VEHICLE COMPARTMENTS ENVIRONMENTAL CONTROL SYSTEM USING SOLAR POWERED THERMOELECTRICS

By

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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)

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

December 2005

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.

Mohamad Faizul B. Mohamad Aziz

ABSTRACT

The report was written to briefly introduce the Final Year Project entitled 'Vehicle Compartments Environmental Control System using solar Powered Thermoelectric'. The project will cover the research on thermoelectric and followed by a fully functioning prototype of a thermoelectric temperature regulator with test data. This project embarks on studying the feasibility of using thermoelectric to regulate the temperature inside the vehicle compartments.

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LIST OF ABBREVIATIONS

Symbol	Meaning	Units
A	Area	m^2 or ft^2
a.m.	Ante Meridiem	
ADC	Analog to Digital	
CLTD	Cooling Load Temperature Difference	K
DC	Direct Current	V
DSA	Double-strength Sheet Glass	
EI	Enable Input	
EO	Enable Output	
EWB	Engineering Work Bench	
ft	feet	ft
GLF	Glass Load Factor	K
GS	Gate Source	
hr	hour	hr
I max	Maximum Current	Ampere (A)
K	Kelvin	K
kW	kilowatt	kW
mW	miliwatt	mW
P	Power	W
P/N	Positive/Negative	
PV	Photovoltaic	
p.m.	Postmortem	
Q	Cooling Load	W
Q_c	Cooling effect	
Q_h	Heating effect	
SHGF	Solar Heat Gain Factor	
SC	Shading Coefficient	
TE	Thermoelectric	
U	Heat Transfer Coefficient	W/m^2K
U max	Maximum Heat Transfer Coefficient	
V	Volts	V

V_{in}	Voltage Input	V
V_{max}	Maximum voltage	V
W	Watt	W or Btu/hr
"	Inch	"
Ω	Ohm	Ω
°C	degree Celsius	°C

CHAPTER 1
INTRODUCTION

Associated with the Electrical and Electronic Engineering technological development, the world is now moving towards nanotechnology applications. Such an application can change the world by benefiting people and improving their life style. This leads to the research of thermoelectric that can be used to control temperature inside vehicle compartments, where the thermoelectric will be solar powered. Thermoelectric coolers are used to manage temperature, but they are not easily integrated with semiconductor devices. This project innovation was to see that thermoelectric could theoretically be used for cooling, at room temperature and below.

1.1 Background Study

This project will concentrate in semiconductors, thermoelectric, thermodynamics, solar energy, temperature cooling, and environmental factor study. Through the whole project, knowledge on those related topic would be applied.

1.2 Problem Statement

In equatorial countries, car owners have to live with overheated compartments if they parked their cars under the sun. The problem with overheating is that it can damage several equipments in a vehicle. This leads to waste of money and high cost maintenance of the vehicle itself. Moreover, by afternoon, the temperature in these countries reaches a very high temperature, which leads to uncomfortable situation and affects human emotions. Human factor is also considered, as a part of valuable information for the project as time and comfort is important.

1.3 Objectives and Scope of Study/Work

1.3.1 Objectives

The objectives of this project are:

1. To do research about thermoelectric cooling system, and solar energy
2. To conduct experiments and collecting data using thermoelectric modules, and methods that involves thermal cooling.
3. To construct a fully functioning prototype of a thermoelectric temperature regulator.

1.3.2 Scope of Study/Work

This study consists of research, designing and constructing a prototype powered by solar in order to achieve the objectives. The vehicle compartment involved during the experiments is the cabin car. By the way, this study will also include the evaluation of the experiment and selected circuit design for thermoelectric connected with solar panel. The evaluation will be concentrated on the energy used, power consumption of the prototype, cost effective and efficiency of the prototype for cooling. The limitations of conducting this project are cost, time and equipments. The prototype will be constructed using the fund provided by Universiti Teknologi PETRONAS.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

THERMOELECTRIC

Early 19th century scientists, Thomas Seebeck and Jean Peltier, first discovered the phenomena that are the basis for today's thermoelectric industry. Seebeck found that electrical current would flow when there is a temperature gradient across the junctions of two dissimilar conductors. Peltier, on the other hand, learned that passing current through two dissimilar electrical conductors, caused heat to be either emitted or absorbed at the junction of the materials. It was only after mid-20th Century advancements in semiconductor technology, however, that practical applications for thermoelectric devices became feasible. With modern techniques, there exist production of thermoelectric 'modules' that deliver efficient solid state heat-pumping for both cooling and heating; many of these units can also be used to generate DC power in special circumstances (e.g., conversion of waste heat). New and often elegant uses for thermoelectric continue to be developed each day.

A typical thermoelectric module consists of an array of Bismuth Telluride semiconductor pellets that have been 'doped' so that one type of charge carrier - either positive or negative - carries the majority of current. The pairs of P/N pellets are configured so that they are connected electrically in series, but thermally in parallel. Metalized ceramic substrates provide the platform for the pellets and the small conductive tabs that connect them. The pellets, tabs and substrates thus form a layered configuration. Module size varies from less than 0.25" by 0.25" to approximately 2.0" by 2.0". Thermoelectric modules can function singularly or in groups with series, parallel, or series/parallel electrical connections. Some applications use stacked multi-stage modules. When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surface and release it to the substrate at the opposite side. The surface where heat energy is absorbed becomes cold; the opposite surface where heat energy was released becomes hot. Using this simple approach to 'heat pumping', thermoelectric technology is applied to many widely varied applications - small laser diode coolers, portable refrigerators, scientific thermal conditioning, liquid coolers, and beyond. Power Generation: Employing the effect that Seebeck observed, thermoelectric power generators convert heat energy to electricity. When a temperature gradient is created across the thermoelectric device, a DC voltage develops across the terminals. When a load is properly connected, electrical current flows. Typical applications for this technology include providing power for remote telecommunication, navigation, and petroleum installations.

The flow of heat with the charge carriers in a thermoelectric device is very similar to the way that compressed refrigerant transfer's heat in a mechanical system. The circulating fluids in the compressor system carry heat from the thermal load to the evaporator where the heat can be dissipated. With TE technology, on the other hand, the circulating direct current carries heat from the thermal load to some type of heat sink that can effectively discharge the heat into the outside environment. Each individual thermoelectric system design will have a unique capacity for pumping heat (in Watts or BTU/hour) and this will be influenced by many factors. The most important variables are ambient temperature, physical & electrical characteristics of the thermoelectric module employed, and efficiency of the heat dissipation system. Typical thermoelectric applications will pump heat loads ranging from several miliwatts to hundreds of watts.

Thermoelectric (Peltier) cooling

In 1834, Peltier[1] described thermal effects at the junctions of dissimilar conductors when an electrical current flows between the materials. Peltier failed however to understand the full implications of his findings and it wasn't until four years later that Lenz[2] concluded that there is heat adsorption or generation at the junctions depending on the direction of current flow.

Thermo-electric cooling, known about since the 1830s, occurs when a current is passed across the junction of two dissimilar metals. *One side of the device becomes hot and the other cold. Although single thermo-electric devices have low cooling capacities they may be connected together electrically to produce more cooling. Because they do not have a circulating fluid heat transfer is more difficult than for vapor compression systems* [3]. For large cooling duties additional heat transfer systems, possibly based on heat pipes would be required. When voltage V_{in} is applied to terminals T1 & T2 an electrical current (I) will flow in the circuit.

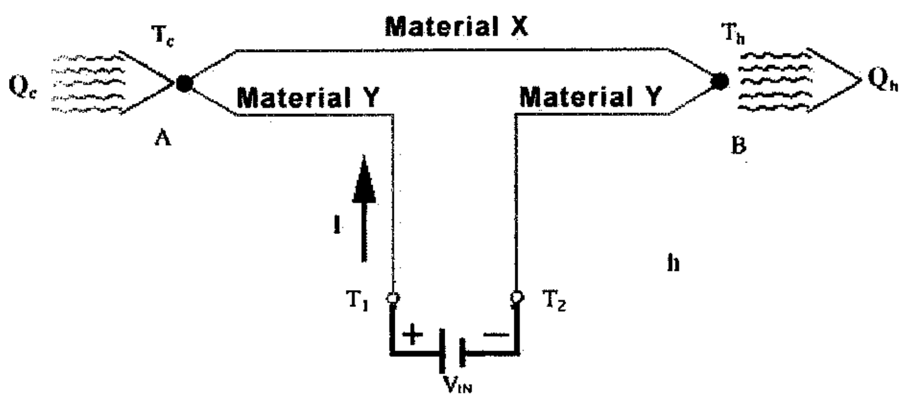


Figure 1: The electric current flow with the thermal change from hot to cold.

As a result of the current flow, a slightly cooling effect (Qc) will occur at point (A) and a heating effect will be experienced at point (B) where it is expelled.

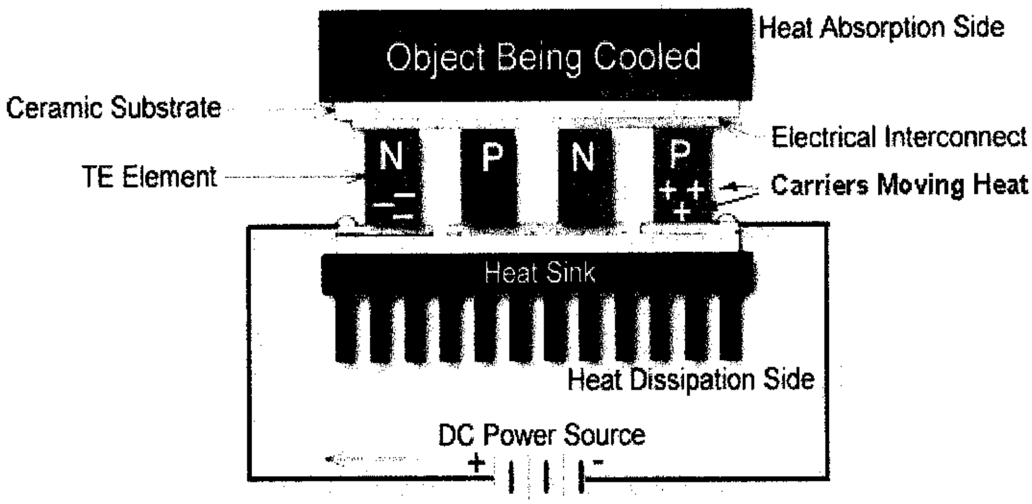


Figure 2: A typical design of a thermoelectric cooler from Ferrotec Corporation

SOLAR ENERGY – The Renewable Energy Source

<u>Principle of operation</u>

Solar panels work on the principle of the photovoltaic effect. The photovoltaic effect is the conversion of sunlight into electricity. This occurs when the PV cell is struck by photons (sunlight), 'freeing' silicon electrons to travel from the PV cell, through electronic circuitry, to a load (Figure 3). Then they return to the PV cell, where the silicon recaptures the electron and the process is repeated.

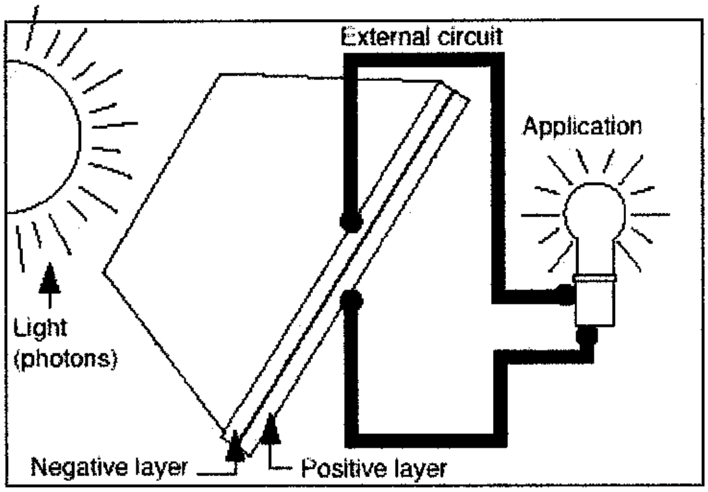


Figure 3: Principle of operation

Simple photovoltaic system

A PV system may have a minimum of two components, the module and the load to be powered. An example of such a system would be a simple ventilation fan driven directly by a module during hot and sunny weather. For twenty-four hour a day operation a battery and blocking diode are required, a voltage regulator is also recommended in order to protect the battery from the effects of overcharge. The solar regulator includes a blocking diode and therefore a blocking diode should only be incorporated in a system when the solar regulator is not being used.

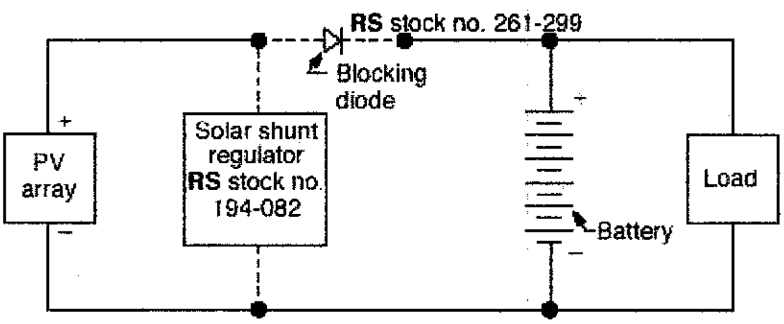


Figure 4: A simple photovoltaic system

CHAPTER 3
METHODOLOGY/PROJECT WORK

3.1 Procedures

3.1.1 Experiments and data gathering

After understanding the concept of thermoelectric and thermal cooling, several experiments will be conducted. The experiments will involve using thermoelectric modules, where the author has to collect temperature data and energy conversion of heat and electric. Then, data from the experiments will be evaluated in order to meet the objective of this project. The author will be focusing on the temperature controller circuit.

3.1.2 Construct a prototype

The prototype will be constructed after a circuit simulation for thermoelectric and solar panel had been done using PSpice and Electronic Work Bench (EWB). The temperature regulator will be built based on the data gathered during the experiments. This method will be the finish line of this project.

3.2 Tools required

1. Thermoelectric (Peltier) modules.
2. Solar energy panel and thermometer.
3. Software such as PSpice, EWB, 3Dmax
4. All the electrical component used in the design such as capacitors, inductors and others

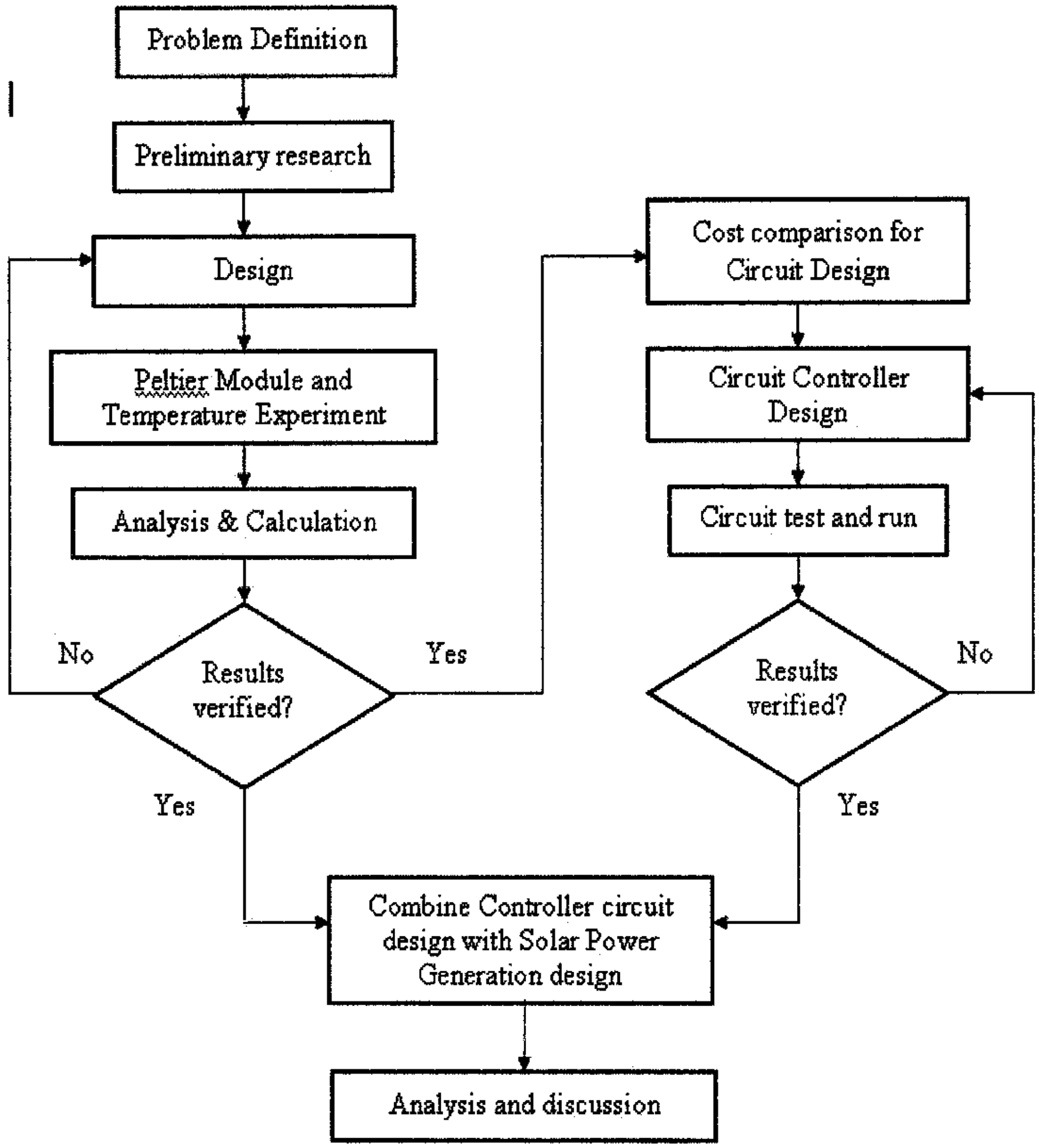


Figure5: Flow chart of methodology for the project

CHAPTER 4
RESULTS

4.1 Experiment Results

Temperature readings have been observed and recorded. The objectives of this experiment were to observe the normal temperature readings inside a car during hot conditions, especially in the afternoon.

TEMPERATURE MEASUREMENTS INSIDE A CAR AT PARKING SITE IN UTP

(DegreeCelsius)

Date/Time	10 A.M	11 A.M	12 P.M	1 P.M	2 P.M	Average
14-Mar-05	42	42	64	56	45	49.8
15-Mar-05	40	41	59	59	58	51.4
16-Mar-05	41	41	62	57	53	50.8
17-Mar-05	42	42	58	55	45	48.4
18-Mar-05			56	57	61	58

Table 1: Experiment results for temperature measurements inside a car

From the data above, it was concluded that the normal temperature inside a cabin car during afternoon, in Malaysia was more than 50°C. For the design temperature, the project must successfully cool the car till 30°C or below. To accomplish the target, several calculation designs must be done. The variables that was important were volume of cabin, heat transfer, power supplied by solar panels, and time.

From the table, the temperature within a car's cabin can reach above 60°C when parked under the sun, in a hot weather. These results show that the temperature regulator system to be designed must have the capacity to cool down temperature of this range to 30°C or below. Nevertheless, if the temperature regulator system is capable of detecting the rising of cabin temperature, and starts to regulate the temperature before it reaches 62°C, then the temperature difference of the thermoelectric module is reduced, hence decreasing its wattage requirement. To calculate the heat load for a typical car cabin, Proton Wira has been chosen as the case study, whereby all calculation would be based on the structure of the concern car. The heat load would define the cooling requirements. The possibility to minimize the heat load allows the cooler to achieve colder temperatures or reduces the power required to reach the defined cooling level. The heat load involved is a passive heat load, which is parasitic in nature and may consist of radiation, convection or conduction. The method used to calculate the heat load is acquired through the 2001 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook [4]. Some assumptions were made during calculation, when selecting the coefficients values to be used. As there are no specific procedures for calculating the heat load in a vehicle, coefficients used are mostly set for the worse circumstance.

The cooling loads caused by ***conduction*** *heat gains through the roof and doors are found from the following equation* [4]:

$$\mathbf{Q = U \times A \times CLTD}$$

Where

Q = cooling load for roof, or the doors (W)

U = overall heat transfer coefficient for roof or the doors (W/m^2K)

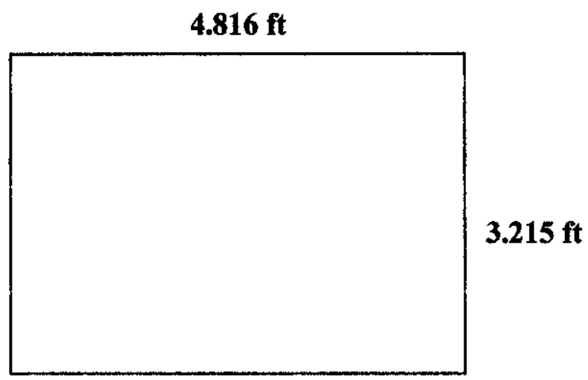
A = area of roof (m^2)

CLTD = corrected cooling load temperature difference (K)

The CLTD is not the actual temperature difference between the outdoor and indoor air, and a modified value that accounts for heat storage and exposure effect of the sun.

