapsulated in a transparent insulating polymer with a tempered glass cover and usually bound into a strong aluminium frame.

4. **Amorphous Silicon**

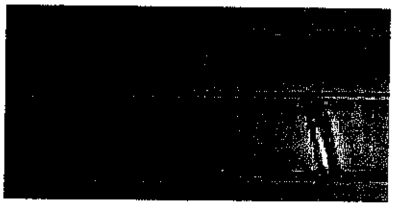


Figure 15 : Amorphous Silicon

Amorphous silicon cells are composed of silicon atoms in a thin homogenous layer rather than a crystal structure. Amorphous silicon absorbs light more effectively than crystalline silicon, so the cells can be thinner. For this reason, amorphous silicon is also known as a "thin film" PV technology. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces and "fold-away" modules. Amorphous cells are, however, less efficient than crystalline based cells, with typical efficiencies of around 6%, but they are easier and therefore cheaper to produce. Their low cost makes they ideally suited for many applications where high efficiency is not required and low cost is important.

5. **Other Thin Films**

A number of other promising materials such as cadmium telluride (CdTe), EFG, copper indium diselenide (CIS), Hybrid Silicon (HIT) are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. New technologies based on the photosynthesis process are not yet on the market.

Table below shows the comparison of different solar cell types with their advantages and disadvantages.

Material	Thickness	Efficiency %	Color	Disadvantages	Advantages and perspectives
Monocrystalline Si solar cells	0,3 mm	15 - 18 %	Dark blue, black with AR coating, grey without AR coating	Lengthy production procedure, wafer sawing necessary	Best researched solar cell material in a next few years it will dominate world market, especially there, where high power/area ratio is required
Polycrystalline Si solar cells	0,3 mm	13 - 15 %	Blue with AR coating, silver-grey without AR coating	In comparison with thin-film technologies lengthier production procedure, wafer sawing necessary	The most important production procedure at least for the next ten years
Polycrystalline transparent Si solar cells	0,3 mm	10 %	Blue with AR coating, silver-grey without AR coating	Lower efficency, special procedures to achieve optical transarency required	Attractive solar cells for different BIPV applications. Possible also production of double sided cells
EFG	0,28 mm	14 %	Blue, with AR coating	Limited use of this production procedure	Very fast crystal growth, no wafer sawing neccesary, significant decrease in production costs possible in the future
Polycrystalline ribbon Si solar cells	0,3 mm	12 %	Blue, with AR coating, silver-grey without AR coating	Limited use of this production procedure	No wafer sawing neccesary, significant decrease in production costs possible in the future

Apex (polycrystaline Si) solar cells	0,03 to 0,1 mm + ceramic substrate	9,5 %	Blue, with AR coating, silver-grey without AR coating	Production procedure used only by one producer	No wafer sawing, production in form of band possible. Promising material. Significant decrease in production costs possible in the future
Monocrystaline dendritic web Si solar cells	0,13 mm incl contacts	13 %	Blue, with AR coating	Limited use of this production procedure	No wafer sawing, production in form of band possible.
Amorphous silicon	0,0001 mm + 1 to 3 mm substrate	5 - 8 %	Red-blue, Black	Lower efficiency, shorter life span.	No sawing necessary, possible production in the form of band. The most promising material in the future if long-term stability increases
Cadmium Telluride (CdTe)	0,008 mm + 3 mm glass substrate	6 - 9 % (module)	Dark green, Black	Poisonous raw materials	Significant decrease in production costs possible in the future
Copper-Indium-Diselenide (CIS)	0,003 mm + 3 mm glass substrate	7,5 - 9,5 % (module)	Black	Limited Indium supply in nature	Significant decrease in production costs possible in the future
Hybrid silicon (HIT) solar cell	0,02 mm	18 %	Dark blue, black	Limited use of this production procedure	Higher efficiency, better temperature coefficient and lower thickness.

Table 2 : Comparison of different solar cell (Source from: http://www. pvresources_com - photovoltaic technologies.htm

2.3 Battery Storage

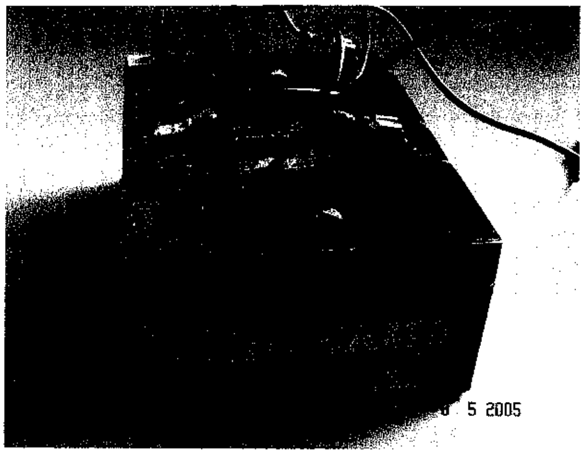


Figure 16 : Yokohama Sealed Lead Acid

The second part in the subsystem is battery storage. Battery storage is used as a back up when solar panel doesn't provide sufficient energy to the control unit. Besides, the battery also can be used to generate other electronic devices in the car. Batteries store the electrical energy generated by the modules during sunny periods, and deliver it whenever the modules cannot supply power.

Normally, batteries are discharged during the night or cloudy weather. But if the load exceeds the array output during the day, the batteries can supplement the energy supplied by the modules. The interval which includes one period of charging and one of discharging is described as a "cycle." Ideally, the batteries are recharged to 100% capacity during the charging phase of each cycle. The batteries must not be completely discharged during each cycle.

No single component in a photovoltaic system is more affected by the size and usage of the load than storage batteries. If a charge controller is not included in the system, oversized loads or excessive Use can drain the batteries charge to the point where they are damaged and must be replaced. If a controller does not stop overcharging, the batteries can be damaged during times of low or no load usage or long periods of full sun. For these reasons, battery systems must be sized to match the load. In addition, different types and brands of batteries have different "voltage set point windows." This refers to the range of voltage the battery has available between a fully discharged and fully charged state. As an example, a battery may have a voltage of 14 volts when fully charged, and 11 when fully discharged. Assume the load will not operate properly below 12 volts. Therefore, there will be times when this battery cannot supply enough voltage for the load. The battery's voltage window does not match that of the load.

There are many types of battery that available in the market. In this project, the battery that has been used in this project is sealed lead acid from Yokohama.

2.3.1 Performance

The performance of storage batteries is described two ways. These are the amp-hour capacity, and the depth of cycling.

1) **Amp-hour capacity**

The first method, the number of amp-hours a battery can deliver, is simply the number of amps of current it can discharge, multiplied by the number of hours it can deliver that current. Designers use amp-hour specifications to determine how long the system will operate without any significant amount of sunlight to recharge the batteries. This measure of "days of autonomy" is an important part of design procedures.

Theoretically, a 200 amp-hour battery should be able to deliver either 200 amps for one hour, 50 amps for 4 hours, 4 amps for 50 hours, or one amp for 200 hours. In this project, the battery is 1.3 Amp for one hour or I Amp for 1.3 hour. This is not really the case, since some batteries, such as automotive ones, are designed for short periods of rapid discharge without damage. However, they are not designed for long time periods of low discharge. This is why automotive batteries are not appropriate for, and should not be used in, photovoltaic systems. Other types of batteries are designed for very low rates of discharge over long periods of time. These are appropriate for photovoltaic applications.

Charge and discharge rates

If the battery is charged or discharged at a different rate than specified, the available amp-hour capacity will increase or decrease. Generally, if the battery is discharged at a slower rate, its capacity will probably be slightly higher. More rapid rates will generally reduce the available capacity. The rate of charge or discharge is defined as the total capacity divided by some number. For example, a discharge rate of C/20 means the battery is being discharged at a current equal to 1/20th of its total capacity. In the case of a 400 amp-hour battery, this would mean a discharge rate of 20 amps.

Temperature

Another factor influencing amp-hour capacity is the temperature of the battery and its surroundings. Batteries are rated for performance at 80°F. Lower temperatures reduce amp-hour capacity significantly. Higher temperatures result in a slightly higher capacity, but this will increase water loss and decrease the number of cycles in the battery life

2) **<u>Depth of discharge</u>**

The second description of performance is depth of discharge. This describes how much of the total amp-hour capacity of the battery is used during a charge-recharge cycle. As an example, "shallow cycle" batteries are designed to discharge from 10% to 25% of their total amp-hour capacity during each cycle. In contrast, most "deep cycle" batteries designed for photovoltaic applications are designed to discharge up to 80% of their capacity without damage. Manufacturers of deep cycle "Ni cad" batteries claim their product can be totally discharged without damage. Even deep cycle batteries are affected by the depth of discharge. The deeper the discharge, the smaller the number of charging cycles the battery will last (Figure 17). They are also affected by the rate of discharge and their temperature.

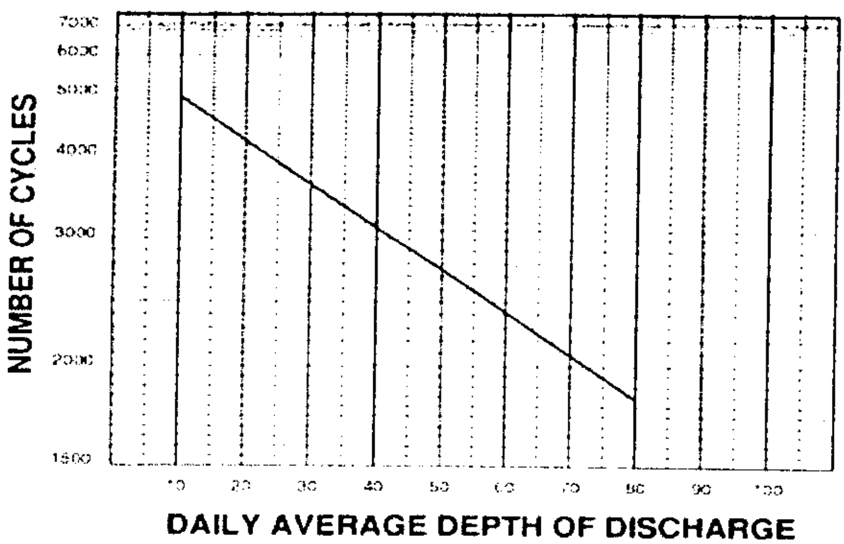


Figure 17 : Number of Cycles for Different Discharge Depths

2.3.2 *Batteries in series and Parallel*

Batteries, like photovoltaic cells, can be connected in series to increase the voltage. They can be connected in parallel to increase the amp-hour capacity of the battery system. Interconnected groups of batteries are usually called "battery banks". Figures below show how the batteries are interconnected.

Connecting batteries in both series and parallel will increase the voltage and the amp-hour capacity. The connections and wiring of the batteries plays a large role in how well the batteries are treated. The quality and method of wiring these systems is very important to maintain acceptable battery health and lifetime. A large voltage drop in the system between the battery and the battery charge controller will change how the battery charge controller operates. This voltage drop, measured during full charging rates, will reduce the voltage regulation set point the battery is charged to and reduce the capacity and lifetime of the battery.

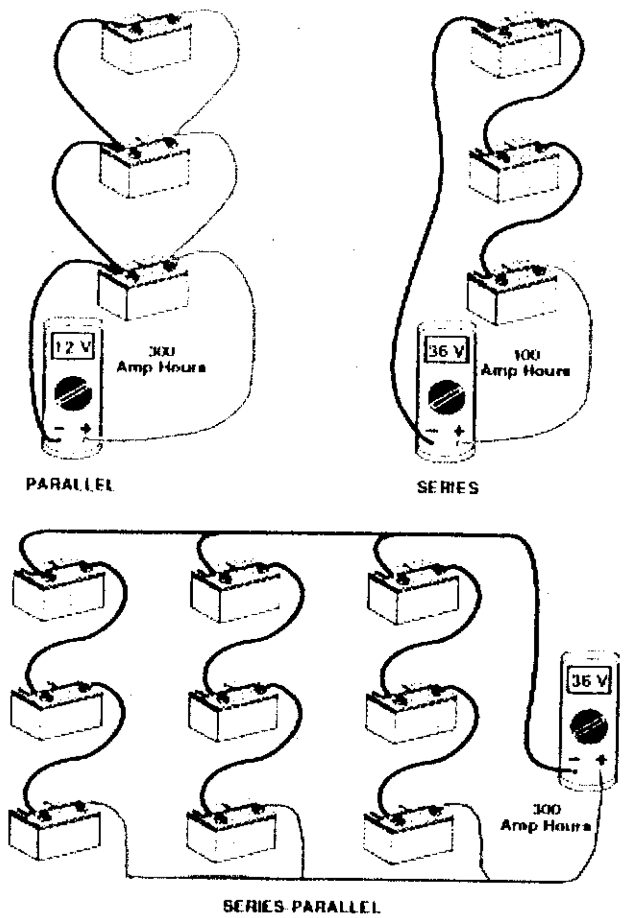


Figure 18 : Batteries Connected in Series, Parallel, and Series-Parallel

2.4 Control Unit

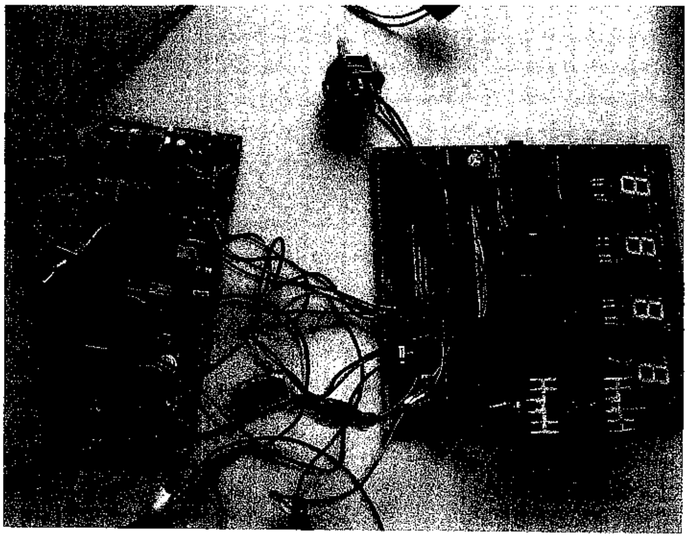


Figure 19 : Control unit circuit

Control Unit is the most important subsystem in the cooling system. The control unit will sense the temperature difference in the circuit and starts cooling. The control unit comprises of two parts of circuits which are calibration circuit and output circuit.

2.4.1 Calibration circuit

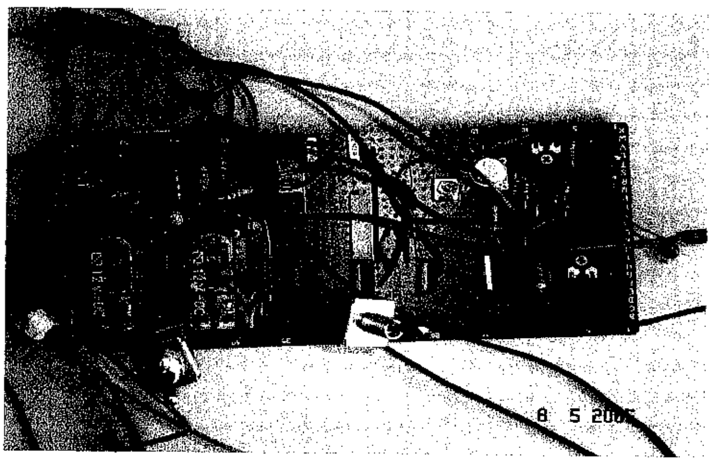


Figure 20 : Calibration Circuit Connection

Calibration circuit is use to sense the temperature difference in the car. Any increment or decrement of temperature is sense by thermistor which can sense until 300°C. The thermistor is also one of a resistor type. When the temperature is high it will give a high resistance and vice versa. The other main component that contains in the circuit is LM308, precision operational amplifier. This amplifier can be able to measure over 0°C to +70°C temperature ranges. It operates with supply voltages from $\pm$2V to $\pm$20V and has sufficient supply rejection to use unregulated supply.