4.2 Design calculations

Roof load calculation



Cooling Load = (Heat Transfer Coefficient) x (Area) x (Cooling Load Temperature Difference)

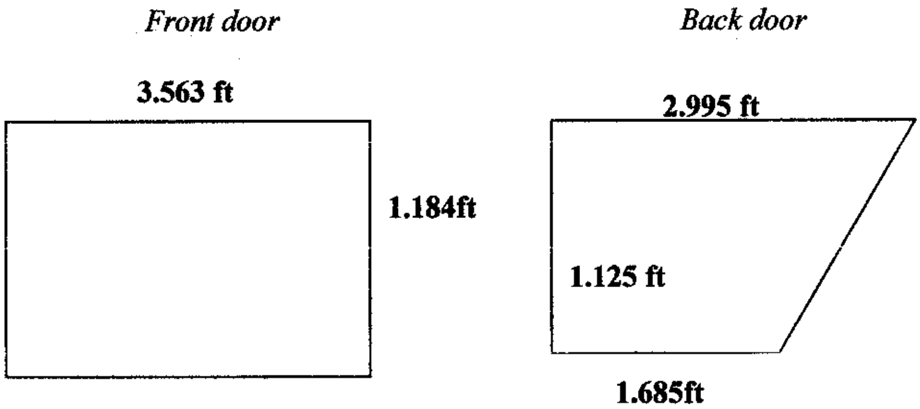
$Q_1 = U \times A \times CLTD$

$= (1.21)(15.483\ ft^2)(24.3)$

$= (1.21)(1.43992\ m^2)(24.3)$

$= 42.337\ W$

Door load calculation



Q_2 = U x A x CLTD x 2[for both sides]

= (1.21)(6.8521 ft^2)(11.3)(2)

= (1.21)(0.6373 m^2)(11.3)(2)

= *17.428 W*

Radiant energy from the sun passes through transparent materials such as glass can become a source of heat gain to the vehicle cabin. Its values vary with time, orientation, shading and storage effect. The **radiation** load can be found from the following equation:

$$Q = (GLF)\ A$$

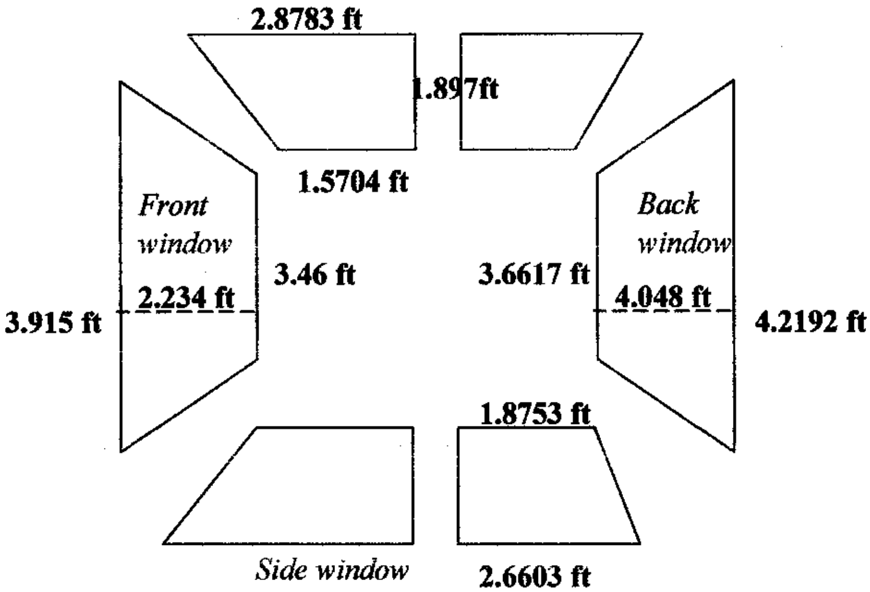
Where

Q = cooling load for glass and windows (W)

A = area of glass (m^2)

GLF = glass load factor, which include the effects of both solar transmission and radiation (K)

Glass load calculation



Referring to the ASHRAE handbook, taking the worse case scenario, in which the orientation of the car is facing west, the load calculation are as below;

Q_3 = (GLF)A

= (2.2968)(290.9) +(0.8257)(120.5) + (0.8257) (179.43)

= *915.79 W*

Also referring to the ASHRAE handbook, the load factor is assumed to be 1.38, which is the worse case scenario.

Total load = Total heat load x Load Factor

= (Q1 + Q2 + Q3) x (1.38)

= (42.337 W + 17.428 W + 915.79 W)(1.38) = **1209.69 W**

All values of **U**, **CLTD** and **GLF** were taken from the ASHRAE handbook as well as the Air Conditioning Principles and System by Edward G. Pita.

It has been determined that the Peltier module will start to trigger when the vehicle cabin's temperature is above 37°C. The Peltier module will regulate the temperature to be 37°C or below. With the highest temperature recorded being 64°C;

$\Delta T = (64\text{-}37)\ °C = 27°C$

$\Delta T = [1 - (\text{Heat Load/Max Cooling Power})] \times (\text{Max Temp Difference})$

$27°C = [1 - (1209.69W / \text{Max Cooling Power})] \times (68°C)$

Max. Cooling power = **2006.32 W**

Parameters

Highest temperature = 62 °C

Target Temperature to Cool Down = 30°C

Solar rating, (7.5 V, 135mA) - used for prototype

$P = IV = 1.0125W$

$\Delta T = 32°C$

Actual $\Delta T = (1 - \frac{(HeatEnergy)}{TEC\ Voltage})$ x $Max\,\Delta T$

Actual Current = $(\frac{12V}{peltier\ V\max})$ x Peltier I*max*

After receiving the Peltier modules, several tests had been conducted on the Peltier modules. The first test was to observe and recognize the side that will produce heat, while the other side will be cold. After the first test, the second test was conducted to determine the minimum and maximum voltage that the Peltier can withstand. It was found out that the Peltier starts to react at 1.0 volt. As the voltage increases, the heat on one side gets hotter, while the other side gets cooler. However, at 5.5 volts, both sides start to get warm and hot. As a result, the amount of voltage that it can receive to operate successfully was 5.5 volts. Nevertheless, the voltage consumption can be increased by using heat sink or small fan, so the Peltier can be used to cool a small space enough for the model. The Peltiers were also tested for parallel and serial connections.

Figure 6: Thermoelectric Cooler, Size 30x30x3.3mm (WxDxH), weight 16g

Specification

$I_{max} = 4.3A$,

$V_{max} = 14.6V$,

$Q_{max} (\Delta T = 0) =$ **36W**

$\Delta T_{max.} = 68°C$, R = 3.10 ohm, 127 couples

Test Results

Minimum Voltage – 1.0 volt

Maximum Voltage – 5.5 volt

4.3 Circuit Design

Binary	Temperature (degree C)	Voltage (V)	Condition
000	7.5	2.0	OFF
001	25	4.0	OFF
010	42.5	6.0	ON
011	60	8.0	ON
100	77.5	10.0	ON
101	95	12.0	ON
110	112.5	14.0	ON
111	130	16.0	ON

Table 2: Logic design for controller circuit including voltage value

AB/C	0	1
00	0	0
01	1	1
11	1	1
10	1	1

Logic Get Implementation = A + AB

Table 3: Karnaugh map for controller circuit

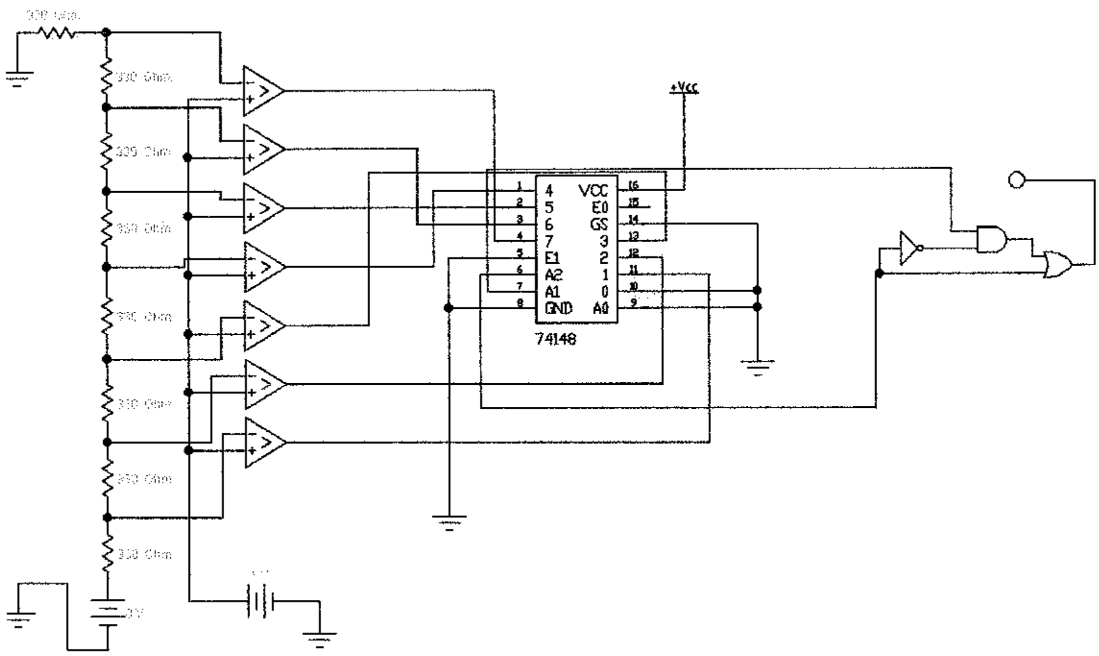


Figure 7: Finalized Circuit design for temperature controller

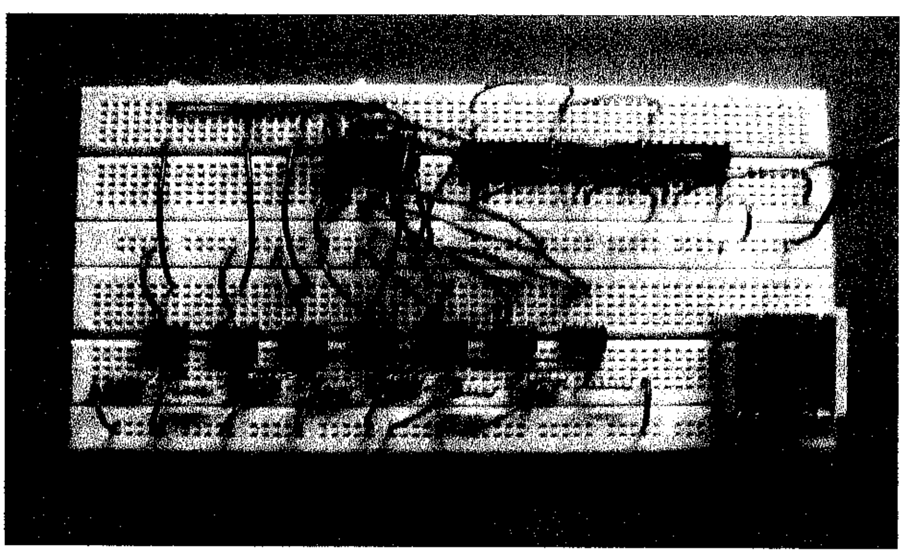


Figure 8: Circuit implemented on breadboard together with attached Peltier module and heat sink.

CHAPTER 5
DISCUSSION

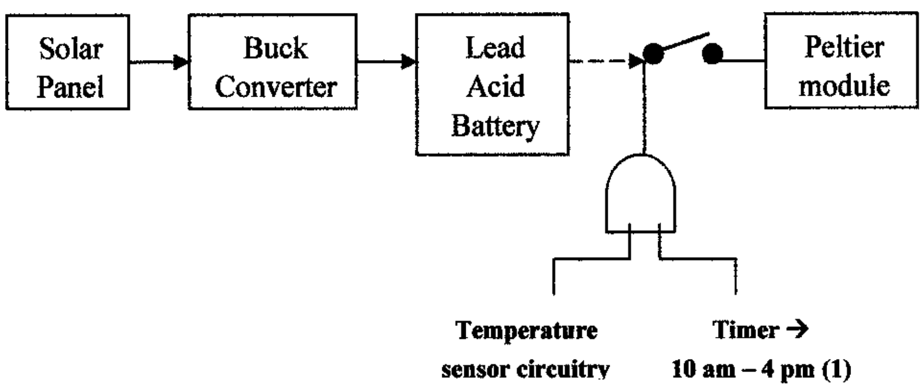


Figure 9: Simplified block diagrams of the overall temperature regulator system

An overview of the overall design is shown above. Figure 10 is a simplified block diagram, showing the operating principle of the car cabin temperature regulator system.

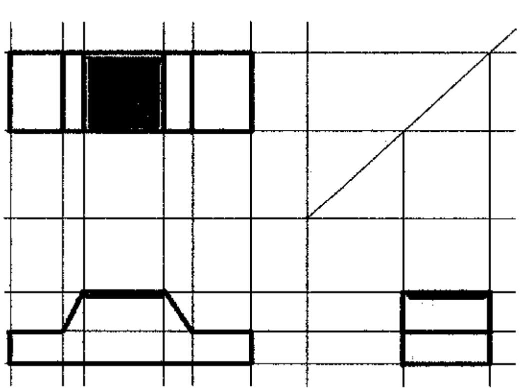


Figure 10: The red area shows the location of Peltier modules and solar panels for the selected design (Orthographic view)

As to attach the system to the car, the above diagram would help to give a simple idea on how the thermoelectric modules are located. The red area shows the location of the Peltier and solar panels. It will be located on the rooftop of the car itself. Expected heat flow is upwards, towards the roof, so it is suitable to place the Peltier modules at the top.

5.1 Thermal Energy and Solar Radiation

Thermal energy can be used to passively heat buildings through the use of certain building materials and architectural design, or used directly to heat water for household use. The energy is one of the most promising of the alternative energy sources. Most of the present energy sources are indirect uses of the sun's energy. The burning of fossil fuels releases solar energy stored millions of years ago. Even though most energy now in use originated from the sun, the term "solar energy" was commonly used to describe the direct control of the sun's energy. The solar energy has the potential of supplying most of the energy we need.

However, in the project description, the project is aiming to reduce heat inside a car during parking condition. Therefore, hot areas gain heat from solar radiation. Solar radiation is the heat, light and other radiation energy that is emitted from the sun. It contains huge amounts of energy and is responsible for almost all the natural processes on earth. The suns energy, although plentiful, has been hard to directly harness until recently. Solar Energy can be classified into two categories, Thermal and Light. PV cells use semiconductor-based technology to convert light energy directly into an electric current that can either be used immediately, or stored, such as in a battery, for later use.

Solar Radiation is an important contributor to the cooling load. It must be properly taken into account so that a practical value of cooling load could be obtained, thus providing satisfactory air-conditioning system. The sun motion causes changing whether. As for Malaysia, though less significant the amount of radiation varies all year round. The total power needed to generate enough power to cool down the temperature is 2006.32 W. The power usage is high. From calculations, if the project used an approximately of one watt solar panel, the overall project needs 40 solar panels to cool down the whole cabin. However, the solar panel comes in different ratings, so a suitable solar panel with a rating of 2kW would be perfect for the passenger's cabin.

Solar Angles

The direction of the sun's ray is related to the followings [5]:

- Location on the earth's surface
- Time of the day
- Day of the year

Solar Heat Gain Factor

The heat gain through a simple window is complicated due to its finite size, the use of frame, and the variation of sun striking angle throughout a day. To simplify the calculation of heat gain from sun radiation, maximum *solar heat gain factor (SHGF)* is used [4]. SHGF is the maximum solar heat gain through single glass at a given month, orientation and latitude. SHGF is also defined as the hourly solar heat gains that occur in a unit area of double-strength sheet glass (DSA) for a given orientation and time.

Unit is $Btu/hr\text{-}ft^2$

Shading Coefficients

Shading coefficient SC is introduced to take into account various fenestration arrangement. It discounts the solar heat gain [4].

$$SC = \frac{Solar\ heat\ gain\ of\ fenestration}{Solar\ heat\ gain\ of\ DSA\ glass}$$

The shading coefficient is determined from the above ratio, obtained experimentally using *solar calorimeter.* The use of blinds, shades, curtain or drapes on the inside part of a window decrease the solar heat gain. SC values for these are available in tables.

5.2 Thermoelectric module

Referring to the project, to a typical car cabin, where the temperature will most likely increase during hot days at noon. Once the temperature increases, the temperature sensor will detect and measure the temperature. As it goes above the set point, for example, 35°C, the temperature sensor will trigger the thermoelectric module to activate. When a voltage DC current was applied to a thermoelectric module, heat can be moved through the thermoelectric coupler from one side to the other. One side was therefore cooled [cold-side] while the opposite side is simultaneously heated [hot-side]. The temperature differences can be upwards 50°C in real world application. Thermoelectric coupler help enhance cooling ability by creating a temperature differential that can be more easily moved out of the system. Thus, the activation of the thermoelectric will absorb heat and released it out of the car cabin to the atmosphere. As the temperature drops to within its specified limits, the thermoelectric module will reduce work, or the thermoelectric module could be turned off. Having the module on all the time increases power usage from the system. Water-cooling systems can only cool an object to ambient temperatures, but they still have excess cooling capacity (provided they have sufficient flow-rate and a capable radiator). Thermoelectric coupler allows more of the cooling capacity to be utilized and therefore achieve lesser-than-ambient temperatures. Originally, for the temperature sensing circuit, thermocouple sensors were initially used. Nevertheless, from further research, it is concluded that thermocouple may have some complexity in the design, due to the need to compensate some inaccuracy aspect. A temperature sensing circuit consist of a thermistor can be used as a sensor.

Thermoelectric Benefits

The choice of a cooling technology will depend heavily on the unique requirements of any given application; however, thermoelectric (TE) coolers offer several distinct advantages over other technologies. TE coolers have no moving parts and, therefore, need substantially less maintenance. Besides that, TE coolers contain no chlorofluorocarbons or other materials that may require periodic replenishment. The cooling effect takes place in environments that are too severe, too sensitive, or too small for conventional refrigeration. Another interesting fact is that life testing has shown the capability of TE devices to exceed 100,000 hours of steady state operation. So temperature control to within fractions of a degree can be maintained using TE devices and the appropriate support circuitry. Furthermore, the direction of heat pumping in a TE system is fully reversible. Changing the polarity of the DC power supply causes heat to be pumped in the opposite direction - a cooler can then become a heater.

5.3 Controller Circuit

The circuit was designed using EWB software. The design consists of three parts, the comparator, the Analog to Digital Converter (ADC) and also the logic gates. Seven comparators were used in the design. Two voltage input were used for comparison of voltage. One input will be supplied with a constant voltage, while another input was connected with a thermistor. The thermistor was used for thermal detection. Different voltages will trigger different combination of comparators. As for example, when the voltage reference was 8V, while another voltage input was 1V, the first comparator will produce an output of 5V. In the simulation, several voltmeters have been placed to examine the amount of output voltage driven through the ADC chip. The input part was a success. The voltage reference was varied using different steps of voltage, to produce the right output shown by the probe. The voltage input will be connected with the thermistor. When there is a change in temperature, the resistance of the thermistor will rise and it will cause the voltage to vary according to the measured temperature.

The next stage was the output of these comparators connected to the ADC, to change it from analog signal to digital signal. The ADC changes 8-bit signal to a 3-bit binary signal. The ADC will produce 3 output signals, where these signals will be manipulated using get logics to create a simple controller. The controller part will be in charge of turning the Peltier modules ON and OFF. The controller circuit will be connected to a relay to turn on the Peltier. The reason to use a relay was because of current drainage caused by the Peltier.

5.4 Problems and Recommendations

During the construction and testing of the circuit, the author encountered several problems. The earliest problem came out from the simulation. It involves the output from the ADC chip. The output doesn't match the requirement of the designer. It happened due to lack of information about the ADC chip itself. There was no information about the connection for E0 (enable output), EI (enable input) and GS (gate source) node. To counter the problem, the author had to search and retrieve more detailed datasheets for ADC and also for other components to troubleshoot the design simulation. Furthermore, the information will also be used for the model construction itself.

The next problem encountered was mainly on the logic inputs. The controller design had to be altered because of several mistakes. The comparators where arranged backwards to fix the design back into its original design requirements. The next problem occurred also on the comparator. The result of the test data below shows that the binary digit 000, 001, and 010 gave and output voltage of zero. By referring to the simulation results (Table 2), 001 and 010 should give voltage reading, not zero.

Binary	Temperature (degree C)	Voltage (V)	Condition
000	-	0.0	OFF
001	25.4	0.0	OFF
010	34.7	0.0	OFF
011	50.2	3.7	ON
100	-	4.3	ON
101	-	5.2	ON
110	-	6.2	ON
111	-	7.2	ON

Table 4: Experiment done on the controller circuit including voltage and temperature measurement (doesn't comply with design)

The solution for the previous problem was by connecting another resistor in series at the comparator input. If the new attached resistor value was bigger than the 330 Ω, the voltage level for binary 000 will be more than 3.0 Volts; however, if the new attached resistor was lower than the 330-ohm resistors, the voltage level for binary 000 will be less than 3.0 Volts. This condition occurred because the first comparator was connected through input 1 of the ADC, not for input 0. Thus, it needs another comparator connected to the input of the ADC, where in this situation; the author only used a 1000 Ω resistor to act as the comparator to solve the problem.

Binary	Temperature (degree C)	Voltage (V)	Condition
000	-	0.0	OFF
001	25.0	2.7	OFF
010	34.1	3.3	ON
011	50.9	4.0	ON
100	-	4.5	ON
101	-	5.1	ON
110	-	5.7	ON
111	-	6.4	ON

Table 5: Experiment done on the controller circuit including voltage and temperature measurement (comply with design)

After completing the controller part, several recommendations was made for further improvements. This project prototype will be using two source of power, battery A and battery B. Another controller can be used to control the supply for the Peltier. When both battery is fully charged, either one will supply to the Peltier module. If one of the batteries was empty, the other battery will take over to supply power to the Peltier modules. As example, when battery A was empty and battery B was fully charged, the controller will chose batter B to supply power to the Peltier and vice versa. The situation continues to create a close loop interaction. Other parts of improvement also involves in implementing other kinds of cooling, not only natural cooling, but also fast cooling. Fast cooling involves heat sink design and shading effects. For heat sink design, it is must to properly design system layout and enclosure for adequate air flow so that heat sinks can operate properly to dissipate heat to the ambient.

Shading effect deals with reducing the amount of heat radiation from the sun. By controlling the amount of heat, it helps to maximize air circulation inside the car cabin. This area of study also considers about the type of material used inside the car cabin. The main idea was to use materials that don't absorb much heat accumulated inside the vehicle. As for example, car owners would be recommended to use leather covered seats rather than using polymer. From several experiments conducted for this project, cars using leather covered seats tend have lower temperature than cars using polymer type of seats. From research, leather reflects most of heat radiation, but it gets very hot on the surface. However, for polymer type, the surface doesn't get too hot like leather, but it absorbs heat and releases the heat back, making the temperature inside the car to reach more than 55°C.

CHAPTER 6
CONCLUSIONS

As for conclusion, the design of vehicle compartments environmental control system using solar powered thermoelectric can help to improve people's living nowadays. As the technology is now advancing to nanotechnology, this project benefits the author in terms of knowledge and technical applications. This project would also be a step towards emerging UTP as an advance level education centre, especially in thermoelectric and nanotechnology area.

Overall, based upon studies, experiments and model development conducted, this project successfully shows that thermoelectric technology provides various cooling approach, but limited for small scale application. It was not favorable for large scale due to high current drainage and high power consumption with limited solar power, where power usage is considered expensive. Nevertheless, the information and research done for this project can be a step towards the advance design of local vehicle that improves on comfort and lifestyle of people living in hot region. Furthermore, this project definitely will create business opportunities in the future.

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APPENDICES

APPENDIX A

GANTT CHART

Gantt chart for Final Year Project I, January Semester 2005

Name: Mohamad Faizul B. Mohamad Aziz   2561

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Problem Definition	■													
2	Research & Experiments		■	■	■	■	■	■	■	■	■	■			
3	Logbook (Weekly Report)			x	x	x	x	x	x	x	x	x			
3	Submission of Progress Report				x										
4	Design Calculations & Research				■	■	■	■							
5	Submission of Progress Report 2								x						
6	Material gathering, Circuit design								■	■	■	■			
7	Submission Draft report												x		
8	Submission of Interim report													x	
9	Oral Presentation														x

x Milestone

■ Process

Gantt chart for Final Year Project II, June Semester 2005

Name: Mohamad Faizul B. Mohamad Aziz 2561

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Resource gathering	■													
2	Contruction of model		■	■	■	■	■	■	■	■	■	■			
3	Logbook (Weekly Report)			×	×	x	x	x	x	x	x	x			
3	Submission of Progress Report				×										
4	Continue on model				■	■	■	■							
5	Submission of Progress Report 2								×						
6	Project work continue								■	■	■	■			
7	Submission Final Draft												×		
8	Submission of Technical Report													×	
9	Oral Presentation														×
10	Final report (Hard cover)														x

× Milestone

■ Process

APPENDIX B

1. TABLE OF PEAK SOLAR HEAT GAIN THROUGH ORDINARY GLASS

2. TABLE OF SHADING COEFFICIENTS FOR GLASS

For Malaysia 3°- 4° latitude, use 0° latitude values

TABLE —PEAK SOLAR HEAT GAIN THRU ORDINARY GLASS*

Btu/(hr)(sq ft)

NORTH LAT.	MONTH	EXPOSURE NORTH LATITUDE									MONTH	SOUTH LAT.
		N	NE	E	SE	S	SW	W	NW	Horiz		
0°	June	59	156	147	41	14	41	147	155	225	Dec	0°
	July & May	48	153	152	57	14	57	152	153	233	Nov & Jan	
	Aug & April	25	141	163	79	14	79	163	141	245	Oct & Feb	
	Sept & March	10	118	167	118	14	118	167	118	250	Sept & March	
	Oct & Feb	10	79	163	141	34	141	163	79	245	Aug & April	
	Nov & Jan	10	57	152	153	67	153	152	57	233	July & May	
	Dec	10	47	147	156	83	156	147	42	226	June	
10°	June	40	153	155	55	14	55	155	153	243	Dec	10°
	July & May	30	146	158	65	14	65	158	146	247	Nov & Jan	
	Aug & April	13	130	163	94	14	94	163	130	250	Oct & Feb	
	Sept & March	10	103	164	127	28	127	164	103	247	Sept & March	
	Oct & Feb	10	66	155	149	73	149	155	66	230	Aug & April	
	Nov & Jan	9	37	143	161	106	161	143	37	210	July & May	
	Dec	9	21	137	163	130	163	137	23	202	June	

Table 5: Peak Solar Heat Gain through Ordinary Glass

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

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

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

Table 6: Shading Coefficients for Glass

APPENDIX C

SOLAR PANEL DATASHEETS FROM RS COMPONENTS

RS

Data Sheet

Solar panels

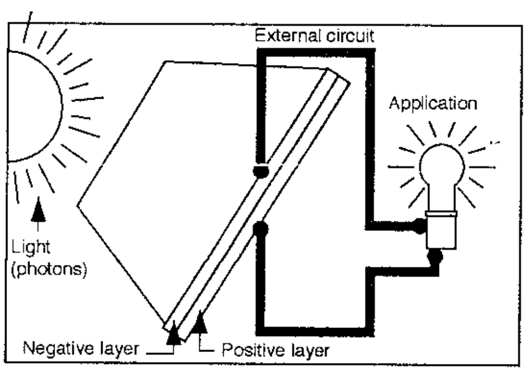
RS stock numbers 194-082 , 194-098, 194-105, 194-111, 194-127, 194-133, 194-149, 194-161, 194-199, 194-183, 768-071, 768-087

range of commercial grade thin film amorphous silicon and dustrial grade polycrystalline photovoltaic modules. These inels are suitable for charging both nickel cadmium and yfit batteries.

rinciple of operation

lar panels work on the principle of the photovoltaic effect. ie photovoltaic effect is the conversion of sunlight into ectricity. This occurs when the PV cell is struck by photons unlight), 'freeing' silicon electrons to travel from the PV ll, through electronic circuitry, to a load (Figure 1). Then ey return to the PV cell, where the silicon recaptures the ectron and the process is repeated.

Figure 1 **Principle of operation**



morphous silicon

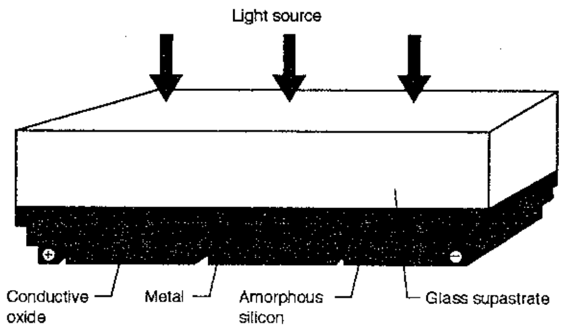
larex thin film amorphous silicon modules are inufactured using automated processes similar to those ed for semiconductor manufacturing. These processes sult in a monolithic module precision-layered with nductive and semiconductive films. These films are laser-ibed, using a patented method, into individual solar cells. e laser's ability to scribe cleanly and precisely produces a perior product in several respects:

Cell divisions are very narrow, allowing more module surface to be devoted to power production. Thus, a module of given size generates more power.

Voltage characteristics and overall performance at low light levels are improved.

e series and parallel connections between cells (which ermine the modules voltage and current output) are npleted internal to the module (Figure 2), resulting in an a-reliable module without solder joints.

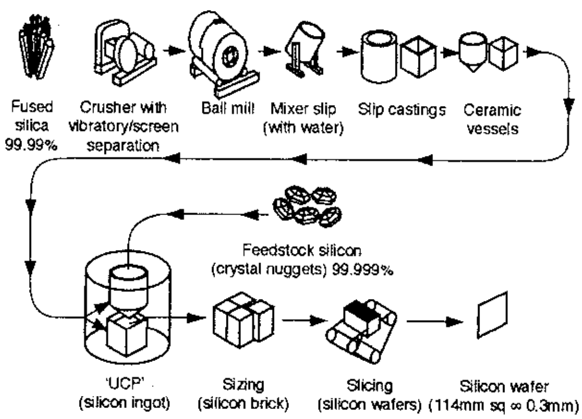
Figure 2 **Module internal structure**



Polycrystalline silicon

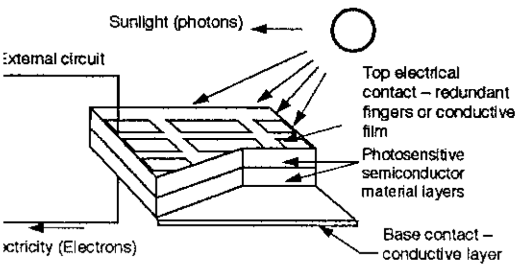
Polycrystalline silicon cells are manufactured using 99.999% pure silicon feedstock nuggets available to the semiconductor chip manufacturers. The nuggets are melted down in a vacuum furnace with a little boron and allowed to cool very slowly so that a pure crystal lattice of P-type material is formed. The resulting block is quartered and then sliced into 0.2mm wafers using either a hole saw or a wire saw (Figure 3).

Figure 3 **Cell production process**



atented process the N-type material is formed as a in layer on one face of each wafer by spraying with a iorous compound gas and baking. This is followed by dition of an anti-reflective filter coating to the upper and conductive layers to both faces. The layer on the ce is optimised in the form of a grid in order to allow ximum amount of light to pass through to the N-type al whilst distributing the maximum number of ns (Figure 4).

ıre 4 **Polycrystalline cell structure**



re then tested and matched together with cells of performance for building up into series and parallel s to give the PV module the desired electrical eristics.

truction

ıous silicon solar plate (**RS** stock no. 194-098)

norphous solar plate is a monolithic construction ing of several layers of conducting and semi- ting materials deposited onto a solar grade glass rate. Each plate comes unframed with integral flying

ledium power amorphous modules
ock nos. 194-105 and 194-111)

ımorphous silicon solar modules consist of several of conducting and semi-conducting materials ed onto a solar grade glass superstrate. Each module complete with a low profile impact reinforced ᵀᴹ frame which protects the back and edges of the nd 1.2m of 2 core 18awg flying leads.

eatures of the panels:

laser patterning: A patented process using a puter-controlled laser interconnects all solar cells. maximises module active area and cell current while nising the area of the interconnects.

r isolation: The plate is encircled by a laser scribe to blish reliable isolation. In the final unit, each part is unded by a thin, inactive border that acts as a barrier ge corrosion.

k appearance: A patented optical coupling nology, combined with a tightly controlled ufacturing process, creates uniform black arance.

xide glass coating: This patented process offers ptionally uniform conductivity and light absorption.

Polycrystalline panels

Low power modules (RS stock nos. 194-127 and 194-133)

These modules consists of high efficiency polycrystalline silicon wafers bonded to an aluminium substrate which is laminated between an ethylene vinyl acetate front sheet and a tough EVA TedlarTM backsheet. Each module comes complete with a black plastic frame, an integral stand and 0.8m flying leads.

Medium/High power modules (RS stock nos. 194-149, 194-161, 194-183, 194-199, 768-071 and 768-087).

These modules have the same basic construction as the low power modules.

Features of these panels include:

Solarex Mega™ Cell

- Advanced polycrystalline technology
- 11.4cm × 11.4cm cell generates superior current.

Reliable outside bussing

- Extends module life
- Resists electrical breakdown
- A unique, patented titanium dioxide AR (anti-reflective) coating for optimum light absorption and power output
- Temperature range –40°C to +90°C or –40°C to +85°C at 85% relative humidity.

Framed versions

Tempered low-iron glass

- High transmissivity
- Hail and wind resistant to JPL block V standards
- Will withstand hailstone of 25.4mm diameter at a terminal velocity 52mph.

Heavy-duty frame

- Corrosion resistant aluminium alloy
- Architectural grade bronze anodised finish
- Withstands 129mph (208km/h).

Weatherproof junction box (20W, 32W and 53W versions only)

- NEMA 4X rated. UL rated terminal block
- Industry standard openings and fittings.

Generous frame clearance

- Prevents electrical breakdown
- Improves module reliability.

Unframed version

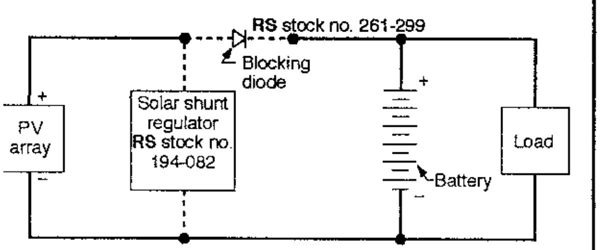
Low profile and lightweight

- The unframed types have a low profile of approximately 9mm and are lightweight, the 18W version weighs only 1.49kg.

mple photovoltaic system

photovoltaic (PV) system may have a minimum of two mponents, the module and the load to be powered. An ample of such a system would be a simple ventilation fan iven directly by a module during hot and sunny weather. r twenty-four hour a day operation a battery and blocking ɔde are required, whilst for UK 'all year round operation' a ltage regulator is also recommended in order to protect ɜ battery from the effects of overcharge, typically during ɜ summer.

Figure 5 **A simple photovoltaic system**

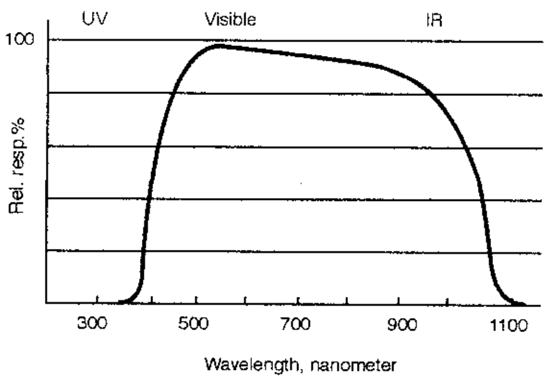


te: The solar regulator includes a blocking diode and therefore a blocking diode should only be incorporated in a system when the solar regulator is not being used.

ɔectral sensitivity of silicon cells

ɡure 6 shows the relative response of crystalline silicon ls to the ultra-violet, visible and infra-red spectrum. sponse is fairly even to most of the visible wavelengths d the near infra-red. Amorphous (thin-film) silicon favours blue end of the spectrum.

Figure 6 **Spectral response of silicon photovoltaic cell**



ɜ crystalline cells are made from boron doped silicon ers and are 12% efficient. The amorphous range of dules is manufactured using automated 'thin film' ɔcesses where precision layers of conductive and semi- ıductive materials are sprayed onto glass and laser ibed to produce individual cells with an efficiency of 7%. modules are optimised for daylight operation where rent is proportional to light intensity and voltage rises y quickly at low light intensities. Both the amorphous and ycrystalline panels will operate in most UK daytime ather conditions.

Electrical specifications

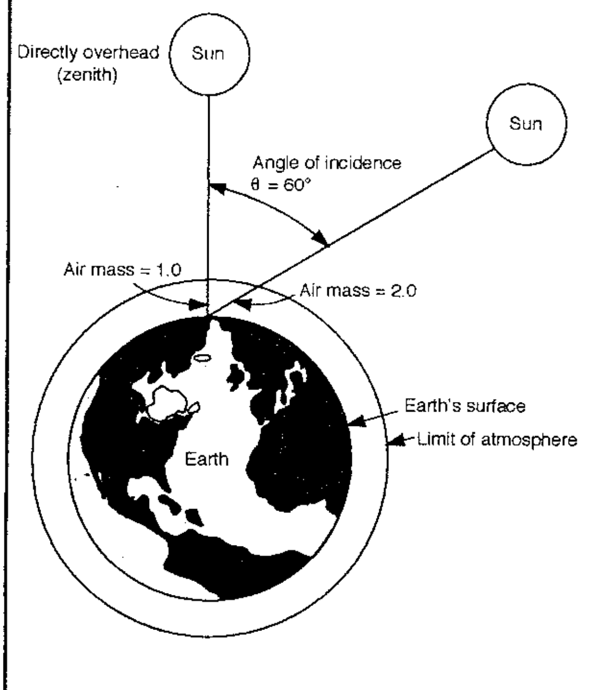
Standard test conditions (STC) – the power of a module is given at STC which is defined as follows:

1. A light intensity of $1kW/m^2$ (equivalent to full sun).
2. A spectral distribution of AM 1.5 (AM – Air Mass = $1/\cos\theta$ where θ is the angle of the sun to the vertical).
3. A cell temperature of 25°C.

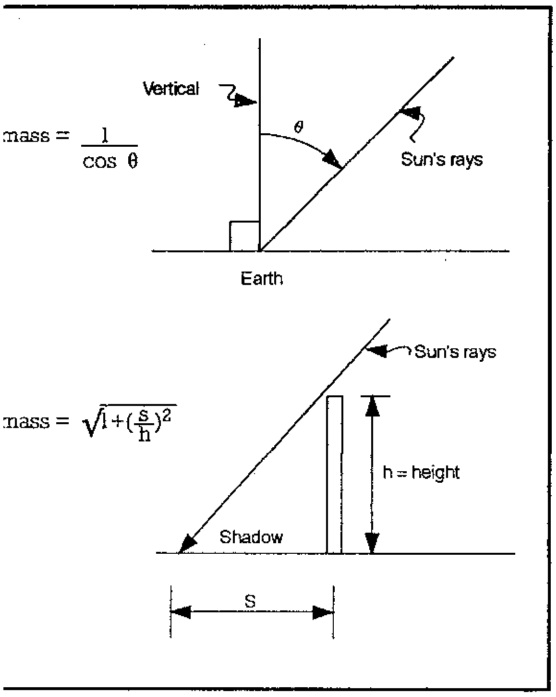
The definition of air mass is as follows:

Air mass, defined as 1/cosu (where u is the angle between the sun and directly overhead) is a useful quantity in dealing with atmospheric effects. Air mass indicates the relative distance that light must travel through the atmosphere to a given location. Because there are no effects due to air attenuation immediately outside the earth's atmosphere, this condition is referred to as air mass zero (AM0). Air mass one (AM1) corresponds to the sun being directly overhead. Air mass 1.5 (AM1.5), however, is considered more representative of average terrestrial conditions and is commonly used as a reference condition in rating photovoltaic modules. Figure 7 shows the relative distance through the earth's atmosphere that the sun's rays must pass at two times during the day.

Figure 7 **Sun's angle of incidence versus distance through atmosphere**



The value of air mass at any given time and location can be easily calculated using the relations shown on next page. The higher the value of air mass, the greater the attenuating effect of the atmosphere.



ıteed performance – all modules carry a limited ty covering performance:

line products – are guaranteed to produce at least the specified minimum power output for a period of 5

hous products – are guaranteed to produce at least the specified Imp (current at maximum power) at STC voltage fixed at Vmp.

Electrical characteristics at STC

Small low power modules

Model **RS stock nos.**	**MSX-005** **194-127**	**MSX-01** **194-133**	**SA-0640** **194-098**
Specified load voltage (Vld)	3.3V	7.5V	7.5V
Nominal battery voltage	2.4V	6V	6V
Typical current at Vld (Ild)	150mA	150mA	45mA
Open circuit voltage (Voc)	4.6V	10.3V	12.0V
Short circuit current (ISC)	160mA	160mA	54mA
Temperature coefficient of voltage per °C	–16mV	–37mV	–30mV
Temperature coefficient of current per °C	0.15mA	0.15mA	0.05mA

Medium to high power modules

The medium to high power modules (table below) are labelled detailing the individual characteristics of their actual performances at STC. The power output of NOCT – Normal Operating Cell Temperature – at an ambient temperature of 20°C is also printed on the label.

Notes: 1. The 20W, 32W and 53W versions are suitable for both 6 and 12V operation and are user configurable, see installation details.