The precision temperature sensor LM335 is also use in the circuit. It is easily calibrated and calibrates between -40°C to 100°C. It operated as a two terminal Zener and the breakdown voltage is directly proportional to the absolute temperature at 10mV/°K. Besides, the precision voltage reference, LM329 is also included in the circuit. It is temperature compensate 6.9V Zener reference which provide stability over time and temperature. It has very low dynamic impedance and a wide operating current range. The operating temperature range is between 0°C to +70°C.

In order to compare the voltage before it will activate the output, the low power dual operational amplifiers LM358 are used. These operational amplifiers are use as comparator. They compare the incoming voltage with the reference voltage. The output will only activate if the input voltage is the same with reference voltage or more. The operational amplifier consist of two independent, high gain and can operated from as single supply over a wide range of voltages which is from 3V to 32°V. All of these components that have been used in the circuit are come in chip sized package except for thermistor.

2.4.2 Output Circuit

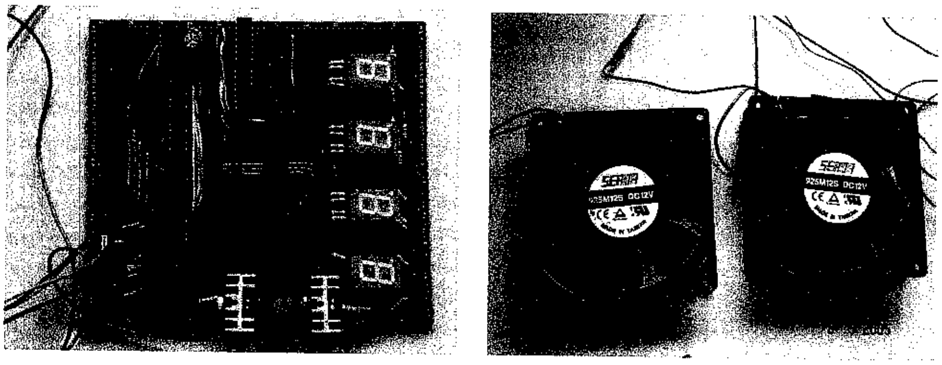


Figure 21 : Seven segment display and fan

The output circuit contains of seven segment display and fans. The seven segment display is used to display the current car temperature and the temperature that has been set to activate fan. The circuit contains analog to digital converter, ICL 7107 which receive the voltage signal in analog form and convert it into digital which can be display by seven segments. This converter comes in chip sized. The other main components are buffers, SN7404 which contains six independent gates in a chip and perform buffer operation before the signal in digital form goes into the seven segment display.

The second outputs are fans. The 12V fans have two functions. The first fan is use to blow the air into the car and the other fan will suck the air out. This operation is used as ventilation and provides cooling in the car. All of these outputs will activate if only the signal from calibration circuit is received.

CHAPTER 3
METHODOLOGY

3.1 Project Work

This final year project, the '*Solar Cooling System of a Car*' will be implemented in duration of two semesters. The project will need several methods in order to complete the task. Therefore, the project will be divided into a few stages. The distributions of the main tasks are listed as below:

1. **First semester:** *Literature review / research / data gathering / calculations.*
2. **Second semester:** *Design / testing / prototype / installation / analysis.*

All the tasks for this project must be based within the allocated time frame, which is two semester. For the first semester, the project will be focused on basic research and principle on car cooling system and circuit design. The concept of the cooling system and how to provide cooling by using electronic devices also should be determined to fulfill the project requirement.

For second semester, the project will be more focused on circuit assemblage, prototype construction and circuitry installation in the prototype. The project will continue with detailed analysis of the performance of cooling system which will include the key elements of project. The ideas from research and all the theories of the project will be apply in this semester.

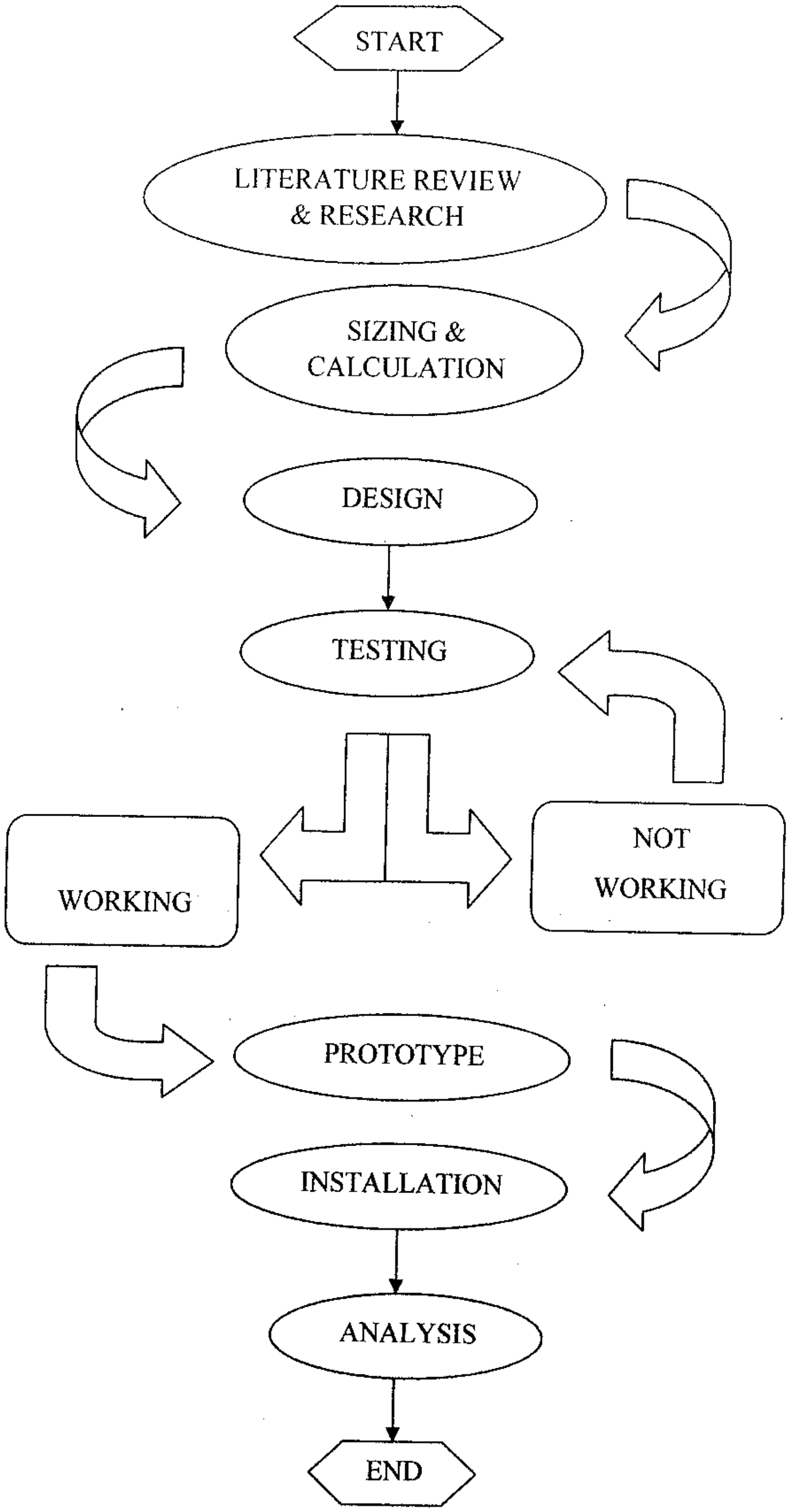


Figure 22 : Project Flow Chart

3.2 Literature Review and Research

Literature review and research should be done before doing the project. It is done by seeking information through books, internet and journals. Literature review and research provides important and useful knowledge for design stage. The research included the cooling system that used for car or other application and circuit design.

3.3 Data Gathering

All the relevant information obtained from research for this project are gathered and revised. The information is important for reference and ideas. It should be used for later stages.

3.4 Sizing and Calculation

The determination of the component sizes, number of component used and amount of parameter such as voltage and current that source will be supply and load will use will be calculated during this stage.

3.5 Design

The model circuit for solar cooling system of a car must be designed first before it can be constructed. The design software will be used to make the design job easier. The determination circuit operation and component selection that fulfilled the design requirement are also done during this stage. Refer to page 31 for circuit schematic diagram.

3.5.1 Tools, Component and Software

There are several tools and component that needed to be used during design and installation stage. All the tools, material and software listed below are defined along the design stages.

Component / Tools	Amount	Component / Tools	Amount
1. Solar Panel	1	30. 0.1uF	1
2. Sealed Lead Acid Battery	4	31. 0.047uF	1
3. 10k	5	32. 0.22uF	1
4. 102k (1%)	1	33. 1000uF	5
5. 294k (1%)	1	35. 0.01uF	1
6. 698k (1%)	1	36. 100pF	1
7. 4.7k	1	37. IN4001	7
8. 100k (1%)	1	38. Thermistor	1
9. 50k	2	39. Fan (12V)	2
10. 1M	4	40. Variable Switch	1
11. 24k	1	41. Seven segment display	4
12. 10k (variable)	4	42. L7805	1
13. 5k (variable)	1	43.L7915	1
14. 330	2	44.L7809	1
15. 150	24	45..L7815	1
16. 10	5	46 .LED	2
17. 25k (variable)	1	47. ICL7107 (A/D converter)	1
18. 100k	1	48. SN 7404	4
19. 470k	1	49. Diode	2
20. LM 335	1	50. Pin Connector	5
21. LM 329B	1	51. Wire Connector (1m)	4
22. LM 308	1	52.Crocodile Clip	3
23. LM 358	2	53. Car Prototype	1
24. L7805	1		
25. L7905	1		
26. Relay (12V)	2		
27. 9013	2		
28. 100pF	2		
29. 0.01uF	2		

Table 3 : List of Component and Tools

Software

- Eagle Win Eng. 4.13
- MATLAB

3.6 Testing

The model circuit that has been designed will be tested on the normal circuit board (bread board) to ensure that the circuit will work. If the circuit is not working, the circuit model will go back to design stage to modified, improvise and check the errors. The project will only proceed to the next stage if the model circuit is working.

3.7 Prototype

After the tested model circuit working, the circuit will transfer into the veraboard to solder. The construction of car prototype is also done at this stage. The size of the car prototype is depends on the solar panel size.

3.8 Installation

When the circuit is already soldered and the car prototype is already constructed, the installation work is begun. The wiring of the circuit inside the car is done depend on car arrangement. The solar panel is also put at a suitable place at the car so that it will more expose to the sunlight.

3.9 Analysis

The prototype of cooling system performance will be tested and analyzed back when the installation is done. The analysis will use MATLAB software

CHAPTER 4
RESULT AND DISCUSSION

4.1 The Photovoltaic System Concept

4.1.1 Solar panel charging concept

Solar panel charges the battery storage instead of giving supply directly to the control unit. The battery storage will give the supply back to the control unit of if the solar panel current is not sufficient. The table below shows the tabulation of voltage and current that will produce by solar panel during sunny and cloudy day.

Day	Voltage	Current
Sunny	21V	300mA
Cloudy	17V	100mA

Table 4 : Voltage and current tabulation

From the study that has been done, the average voltage and current that the solar panel can produce during normal sunny day are ± 21V and ± 300mA. While during cloudy day the average voltage and current are ± 17V and ± 100mA. The voltage and current produce are depends on the type of solar panel. The higher efficiency of the solar panel, the more voltage and current it will produce. In this project, the solar panel that has been used is Amorphous Silicon. Amorphous Silicon has a low efficiency which is between 5% - 8% but low in cost. The suitable solar panel that can be used for this project is **Polycrystalline Silicon** which has 13% - 15% efficiency but higher in cost. This means that, one Polycrystalline Silicon solar panel is equals to three times efficiencies of Amorphous Silicon solar panel

Calculation

Amount of battery discharge per hour = 1.3AH

1. **Sunny day:**

Solar Charging Current = 300mA

By using formula:

Q = It

t = Q / I

= 1.3Ah / 300mA

≈ 4 h (hours to charge the battery)

2. **Cloudy day**

Solar Charging Current = 15mA

By using formula:

Q = It

t = Q / I

t = 1.3A / 100mA

≈ 13h (hours to charge the battery)

(* resistance is negligible)

The calculation above shows that during normal sunny day, the solar panel can fully charge the battery up to 4 hours. As for cloudy day, the time that take for solar panel to fully charge the battery is a bit longer, which about 13 hours. This is because the light intensity is low.

4.1.2 Solar panel arrangement and circuit

The solar panel must be connected to the protection circuit before it will connect to the battery and the control unit. The protection circuit contains a blocking diode which can prevent the overcharging current flow from solar panel to the battery. The battery will produce a reverse flow of current to the solar panel especially at night. This flow will drain power from batteries. The battery will damage if the protection diode is not included. The arrangement of solar panel, batteries and protection circuit are shown below:

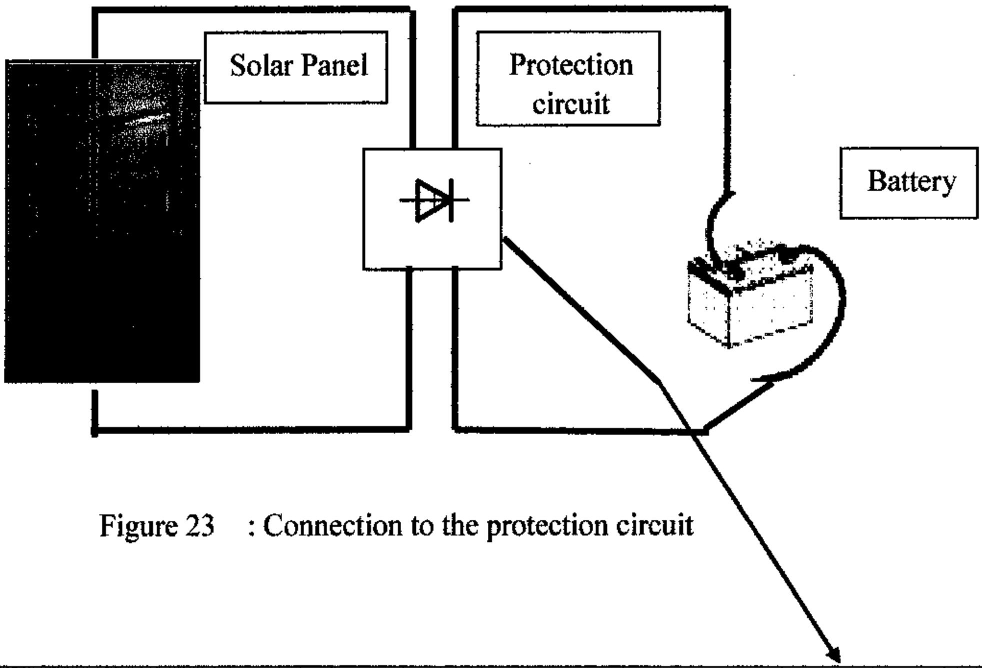


Figure 23 : Connection to the protection circuit

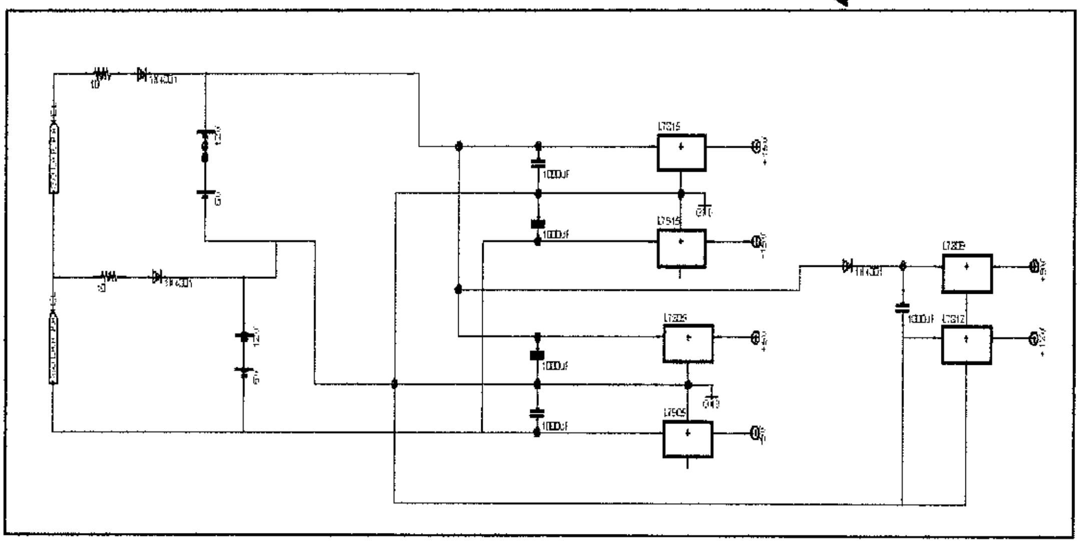


Figure 24 : Protection circuit schematic

Figure 23 shows the connection between solar panel protection circuit and battery. Diode is used in the protection circuit to stop the reverse current. Diode will only allow the current to flow in one direction. In this circuit, diode is connected between solar panel and batteries for protection. Batteries are then connected to the capacitor to store the access charge. From capacitors, the wire is connected to the voltage regulator to produce a stable output to the control unit. Basically, this is how the source circuit connection to the control unit. The detail circuit connection and operation of diode is shown at Figure 24.