2. The MSX light series are the unframed versions.

l ›ck nos.	SA-1 194-105	SA-5 194-111	MSX-5 194-149	MSX-10 194-161	MSX 18 light 194-199	MSX-20 194-183	VLX-32 768-071	VLX-53 768-087
′)	17.5	17.5	17.5	17.5	17.5	17.1	17.2	17.2
A)	80	290	270	580	1060	1170	1860	3080
)	24.0	23.0	21.2	21.2	21.0	20.8	21.3	21.3
\)	110	340	290	600	1160	1270	2010	3330
of V_{OC}	-65	-60	-72	-72	-73	-73	-73	-73
f I_{SC}	100	300	275	500	1200	1200	1500	2500
@ - W			3.1	7.3	14.1	18.5	29.1	48.2
- mA			275.5	590	1084	1194	1896	3140

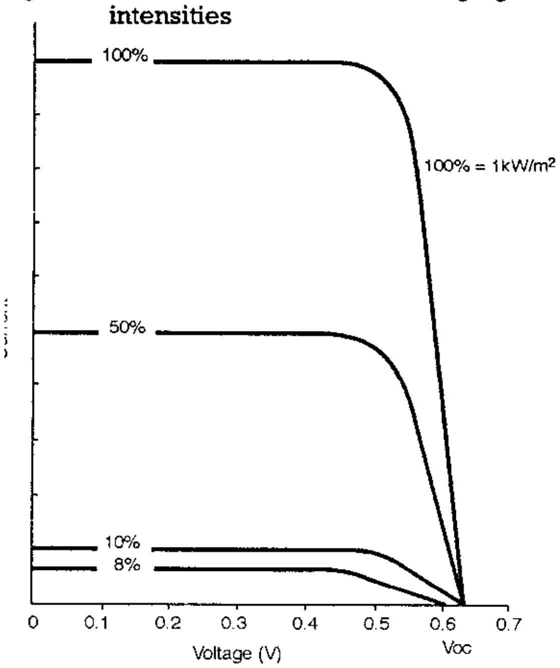
V_{PP} – Voltage at peak power
I_{PP} – Current at peak power
V_{OC} – Open circuit voltage
I_{SC} – Short circuit current
V_{OC} – Temperature coefficient of open circuit voltage
I_{SC} – Temperature coefficient of short circuit current

- Nominal Operating Cell Temperature – 49°C (VLX Modules)
– 45°C (MSX Modules)

ʳ characteristics with varying light intensity

ycrystalline cells each give approximately 0.45 Volts en illuminated dependent upon the light intensity and the d but independent of surface area. The important iracteristic which makes them so suitable for supplying ctrical power is that the voltage builds up quickly to a iable plateau at very low light levels (about 8% of peak ensity). This means that voltages suitable for battery irging are reached even on a dull day. Current, however, directly proportional to both light intensity and surface ea.

Figure 8 **I-V characteristics at reducing light intensities**



graph above shows that there is no significant drop in voltage until insolation drops to 80W/m2.

ʼigure 9a **I-V characteristics with varying temperature**

ʼolycrystalline panel

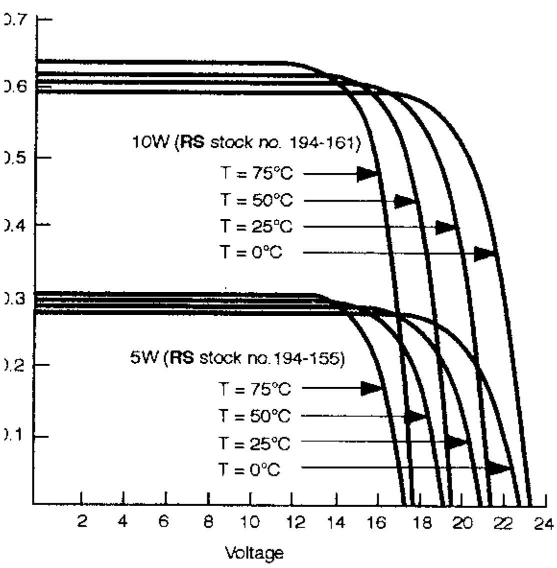
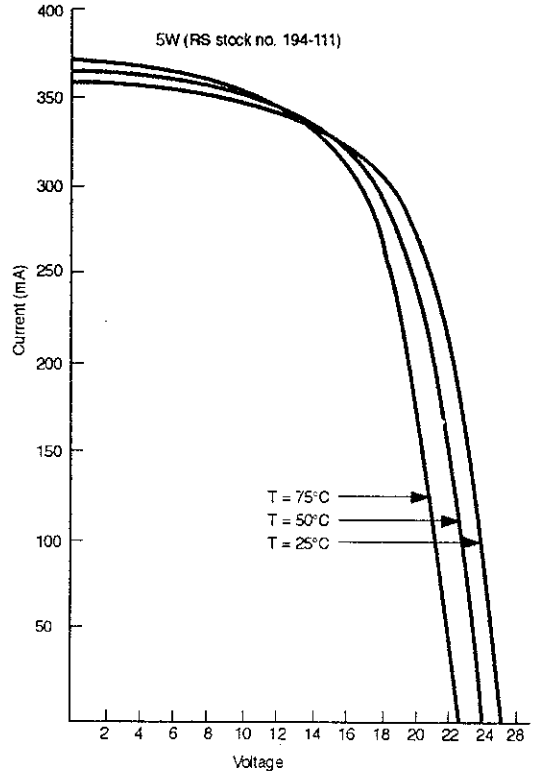


Figure 9b **I-V characteristics with varying temperature**

Amorphous silicon panel



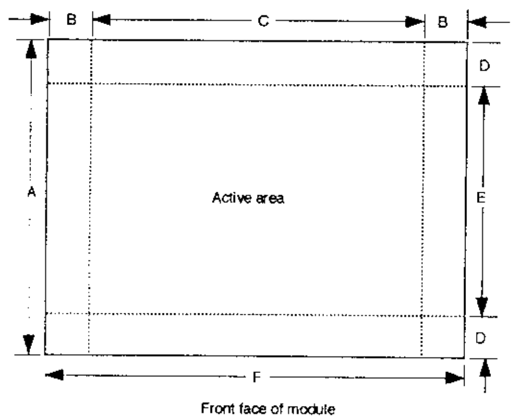
Design considerations for the mounting and installation of the small low power modules

Great care must be exercised during the design stage to ensure that both the edges and rear of OEM (frameless) modules are protected from the environment as well as insulating them from stress through dynamic, static or thermal sources.

Active area

A modules active area – the frontal area that generates electrical power – is a critical design consideration in using any photovoltaic product. If this area is covered by a mounting bezel, power may be reduced and the product may cease to function. For optimal performance, the active area must never be shaded.

Figure 10 **Active area of modules**



ꜧ area dimensions

	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)
ɔck no. ɔ5) ɔ05	114.3	7.49	57	9.86	95.8	71.88
ɔck no. 11))1	127	5.84	115.32	10.39	106.22	127
ɔck no. 38) 40	54.86	6.35	139.7	3.176	48.52	152.4

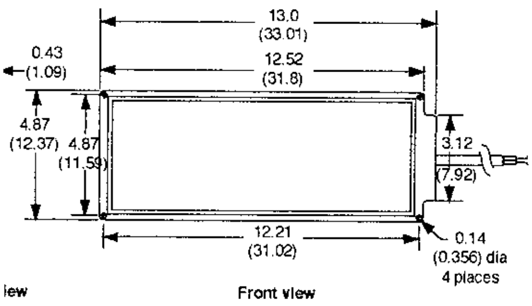
ıanical and dimensional details for ıedium/high power modules

ıorphous module (**RS** stock no. 194-105)

ınical characteristics

t: 0.4kg

sions: Dimensions in brackets are in centimetres. Unbracketed dimensions are in inches.

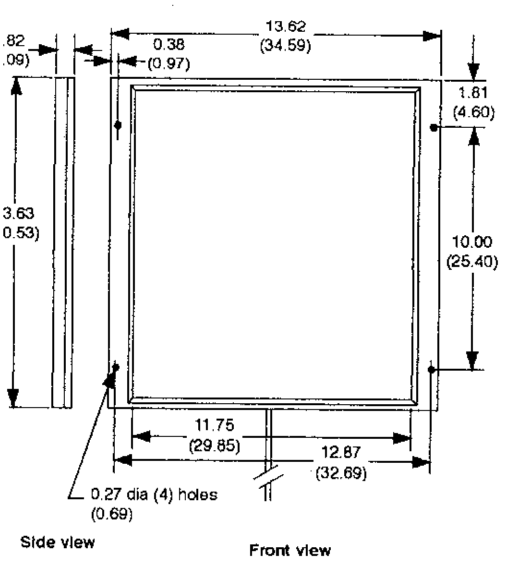


ıorphous module (**RS** stock no. 194-111)

ınical characteristics

: 1.5kg

sions: Dimensions in brackets are in centimetres. Unbracketed dimensions are in inches.



Polycrystalline light modules

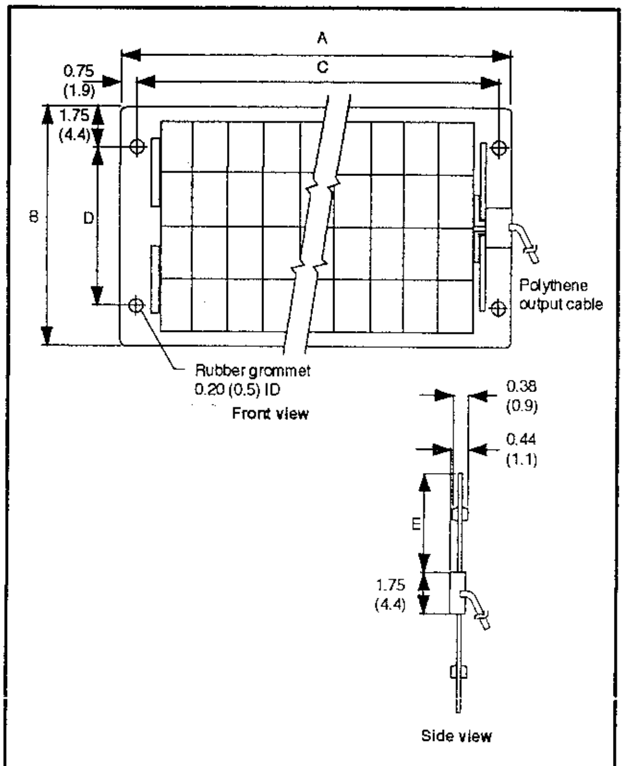
Mechanical characteristics

Output cable: 3 metres long, AWG 18-2, polyethylene jacketed.

Weight:

RS stock no. 194-199 MSX-18 light 1.49kg

Dimensions: Dimensions in brackets are in centimetres. Unbracketed dimensions are in inches.



	Dim. A	Dim. B	Dim. C	Dim. D	Dim. E
MSX-18 light (**RS** stock no. 194-199)	17.50 (44.4)	19.50 (49.5)	16.00 (40.6)	16.00 (40.6)	8.88 (22.5)

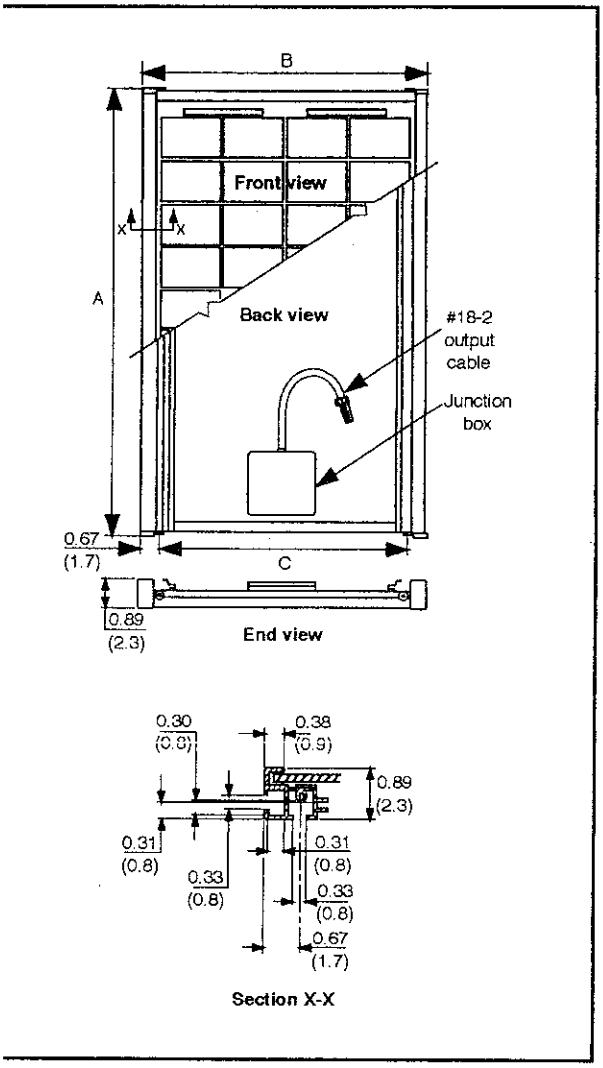
echanical characteristics

utput cable: 15 feet long, AWG 18-2, polyethylene :keted.

eight:

; stock no. 194-161	MSX-10	1.5kg
; stock no. 194-149	MSX-5	0.77kg

mensions: Dimensions in brackets are centimetres. Unbracketed dimensions are in inches.



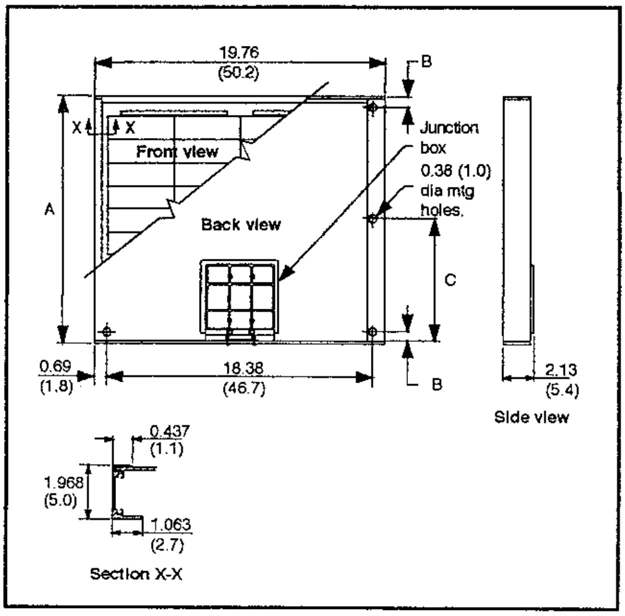
	Dim. A	Dim. B	Dim. C
⁄ISX-5	9.82	10.59	9.25
RS stock no. 194-149)	(24.9)	(26.9)	(23.5)
⁄ISX-10	16.54	10.59	9.25
RS stock no. 194-161)	(42.0)	(26.9)	(23.5)

Mechanical characteristics

Weight:

RS stock no. 194-183 MSX-20 2.95kg

Dimensions: Dimensions in brackets are centimetres. Unbracketed dimensions are in inches.



	Dim. A	Dim. B	Dim. C
MSX-20	16.5	0.75	8.29
(RS stock no. 194-183)	(42.1)	(1.9)	(21.1)

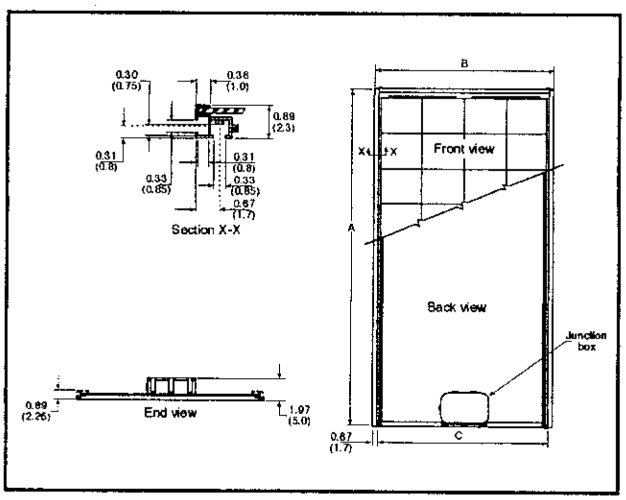
Mechanical characteristics

Weight

RS stock no. 768-071 VLX-32 3.5kg

RS stock no. 768-087 VLX-53 5.5kg

Dimensions: Dimensions in brackets are centimetres. Unbracketed dimensions are in inches.



	Dim. A	Dim. B	Dim. C
VLX-32 (RS stock no. 768-071)	23.28 (59.1)	19.72 (50.0)	18.38 (46.7)
VLX-53 (RS stock no. 768-087)	36.88 (93.7)	19.72 (50.0)	18.38 (46.7)

llation and mounting

tation

installing photovoltaic modules, be aware that they te maximum power when facing the sun directly. The osition which approximates this ideal over the course year, thus maximising annual energy production, is due south (in the northern hemisphere) or due north southern hemisphere) at the angle listed in the table

These orientations are true, not magnetic north and south.

gle

ole below shows the fixed angle above horizontal at modules should be installed in order to maximise energy output. At some installations, it may be cost-ve to adjust the tilt seasonally. At most latitudes, nance can be improved during the summer by using e flatter than the chart's recommendation; conversely, er angle can improve winter performance.

les are not cleaned regularly, it is recommended that e not mounted at an angle flatter than 15°. Flatter cannot take full advantage of the cleansing action of

ıtitude of site	Tilt angle
0-4°	10°
5-20°	Add 5° to local latitude
21-45°	Add 10° to local latitude
45-65°	Add 15° to local latitude
65-75°	80°

ıg

modules so they are as free as possible from shading all seasons, particularly during the middle (the most -productive) part of the day.

ing

ıorphous modules and the polycrystalline light es can be mounted via the integral holes. It is nt that the mounting hardware is not over tightened he module is bent during installation.

s can also be mounted on a flat wooden surface, such n thick plywood. Such an installation, however, s natural airflow from cooling the back of the module, t which enhances module performance slightly. If this ement is desired, the installation should allow airflow he module back.

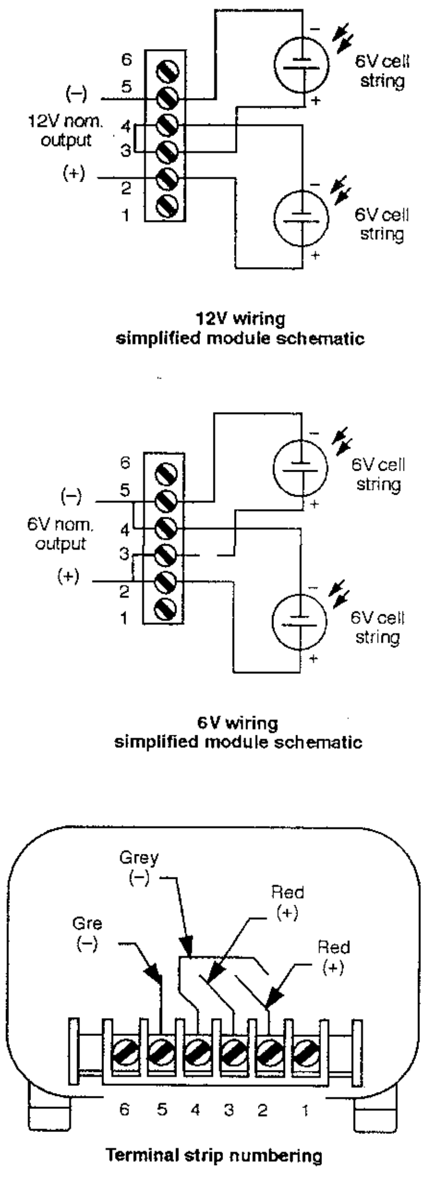
and 10W polycrystalline panels have a multi-mount This consists of dual channels oriented parallel to the nd back of the module. The channels accept the f 5/16in or 8mm hex bolts, and allow the module to - or side-mounted. The channels prevent the bolt om turning.

W, 32W and 53W polycrystalline panels have a l mount frame. This frame can be mounted via the m holes in the dual channels. To mount the module e use the two centre holes.

MSX-20, VLX 32 and 53 modules – wiring for 6V or 12V operation

The two strings of 18 cells which make up the modules may either be connected in series or parallel for 12V or 6V operation as shown in Figure 11. Positive conductors have red insulation whilst the negative ones are grey. The module is shipped in 12V configuration. All other finished modules are configured as 12V and cannot be altered.

Figure 11 **Wiring schematics**



aily average insolation levels in the nited Kingdom

e following tables of mean daily ESH (equivalent sunshine urs) may be used to calculate the size of module required:

ocation	(OT)	Equivalent sunshine hours – kWhrs/m²/day					
		Summer – mean for June			Winter – mean for Dec		
		H	Vs	Sot	H	Vs	Sot
lymouth	65°	5.56	2.85	4.20	0.69	1.35	1.40
lanchester	68°	5.17	2.80	3.86	0.46	0.88	0.91
lasgow	71°	4.94	2.76	3.62	0.33	0.64	0.65

Legend: OT – Optimum tilt angle (degrees from horizontal)
H – Horizontal
Vs – Vertical south facing
Sot – South facing at optimum tilt

(Data taken from *Climate in the UK* – ISBN 0 11 412301 2)

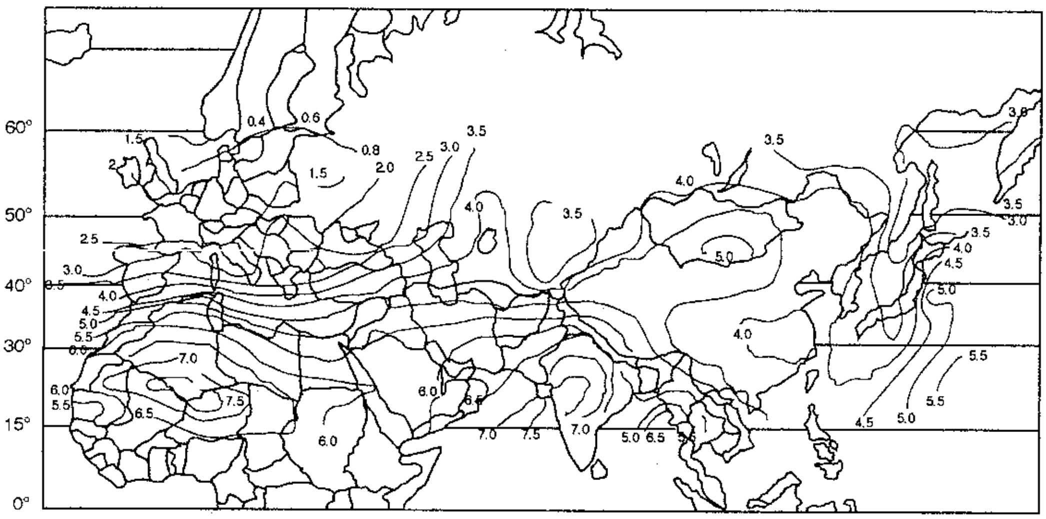
Notes:

1. For areas of higher or lower latitude in the UK appropriate insolation levels may be extrapolated from the figures shown.
2. The data above should be used with care as these figures were gained from 'ideal' sites, please consider all the potential performance derating factors listed below.
3. If sizing a system outside the UK then an approximate guide to mean daily wintertime (worst case) insolation levels is given in the following maps:

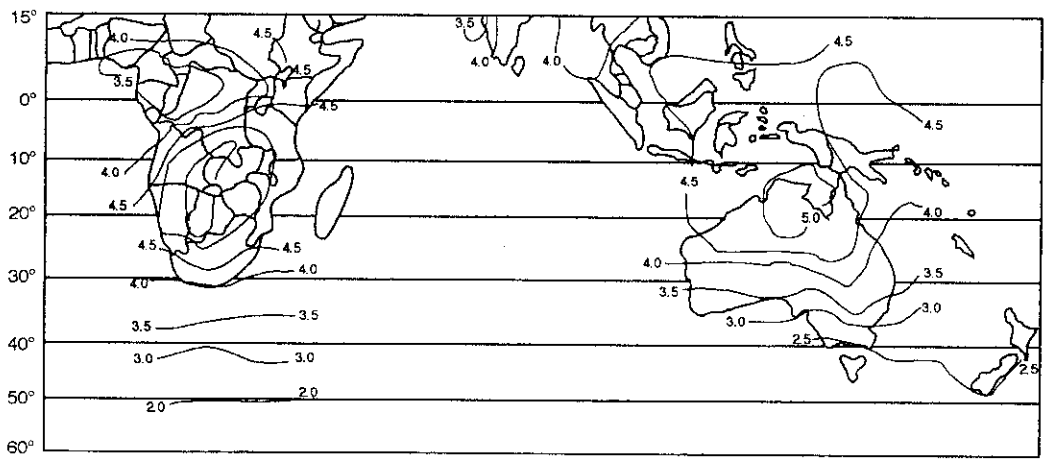
gure 12 Worldwide insolation availability maps

These maps indicate worst case (wintertime) solar radiation based on a Solar Array tilted towards the sun at an angle equal to the latitude of the location +15°.

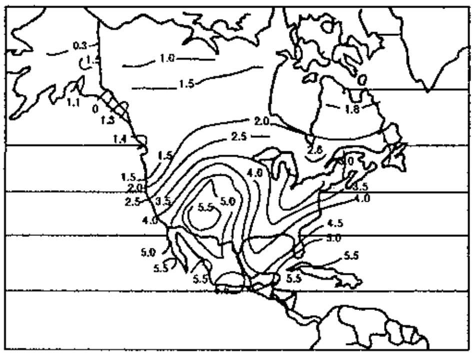
Eastern hemisphere – insolation map (winter)



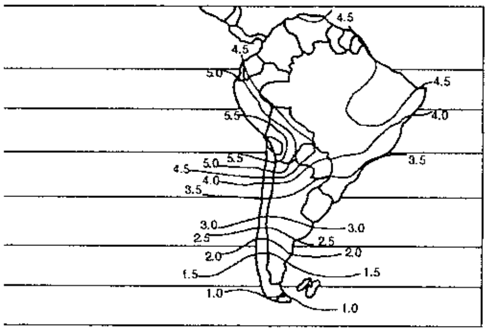
Eastern hemisphere – insolation map (winter)



ıtern hemisphere – insolation map (winter)



ıtern hemisphere – insolation map (winter)



ıle performance derating factors

propriate to consider the many factors which can the performance of a solar module prior to ting any sizing calculations:

ıperature – as a guide the typical cell operating perature will be 20°C to 25°C higher than ambient.

ınliness – the modules active area should be cleaned periodically to maintain performance.

luction tolerances – these are catered for with an ropriate safety factor in the sizing calculation.

ection/Refraction – if the module is mounted behind s or some other clear medium then reflection and action will typically account for losses of 20%.

lowing – during sunny conditions the possibility of lows falling across the module should be reduced to inimum as the performance of all cells will be ıced to that with the lowest output.

ıuth and tilt angle – as an example it will be seen ı the UK insolation table above that horizontal ınting gives excellent summer performance but mal in winter – for best all year round performance nodule should be fixed at an angle of latitude +15, g true south.

ctral distribution of light – the performance of Solarex ules is optimised for daylight. Performance under cial light sources must be found by measurement.

Daily system load

In order to ensure reliable system operation all year round it is imperative that the worst case daily load in winter is known. It is also very important to ensure that adequate account is taken of quiescent loads, switching losses and if a voltage regulator is employed its own consumption characteristics.

Battery sizing

The battery stores energy from the module enabling the system load to operate day or night. Due to the vagaries of the weather we must allow for long periods of below average insolation 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'. At UK latitudes this should not be less than 20 days.

We must also consider several important points;

a) that should this situation occur it is not advisable to allow the battery to discharge to 0% capacity

b) capacity reduces with temperature

c) the effects of self discharge and charging efficiency may be significant

d) battery capacity is a function of discharge rate.

Typically, therefore, do not discharge the battery below its 30% charge state and allow for a 10% capacity reduction in winter. Thus a system supplying a load consuming 0.75Ah/day would require a battery capacity of:

$$0.75 \times 20 \times 1.3 \times 1.1 = 21.45\text{Ah}$$

Battery choice – The **RS** Dryfit range of sealed lead acid batteries is ideal for solar systems having high charge efficiency, low self-discharge and good recovery from high discharge.

Module sizing

Having determined the load requirements and local insolation the last step is to calculate the size of module required.

$$SA = \frac{L \times SF}{ESH}$$

SA = System Amps (to be provided by module)
L = Load
SF = Safety factor (use 1.2)
ESH = Equivalent sunshine hours (kWhrs/m²/day)

Example: Thus for a system consuming 0.75Ah/day all year round in the Manchester area with a module facing true south, tilted at latitude +15 (= 68) and unshadowed:

$$SA = (0.75 \times 1.2)/0.91 = 0.99 \text{ Amps}$$

From the table of module performance characteristics we will see that the MSX-18 module has an I_{PP} of 1.06 amps. This is the correct choice as the smaller MSX-10 only has an I_{PP} of 0.58 Amps.

Note: A regulator would be required in this system thus the daily load is inclusive of its power requirements.

ɘgulation

the UK with its high ratio of summer to winter insolation it is ıost always essential for a solar system to be fitted with a ltage regulator to protect the battery against the effects of ercharge during the long summer days. A regulator would t be required if during the period of operation of the ɜtem the daily load was matched to the mean module tput. Regulators incorporate blocking diodes that prevent ttery discharge through the module at night, so in an regulated system a blocking diode would be required. A table blocking diode would be a 1N5401 (RS stock no. 1-299) 3A, 100V.

unt regulator (RS stock no. 194-082)

ɘ performance specifications of the shunt regulator are as ows:

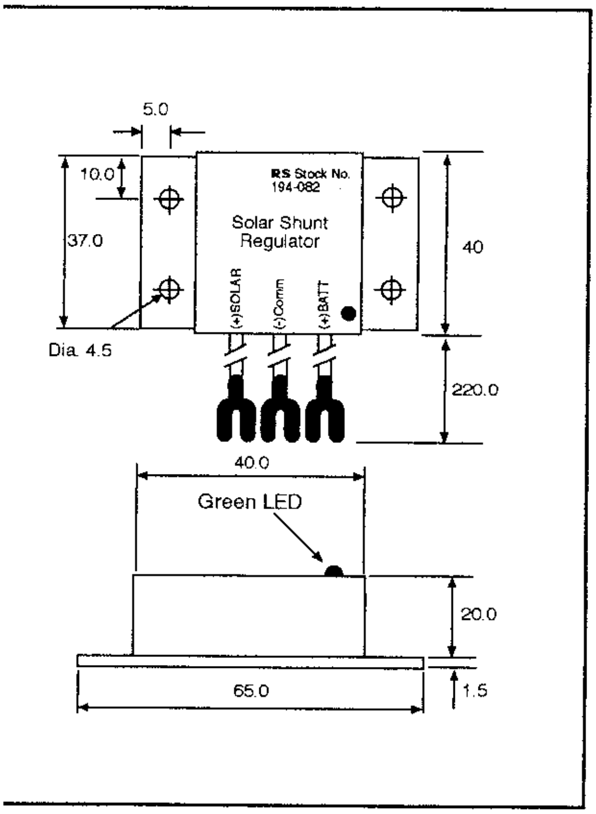
minal voltage	12.0V
ıximum input current	6.0A
ınt set point voltage	13.8V
iescent current	<1.0mA
ıcking diode voltage drop	0.4V
mp. coeff. of output voltage	45mV/deg C

ɘ three output leads are colour coded as follows:

D	SOLAR MODULE +ve
ACK	COMMON –ve
LLOW	BATTERY +ve

ch 1.0mm² lead is 220mm in length and terminated with an spade terminal.

gulator status is indicated by a single, green LED which is minated when the set point voltage of 13.8V is reached d shunting of the module output commences. When tery voltage drops to 12.8V the LED is extinguished and module output is redirected to the battery.



The matrix below provides general guidelines for choosing either a blocking diode or a regulator.

Location	(OT)	Equivalent sunshine hours – kWhrs/m²/day					
		Summer – mean for June			Winter – mean for Dec		
		H	Vs	Sot	H	Vs	Sot
Plymouth	65°	5.56	2.85	4.20	0.69	1.35	1.40
Manchester	68°	5.17	2.80	3.86	0.46	0.88	0.91
Glasgow	71°	4.94	2.76	3.62	0.33	0.64	0.65

Glossary of solar terms

Air mass – A measure of distance that light travels through the earth's atmosphere.

Ampere-hour – A measure of electrical charge.

Array – A collection of photovoltaic modules, electrically wired together and mechanically installed in their working environment.

Block V – Module qualification tests designed and conducted by the Jet Propulsion Laboratory. Modules undergo electrical performance measurements and mechanical tests, such as thermal cycling, humidity-freezing, cyclic pressure loading, hail-impact and twisted mounting surface requirements.

Blocking diode – A device for preventing a reverse flow of current through photovoltaic modules (also called a series diode or an isolation diode).

Bypass diode – A device placed in parallel with a photovoltaic module or group of modules allowing a route for the current under conditions of shading and cell failure (also called a shunt diode).

Cell efficiency – The ratio of the electrical energy produced by a photovoltaic cell (under full sun conditions) to the energy from sunlight falling upon the cell.

Design tilt – The tilt of the array at which design and sizing calculations are made. Often the design tilt is optimised for energy output under prescribed conditions.

Diffuse radiation – Sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust or other substances in the atmosphere.

Direct radiation – Light that has travelled in a straight path from the sun (also referred to as beam radiation). An object in the path of direct radiation casts as a shadow on a clear day.

Fill factor – The ratio of maximum power to the product of open-circuit voltage and short-circuit current. Fill factor is the 'squareness' of the I-V curve shape.

Flat-plate array – A photovoltaic array in which the incident solar radiation strikes a flat surface and no concentration of sunlight is involved.

Grid-connected – An energy producing system connected to the utility grid (also called utility-interactive).

Grounding – Connection to a large conducting body (such as the earth), which is used as a common return for an electrical circuit and as an arbitrary zero potential.

Holes – Vacancies, where electrons should normally be in a perfect crystalline structure.

system – A power system consisting of two or more generating subsystems (e.g. the combination of a rbine and a photovoltaic system).

on – The amount of sunlight reaching an area. Usually ›ed in watts per square metre per day.

ı box – A protective enclosure into which wires or are led and connected.

· Electrical power being consumed at any given .t. The load that an electric generating system ›s varies greatly with time of day and to some extent of year. Also, in an electrical circuit, the load is any or appliance that is using power.

um power current (Imp) – The corresponding for the maximum power point on an I-V curve.

um power point (Pmax) – The desired operating ı an I-V curve where the product of the current and (power) is maximised.

um power voltage (Vmp) – The corresponding for the maximum power point on an I-V curve.

: – A number of photovoltaic cells electrically wired r, usually in a sealed unit of convenient size for ɡ and assembling into panels and arrays.

ıl operating cell temperature (NOCT) – The ›ltaic cell junction temperature corresponding to l operating conditions in a standard reference .ment of 1kW/m² irradiance, 20°C ambient air ature, 1m/s wind, and electrically open circuit.

ircuit voltage (Voc) – The voltage output of a ›ltaic device when no current is flowing through a

A number of modules wired together, which in turn, wired to other panels to form an array.

connected – A method of connection in which terminals are connected together and negative .s are connected together. Current output adds and ıge remains the same.

.n hours – The equivalent number of hours at peak .ditions (i.e. 1kW/m²) that produces the same total n as actual sun conditions.

›ltaic cell – The basic device that converts light into dc electricity; the building block of photovoltaic modules.

p-n junction – The junction formed at the interface between two differently doped layers of semiconductor material, one layer being doped with a positive-type dopant, the other with a negative-type dopant. An electric field is established at the p-n junction which gives direction to the flow of light-stimulated electrons.

Series connected – A method of connection in which the positive terminal of one device is connected to the negative terminal of another. the voltages add and the current is limited to the least of any device in the string.

Short-circuit current (Isc) – The current flowing freely from a photovoltaic cell through an external circuit that has no load or resistance; the maximum current possible under normal operating conditions.

Solar constant – The rate at which energy is received from the sun just outside the earth's atmosphere on a surface perpendicular to the sun's rays. Approximately equal to 1.36kW/m².

Standard test conditions (STC) – Test conditions in a standard reference environment of 1kW/m², 25°C cell temperature, and 1.5 air mass spectrum.

Thick cells – Conventional cells, such as crystalline silicon cells, which are typically from 4 to 17mm thick. In contrast, thin-film cells are several microns thick.

Thin-film cells – Photovoltaic cells made from a number of layers of photo-sensitive materials. These layers are typically applied using a chemical vapour deposition process in the presence of an electric field.

Voltage regulator – A device that controls the operating voltage of a photovoltaic array.

Watt – A measure of electrical power or amount of work done in a unit of time. One Amp of current flowing at a potential of one Volt produces one Watt of power.

APPENDIX D

QUAD 2-INPUT AND, OR, AND NOT GATE DATA SHEETS FROM PHILIPS

INTEGRATED CIRCUITS

DATA SHEET

For a complete data sheet, please also download:

- The IC06 74HC/HCT/HCU/HCMOS Logic Family Specifications
- The IC06 74HC/HCT/HCU/HCMOS Logic Package Information
- The IC06 74HC/HCT/HCU/HCMOS Logic Package Outlines

74HC/HCT08

Quad 2-input AND gate

'roduct specification
ile under Integrated Circuits, IC06

December 1990

ıilips
ːmiconductors

PHILIPS

ʖuad 2-input AND gate 74HC/HCT08

ⱡTURES

ˌutput capability: standard

ɔc category: SSI

ˀERAL DESCRIPTION

· 74HC/HCT08 are high-speed Si-gate CMOS devices and are pin compatible with low power Schottky TTL (LSTTL). ·y are specified in compliance with JEDEC standard no. 7A. The 74HC/HCT08 provide the 2-input AND function.

ICK REFERENCE DATA

Ɔ = 0 V; T_{amb} = 25 °C; $t_r = t_f$ = 6 ns

YMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			HC	HCT	
$_L$/ t_{PLH}	propagation delay nA, nB to nY	C_L = 15 pF; V_{CC} = 5 V	7	11	ns
	input capacitance		3.5	3.5	pF
$_D$	power dissipation capacitance per gate	notes 1 and 2	10	20	pF

es

C_{PD} is used to determine the dynamic power dissipation (P_D in μW):

$P_D = C_{PD} \times V_{CC}^2 \times f_i + \sum (C_L \times V_{CC}^2 \times f_o)$ where:

f_i = input frequency in MHz

f_o = output frequency in MHz

C_L = output load capacitance in pF

V_{CC} = supply voltage in V

$\sum (C_L \times V_{CC}^2 \times f_o)$ = sum of outputs

For HC the condition is V_I = GND to V_{CC}

For HCT the condition is V_I = GND to V_{CC} −1.5 V

ƆERING INFORMATION

"74HC/HCT/HCU/HCMOS Logic Package Information".

DESCRIPTION

I NO.	SYMBOL	NAME AND FUNCTION
1, 9, 12	1A to 4A	data inputs
5, 10, 13	1B to 4B	data inputs
3, 8, 11	1Y to 4Y	data outputs
	GND	ground (0 V)
	V_{CC}	positive supply voltage

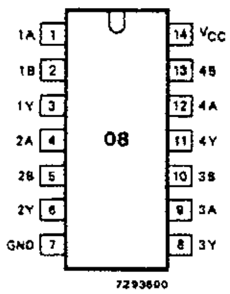


Fig.1 Pin configuration.

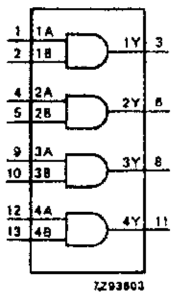


Fig.2 Logic symbol.

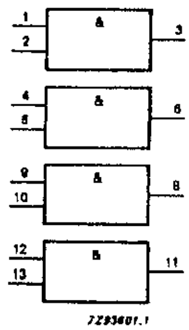


Fig.3 IEC logic symbol.

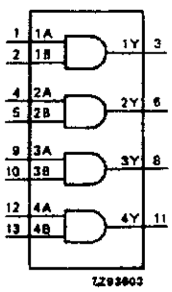


Fig.4 Functional diagram.

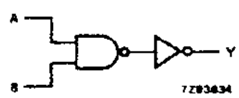


Fig.5 HC logic diagram (one gate).

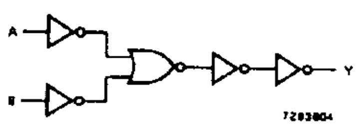


Fig.6 HCT logic diagram (one gate).

FUNCTION TABLE

INPUTS		OUTPUT
nA	nB	nY
L	L	L
L	H	L
H	L	L
H	H	H

Note

1. H = HIGH voltage level
   L = LOW voltage level

CHARACTERISTICS FOR 74HC

the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

ɔut capability: standard
ɔategory: SSI

CHARACTERISTICS FOR 74HC

) = 0 V; $t_r = t_f$ = 6 ns; C_L = 50 pF

MBOL	PARAMETER	T_{amb} (°C) 74HC +25 min.	typ.	max.	−40 to +85 min.	max.	−40 to +125 min.	max.	UNIT	TEST CONDITIONS V_{CC} (V)	WAVEFORMS
/ t_{PLH}	propagation delay nA, nB to nY		25 9 7	90 18 15		115 23 20		135 27 23	ns	2.0 4.5 6.0	Fig.7
/ t_{TLH}	output transition time		19 7 6	75 15 13		95 19 16		110 22 19	ns	2.0 4.5 6.0	Fig.7

Quad 2-input AND gate 74HC/HCT08

CHARACTERISTICS FOR 74HCT

the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

tput capability: standard
category: SSI

te to HCT types

value of additional quiescent supply current (ΔI_{CC}) for a unit load of 1 is given in the family specifications. determine ΔI_{CC} per input, multiply this value by the unit load coefficient shown in the table below.

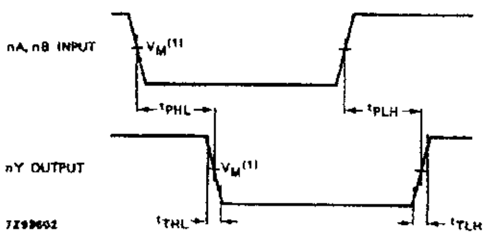
PUT	UNIT LOAD COEFFICIENT
., nB	0.6

CHARACTERISTICS FOR 74HCT

D = 0 V; $t_r = t_f$ = 6 ns; C_L = 50 pF

MBOL	PARAMETER	T_{amb} (°C)							UNIT	TEST CONDITIONS	
		74HCT								V_{CC} (V)	WAVEFORMS
		+25			−40 to +85		−40 to +125				
		min.	typ.	max.	min.	max.	min.	max.			
L/ t_{PLH}	propagation delay nA, nB to nY		14	24		30		36	ns	4.5	Fig.7
L/ t_{TLH}	output transition time		7	15		19		22	ns	4.5	Fig.7

WAVEFORMS



1) HC : V_M = 50%; V_I = GND to V_{CC}.
HCT: V_M = 1.3 V; V_I = GND to 3 V.

Fig.7 Waveforms showing the input (nA, nB) to output (nY) propagation delays and the output transition times.

KAGE OUTLINES

"74HC/HCT/HCU/HCMOS Logic Package Outlines".