4.2 Battery Storage

4.2.1 Battery sizing

The battery stores energy from the solar panel enabling the system load to operate when necessary. Due to the vagaries of the weather, the long periods of below average must be allowed in order to ensure reliable operation. In effect this means that the battery size is calculated to allow for a certain number of days without energy input, the system autonomy.

Several important points need to be considered:

1. The situation occur which it is not advisable to allow the battery to discharge to 0% capacity
2. Capacity reduces with temperature
3. The effect of self discharge and charging effect may be significant
4. The battery capacity is a function of discharge rate

Typically, the battery can't be discharge below its 30% charge state and allow for a 10% capacity reduction in cloudy day. Thus the suitable batteries choice are sealed acid that ideal for solar systems. Its have high charge efficiency, low self discharge and good recovery from high discharge.

4.2.2 Battery supply

Battery needs to supply the control unit when solar panel doesn't provide a sufficient energy. Table 3 shows the discharge current produce and the period for battery can be used to supply the current to control unit:

Battery Capacity = 5.0 Ah

Discharge Current (A)	**Hours battery can be used (h)**
1	5
1.25	4
1.67	3
2.5	2

Table 5 : Discharge current and hour for 5.0Ah batteries can be used

Based on the table above, batteries can supply for 5 hours if its discharge for 1 Ampere. Other than that, the batteries can only supply for 2 hours if its discharge for 2.5Ampere. This means that, the more current discharge, the shorter hours that battery can stand.

4.3 Control Unit

Control unit is the important part in the cooling system operation. It contains calibration circuit which provides a signal to the output circuit and the output will start cooling. Figure 25 shows the schematic diagram of control unit:

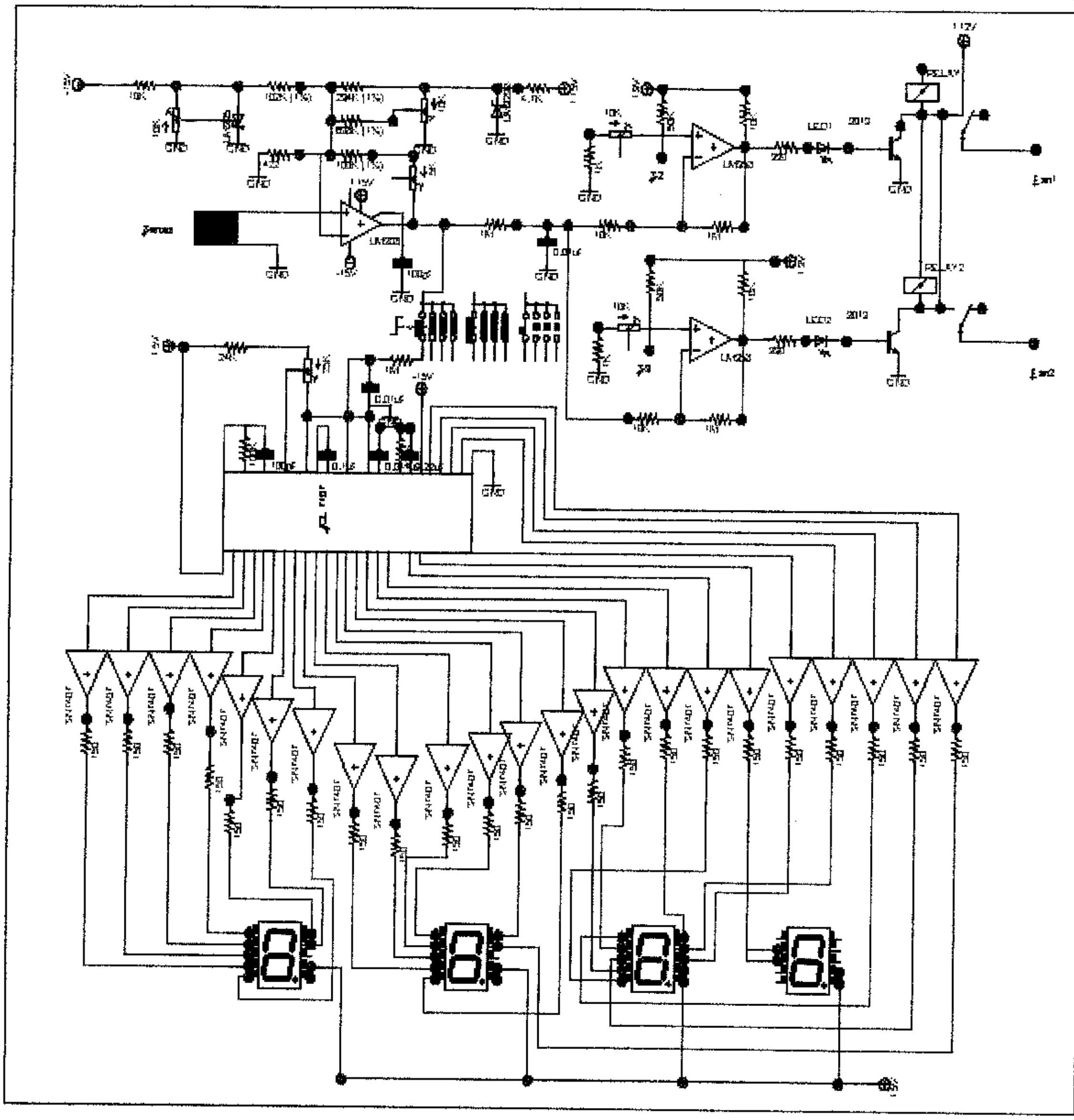


Figure 25 : Control unit circuit diagram

4.3.1 Circuit operation

The operation of the circuit starts when the sensor (thermistor) senses the temperature difference between two blocks, which are positive and negative. The precision operational amplifier (LM308) will measure how fast or slow current flows from sensor to become an output voltage. The precision temperature sensor (LM 335) will get the voltage reading and calibrate it. Every output voltage of 10mV for operational amplifier is equals to 1K° increment. The output from precision operational amplifier that measures the voltage will be obtained by (LM358) operational amplifiers which operate as comparators. The output from (LM308) precision operational amplifier will be an input to (LM358) comparators. The comparator will compare the voltage. If the input voltage is the same or more than voltage reference, outputs will high, relays will turn on and fan will activate. If input voltage is below than voltage reference, output will low, relay and fan will not activate. The voltage difference cannot be seen, so display will be connected to show the voltage difference. The analog to digital converter (ICL7107) will change the analog voltage reading from output of the selector switch to C° (digital). The ICL7107 will connect with buffer (SN7404) that will buff the signal to seven segment display. The temperature increment and decrement will be seen at the display.

The 32V control unit circuit is using the selector circuit to show the current temperature (surrounding temperature) and the temperature that have been set to activate the system. This is how the switch operates:

- There are 3 selector switch to select the temperature that has been set:
    1. The first switch is used to display the current temperature
    2. The second switch is to show the temperature that has been set to turn on the blowing fan.
    3. The third switch is to show the temperature that has been set to turn on the sucking fan.

After the temperature have been set by using the variable resistor, the fan will activated regarding to the temperature that have been set. Say if the second switch and the third switch are set to 32°C, the blowing and the sucking fan turn on equally. But the temperature can be set at different value in order to make the fan turn on at different time. It depends on design requirement.

4.4 The Cooling System

4.4.1 Features

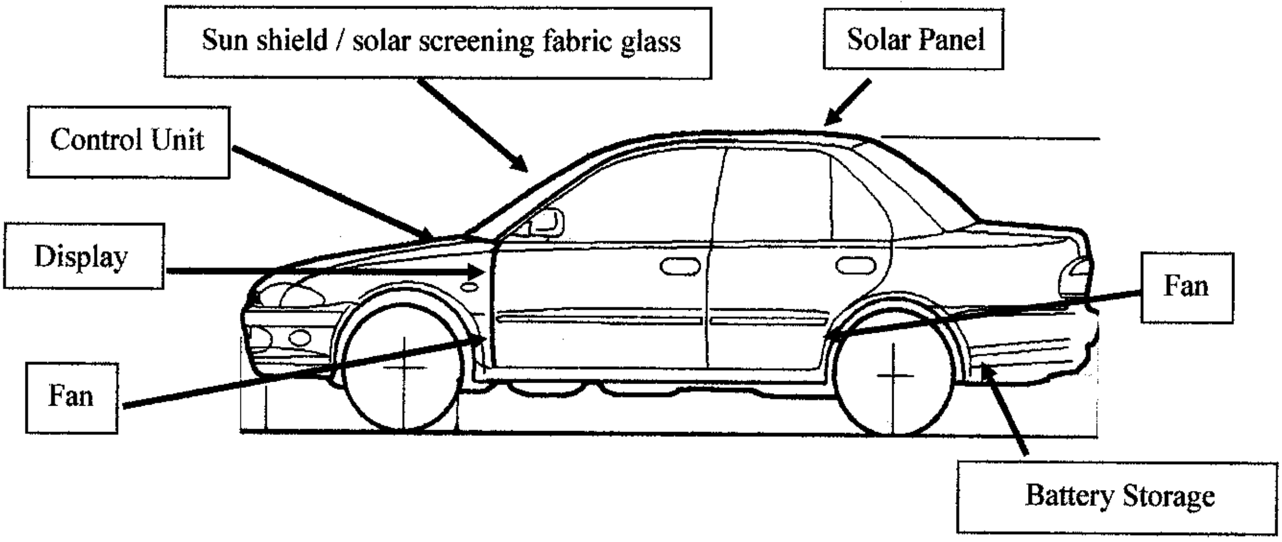


Figure 26 : Cooling system features

The implementation and construction of cooling system to a car can be modeled as in the figure 26. At the front side of the car, the main component such as control unit, temperature display and the blowing fan will be placed. While at the back side of the car, the sucking fan and the battery storage will be placed. On the roof top of the car, the solar panel will be mounted for maximum exposure. The suggested glasses that can to be used for this system are sun shield or solar screening fabric glasses. These glasses can work as insulator so that the temperature inside the car will keep cooling even though the temperature outside is hot. This method of cooling is known as passive cooling.

4.4.2 System Operation and Comparison

NORMAL SYSTEM

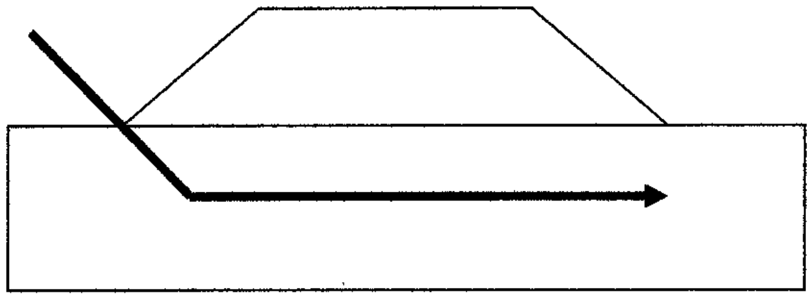


Figure 27 : Normal system

The normal system will suck the outside air and blow inside the car when the intake control level is set. Usually air intake is selected to save the energy instead of using air conditioner and during the glass become fogged or the air inside the car becomes stuffy. Some innovation has been made to the normal system to make the normal system become more beneficial. There are two designs that have been suggested to be implemented in the real system.

COOLING SYSTEM (1st design)

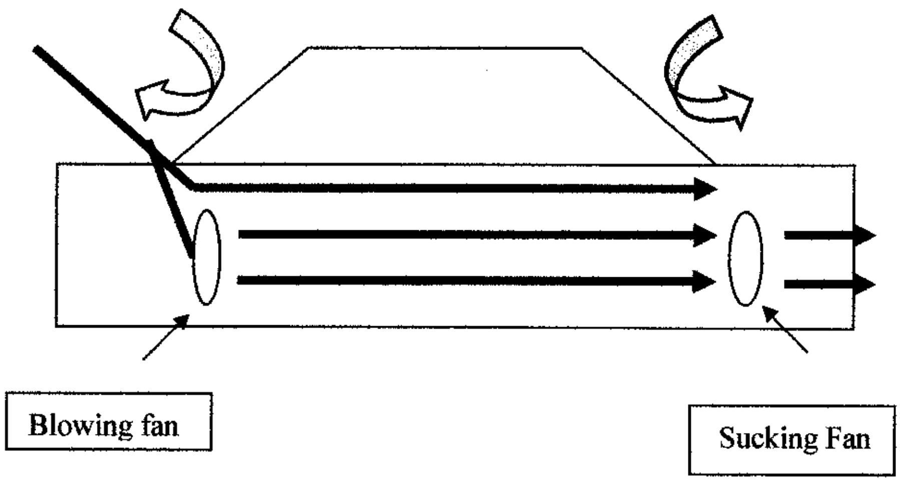


Figure 28 : First Design

For the first cooling system design; the air intake control lever is still selected so that the outside air is introduced and the system will operate more efficiently. The cooling system will operate during two conditions. The first condition is during parking (static) and the second condition is during the car is moving. For the first condition, the car is parked. All the windows and doors will be closed and the temperature inside the car started increasing. If the cooling system is set 32°C to activate, the blowing fan and the sucking fan will turn on. The outside air will be sucked in by the blowing fan and it will blow inside the car. The second fan which is the sucking fan will suck the hot air inside the car out. As for second condition, the system operates during the car is moving. In order to save energy and cost, the windows will open by the passenger and air conditioning is turning off. The warm or hot air will go inside the car. If the temperature inside the car has reaching the temperature of the system has set, the both fans will turn on. This will provide more cooling to the passenger and energy saving because the system is straight away energize from solar. Basically that is how the ventilation inside the car operates to provide cooling. Sun shield or solar screening glasses are use to reflect the sunlight so that the system will not operate at maximum efficiency and less energy consumption. It also will increase the cooling temperature inside the car.