INTEGRATED CIRCUITS

DATA SHEET

For a complete data sheet, please also download:

- The IC06 74HC/HCT/HCU/HCMOS Logic Family Specifications
- The IC06 74HC/HCT/HCU/HCMOS Logic Package Information
- The IC06 74HC/HCT/HCU/HCMOS Logic Package Outlines

74HC/HCT32
Quad 2-input OR gate

roduct specification
ile under Integrated Circuits, IC06

December 1990

ıilips
:miconductors

PHILIPS

ATURES

)utput capability: standard

ᴄᴄ category: SSI

GENERAL DESCRIPTION

The 74HC/HCT32 are high-speed Si-gate CMOS devices and are pin compatible with low power Schottky TTL (LSTTL). They are specified in compliance with JEDEC standard no. 7A.

The 74HC/HCT32 provide the 2-input OR function.

ICK REFERENCE DATA

D = 0 V; T_{amb} = 25 °C; $t_r = t_f$ = 6 ns

SYMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			HC	HCT	
$_{IL}$/ t_{PLH}	propagation delay nA, nB to nY	C_L = 15 pF; V_{CC} = 5 V	6	9	ns
	input capacitance		3.5	3.5	pF
$_D$	power dissipation capacitance per gate	notes 1 and 2	16	28	pF

:es

C_{PD} is used to determine the dynamic power dissipation (P_D in µW):

$$P_D = C_{PD} \times V_{CC}^2 \times f_i + \sum (C_L \times V_{CC}^2 \times f_o) \text{ where:}$$

f_i = input frequency in MHz
f_o = output frequency in MHz
$\sum (C_L \times V_{CC}^2 \times f_o)$ = sum of outputs
C_L = output load capacitance in pF
V_{CC} = supply voltage in V

For HC the condition is V_I = GND to V_{CC}
For HCT the condition is V_I = GND to V_{CC} − 1.5 V

DERING INFORMATION

"74HC/HCT/HCU/HCMOS Logic Package Information".

ʖuad 2-input OR gate 74HC/HCT32

DESCRIPTION

PIN NO.	SYMBOL	NAME AND FUNCTION
4, 9, 12	1A to 4A	data inputs
5, 10, 13	1B to 4B	data inputs
6, 8, 11	1Y to 4Y	data outputs
	GND	ground (0 V)
	V_{CC}	positive supply voltage

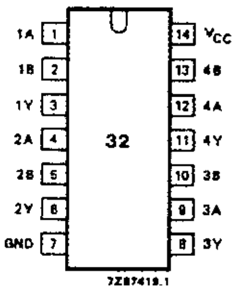


Fig.1 Pin configuration.

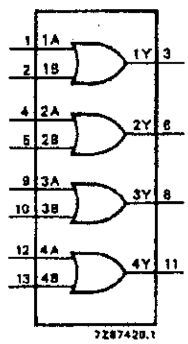


Fig.2 Logic symbol.

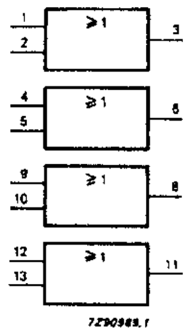


Fig.3 IEC logic symbol.

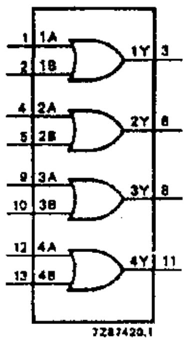


Fig.4 Functional diagram.

FUNCTION TABLE

INPUTS		OUTPUT
nA	nB	nY
L	L	L
L	H	H
H	L	H
H	H	H

Notes

1. H = HIGH voltage level
   L = LOW voltage level

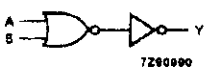


Fig.5 Logic diagram 74HC (one gate).

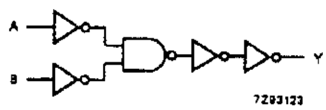


Fig.6 Logic diagram 74HCT (one gate).

CHARACTERISTICS FOR 74HC

the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

put capability: standard
category: SSI

CHARACTERISTICS FOR 74HC

ɔ = 0 V; t_r = t_f = 6 ns; C_L = 50 pF

MBOL	PARAMETER	T_{amb} (°C) 74HC +25 min.	typ.	max.	−40 to +85 min.	max.	−40 to +125 min.	max.	UNIT	TEST CONDITIONS V_{CC} (V)	WAVEFORMS
$_L$/ t_{PLH}	propagation delay nA, nB to nY		22 8 6	90 18 15		115 23 20		135 27 23	ns	2.0 4.5 6.0	Fig.7
_/ t_{TLH}	output transition time		19 7 6	75 15 13		95 19 16		110 22 19	ns	2.0 4.5 6.0	Fig.7

CHARACTERISTICS FOR 74HCT

the DC characteristics see *"74HC/HCT/HCU/HCMOS Logic Family Specifications"*.

ɔut capability: standard
ɔategory: SSI

ɜ to HCT types

value of additional quiescent supply current (ΔI_{CC}) for a unit load of 1 is given in the family specifications.
etermine ΔI_{CC} per input, multiply this value by the unit load coefficient shown in the table below.

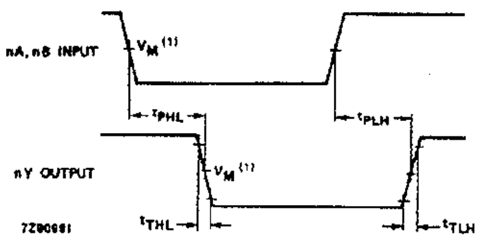
'UT	UNIT LOAD COEFFICIENT
nB	1.20

ɔHARACTERISTICS FOR 74HCT

) = 0 V; t_r = t_f = 6 ns; C_L = 50 pF

ИBOL	PARAMETER	T_{amb} (°C) 74HCT +25 min.	typ.	max.	−40 to +85 min.	max.	−40 to +125 min.	max.	UNIT	TEST CONDITIONS V_{CC} (V)	WAVEFORMS
/ t_{PLH}	propagation delay nA, nB to nY		11	24		30		36	ns	4.5	Fig.7
/ t_{TLH}	output transition time		7	15		19		22	ns	4.5	Fig.7

WAVEFORMS



1) HC : V_M = 50%; V_I = GND to V_{CC}.
HCT: V_M = 1.3 V; V_I = GND to 3 V.

Fig.7 Waveforms showing the input (nA, nB) to output (nY) propagation delays and the output transition times.

:KAGE OUTLINES

"74HC/HCT/HCU/HCMOS Logic Package Outlines".

APPENDIX E

ANALOGUE TO DIGITAL CONVERTER; 74148 DATA SHEETS

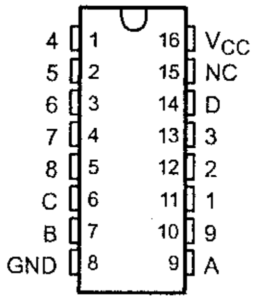
'147, 'LS147

- **Encode 10-Line Decimal to 4-Line BCD**
- **Applications Include:**
  - Keyboard Encoding
  - Range Selection

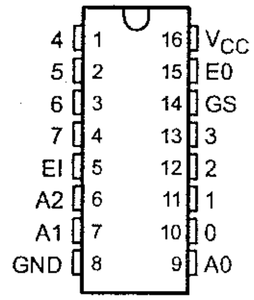
'148, 'LS148

- **Encode 8 Data Lines to 3-Line Binary (Octal)**
- **Applications Include:**
  - n-Bit Encoding
  - Code Converters and Generators

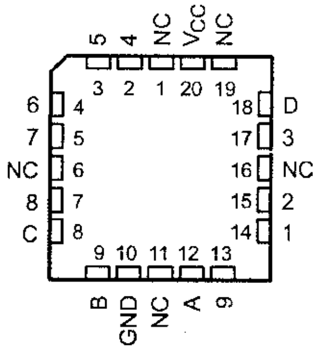
SN54147, SN54LS147 . . . J OR W PACKAGE
SN74147, SN74LS147 . . . D OR N PACKAGE
(TOP VIEW)



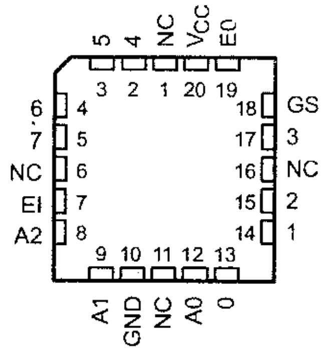
SN54148, SN54LS148 . . . J OR W PACKAGE
SN74148, SN74LS148 . . . D, N, OR NS PACKAGE
(TOP VIEW)



SN54LS147 . . . FK PACKAGE
(TOP VIEW)



SN54LS148 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

TYPE	TYPICAL DATA DELAY	TYPICAL POWER DISSIPATION
'147	10 ns	225 mW
'148	10 ns	190 mW
'LS147	15 ns	60 mW
'LS148	15 ns	60 mW

TE: The SN54147, SN54LS147, SN54148, SN74147, SN74LS147, and SN74148 are obsolete and are no longer supplied.

iption/ordering information

hese TTL encoders feature priority decoding of the inputs to ensure that only the highest-order data line is ncoded. The '147 and 'LS147 devices encode nine data lines to four-line (8-4-2-1) BCD. The implied decimal ero condition requires no input condition, as zero is encoded when all nine data lines are at a high logic level. 'he '148 and 'LS148 devices encode eight data lines to three-line (4-2-1) binary (octal). Cascading circuitry enable input EI and enable output EO) has been provided to allow octal expansion without the need for external ircuitry. For all types, data inputs and outputs are active at the low logic level. All inputs are buffered to represent ne normalized Series 54/74 or 54/74LS load, respectively.

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP – N	Tube	SN74LS148N	SN74LS148N
	SOIC – D	Tube	SN74LS148D	LS148
		Tape and reel	SN74LS148DR	
	SOP – NS	Tape and reel	SN74LS148NSR	74LS148
–55°C to 125°C	CDIP – J	Tube	SNJ54LS148J	SNJ54LS148J
	CFP – W	Tube	SNJ54LS148W	SNJ54LS148W
	LCCC – FK	Tube	SNJ54LS148FK	SNJ54LS148FK

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

FUNCTION TABLE – '147, 'LS147

INPUTS									OUTPUTS			
1	2	3	4	5	6	7	8	9	D	C	B	A
H	H	H	H	H	H	H	H	H	H	H	H	H
X	X	X	X	X	X	X	X	L	L	H	H	L
X	X	X	X	X	X	X	L	H	L	H	H	H
X	X	X	X	X	X	L	H	H	H	L	L	L
X	X	X	X	X	L	H	H	H	H	L	L	H
X	X	X	X	L	H	H	H	H	H	L	H	L
X	X	X	L	H	H	H	H	H	H	L	H	H
X	X	L	H	H	H	H	H	H	H	H	L	L
X	L	H	H	H	H	H	H	H	H	H	L	H
L	H	H	H	H	H	H	H	H	H	H	H	L

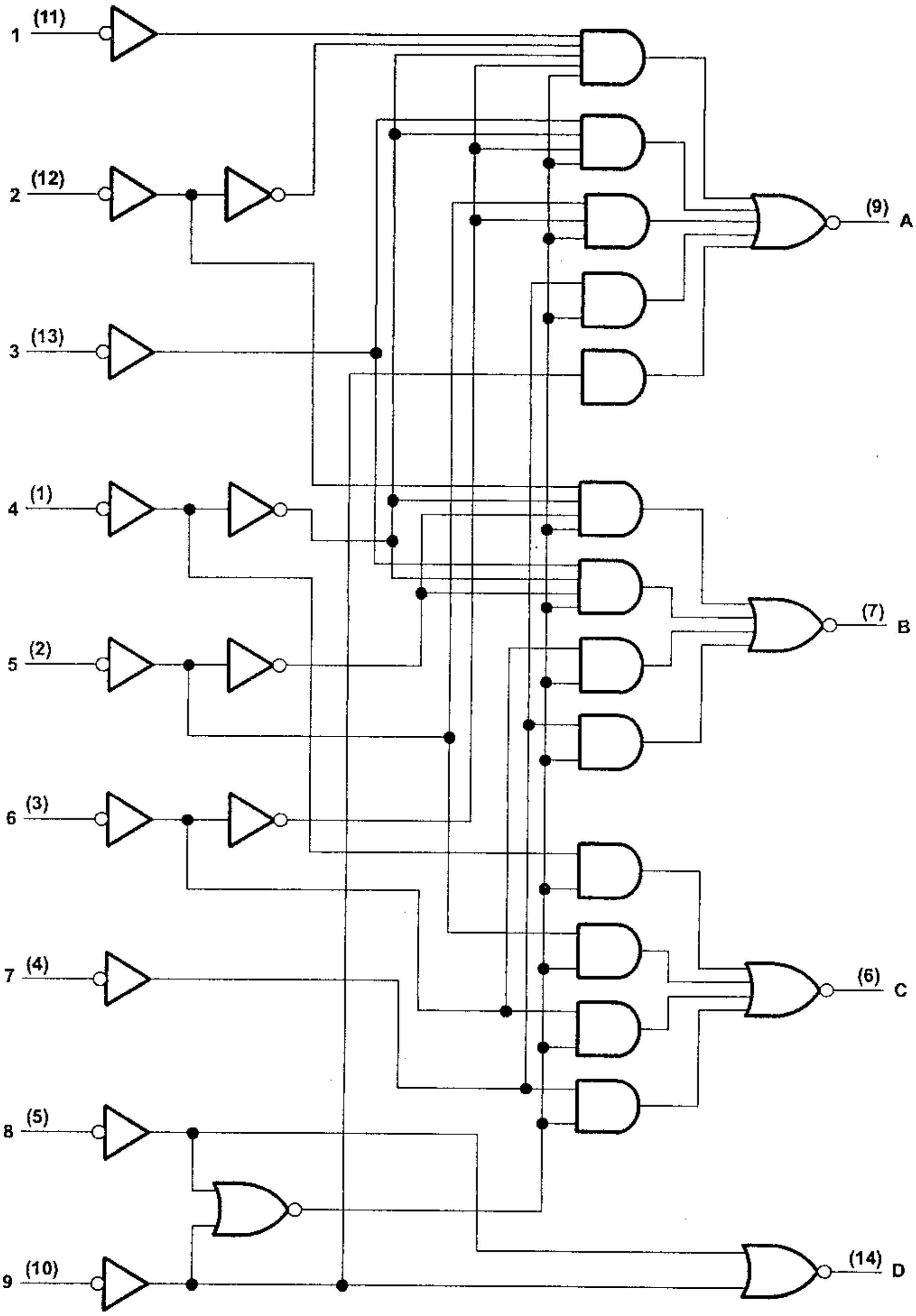
H = high logic level, L = low logic level, X = irrelevant

FUNCTION TABLE – '148, 'LS148

INPUTS									OUTPUTS				
EI	0	1	2	3	4	5	6	7	A2	A1	A0	GS	EO
H	X	X	X	X	X	X	X	X	H	H	H	H	H
L	H	H	H	H	H	H	H	H	H	H	H	H	L
L	X	X	X	X	X	X	X	L	L	L	L	L	H
L	X	X	X	X	X	X	L	H	L	L	H	L	H
L	X	X	X	X	X	L	H	H	L	H	L	L	H
L	X	X	X	X	L	H	H	H	L	H	H	L	H
L	X	X	X	L	H	H	H	H	H	L	L	L	H
L	X	X	L	H	H	H	H	H	H	L	H	L	H
L	X	L	H	H	H	H	H	H	H	H	L	L	H
L	L	H	H	H	H	H	H	H	H	H	H	L	H

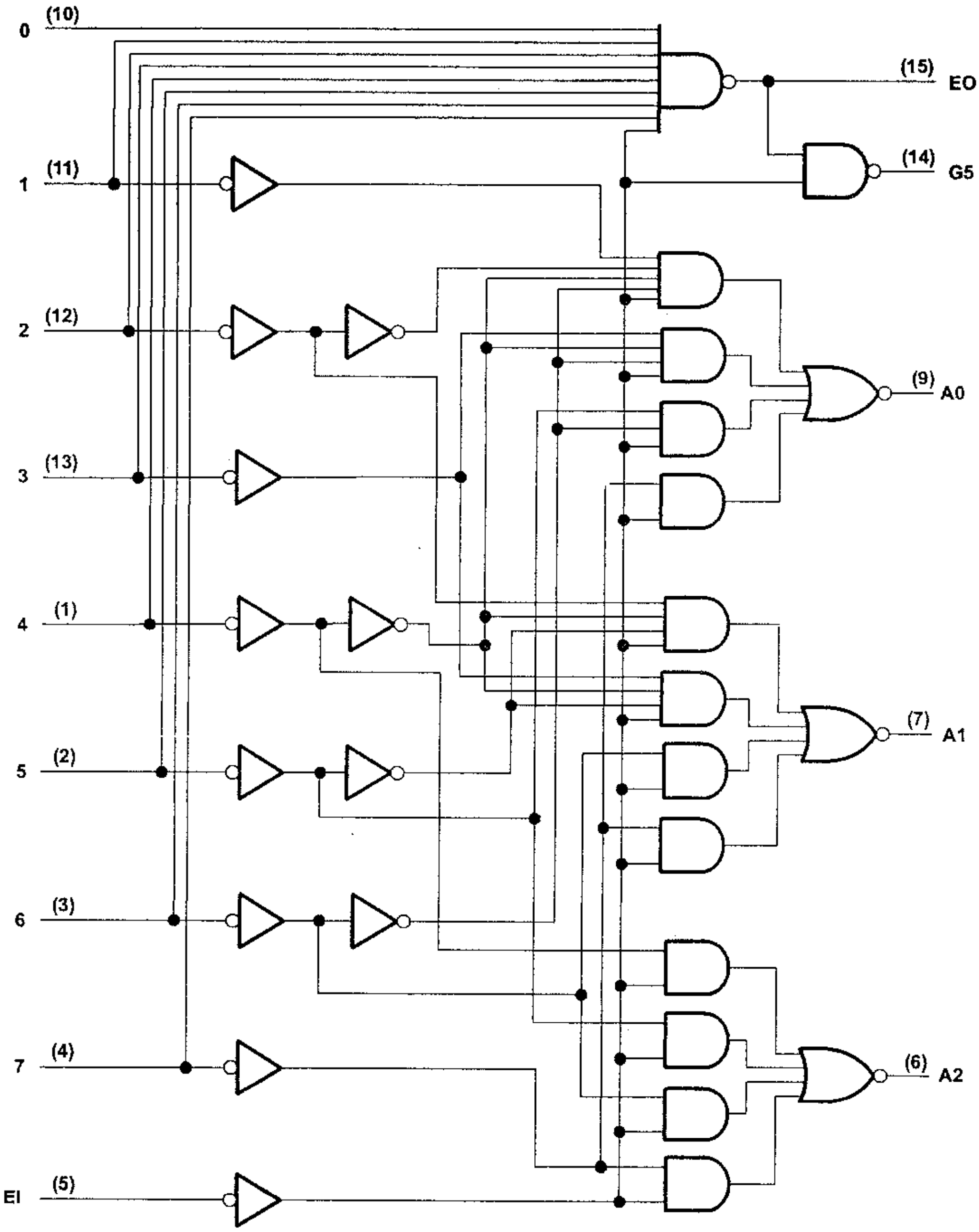
H = high logic level, L = low logic level, X = irrelevant

'LS147 logic diagram (positive logic)



ıbers shown are for D, J, N, and W packages.