COOLING SYSTEM (2nd design)

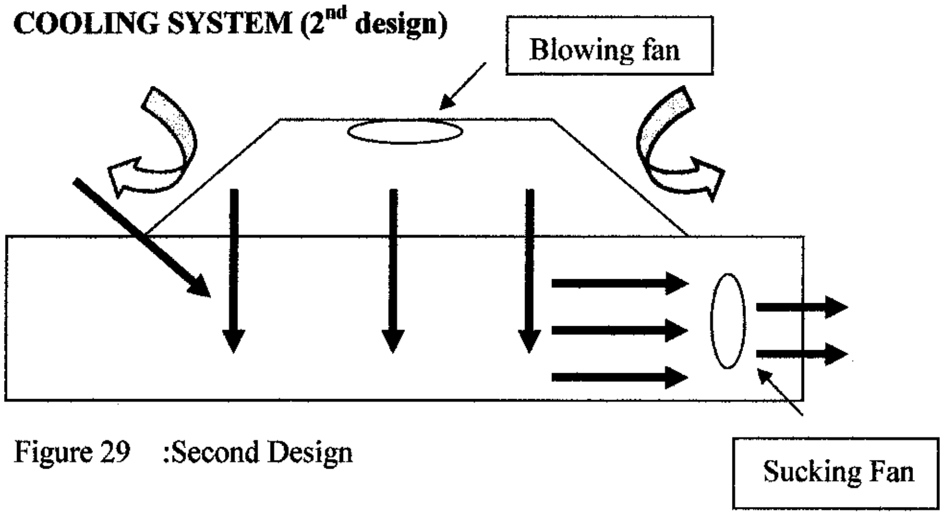


Figure 29 :Second Design

Another design that can be used in the system is shown as in the figure 29. The operation of the cooling system is still the same. Blowing fan has been located on the top of the roof in the car. The reason of putting the fan at the top of the roof is because the hot air is lighter than the cold air. The blowing fan will blow the hot air to the bottom of the car and the hot air will be suck out by the sucking fan.

4.4.3 *Analysis*

An analysis need to be done to the system so that it can be applied to the real application. The analysis is basically to calculate the capacity of heat to be removed and power that needed by a car to energize the fan. This calculation is important for battery sizing and to determine the number of fans that are going to use. The capacity of the heat to be removed and power needed are depending on the car size. There are two types of car that has been studied. The first car that had been reviewed from *Owner's Manual proton* on the specification is Proton Wira 1.3 Lxi 4 door. From the specifications, the volume of a car is obtained. The volume is calculated in order to determine on how much power can be injected into the car in order to cool down the car.

Item/ Model	Proton Wira 1.3 GL
Interior Length (m)	1.825
Interior Width (m)	1.400
Interior Height (m)	1.160

Table 6 : Proton Wira 1.3 Lxi 4 door specification

The volume inside Wira is:

$$V = l * w * h \qquad \textbf{(1.0)}$$

By using Matlab:

>> 1.825 * 1.400 * 1.160

ans = 2.996

The approximate volume is ≈ 2.996m^3

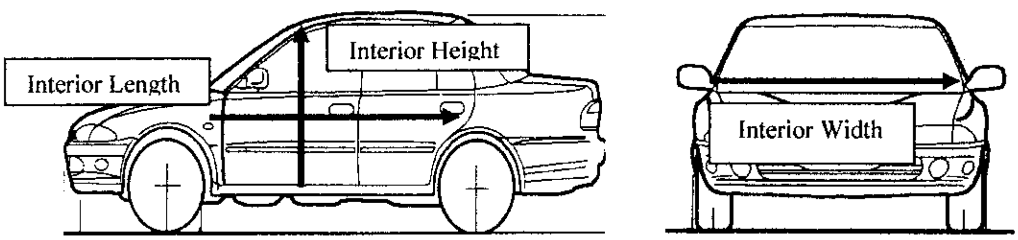


Figure 30 : Interior Height, Length and Width for Wira

The second car that has been reviewed on the specification is Perodua Kancil model 660EX, 660EX and 850EZi. From here the volume inside the car can be calculated:

Item/ Model	**Perodua Kancil 660EX, 660EX,850EZi**
Interior Length (mm)	1710
Interior Width (mm)	1185
Interior Height (mm)	1170

Table 7 : Perodua Kancil model 660EX, 660EX and 850EZi specification

The volume inside Perodua Kancil is:

$$V = l * w * h \tag{2.0}$$

By using Matlab:

```
>> 1.710 * 1.185 * 1.170

ans = 2.371
```

The approximate volume is $\approx 2.371 m^3$

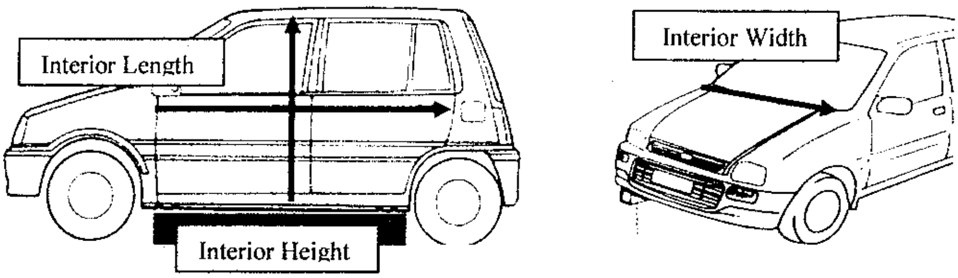


Figure 31 : Interior Height, Length and Width for Kancil

The interior volumes of both cars are measured by neglecting the seats. After the value of volumes for both cars are obtained, the mass flow rate of air inside the car must be calculated. To achieve the velocity of hot air, the swept area for the hot air to be removed or blow must be calculated first. The swept area is based on the fan sizing. For a bigger car, the bigger fan or more fans are going to be used to provide cooling. The value for the swept area in calculation below is only a suggested value based on the fan measurement and calculation that is going to use inside the car. The fan swept area is calculated by using circle formula, πr^2. The theory on mass flow rate is shown in the figure below.

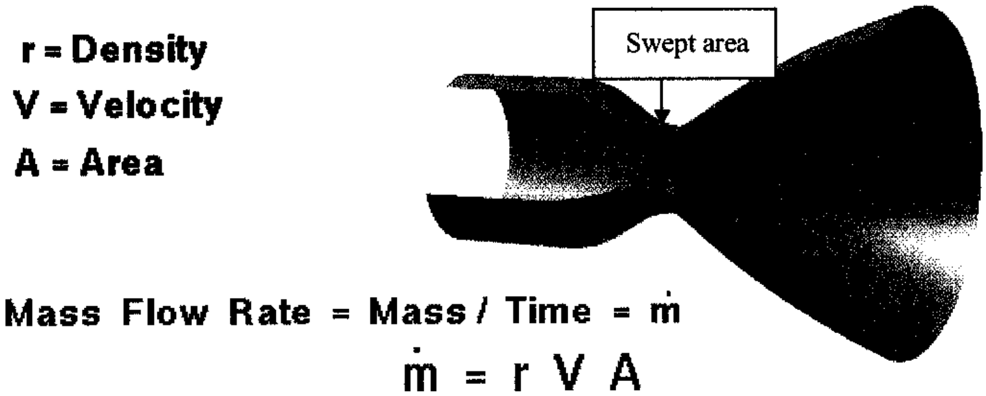


Figure 32 : Mass Flow Rate theory

After the mass flow rate calculation is done, the calculation for heat quantity that needs to be removed can be implemented. The calculated value of heat quantity is then converted into power. From here, the amount of power required by a car to provide cooling can be obtained. The formulas and examples of calculation that have been use to calculate the approximate quantity of heat, mass and conversion of heat quantity to power are presented in the next section.

Quantity of heat

$$Q_h = \dot{m} * C_a * (T_1 - T_2) \qquad (3.0)$$

Q_h = Quantity of heat inside the car

$\dot{m}$ = Mass flow rate

C_a = Specific Heat for air

T_1 = Temperature inside the car

T_2 = Temperature outside the car

Mass flow rate of air inside the car

$$\dot{m} = \rho_a * V * A \qquad (4.0)$$

$\dot{m}$ = Mass flow rate

ρ_a = Density of air

V = Velocity of air

A = Swept area

Velocity of air

$$V = \frac{v}{A * t} \qquad (5.0)$$

V = Velocity of air

v = A volume of mass to be swept out

A = Swept area

t = Time of air flow rate

Power

Conversion of Q_h from Calorie to Watt

$$cal = \frac{cal * 4.18}{60 * 60} = watt \qquad (6.0)$$

CALCULATIONS

Velocity of air

Wira

v = 2.996m^3

A = 2.545m^2

t = 1 sec

By using Matlab:

>> 2.996 / (2.545 * 1)

ans = 1.1772

The velocity, V ≈ 1.1772m/sec

Kancil

v = 2.371m^3

A = 1.539m^2

t = 1 sec

By using Matlab:

>> 2.371 / (1.539 * 1)

ans = 1.5406

The velocity, V ≈ 1.5406m/sec

Next are the examples of calculations for mass flow rate, quantity of heat and power which are ranges from 24°C – 28.5°C. The other calculation works are shown in APPENDIX 1-3. After calculations are done, several graphs are plotted.

Mass flow rate calculations

Wira

V = 1.1772m/sec

A = 2.545m^2

By using Matlab:

T_1 = 24°C,

>> 1.1917 * 1.1772 * 2.545

ans = 3.5703

The mass flow rate is = 3.5703kg /sec

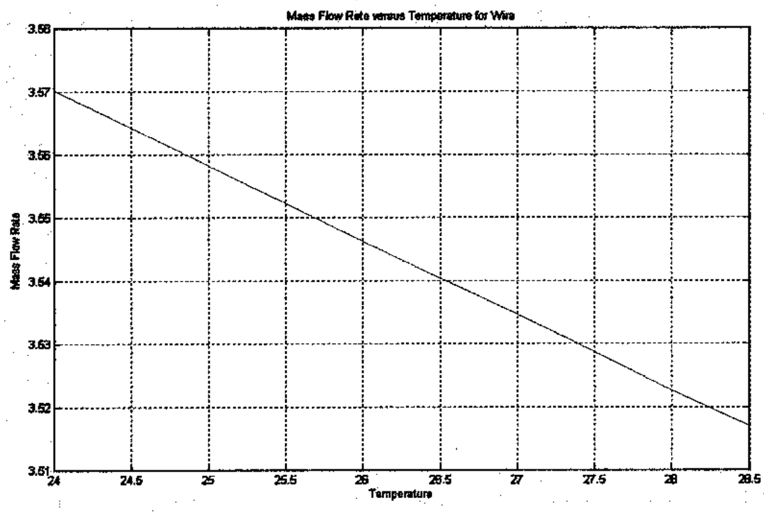


Figure 33 : Mass Flow Rate versus Temperature for Wira

<u>Kancil</u>

V = 1.5406m/sec

A = 1.539m^2

By using Matlab:

T_1 = 24°C,

>> 1.1917* 1.5406 * 1.539

ans = 2.8255

The mass flow rate is = 2.8255 kg /sec

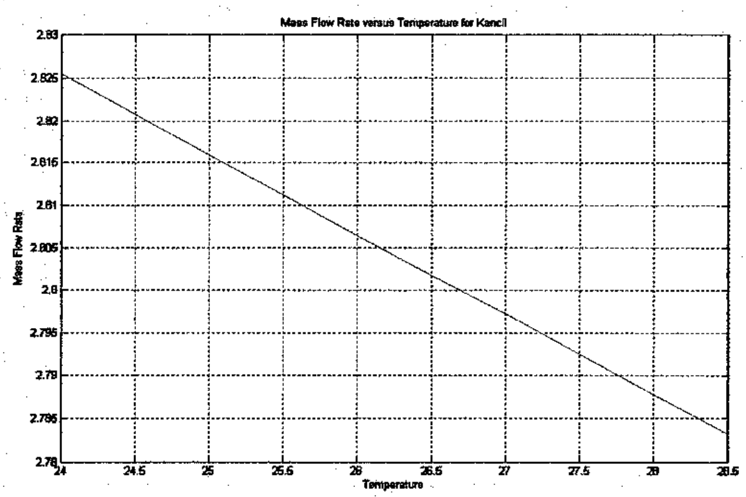


Figure 34 : Mass Flow Rate versus Temperature for Kancil

Quantity of heat

Wira

$T_1 = 24°C$

By using Matlab:

```
>> 3.5703 * 1005.3423 * 8
ans = 2.8715e+004
```

Heat quantity that needs to be removed is: 28 715 cal

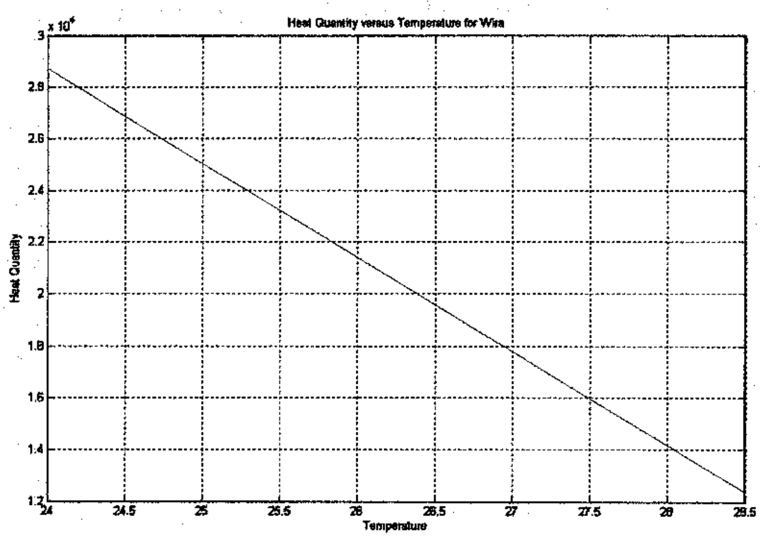


Figure 35 : Heat Quantity versus Temperature for Wira

Kancil

$T_1 = 24°C$

By using Matlab:

```
>> 2.8255 * 1005.3423 * 8
ans = 2.2725e+004
```

Heat quantity that needs to be removed is: 22 725 cal

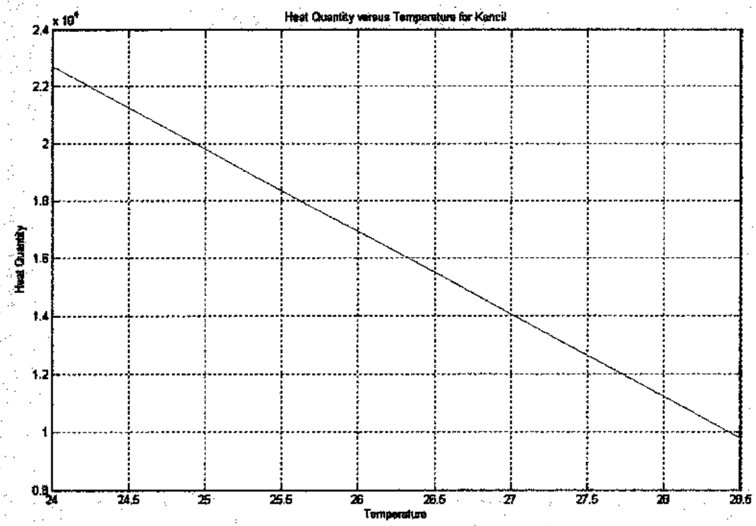


Figure 36 : Heat Quantity versus Temperature for Kancil

Power

Wira

$T_1 = 24°C$

By using Matlab:

>> (28715 * 4.18)/(60 * 60)

ans = 33.3413

The amount of power needed is: 33.3413 watt

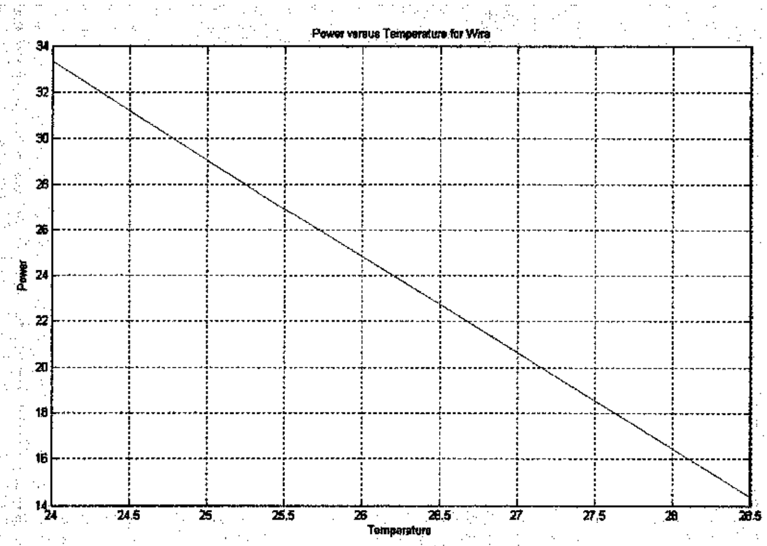


Figure 37 : Power versus Temperature for Wira

Kancil

$T_1 = 24°C$

By using Matlab:

>> (22725 * 4.18)/(60 * 60)

ans = 26.3863

The amount of power needed is: 26.3863 watt

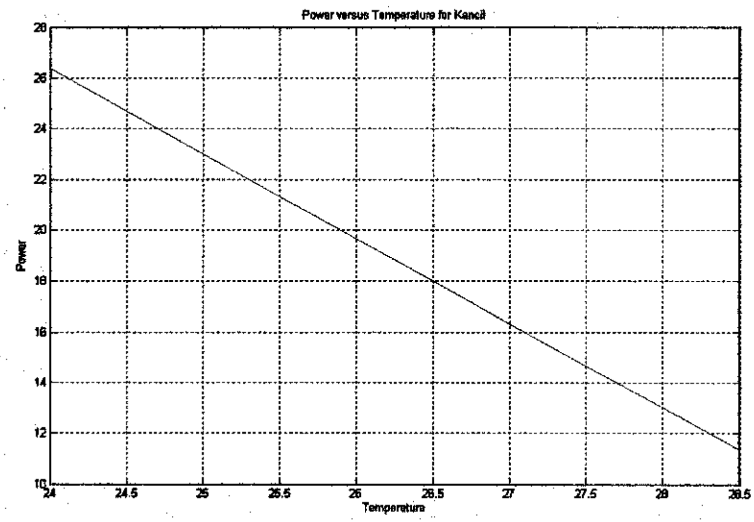


Figure 38 : Power versus Temperature for Kancil

Results

Inside Temp T_1(°C)	Outside Temp (Fix) T_2(°C)	Temp Diff. (T_2-T_1)	Density ρ_a (kg/m^3)	Specific Heat C_a (kJ/kg.K)	Vol. for Kancil (m^3)	Vol. for Wira (m^3)	Mass Flow Rate for Kancil M_a (kg)	Mass Flow Rate for Wira M_a (kg)	Heat Quantity for Kancil Q_h (cal)	Heat Quantity for Wira Q_h (cal)	Power needed for Kancil (Watt)	Power needed for Wira (Watt)
24	32	8	1.1917	1005.3423	2.371	2.996	2.8255	3.5703	22 725	28 715	26.3863	33.3413
24.5	32	7.5	1.1897	1005.3611	2.371	2.996	2.8208	3.5643	21 269	26 876	24.6957	31.2060
25	32	7	1.1877	1005.3801	2.371	2.996	2.8160	3.5583	19 818	25 042	23.0109	29.0765
25.5	32	6.5	1.1857	1005.3993	2.371	2.996	2.8113	3.5523	18 372	23 215	21.3319	26.9552
26	32	6	1.1837	1005.4189	2.371	2.996	2.8065	3.5463	16 930	21 393	19.6576	24.8396
26.5	32	5.5	1.1817	1005.4387	2.371	2.996	2.8018	3.5403	15 494	19 578	17.9903	22.7322
27	32	5	1.1798	1005.4588	2.371	2.996	2.7973	3.5347	14 063	17 770	16.3287	20.6329
27.5	32	4.5	1.1778	1005.4791	2.371	2.996	2.7925	3.5287	12 635	15 966	14.6706	18.5383
28	32	4	1.1758	1005.4997	2.371	2.996	2.7878	3.5227	11 213	14 168	13.0195	16.4506
28.5	32	3.5	1.1739	1005.5205	2.371	2.996	2.7833	3.5170	9 795	12 377	11.3731	14.3711

Table 8 : Calculation for heat quantity, mass and power

From the results that have been shown above, it can be conclude that the power are going to be needed for Perodua Kancil is range from 11 W to 26 W and the power that are going to be needed for Wira is range from 14 W to 33 W. The outside temperature is fixed to 32°C because it is the normal room temperature nowadays and this is where the system starts cooling. The temperatures inside the car are chosen from 24°C to 28°C because this is where the temperature of cooling that is going to be maintained.

From all the graphs that have been plotted above, it is shown that the relationship between power and temperature are inverse relationship. This means that if more cooling is needed inside the car, the more power that is going to be supplied.

4.4.4 System Advantages

There are several advantages that can be obtained from the cooling system that has been improvised. The advantages are:

1. The system will automatically operate as it reached the setting temperature and also automatically off if it is below than the setting temperature. The system also can manually off if the cooling temperature is sufficient.
2. The system can be used at both conditions; during the car is stop (parking) and while the car is moving.
3. The battery that has been charge by the solar panel can be used for other applications such as energizes the electronic devices instead providing backups to the control unit.
4. The cooling system is energy saving and cost effective because solar energy is directly supply to the circuit and charges the battery. The system can be used everyday life.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

All of the work is successfully done within the timeframe. The theory and concept of cooling system of a car has been studied. The system has been designed and a working prototype is also constructed. The circuit designed is based on the temperature difference and provides cooling to the car as the sensor sense the temperature changes. The study on battery charger is also important so that it will provide a sufficient supply if the solar panel supply is not affordable. The system is energy and cost saving because it is using solar energy which is free from the sun and can be used everyday life.
Generally this project is completed in two semesters. In the first semester, the project is more on gaining the ideas by studying the literature review, doing research and data gathering. After all the data has been obtained and gathered, some calculation is done before designing the system. As for second semester, the project is more focused on designing, construction of the prototype, the circuit installation and analysis. This is where all the theories and ideas are implemented. The project has enhanced the student's knowledge especially in solar energy and cooling system. The implementation of this project has exposed the student in learning to design and handle the circuit and car prototypes by using software or hardware tools.

As for recommendations, it is recommended that this system is applied to the real life application. This is because the system is applicable and beneficial. In order to make the system more efficient, a high quality solar panel can be use to generate more electricity and energize other devices instead of the controlling unit. Fans can be replaced by **Peltier thermoelectric cooling module** to provide more cooling inside the car. Further research and study will contribute to the successfulness of this project.

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APPENDICES

Appendix: Milestone for the First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■	■											
	-Propose Topic	■													
	-Topic assigned to students		■	■											
2	Preliminary Research Work		■	■	■	■	■	■							
	-Project planning		■												
	-Research on photovoltaic (PV) cells			■											
	-Research on solar battery storage				■	■									
	-Research on cooling system					■	■								
	-Research on temperature difference circuit							■							
	-Research on charger circuit							■							
3	Submission of Preliminary Report			◇											
4	Project Design Work								■	■	■				
	-Design the control unit circuit								■	■					
	-Design the charger circuit									■	■				
5	Submission of Progress Report					◇									
												■	■	■	
6	Project work continue											■	■	■	
	-Combining the design circuit														
7	Submission of Interim Report Final Draft											◇			
8	Submission of Interim Report													◇	
9	Oral Presentation														◇

■ Progress ◇ Suggested Milestone ■ Summary

Appendix: Milestone for the Second Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Project Work Continue	■	■	■													
	-Continue on the research from first semester	■	■														
	-Find the component by specification			■													
2	Submission of Progress Report 1			◇													
3	Project Work Continue				■	■	■										
	-Implementation of the design				■	■	■										
4	Submission of Progress Report 2							◇									
5	Project work continue							■	■	■	■	■	■				
	-Testing and refinement							■	■	■							
	-Build model prototype									■	■						
	-Pre EDX exhibition											■					
	-EDX exhibition												■				
6	Submission of Dissertation Final Draft													◇			
7	Submission of Project Dissertation (soft cover)														◇		
8	Submission of Technical Report														◇		
7	Oral Presentation															◇	
8	Submission of Project Dissertation(hard cover)																◇

■ Progress ◇ Suggested Milestone ■ Summary

APPENDIX 1-3: Matlab source code for analysis calculations

Mass flow rate calculations w.r.t. temperature

Kancil

V = 1.5406m/sec

A = 1.539m^2

By using Matlab:

T_1 = 24.5°C

>> 1.1897 * 1.5406 * 1.539

ans = 2.8208

T_1 = 25°C

>> 1.1877 * 1.5406 * 1.539

ans = 2.8160

T_1 = 25.5°C

>> 1.1857 * 1.5406 * 1.539

ans = 2.8113

T_1 = 26°C

>> 1.1837 * 1.5406 * 1.539

ans = 2.8065

T_1 = 26.5°C

>> 1.1817 * 1.5406 * 1.539

ans = 2.8018

T_1 = 27°C

>> 1.1798 * 1.5406 * 1.539

ans = 2.7973

T_1 = 27.5°C

>> 1.1778 * 1.5406 * 1.539

ans = 2.7925

T_1 = 28°C

>> 1.1758 * 1.5406 * 1.539

ans = 2.7878

T_1 = 28.5°C

>> 1.1739 * 1.5406 * 1.539

ans = 2.7833

Wira

$V = 1.1772 m/sec$

$A = 2.545 m^2$

By using Matlab:

$T_1 = 24.5°C$

```
>> 1.1897 * 1.1772 * 2.545
ans = 3.5643
```

$T_1 = 25°C$

```
>> 1.1877 * 1.1772 * 2.545
ans = 3.5583
```

$T_1 = 25.5°C$

```
>> 1.1857 * 1.1772 * 2.545
ans = 3.5523
```

$T_1 = 26°C$

```
>> 1.1837 * 1.1772 * 2.545
ans = 3.5463
```

$T_1 = 26.5°C$

```
>> 1.1817 * 1.1772 * 2.545
ans = 3.5403
```

$T_1 = 27°C$

```
>> 1.1798 * 1.1772 * 2.545
ans = 3.5347
```

$T_1 = 27.5°C$

```
>> 1.1778 * 1.1772 * 2.545
ans = 3.5287
```

$T_1 = 28°C$

```
>> 1.1758 * 1.1772 * 2.545
ans = 3.5227
```

$T_1 = 28.5°C$

```
>> 1.1739 * 1.1772 * 2.545
ans = 3.5170
```

Quantity of heat

Kancil

By using Matlab:

T_1 = 24.5°C

```
>> 2.8208 * 1005.3611 * 7.5
ans =  2.1269e+004
```

T_1 = 25°C

```
>> 2.8160 * 1005.3801 * 7
ans = 1.9818e+004
```

T_1 = 25.5°C

```
>> 2.8113 * 1005.3993 * 6.5
ans = 1.8372e+004
```

T_1 = 26°C

```
>> 2.8065 * 1005.4189 * 6
ans = 1.6930e+004
```

T_1 = 26.5°C

```
>> 2.8018 * 1005.4387 * 5.5
ans = 1.5494e+004
```

T_1 = 27°C

```
>> 2.7973 * 1005.4588 * 5
ans = 1.4063e+004
```

T_1 = 27.5°C

```
>> 2.7925 * 1005.4791 * 4.5
ans = 1.2635e+004
```

T_1 = 28°C

```
>> 2.7878 * 1005.4997 * 4
ans = 1.1213e+004
```

T_1 = 28.5

```
>> 2.7833 * 1005.5205 * 3.5
ans = 9.7953e+003
```

Wira

By using Matlab:

$T_1 = 24.5°C$

>> 3.5643 * 1005.3611 * 7.5

ans = 2.6876e+004

$T_1 = 25°C$

>> 3.5583 * 1005.3801 * 7

ans = 2.5042e+004

$T_1 = 25.5°C$

>> 3.5523 * 1005.3993 * 6.5

ans = 2.3215e+00426°C

$T_1 = 26°C$

>> 3.5463* 1005.4189 * 6

ans = 2.1393e+004

$T_1 = 26.5°C$

>> 3.5403* 1005.4387 * 5.5

ans = 1.9578e+004

$T_1 = 27°C$

>> 3.5347* 1005.4588 * 5

ans = 1.7770e+004

$T_1 = 27.5°C$

>> 3.5287* 1005.4791 * 4.5

ans = 1.5966e+004

$T_1 = 28°C$

>> 3.5227 * 1005.4997 * 4

ans = 1.4168e+004

$T_1 = 28.5°C$

>> 3.5170 * 1005.5205 * 3.5

ans =1.2377e+004

Power

Kancil

By using Matlab

$T_1 = 24°C$

>> (22725 * 4.18)/(60 * 60)

ans = 26.3863

$T_1 = 24.5°C$

>> (21269 * 4.18)/(60 * 60)

ans = 24.6957

$T_1 = 25°C$

>> (19818 * 4.18)/(60 * 60)

ans = 23.0109

$T_1 = 25.5°C$

>> (18372 * 4.18)/(60 * 60)

ans = 21.3319

$T_1 = 26°C$

>> (16930 * 4.18)/(60 * 60)

ans = 19.6576

$T_1 = 26.5°C$

>> (15494 * 4.18)/(60 * 60)

ans = 17.9903

$T_1 = 27°C$

>> (14063 * 4.18)/(60 * 60)

ans = 16.3287

$T_1 = 27.5°C$

>> (12635 * 4.18)/(60 * 60)

ans = 14.6706

$T_1 = 28°C$

>> (11213 * 4.18)/(60 * 60)

ans = 13.0195

$T_1 = 28.5$

>> (9795 * 4.18)/(60 * 60)

ans = 11.3731

Wira

By using Matlab:

$T_1 = 24.5°C$

```
>> (26876 * 4.18)/(60 * 60)
ans = 31.2060
```

$T_1 = 25°C$

```
>> (25042 * 4.18)/(60 * 60)
ans = 29.0765
```

$T_1 = 25.5°C$

```
>> (23215 * 4.18)/(60 * 60)
ans = 26.9552
```

$T_1 = 26°C$

```
>> (21393  * 4.18)/(60 * 60)
ans = 24.8396
```

$T_1 = 26.5°C$

```
>> (19578 * 4.18)/(60 * 60)
ans = 22.7322
```

$T_1 = 27°C$

```
>> (17770 * 4.18)/(60 * 60)
ans = 20.6329
```

$T_1 = 27.5°C$

```
>> (15966 * 4.18)/(60 * 60)
ans = 18.5383
```

$T_1 = 28°C$

```
>> (14168 * 4.18)/(60 * 60)
ans = 16.4506
```

$T_1 = 28.5°C$

```
>> (12377 * 4.18)/(60 * 60)
ans =14.3711
```

Matlab source code for Mass Flow Rate graphs

Kancil

```
x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
y = [2.8255 2.8208 2.8160 2.8113 2.8065 2.8018 2.7973 2.7925 2.7878 2.7833];
plot(x,y)
title ('Mass Flow Rate versus Temperature for Kancil');
xlabel('Temperature');
ylabel('Mass Flow Rate');
grid
```

Wira

```
x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
y = [3.5703 3.5643 3.5583 3.5523 3.5463 3.5403 3.5347 3.5287 3.5227 3.5170];
plot(x,y)
title ('Mass Flow Rate versus Temperature for Wira');
xlabel('Temperature');
ylabel('Mass Flow Rate');
grid
```

Matlab source code for Heat Quantity Rate graphs

Kancil

```
>> x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
>> y = [22725 21269 19818 18372 16930 15494 14063 12635 11213 9795];
>> plot(x,y)
>> title ('Heat Quantity versus Temperature for Kancil');
>> xlabel('Temperature');
>> ylabel('Heat Quantity');
>> grid
```

Wira

```
>> x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
>> y = [28715 26876 25042 23215 21393 19578 17770 15966 14168 12377];
>> plot(x,y)
>> title ('Heat Quantity versus Temperature for Wira');
>> xlabel('Temperature');
>> ylabel('Heat Quantity');
>> grid
```

Matlab source code for Power Rate graphs

Kancil

```
>> x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
>> y = [26.3863 24.6957 23.0109 21.3319 19.6576 17.9903 16.3287 14.6706 13.0195 11.3731];
>> plot(x,y)
>> title ('Power versus Temperature for Kancil');
>> xlabel('Temperature');
>> ylabel('Power');
>> grid
```

Wira

```
>> x = [24 24.5 25 25.5 26 26.5 27 27.5 28 28.5];
>> y = [33.3413 31.2060 29.0765 26.9552 24.8396 22.7322 20.6329 18.5383 16.4506 14.3711];
>> plot(x,y)
>> title ('Power versus Temperature for Wira');
>> xlabel('Temperature');
>> ylabel('Power');
>> grid
```

APPENDIX 1-4: DM7404 - Hex Buffers with High Voltage Open-Collector Outputs

FAIRCHILD
SEMICONDUCTOR™

December 1986
Revised February 2000

DM7407
Hex Buffers with High Voltage Open-Collector Outputs

General Description

This device contains six independent gates each of which performs a buffer function. The open-collector outputs require external pull-up resistors for proper logical operation.

Pull-Up Resistor Equations

$$R_{MAX} = \frac{V_O\,(Min) - V_{OH}}{N_1\,(I_{OH}) + N_2\,(I_{IH})}$$

$$R_{MIN} = \frac{V_O\,(Max) - V_{OL}}{I_{OL} - N_3\,(I_{IL})}$$

Where: $N_1\,(I_{OH})$ = total maximum output high current for all outputs tied to pull-up resistor

$N_2\,(I_{IH})$ = total maximum input high current for all inputs tied to pull-up resistor

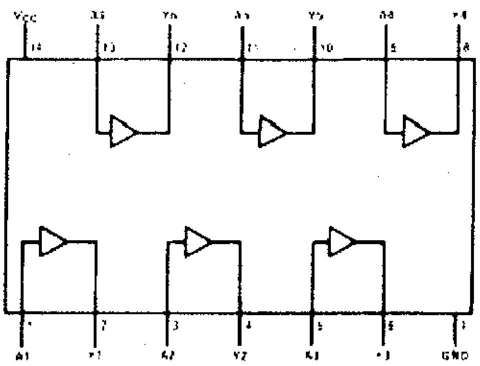
$N_3\,(I_{IL})$ = total maximum input low current for all inputs tied to pull-up resistor

Ordering Code:

Order Number	Package Number	Package Description
DM7407M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-012, 0.150 Narrow
DM7407N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter "X" to the ordering code.

Connection Diagram



Function Table

$Y = A$

Input	Output
A	Y
L	L
H	H

H = HIGH Logic Level
L = LOW Logic Level

 DS006497 www.fairchildsemi.com

Absolute Maximum Ratings (Note 1)

Supply Voltage	7V
Input Voltage	5.5V
Output Voltage	30V
Operating Free Air Temperature Range	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Note 1: The "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. The device should not be operated at these limits. The parametric values defined in the Electrical Characteristics tables are not guaranteed at the absolute maximum ratings. The "Recommended Operating Conditions" table will define the conditions for actual device operation.

Recommended Operating Conditions

Symbol	Parameter	Min	Nom	Max	Units
V_{CC}	Supply Voltage	4.75	5	5.25	V
V_{IH}	HIGH Level Input Voltage	2			V
V_{IL}	LOW Level Input Voltage			0.8	V
V_{OH}	HIGH Level Output Voltage			30	V
I_{OL}	LOW Level Output Current			40	mA
T_A	Free Air Operating Temperature	0		70	°C

Electrical Characteristics

over recommended operating free air temperature range (unless otherwise noted)

Symbol	Parameter	Conditions	Min	Typ (Note 2)	Max	Units
V_I	Input Clamp Voltage	V_{CC} = Min, I_I = −12 mA			−1.5	V
I_{CEX}	HIGH Level Output Current	V_{CC} = Min, V_O = 30V, V_{IH} = Min			250	µA
V_{OL}	LOW Level Output Voltage	V_{CC} = Min, I_{OL} = Max, V_{IL} = Max			0.7	V
		I_{OL} = 16 mA, V_{CC} = Min			0.4	
I_I	Input Current @ Max Input Voltage	V_{CC} = Max, V_I = 5.5V			1	mA
I_{IH}	HIGH Level Input Current	V_{CC} = Max, V_I = 2.4V			40	µA
I_{IL}	LOW Level Input Current	V_{CC} = Max, V_I = 0.4V			−1.6	mA
I_{CCH}	Supply Current with Outputs HIGH	V_{CC} = Max		29	41	mA
I_{CCL}	Supply Current with Outputs LOW	V_{CC} = Max		21	30	mA

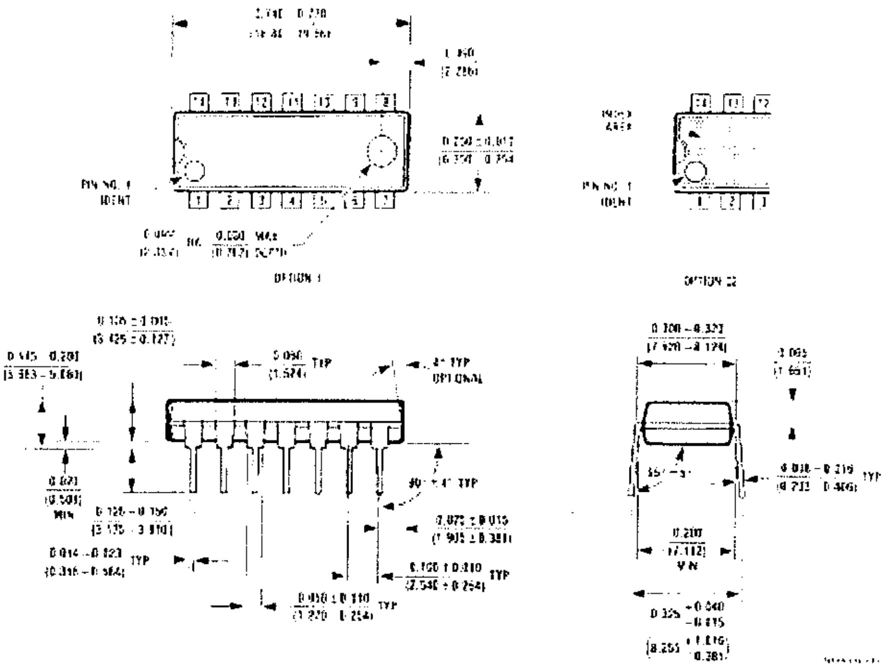
Note 2: All typicals are at V_{CC} = 5V, T_A = 25°C.

Switching Characteristics

at V_{CC} = 5V and T_A = 25°C

Symbol	Parameter	Conditions	Min	Max	Units
t_{PLH}	Propagation Delay Time LOW-to-HIGH Level Output	C_L = 15 pF, R_L = 110Ω		10	ns
t_{PHL}	Propagation Delay Time HIGH-to-LOW Level Output			30	ns

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



14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300 Wide
Package Number N14A

intersil

ICL7106, ICL7107, ICL7107S

Data Sheet October 25, 2004 FN3082.5

$3^1/_2$ Digit, LCD/LED Display, A/D Converters

The Intersil ICL7106 and ICL7107 are high performance, low power, $3^1/_2$ digit A/D converters. Included are seven segment decoders, display drivers, a reference, and a clock. The ICL7106 is designed to interface with a liquid crystal display (LCD) and includes a multiplexed backplane drive; the ICL7107 will directly drive an instrument size light emitting diode (LED) display.

The ICL7106 and ICL7107 bring together a combination of high accuracy, versatility, and true economy. It features auto-zero to less than 10μV, zero drift of less than 1μV/°C, input bias current of 10pA (Max), and rollover error of less than one count. True differential inputs and reference are useful in all systems, but give the designer an uncommon advantage when measuring load cells, strain gauges and other bridge type transducers. Finally, the true economy of single power supply operation (ICL7106), enables a high performance panel meter to be built with the addition of only 10 passive components and a display.

Ordering Information

PART NO.	TEMP. RANGE (°C)	PACKAGE	PKG. DWG. #
ICL7106CPL	0 to 70	40 Ld PDIP	E40.6
ICL7106CPLZ (Note 2)	0 to 70	40 Ld PDIP (Pb-free) (Note 3)	E40.6
ICL7106CM44	0 to 70	44 Ld MQFP	Q44.10x10
ICL7107CPL	0 to 70	40 Ld PDIP	E40.6
ICL7107CPLZ (Note 2)	0 to 70	40 Ld PDIP (Pb-free) (Note 3)	E40.6
ICL7107RCPL	0 to 70	40 Ld PDIP (Note 1)	E40.6
ICL7107RCPLZ (Note 2)	0 to 70	40 Ld PDIP (Pb-free)(Notes 1, 3)	E40.6
ICL7107SCPL	0 to 70	40 Ld PDIP (Notes 1, 3)	E40.6
ICL7107SCPLZ (Note 2)	0 to 70	40 Ld PDIP (Pb-free) (Notes 1, 3)	E40.6
ICL7107CM44	0 to 70	44 Ld MQFP	Q44.10x10
ICL7107CM44T	0 to 70	44 Ld MQFP (Tape and Reel)	Q44.10x10

NOTES:

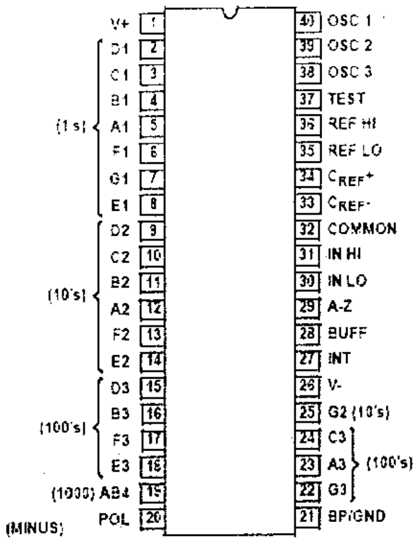
1. "R" indicates device with reversed leads for mounting to PC board underside. "S" indicates enhanced stability
2. Intersil Pb-free products employ special Pb-free material sets; molding compounds/die attach materials and 100% matte tin plate termination finish, which are RoHS compliant and compatible 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-020C.
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.

Features

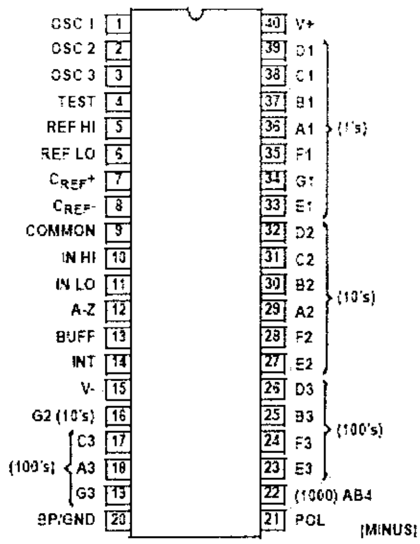
- Guaranteed Zero Reading for 0V Input on All Scales
- True Polarity at Zero for Precise Null Detection
- 1pA Typical Input Current
- True Differential Input and Reference, Direct Display Drive - LCD ICL7106, LED ICL7107
- Low Noise - Less Than $15\mu V_{P-P}$
- On Chip Clock and Reference
- Low Power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

Pinouts

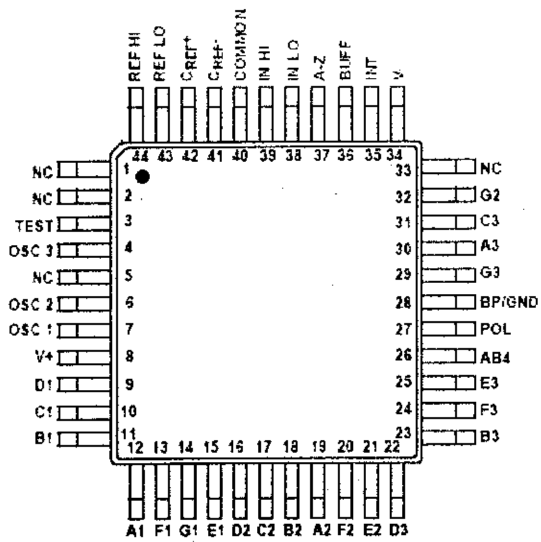
ICL7106, ICL7107 (PDIP)
TOP VIEW



ICL7107R (PDIP)
TOP VIEW



ICL7106, ICL7107 (MQFP)
TOP VIEW



Absolute Maximum Ratings

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

Analog Input Voltage (Either Input) (Note 1) . . . . V+ to V-
Reference Input Voltage (Either Input) . . . . V+ to V-
Clock Input
- ICL7106 . . . . TEST to V-
- ICL7107 . . . . GND to V-

Operating Conditions

Temperature Range . . . . 0°C to 70°C

Thermal Information

Thermal Resistance (Typical, Note 2) . . . . θ_{JA} (°C/W)
- PDIP Package 50
- MQFP Package 75

Maximum Junction Temperature . . . . 150°C
Maximum Storage Temperature Range . . . . -65°C to 150°C
Maximum Lead Temperature (Soldering 10s) . . . . 300°C
(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.

CAUTION: 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 device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTES:

1. Input voltages may exceed the supply voltages provided the input current is limited to ±100μA.
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.

Electrical 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°C To 70°C (Note 5)	-	0.2	1	μV/°C
Scale Factor Temperature Coefficient	V_{IN} = 199mV, 0°C To 70°C, (Ext. Ref. 0ppm/x°C) (Note 5)	-	1	5	ppm/°C
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)	-	30	-	ppm/°C
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

APPENDIX 1-6: KTC 9013 – NPN Transistor

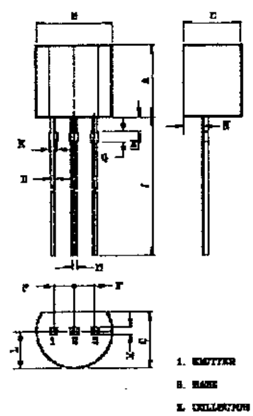
KEC

SEMICONDUCTOR
TECHNICAL DATA

KTC9013
EPITAXIAL PLANAR NPN TRANSISTOR

GENERAL PURPOSE APPLICATION.
SWITCHING APPLICATION.