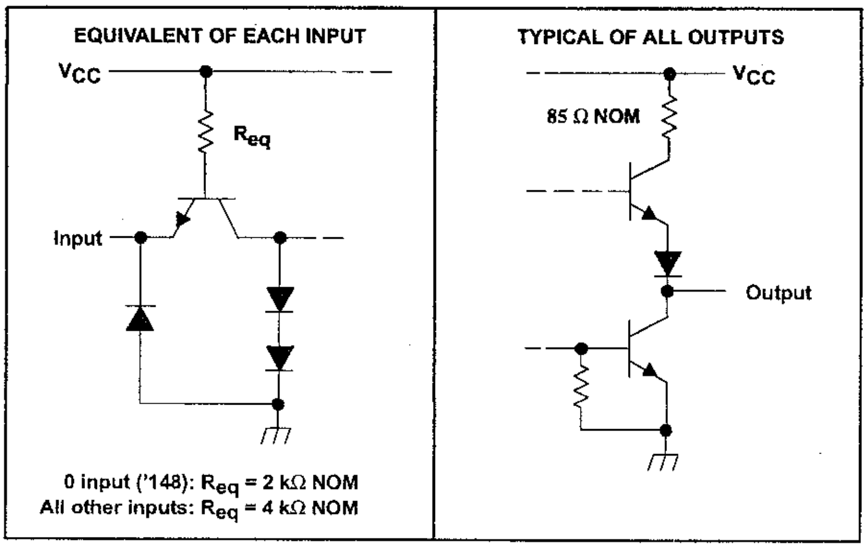
48, 'LS148 logic diagram (positive logic)



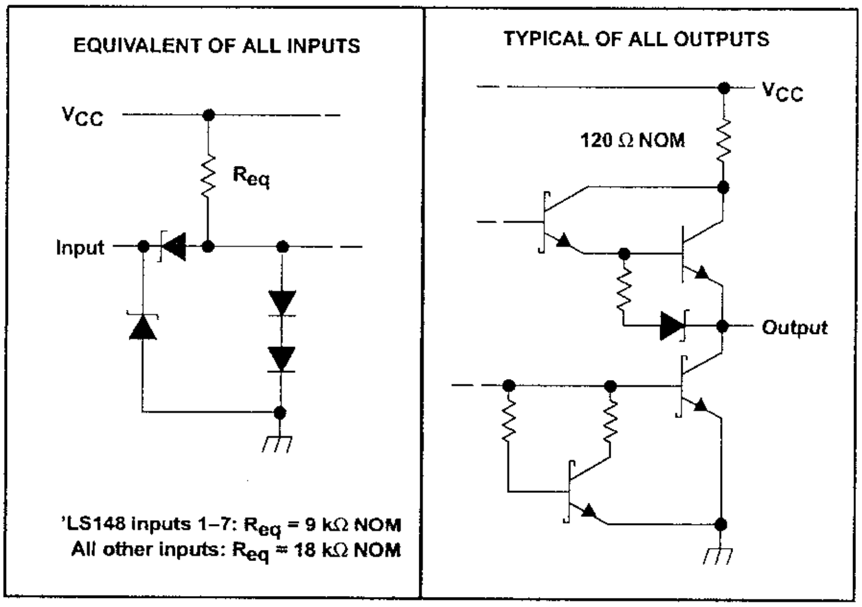
in numbers shown are for D, J, N, NS, and W packages.

natics of inputs and outputs

'147, '148



'LS147, 'LS148



bsolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Supply voltage, V_{CC} (see Note 1) .... 7 V
Input voltage, V_I: '147, '148 .... 5.5 V
'LS147, 'LS148 .... 7 V
Inter-emitter voltage: '148 only (see Note 2) .... 5.5 V
Package thermal impedance θ_{JA} (see Note 3): D package .... 73°C/W
N package .... 67°C/W
NS package .... 64°C/W
Storage temperature range, T_{stg} .... −65°C to 150°C

Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not 'mplied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

OTES: 1. Voltage values, except inter-emitter voltage, are with respect to the network ground terminal.
2. This is the voltage between two emitters of a multiple-emitter transistor. For '148 circuits, this rating applies between any two of the eight data lines, 0 through 7.
3. The package thermal impedance is calculated in accordance with JESD 51-7.

ecommended operating conditions (see Note 4)

		SN54'			SN74'			SN54LS'			SN74LS'			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	
'CC	Supply voltage	4.5	5	5.5	4.75	5	5.25	4.5	5	5.5	4.75	5	5.25	V
OH	High-level output current			−800			−800			−400			−400	μA
OL	Low-level output current			16			16			4			8	mA
'A	Operating free-air temperature	−55		125	0		70	−55		125	0		70	°C

OTE 4: All unused inputs of the device must be held at V_{CC} or GND to ensure proper device operation. Refer to the TI application report, *Implications of Slow or Floating CMOS Inputs*, literature number SCBA004.

·ical characteristics over recommended operating free-air temperature range (unless wise noted)

PARAMETER		TEST CONDITIONS†		'147 MIN	'147 TYP‡	'147 MAX	'148 MIN	'148 TYP‡	'148 MAX	UNIT
High-level input voltage				2			2			V
Low-level input voltage						0.8			0.8	V
Input clamp voltage		V_{CC} = MIN,	I_I = −12 mA			−1.5			−1.5	V
High-level output voltage		V_{CC} = MIN, V_{IL} = 0.8 V,	V_{IH} = 2 V, I_{OH} = −800 μA	2.4	3.3		2.4	3.3		V
Low-level output voltage		V_{CC} = MIN, V_{IL} = 0.8 V,	V_{IH} = 2 V, I_{OL} = 16 mA		0.2	0.4		0.2	0.4	V
Input current at maximum input voltage		V_{CC} = MIN,	V_I = 5.5 V			1			1	mA
High-level input current	0 input	V_{CC} = MAX,	V_I = 2.4 V						40	μA
	Any input except 0					40			80	
Low-level input current	0 input	V_{CC} = MAX,	V_I = 0.4 V						−1.6	mA
	Any input except 0					−1.6			−3.2	
Short-circuit output current§		V_{CC} = MAX		−35		−85	−35		−85	mA
Supply current		V_{CC} = MAX (See Note 5)	Condition 1		50	70		40	60	mA
			Condition 2		42	62		35	55	

nditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
cal values are at V_{CC} = 5 V, T_A = 25°C.
›re than one output should be shorted at a time.
: For '147, I_{CC} (Condition 1) is measured with input 7 grounded, other inputs and outputs open; I_{CC} (Condition 2) is measured with all inputs and outputs open. For '148, I_{CC} (Condition 1) is measured with inputs 7 and EI grounded, other inputs and outputs open; I_{CC} (Condition 2) is measured with all inputs and outputs open.

147, SN74147 switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

\METER	FROM (INPUT)	TO (OUTPUT)	WAVEFORM	TEST CONDITIONS	MIN	TYP	MAX	UNIT
PLH	Any	Any	In-phase output	C_L = 15 pF, R_L = 400 Ω		9	14	ns
PHL						7	11	
PLH	Any	Any	Out-of-phase output			13	19	ns
PHL						12	19	

N54148, SN74148 switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 1)

PARAMETER†	FROM (INPUT)	TO (OUTPUT)	WAVEFORM	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{PLH}	1–7	A0, A1, or A2	In-phase output	C_L = 15 pF, R_L = 400 Ω		10	15	ns
t_{PHL}						9	14	
t_{PLH}	1–7	A0, A1, or A2	Out-of-phase output			13	19	ns
t_{PHL}						12	19	
t_{PLH}	0–7	EO	Out-of-phase output			6	10	ns
t_{PHL}						14	25	
t_{PLH}	0–7	GS	In-phase output			18	30	ns
t_{PHL}						14	25	
t_{PLH}	EI	A0, A1, or A2	In-phase output			10	15	ns
t_{PHL}						10	15	
t_{PLH}	EI	GS	In-phase output			8	12	ns
t_{PHL}						10	15	
t_{PLH}	EI	EO	In-phase output			10	15	ns
t_{PHL}						17	30	

PLH = propagation delay time, low-to-high-level output.
PHL = propagation delay time, high-to-low-level output.

ectrical characteristics over recommended operating free-air temperature range (unless :herwise noted)

PARAMETER			TEST CONDITIONS†		SN54LS' MIN	SN54LS' TYP‡	SN54LS' MAX	SN74LS' MIN	SN74LS' TYP‡	SN74LS' MAX	UNIT
IH	High-level input voltage				2			2			V
IL	Low-level input voltage						0.7			0.8	V
IK	Input clamp voltage		V_{CC} = MIN,	I_I = −18 mA			−1.5			−1.5	V
OH	High-level output voltage		V_{CC} = MIN, V_{IL} = 0.8 V,	V_{IH} = 2 V, I_{OH} = −400 μA	2.5	3.4		2.7	3.4		V
OL	Low-level output voltage		V_{CC} = MIN, V_{IH} = 2 V, V_{IL} = V_{IL} MAX	I_{OL} = 4 mA		0.25	0.4		0.25	0.4	V
				I_{OL} = 8 mA					0.35	0.5	
	Input current at maximum input voltage	'LS148 inputs 1–7	V_{CC} = MAX,	V_I = 7 V			0.2			0.2	mA
		All other inputs					0.1			0.1	
H	High-level input current	'LS148 inputs 1–7	V_{CC} = MAX,	V_I = 2.7 V			40			40	μA
		All other inputs					20			20	
-	Low-level input current	'LS148 inputs 1–7	V_{CC} = MAX,	V_I = 0.4 V			−0.8			−0.8	mA
		All other inputs					−0.4			−0.4	
)S	Short-circuit output current§		V_{CC} = MAX		−20		−100	−20		−100	mA
:C	Supply current		V_{CC} = MAX (See Note 6)	Condition 1		12	20		12	20	mA
				Condition 2		10	17		10	17	

or conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
.ll typical values are at V_{CC} = 5 V, T_A = 25°C.
lot more than one output should be shorted at a time.
ITE 6: For 'LS147, I_{CC} (Condition 1) is measured with input 7 grounded, other inputs and outputs open; I_{CC} (Condition 2) is measured with all inputs and outputs open. For 'LS148, I_{CC} (Condition 1) is measured with inputs 7 and EI grounded, other inputs and outputs open; I_{CC} (Condition 2) is measured with all inputs and outputs open.

LS147, SN74LS147 switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 2)

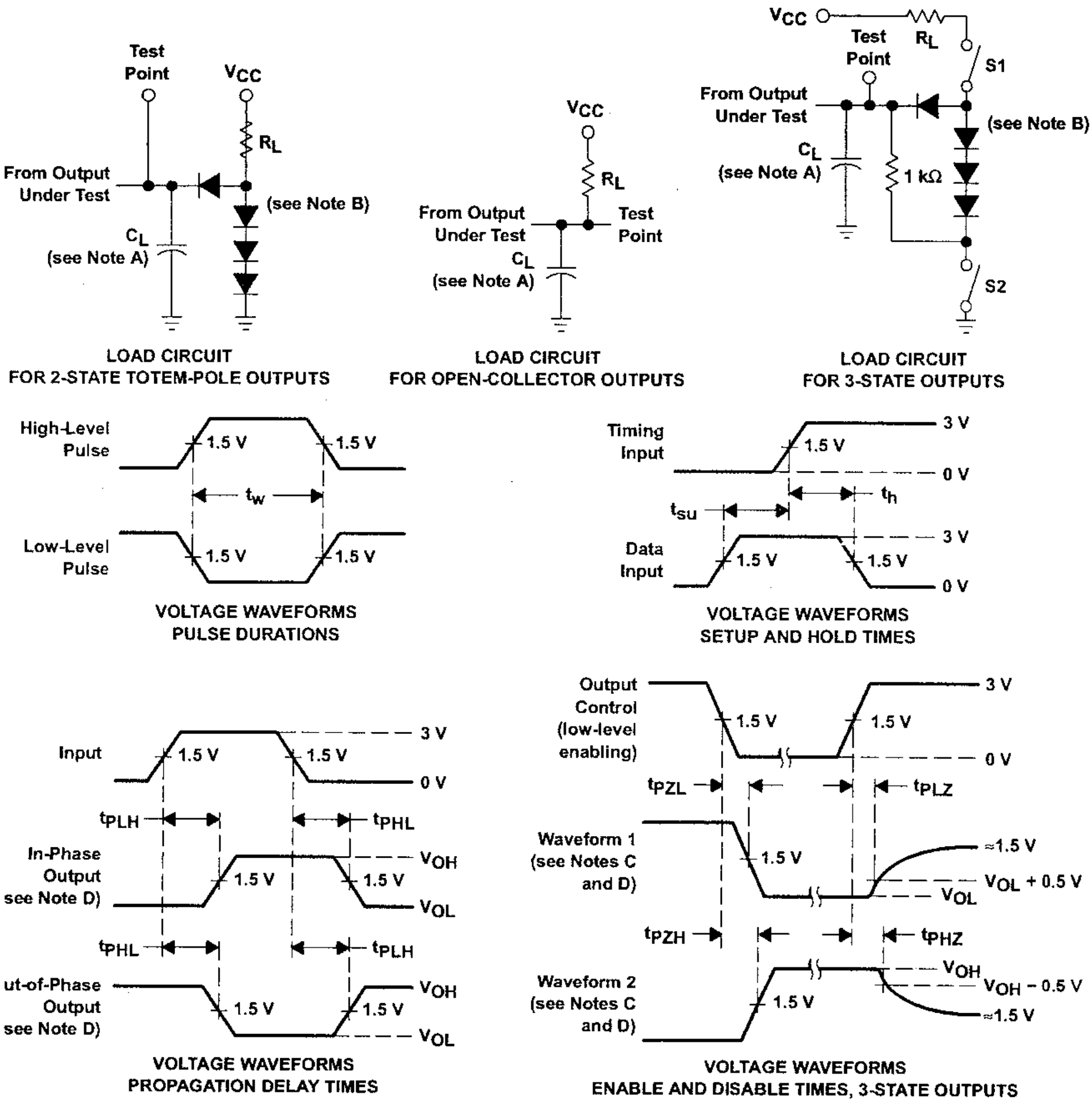
AMETER	FROM (INPUT)	TO (OUTPUT)	WAVEFORM	TEST CONDITIONS	MIN	TYP	MAX	UNIT
PLH	Any	Any	In-phase output	C_L = 15 pF, R_L = 2 kΩ		12	18	ns
PHL						12	18	
PLH	Any	Any	Out-of-phase output			21	33	ns
PHL						15	23	

LS148, SN74LS148 switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Figure 2)

METER†	FROM (INPUT)	TO (OUTPUT)	WAVEFORM	TEST CONDITIONS	MIN	TYP	MAX	UNIT
PLH	1–7	A0, A1, or A2	In-phase output	C_L = 15 pF, R_L = 2 kΩ		14	18	ns
PHL						15	25	
PLH	1–7	A0, A1, or A2	Out-of-phase output			20	36	ns
PHL						16	29	
PLH	0–7	EO	Out-of-phase output			7	18	ns
PHL						25	40	
PLH	0–7	GS	In-phase output			35	55	ns
PHL						9	21	
PLH	EI	A0, A1, or A2	In-phase output			16	25	ns
PHL						12	25	
PLH	EI	GS	In-phase output			12	17	ns
PHL						14	36	
PLH	EI	EO	In-phase output			12	21	ns
PHL						23	35	

propagation delay time, low-to-high-level output
propagation delay time, high-to-low-level output

PARAMETER MEASUREMENT INFORMATION
SERIES 54/74 DEVICES



OTES: A. C_L includes probe and jig capacitance.
B. All diodes are 1N3064 or equivalent.
C. Waveform 1 is for an output with internal conditions such that the output is low, except when disabled by the output control. Waveform 2 is for an output with internal conditions such that the output is high, except when disabled by the output control.
D. S1 and S2 are closed for t_{PLH}, t_{PHL}, t_{PHZ}, and t_{PLZ}; S1 is open, and S2 is closed for t_{PZH}; S1 is closed, and S2 is open for t_{PZL}.
E. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, $Z_O \approx 50\ \Omega$; t_r and t_f ≤ 7 ns for Series 54/74 devices and t_r and t_f ≤ 2.5 ns for Series 54S/74S devices.
F. The outputs are measured one at a time, with one input transition per measurement.

Figure 1. Load Circuits and Voltage Waveforms

National Semiconductor

November 1994

LM741 Operational Amplifier

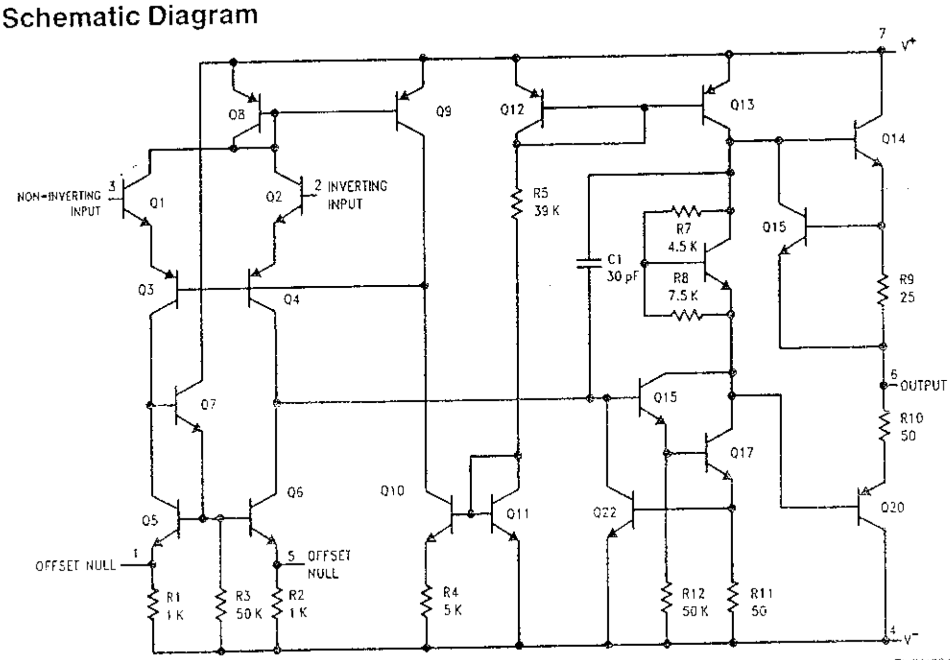
General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

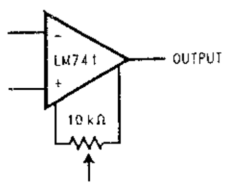
The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



TL/H/9341-1

Offset Nulling Circuit



TL/H/9341-7

bsolute Maximum Ratings

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

ote 5)

	LM741A	LM741E	LM741	LM741C
pply Voltage	±22V	±22V	±22V	±18V
wer Dissipation (Note 1)	500 mW	500 mW	500 mW	500 mW
ferential Input Voltage	±30V	±30V	±30V	±30V
ut Voltage (Note 2)	±15V	±15V	±15V	±15V
tput Short Circuit Duration	Continuous	Continuous	Continuous	Continuous
erating Temperature Range	−55°C to +125°C	0°C to +70°C	−55°C to +125°C	0°C to +70°C
orage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
nction Temperature	150°C	100°C	150°C	100°C
ldering Information				
N-Package (10 seconds)	260°C	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C	300°C
M-Package				
Vapor Phase (60 seconds)	215°C	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C	215°C

e AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering rface mount devices.

D Tolerance (Note 6)	400V	400V	400V	400V

lectrical Characteristics (Note 3)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
ıt Offset Voltage	$T_A = 25°C$, $R_S \le 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \le 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \le T_A \le T_{AMAX}$, $R_S \le 50\Omega$			4.0							mV
	$R_S \le 10\ k\Omega$						6.0			7.5	mV
rage Input Offset age Drift				15							µV/°C
ıt Offset Voltage ustment Range	$T_A = 25°C$, $V_S = \pm 20V$	±10				±15			±15		mV
ıt Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			70		85	500			300	nA
rage Input Offset rent Drift				0.5							nA/°C
ıt Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	µA
ut Resistance	$T_A = 25°C$, $V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \le T_A \le T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
ut Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \le T_A \le T_{AMAX}$				±12	±13					V
ge Signal Voltage Gain	$T_A = 25°C$, $R_L \ge 2\ k\Omega$, $V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \le T_A \le T_{AMAX}$, $R_L \ge 2\ k\Omega$, $V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV

Electrical Characteristics (Note 3) (Continued)

Parameter	Conditions	LM741A/LM741E			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$ $R_L \geq 10\ k\Omega$ $R_L \geq 2\ k\Omega$	±16 ±15									V V
	$V_S = \pm 15V$ $R_L \geq 10\ k\Omega$ $R_L \geq 2\ k\Omega$				±12 ±10	±14 ±13		±12 ±10	±14 ±13		V V
Output Short Circuit Current	$T_A = 25°C$ $T_{AMIN} \leq T_A \leq T_{AMAX}$	10 10	25	35 40		25			25		mA mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$ $R_S \leq 10\ k\Omega, V_{CM} = \pm 12V$ $R_S \leq 50\Omega, V_{CM} = \pm 12V$	80	95		70	90		70	90		dB dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$ to $V_S = \pm 5V$ $R_S \leq 50\Omega$ $R_S \leq 10\ k\Omega$	86	96		77	96		77	96		dB dB
Transient Response Rise Time Overshoot	$T_A = 25°C$, Unity Gain		0.25 6.0	0.8 20		0.3 5			0.3 5		μs %
Bandwidth (Note 4)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/μs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$ $V_S = \pm 20V$ $V_S = \pm 15V$		80	150		50	85		50	85	mW mW
LM741A	$V_S = \pm 20V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$			165 135							mW mW
LM741E	$V_S = \pm 20V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$			150 150							mW mW
LM741	$V_S = \pm 15V$ $T_A = T_{AMIN}$ $T_A = T_{AMAX}$					60 45	100 75				mW mW

Note 1: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 2: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 3: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

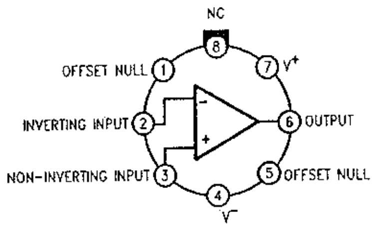
Note 4: Calculated value from: BW (MHz) = 0.35/Rise Time(μs).