FEATURES
- Excellent h_{FE} Linearity.
- Complementary to KTC9012



DIM	MILLIMETERS
A	4.70 MAX
B	4.80 MAX
C	3.70 MAX
D	0.45
E	1.00
F	1.27
G	0.85
H	0.45
J	14.00±0.50
K	0.55 MAX
L	2.30
M	0.45 MAX
N	1.00

TO–92

MAXIMUM RATINGS (Ta=25℃)

CHARACTERISTIC	SYMBOL	RATING	UNIT
Collector-Base Voltage	V_{CBO}	40	V
Collector-Emitter Voltage	V_{CEO}	30	V
Emitter-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	500	mA
Emitter Current	I_E	-500	mA
Collector Power Dissipation	P_C	625	mW
Junction Temperature	T_j	150	℃
Storage Temperature Range	T_{stg}	-55 ~ 150	℃

ELECTRICAL CHARACTERISTICS (Ta=25℃)

CHARACTERISTIC	SYMBOL	TEST CONDITION	MIN.	TYP.	MAX.	UNIT
Collector Cut-off Current	I_{CBO}	V_{CB}=35V, I_E=0	-		0.1	μA
Emitter Cut-off Current	I_{EBO}	V_{EB}=5V, I_C=0	-	-	0.1	μA
DC Current Gain	h_{FE}(Note)	V_{CE}=1V, I_C=50mA	64	-	246	
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_C=100mA, I_B=10mA	-	0.1	0.25	V
Base-Emitter Voltage	V_{BE}	I_C=100mA, V_{CE}=1V	-	0.8	1.0	V
Transition Frequency	f_T	V_{CE}=6V, I_C=20mA, f=100MHz	140			MHz
Collector Output Capacitance	C_{ob}	V_{CB}=6V, I_E=0, f=1MHz		7.0		pF

Note : h_{FE} Classification D:64 ~ 91, E:78 ~ 112, F:96 ~ 135, G:118 ~ 166, H:144 ~ 202, I:176 ~ 246

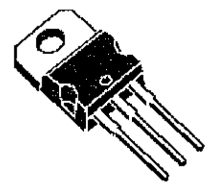
L7900AC SERIES

2% NEGATIVE VOLTAGE REGULATORS

- OUTPUT CURRENT TO 1.5A
- OUTPUT VOLTAGES OF -5; -5.2; -6; -8; -12; -15; -18; -20; -22; -24V
- THERMAL OVERLOAD PROTECTION
- SHORT CIRCUIT PROTECTION
- OUTPUT TRANSITION SOA PROTECTION

DESCRIPTION

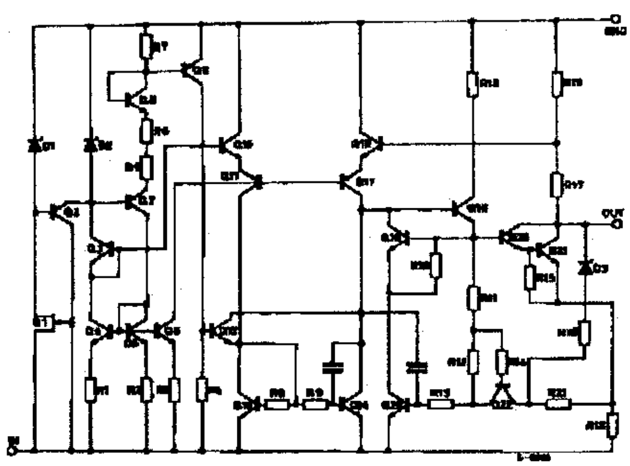
The L7900AC series of three-terminal negative regulators is available in TO-220 and D^2PAK packages and several fixed output voltages. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation; furthermore, having the same voltage option as the L7800A positive standard series, they are particularly suited for split power supplies. In addition, the -5.2V is also available for ECL system. If adequate heat sinking is provided, they can deliver over 1.5A output current.
Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



TO-220

D^2PAK

SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

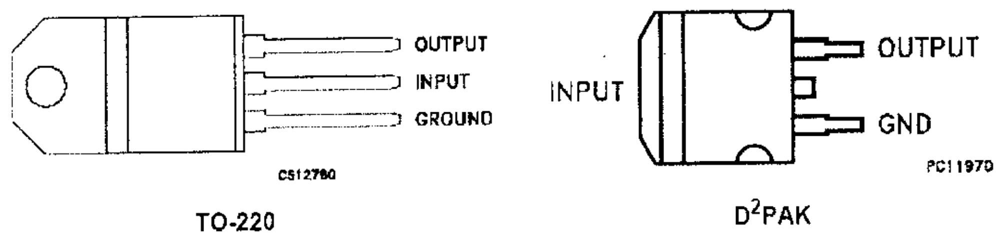
Symbol	Parameter[2]		Value	Unit
V_I	DC Input Voltage	for V_O = -5 to -18V	-35	V
		for V_O = -20, -24V	-40	
I_O	Output Current		Internally Limited	
P_{tot}	Power Dissipation		Internally Limited	
T_{stg}	Storage Temperature Range		-65 to 150	°C
T_{op}	Operating Junction Temperature Range		0 to 125	°C

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.

THERMAL DATA

Symbol	Parameter		D^2PAK	TO-220	Unit
$R_{thj\text{-}case}$	Thermal Resistance Junction-case	Max	3	3	°C/W
$R_{thj\text{-}amb}$	Thermal Resistance Junction-ambient	Max	62.5	50	°C/W

CONNECTION DIAGRAM (top view)



ORDERING CODES

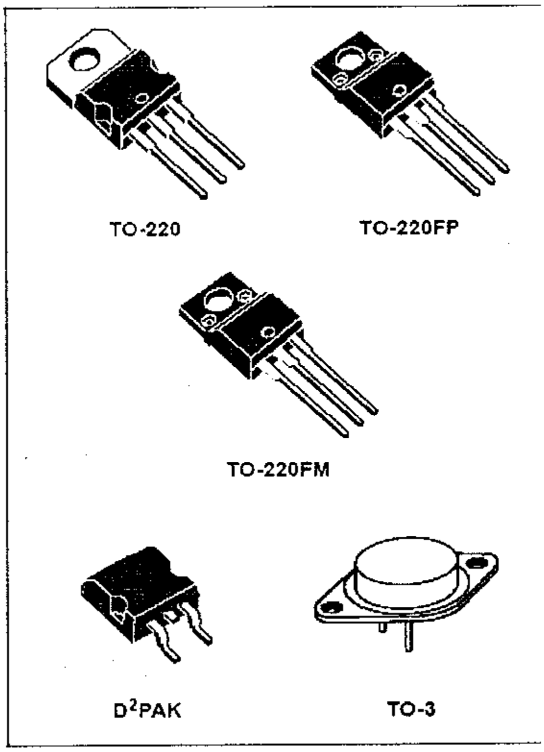
TYPE	TO-220	D^2PAK (*)	OUTPUT VOLTAGE
L7905AC	L7905ACV	L7905ACD2T	-5 V
L7952AC	L7952ACV	L7952ACD2T	-5.2 V
L7906AC	L7906ACV	L7906ACD2T	-6 V
L7908AC	L7908ACV	L7908ACD2T	-8 V
L7912AC	L7912ACV	L7912ACD2T	-12 V
L7915AC	L7915ACV	L7915ACD2T	-15 V
L7918AC	L7918ACV	L7918ACD2T	-18 V
L7920AC	L7920ACV	L7920ACD2T	-20 V
L7922AC	L7922ACV	L7922ACD2T	-22 V
L7924AC	L7924ACV	L7924ACD2T	-24 V

(*) Available in Tape & Reel with the suffix "-TR".

L7800 SERIES

POSITIVE VOLTAGE REGULATORS

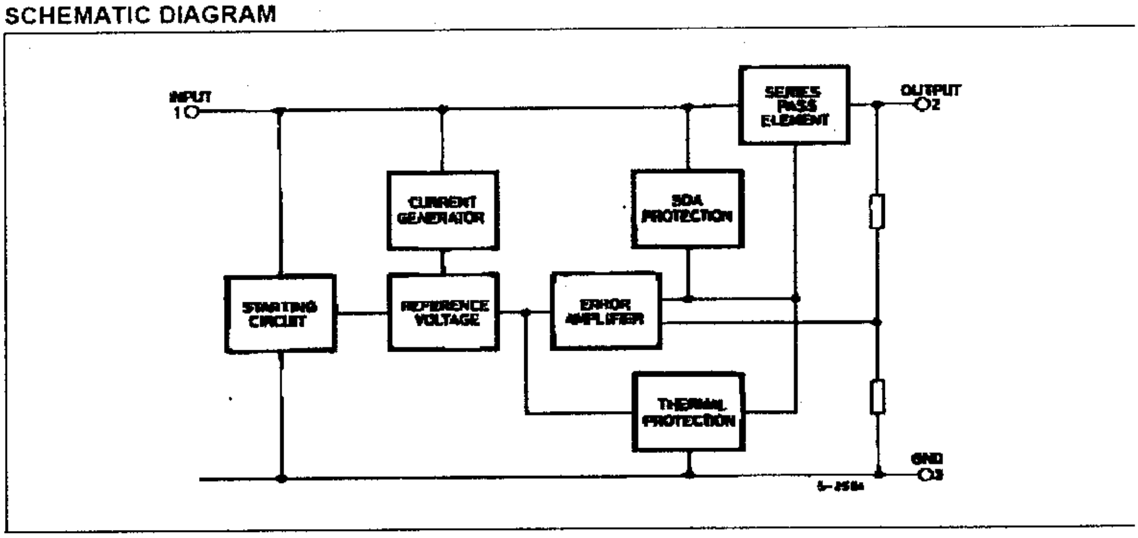
- OUTPUT CURRENT TO 1.5A
- OUTPUT VOLTAGES OF 5; 5.2; 6; 8; 8.5; 9; 12; 15; 18; 24V
- THERMAL OVERLOAD PROTECTION
- SHORT CIRCUIT PROTECTION
- OUTPUT TRANSITION SOA PROTECTION



DESCRIPTION

The L7800 series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-220FM, TO-3 and D^2PAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.

SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

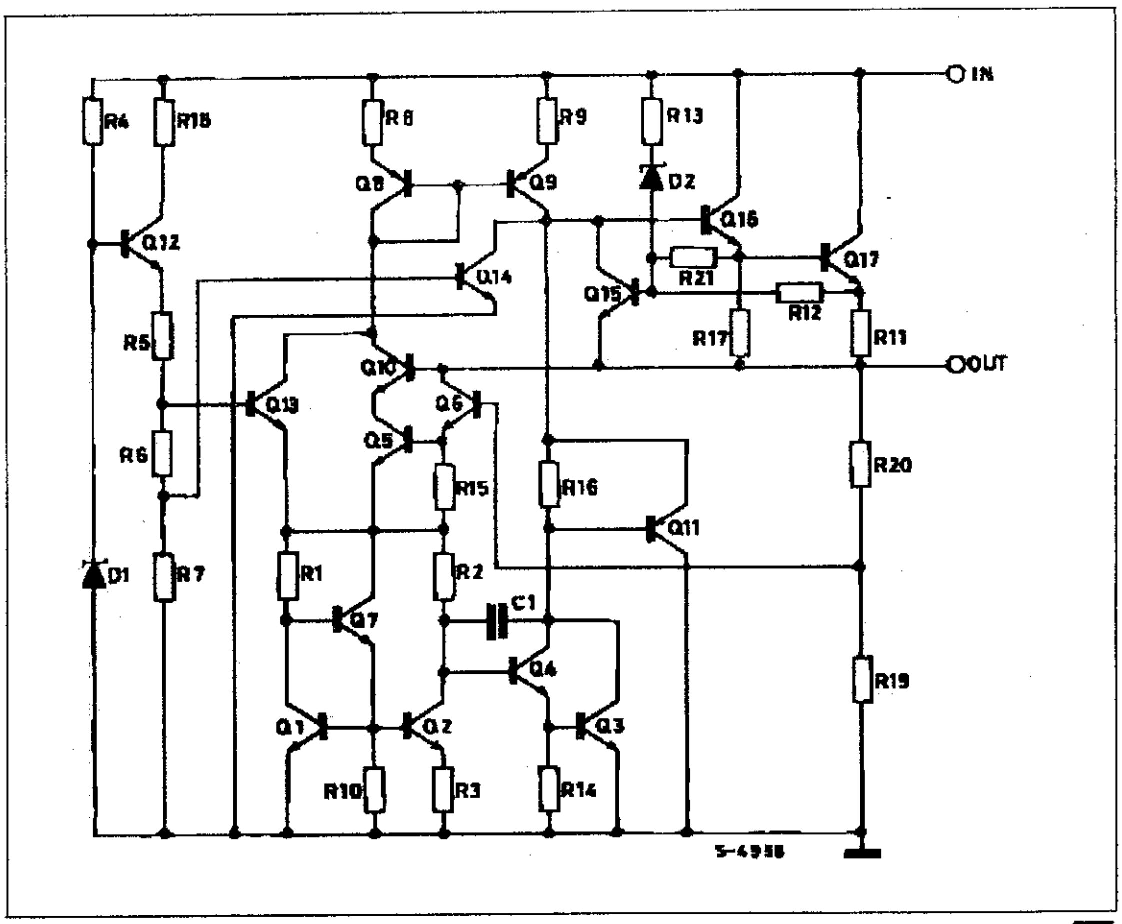
Symbol	Parameter[2]		Value	Unit
V_I	DC Input Voltage	for V_O= 5 to 18V	35	V
		for V_O= 20, 24V	40	
I_O	Output Current		Internally Limited	
P_{tot}	Power Dissipation		Internally Limited	
T_{stg}	Storage Temperature Range		-65 to 150	°C
T_{op}	Operating Junction Temperature Range	for L7800	-55 to 150	°C
		for L7800C	0 to 150	

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.

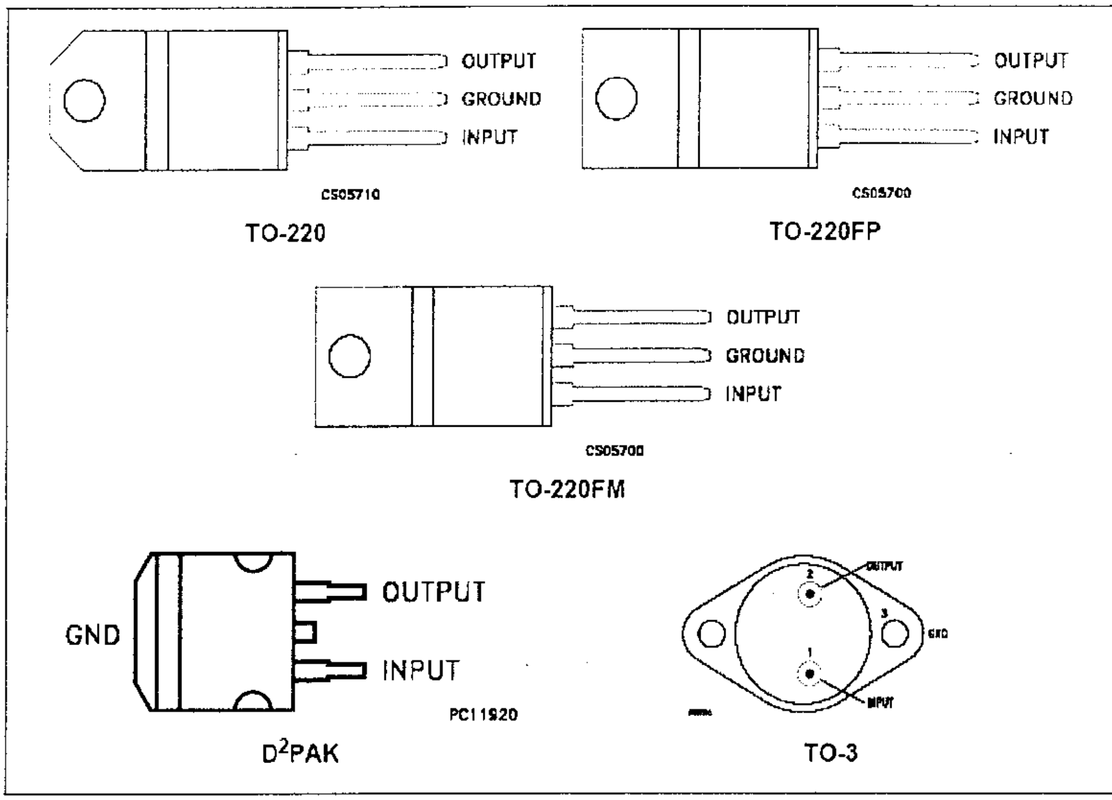
THERMAL DATA

Symbol	Parameter	D^2PAK	TO-220	TO-220FP	TO-220FM	TO-3	Unit
$R_{thj-case}$	Thermal Resistance Junction-case Max	3	5	5	5	4	°C/W
$R_{thj-amb}$	Thermal Resistance Junction-ambient Max	62.5	50	60	60	35	°C/W

SCHEMATIC DIAGRAM



CONNECTION DIAGRAM (top view)



ORDERING CODES

TYPE	TO-220	D²PAK (*)	TO-220FP	TO-220FM	TO-3	OUTPUT VOLTAGE
L7805					L7805T	5 V
L7805C	L7805CV	L7805CD2T	L7805CP	L7805CF	L7805CT	5 V
L7852C	L7852CV	L7852CD2T	L7852CP	L7852CF	L7852CT	5.2 V
L7806					L7806T	6 V
L7806C	L7806CV	L7806CD2T	L7806CP	L7806CF	L7806CT	6 V
L7808					L7808T	8 V
L7808C	L7808CV	L7808CD2T	L7808CP	L7808CF	L7808CT	8 V
L7885C	L7885CV	L7885CD2T	L7885CP	L7885CF	L7885CT	8.5 V
L7809C	L7809CV	L7809CD2T	L7809CP	L7809CF	L7809CT	9 V
L7812					L7812T	12 V
L7812C	L7812CV	L7812CD2T	L7812CP	L7812CF	L7812CT	12 V
L7815					L7815T	15 V
L7815C	L7815CV	L7815CD2T	L7815CP	L7815CF	L7815CT	15 V
L7818					L7818T	18 V
L7818C	L7818CV	L7818CD2T	L7818CP	L7818CF	L7818CT	18 V
L7820					L7820T	20 V
L7820C	L7820CV	L7820CD2T	L7820CP	L7820CF	L7820CT	20 V
L7824					L7824T	24 V
L7824C	L7824CV	L7824CD2T	L7824CP	L7824CF	L7824CT	24 V

(*) Available in Tape & Reel with the suffix "-TR".

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.

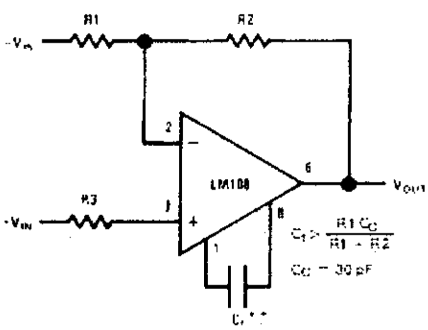
The LM108 is guaranteed from −55°C to +125°C, the LM208 from −25°C to +85°C, and the LM308 from 0°C to +70°C.

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

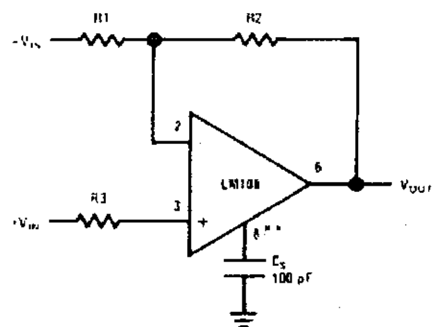
Standard Compensation Circuit



TL/H/7758-1

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

Alternate* Frequency Compensation

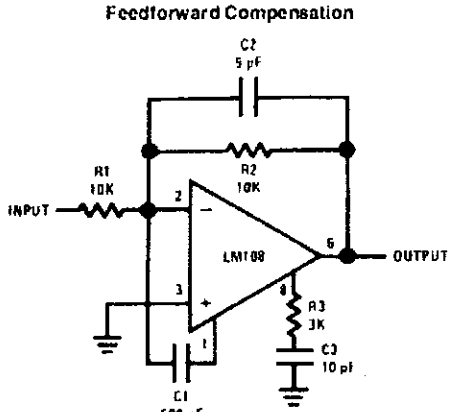


TL/H/7758-2

*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/7758-3

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

National Semiconductor

December 1994

LM108/LM208/LM308 Operational Amplifiers

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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.

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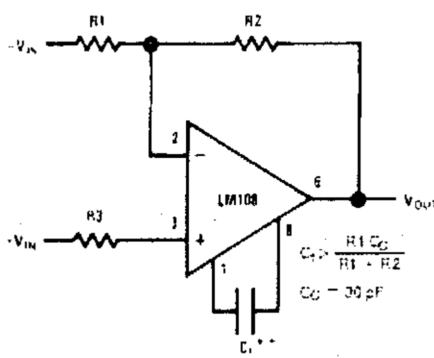
Compensation Circuits

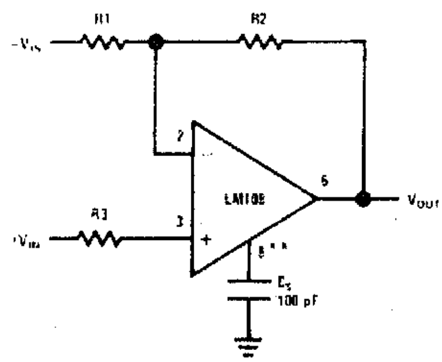
Standard Compensation Circuit



TL/H/7758–1

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

Alternate* Frequency Compensation

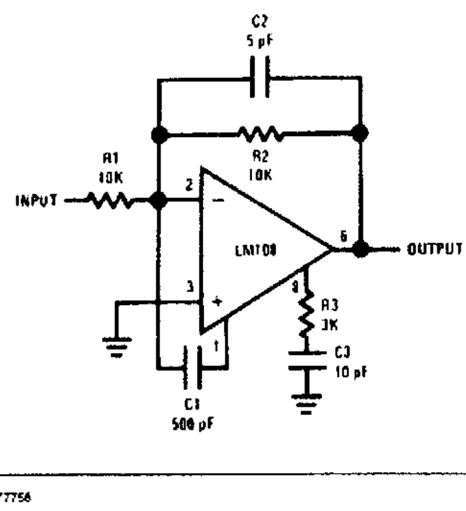


TL/H/7758–2

*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/7758–3

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

National Semiconductor

December 1994

LM108/LM208/LM308 Operational Amplifiers

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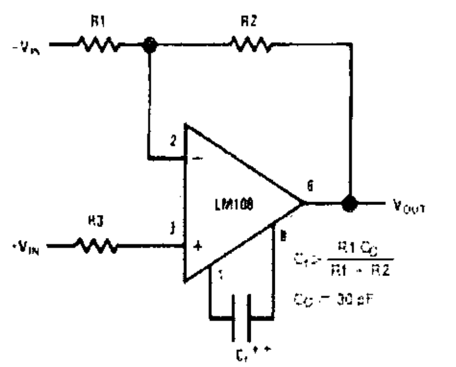
Compensation Circuits

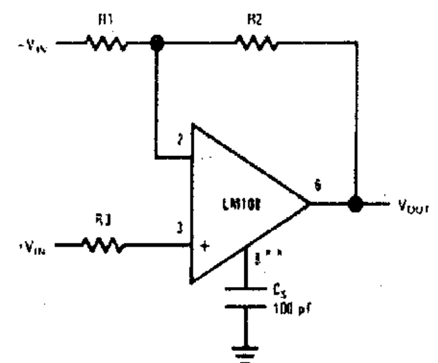
Standard Compensation Circuit



TL/H/7758-1

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

Alternate* Frequency Compensation

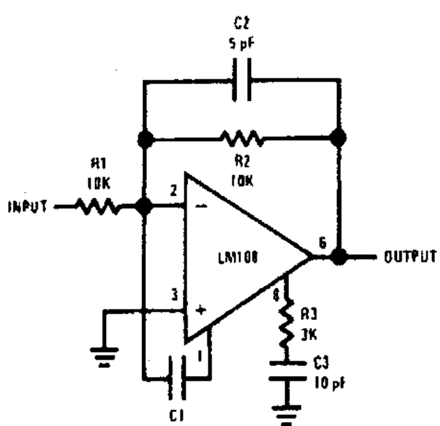


TL/H/7758-2

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

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

Feedforward Compensation

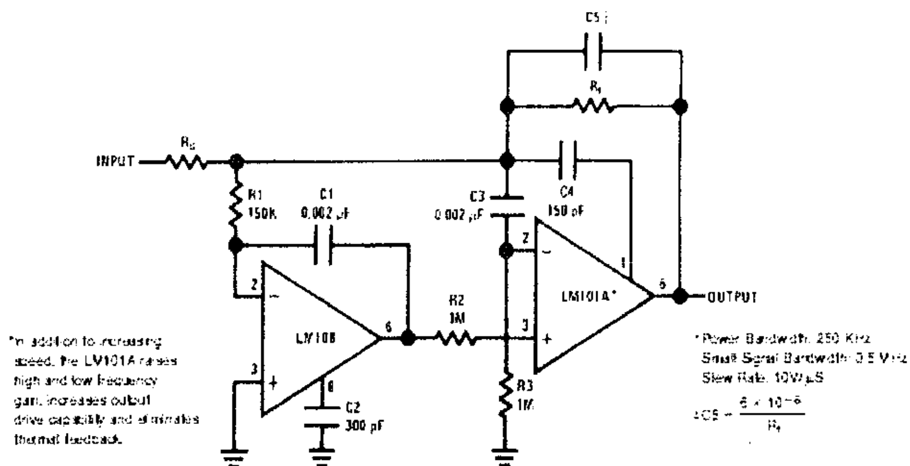


TL/H/7758-3

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

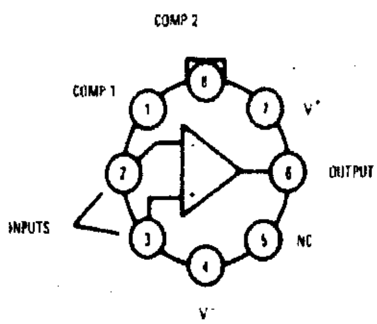
Typical Applications (Continued)

Fast Summing Amplifier



Connection Diagrams

Metal Can Package

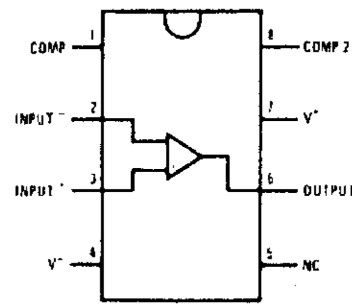


*Package is connected to Pin 4 (V⁻)

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

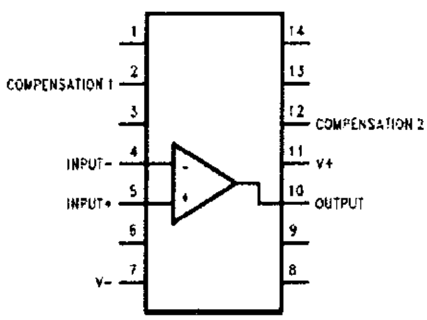
Order Number LM108H, LM108H/883, LM308AH or LM308H
See NS Package Number H08C

Dual-In-Line Package



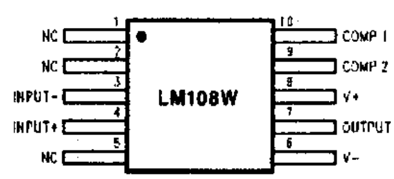
Top View

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



Top View

Order Number LM108J/883
See NS Package Number J14A



Order Number LM108W/883
See NS Package Number W10A

*Also available per JM38510/10104

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.

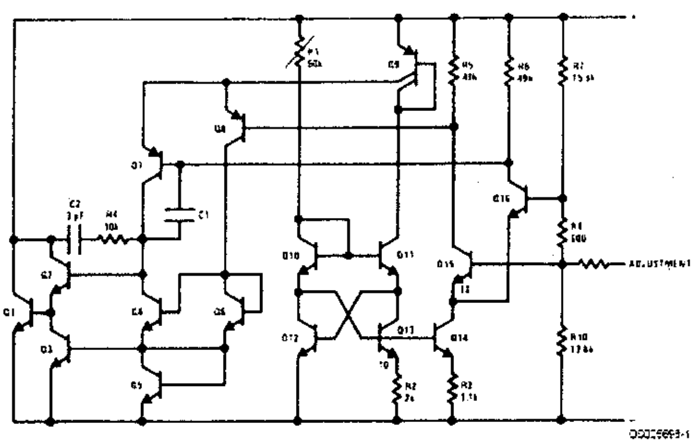
Applications for the LM135 include almost any type of temperature sensing over a −55°C to +150°C temperature range. The low impedance and linear output make interfacing to readout or control circuitry especially easy.

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

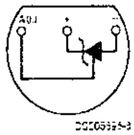
- Directly calibrated in °Kelvin
- 1°C initial accuracy available
- Operates from 400 µA to 5 mA
- Less than 1Ω dynamic impedance
- Easily calibrated
- Wide operating temperature range
- 200°C overrange
- Low cost

Schematic Diagram



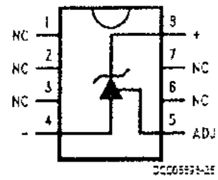
Connection Diagrams

TO-92
Plastic Package



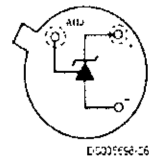
Bottom View
Order Number LM335Z
or LM335AZ
**See NS Package
Number Z03A**

**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

FAIRCHILD
SEMICONDUCTOR®

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LM2904,LM358/LM358A,LM258/ LM258A

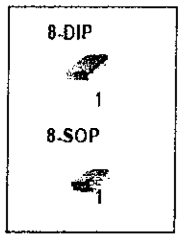
Dual Operational Amplifier

Features

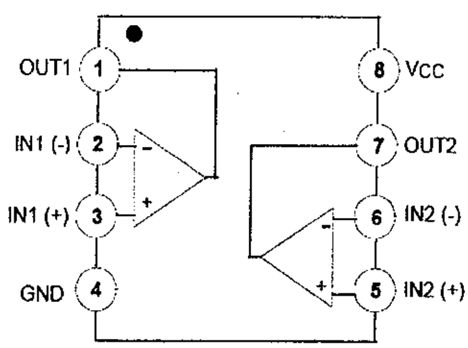
- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM258/LM258A, LM358/LM358A: 3V~32V (or ±1.5V ~ 16V)
  LM2904 : 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation.

Description

The LM2904,LM358/LM358A, LM258/LM258A consist 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 voltage. 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 amplifier, DC gain blocks and all the conventional OP-AMP circuits which now can be easily implemented in single power supply systems.



Internal Block Diagram



Rev. 1.0.2