Note 5: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

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

onnection Diagrams

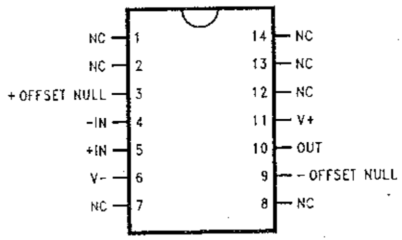
Metal Can Package



TL/H/9341-2

Order Number LM741H, LM741H/883*, LM741AH/883 or LM741CH
See NS Package Number H08C

Ceramic Dual-In-Line Package

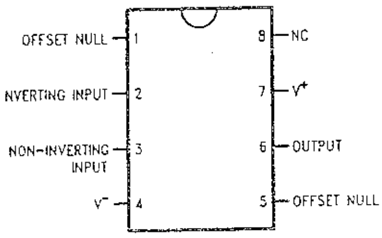


TL/H/9341-5

Order Number LM741J-14/883*, LM741AJ-14/883**
See NS Package Number J14A

*also available per JM38510/10101
**also available per JM38510/10102

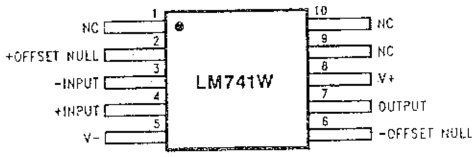
Dual-In-Line or S.O. Package



TL/H/9341-3

Order Number LM741J, LM741J/883, LM741CM, LM741CN or LM741EN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

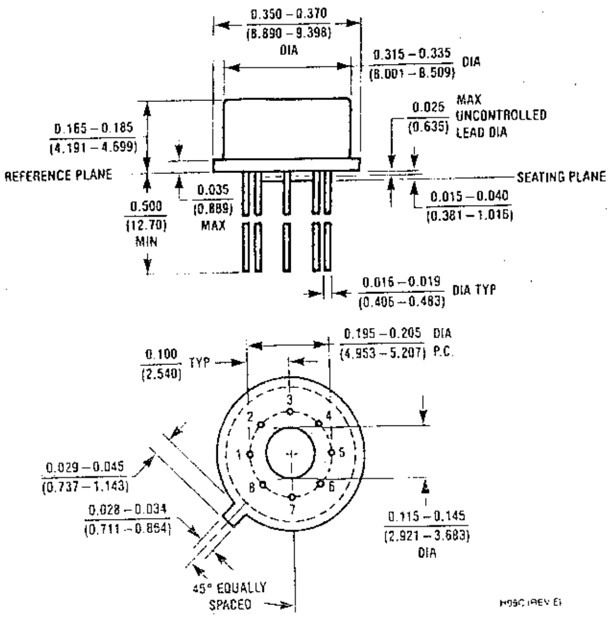


TL/H/9341-6

Order Number LM741W/883
See NS Package Number W10A

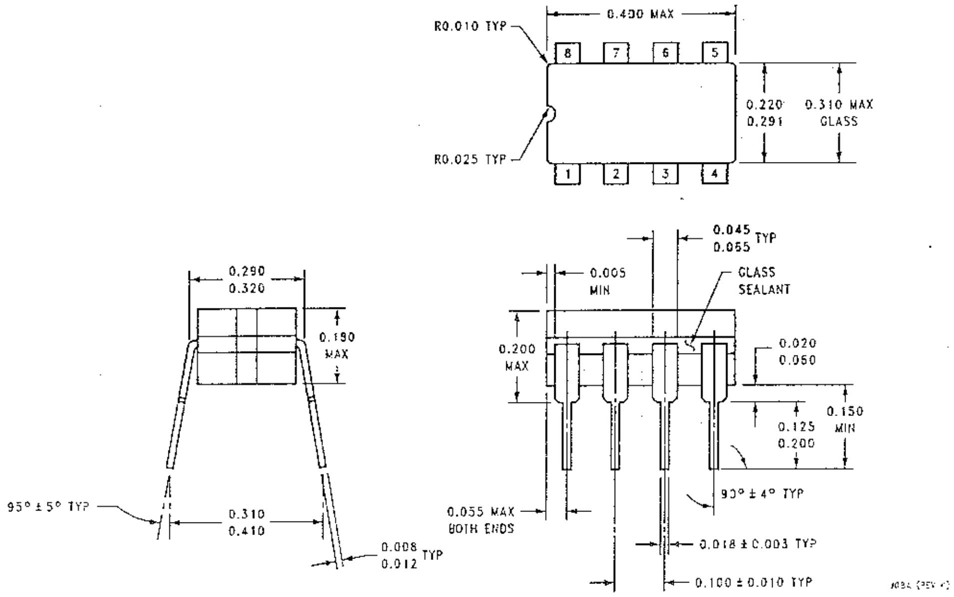
LM741H is available per JM38510/10101

Physical Dimensions inches (millimeters)

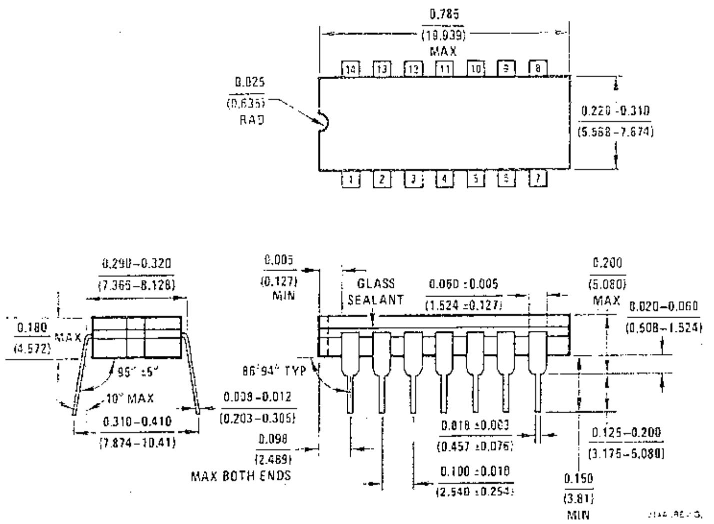


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741CH or LM741EH
NS Package Number H08C

hysical Dimensions inches (millimeters) (Continued)

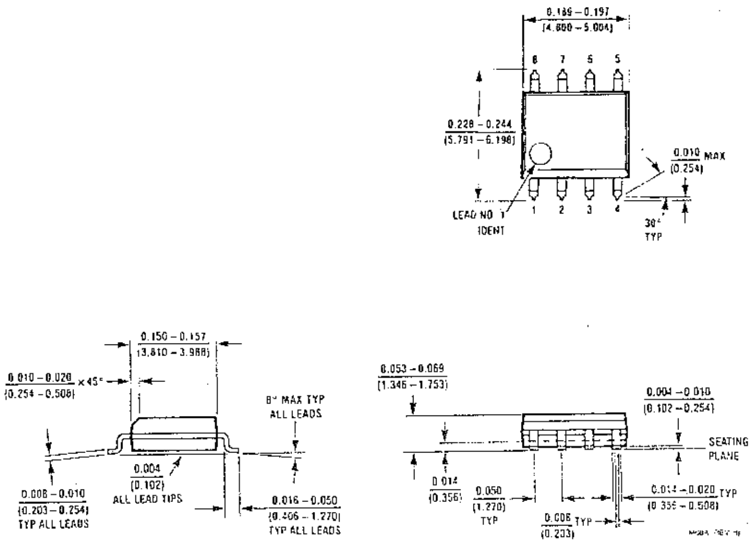


Ceramic Dual-In-Line Package (J)
Order Number LM741CJ or LM741J/883
NS Package Number J08A

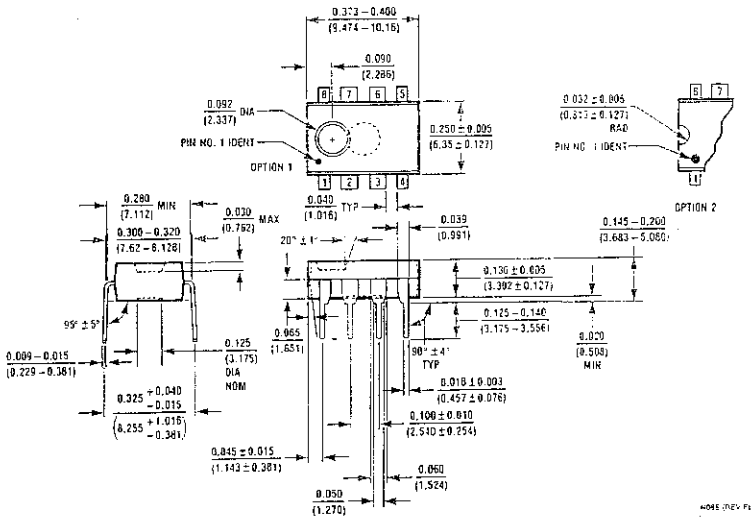


Ceramic Dual-In-Line Package (J)
Order Number LM741J-14/883 or LM741AJ-14/883
NS Package Number J14A

Physical Dimensions inches (millimeters) (Continued)

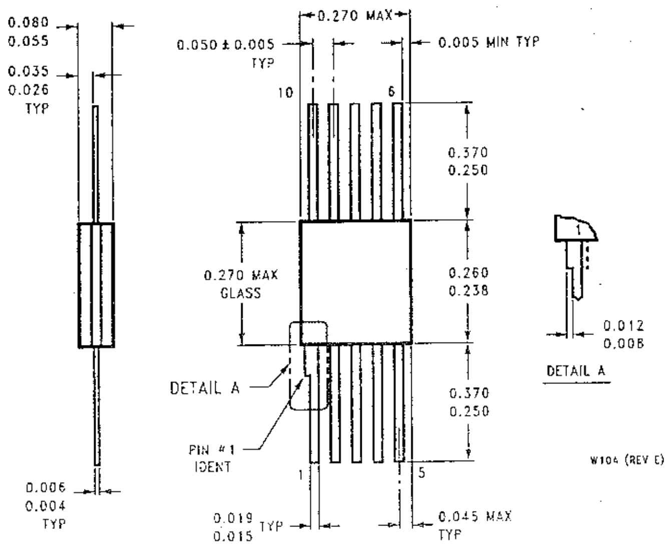


Small Outline Package (M)
Order Number LM741CM
NS Package Number M08A



Dual-In-Line Package (N)
Order Number LM741CN or LM741EN
NS Package Number N08E

Physical Dimensions inches (millimeters) (Continued)



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883
NS Package Number W10A

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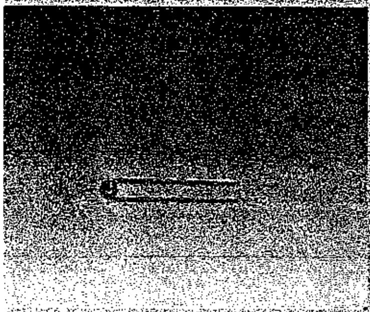
Fax: 81-043-299-2408

APPENDIX F

THERMISTOR DATASHEETS

Related Order Codes Done



disc NTC thermistors for temperature compensation, measurement and control.

e 25 degrees C +/-5%	Beta Value 25 degrees C to 100 degrees C, +/-3%	Mftrs. List No.	Order Code
	3200	B576164K101J	679-320
	3730	B576164K102J	679-331
	3950	B576164K472J	679-343
	4300	B576164K103J	679-355
	4600	B576164K104J	679-367
	5000	B576164K474J	679-379

e 25 degrees C	Order Code	Price Each				
		1+	50+	100+	250+	500+
	679-320					
	679-331					
	679-343					
	679-355					
	679-367					
	679-379					

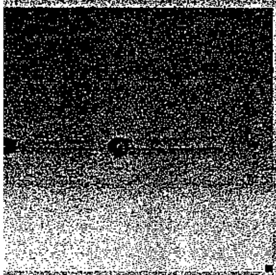
Related Order Codes Zoom Out 100% Zoom In Print Back Done

TC thermistors for high precision temperature measurement in measuring and control engineering.

25 degrees C	Beta Value 25 degrees C to 100 degrees C	Non-Insulated		PTFE Insulated	
		Mftrs. List No.	Order Code	Mftrs. List No.	Order Code
	3988 +/-1%	B57867S302F40	679-380	B57861S302F40	679-422
	3988 +/-1%	B57867S502F40	679-392	B57861S502F40	679-434
%	3988 +/-1%	B57867S103F40	679-409	B57861S103F40	679-446
6	3964 +/-1%	B57867S303F40	679-410	B57861S303F40	679-458

25 degrees C	Leads	Order Code	Price Each				
			1+	50+	100+	250+	500+
	Non-insulated	679-380					
	Non-insulated	679-392					
	Non-insulated	679-409					
	Non-insulated	679-410					
	PTFE-insulated	679-422					
	PTFE-insulated	679-434					
	PTFE-insulated	679-446					
	PTFE-insulated	679-458					

25 degrees C 60mW



ıermistors designed for use in temperature measurement, control and

ion applications

e	Beta Value 25 degrees C to 100 degrees C	Mftrs. List No.	Order Code
%	3000 +/- 3%	KED150CY	151-116
0%	3650 +/- 3%	KED221CY	731-330
0%	3750 +/- 3%	KED331CY	731-341
0%	3850 +/- 3%	KED471CY	731-353
0%	3950 +/- 3%	KED681CY	731-365
%	4000 +/- 3%	KED102CY	151-117
0%	4150 +/- 3%	KED222CY	151-118
0%	4300 +/- 3%	KED472CY	151-119
0%	4400 +/- 3%	KED103CY	151-120

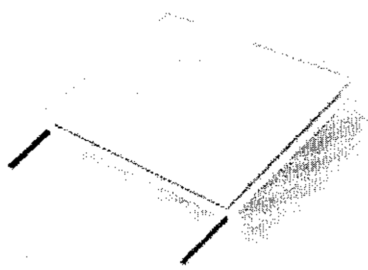
	Price Each			
	1+	25+	50+	100+
odes				

re, max. +125 degrees C Rated dissipation 25 degrees C 900mWDissipation factor 9mW/ degrees C

APPENDIX G

FUNDAMENTAL THERMOELECTRIC BY ADVANCE THERMOELECTRICS

Thermoelectric modules are solid-state devices (no moving parts) that convert electrical energy into a temperature gradient, known as the "Peltier effect" or convert thermal energy from a temperature gradient into electrical energy, the "Seebeck effect." Thermoelectric modules used as TE generators or TEGs are rather inefficient and little power is produced. Typical applications of this type include NASA supplying power to spacecraft and electronic equipment along fuel pipelines where fuel may be burned off. TE modules may also be used as thermocouples for temperature measurement. This discussion will focus on the use of thermoelectric modules TEMs for cooling TECs and for temperature stabilization.



With no moving parts, thermoelectric modules are rugged, reliable and quiet heat pumps, typically 1.5 inches (40 x 40mm) square or smaller and approximately ¼ inch (4 mm) thick. The industry standard mean time between failures is around 200,000 hours or over 20 years for modules left in the cooling mode. When the appropriate power is applied, from a battery or other DC source, one side of the module will be made cold while the other is made hot. Click here to see how they work. Interestingly, if the polarity or current flow through the module is revered the cold side will become the hot side and vice versa. This allows TE modules to be used for heating, cooling and temperature stabilization.

Since TE modules are electrical in nature, in a closed-loop system with an appropriate temperature sensor and controller, TE modules can easily maintain temperatures that vary by less than one degree Celsius. Simpler on - off control can also be produced with a thermostat.

Because the cold side of the module contracts while the hot side expands modules with a footprint larger than 1.5 - 2 inches square usually suffer from thermally induced stresses, at the electrical connection points inside the module causing a short, so they are not common. Long, thin modules want to bow for the same reason and are also rare. Larger areas than an individual module can maintain are cooled or have the temperature controlled by using multiple modules.

We know from the second law of thermodynamics that heat will move to a cooler area. Essentially, the module will absorb heat on the "cold side" and eject it out the "hot side" to a heat sink. The addition of a heat sink to a module creates a thermoelectric device or TED. In addition to the heat being removed from the object being cooled, the heat sink must be capable of dissipating the electrical power applied to the module, which also exits through the modules hot side.

As any Electrical Engineer will tell you the resistive or "Joule heat" created is proportional to the square of the current applied (I^2 R). This is NOT the case with thermoelectric modules. The heat created is actually proportional to the current (amperes x volts) because of the flow of current is working in two directions (the Peltier effect). Therefore, the total heat ejected by the module is the sum of the current times the voltage plus the heat being pumped through the cold side.

To understand the capabilities of a thermoelectric module, and related assembly, it is necessary to understand what TE module specifications represent and their implications. The four standard specifications for a module are 1.) The heat pumping capacity or Qmax in watts 2.) The maximum achievable difference in temperature between the hot and cold sides of the module known as the Delta Tmax or ΔTmax, usually represented in degrees Celsius 3.) The maximum (optimal) input current in amps or Imax 4.) The maximum input voltage or Vmax when the current input is optimal (Imax).

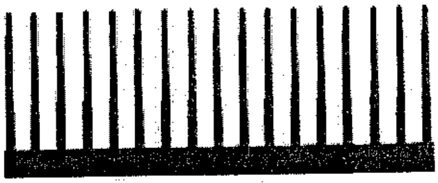
As a practical matter it is only possible reach either heat pumping capacity in watts or to obtain the maximum temperature differential in degrees. In other words, the DTmax is the maximum temperature difference between the hot and cold side of the module when optimal power is applied and there is no heat load (Q=0). As a thermal load Q is added, the difference in temperature between the two surfaces will decrease until the heat pumping capacity or Qmax value is achieved and there is no net cooling (DT=0). Since your application will likely require net cooling of an object with a thermal mass, the actual heat pumped or Q will be less than Qmax and the actual difference in temperature will be less than the DTmax.

Curves may be produced to show the relationship between power applied to a module and net cooling. From our module specifications page you may see the curves for our most popular modules by clicking on the appropriate part number in the first column.

After learning what power is required for an appropriate module to reach the desired level of cooling it is necessary to focus on the assembly required, specifically heat sink selection, in order to allow the module to maintain the desired results.

The actual temperature achieved, with a given level of cooling or DT on the module, in an assembly is derived by subtracting the temperature of the cold side Tc from the temperature of the hot side Th. (The advanced user should be aware that hot and cold side temperatures are expressed in degrees Kelvin when used in equations.) Naturally, the cooler the hot side of the module, the cooler the cold side will be. Many people not familiar with thermoelectrics assume that the temperature of the hot side will be the same as the ambient temperature. This is probably not the case. As mentioned earlier, as soon as power is applied to the module the hot side of the module will begin ejecting this as heat to the heat sink causing it to rise in temperature. The ability of the heat sink to dissipate this heat as well as the heat being pumped through the cold side will determine the actual operating temperature of the hot side thus, the cold side.

This brings us to the importance of selecting an appropriate heat sink. In general, the better (the lower the thermal resistance of) the heat sink the easier it is to keep the hot side temperature from increasing. Liquid heat sinks typically have the lowest thermal resistance however they are relatively expensive and plumbing is required. The use of a liquid heat sink assumes that a "house water supply" or chiller is available to cool the water or liquid being circulated through the heat sink. The most common type of heat sink used in thermoelectric applications is made from a thermally conductive material like aluminum or copper and has fins that are perpendicular to a base.



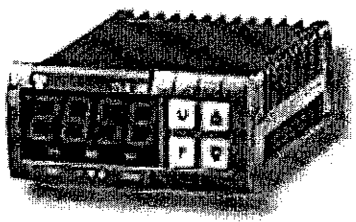
A typical extruded heat sink profile

It is recommended that you select the largest (greatest surface area) heat sink that you can accommodate. In general, to reduce the thermal resistance of a heat sink by 50% it is necessary to increase it's volume by 400%.

In most TE applications that our modules will be appropriate for, a heat sink alone will not be able to remove a sufficient amount of heat by natural convection keep the hot side at an acceptably low temperature. In order to help the heat sink remove heat on and around the heat sink fins, a fan or blower must be attached which forces ambient temperature air over the fins and exhausts the heat to ambient. This is known as a forced convection heat sink. Even with a forced convection heat sink it is common that the hot side will stabilize at 10 - 15°C above ambient.

When installing TE modules in an assembly it is most common to compress or "clamp" them between a heat sink and something to be cooled. The object cooled can be a block of metal creating a cold plate, another forced convection heat sink making an air-to-air exchanger, a liquid heat sink forming a liquid-to-air exchanger, a probe for a water cooler or just about anything else with a flat surface.

Thermoelectric modules are operated from a DC (Direct Current) power source rather than AC (Alternating Current) sources such as most homes have available. DC power supplies, AC/DC converters, batteries and battery chargers (without too much AC ripple) can all be used as sources of power. When precise temperature control is required the power supply must be adjustable so that as information is returned from a temperature controller, corrections to input power can be made.



We sell Tecnologic brand temperature controllers because of their outstanding value. These compact microprocessor based temperature controllers are about the size of a deck of cards but are pretty big features. They are very easy to program and built to last. TLZ10 should be selected for single set point applications like cold plates. The more feature rich TLK38 is designed for operation with one or two set points and is popular with customers using our PowerCOOL outdoor air conditioning units because they allow for our units to be used both for heating in winter as well as cooling in summer. After selecting the desired temperature/s for action, including, if you wish, neutral zone, simply place the unit within the enclosure and you're done. For more details see the links below:

- Tecnologic's 16-amp, Single Set Point TLZ10-12V Temperature Controller Technical Data Sheet

- TLZ10 User Manual Replaces TDH01 (manual)

- Tecnologic's TLK38 Dual Set Point Temperature Controller Technical Data Sheet
- Tecnologic TLK38 User Manual Replaces TDH02 (manual)

With these basics guidelines to work with you should be able to evaluate the use of thermoelectric modules as a possible solution to your thermal management challenge. If you would like to learn more, we highly recommend:

- DARPA/ONR/DOE High Efficiency Thermoelectric Workshop (March 2002)

- CRC Handbook of Thermoelectrics (1995)
- Chemistry, Physics and Materials Science of Thermoelectric Materials: Beyond Bismuth Telluride (2003)
- Principles of Thermoelectrics: Basics and New Materials Development (2001)
- Thermoelectric Materials 2000 - The Next Generation Materials for Small-Scale Refrigeration and Power Generation (2001)
- Semiconductors and Semimetals, Volume 69: Recent Trends in Thermoelectric Materials Research, Part One (2000)
- Semiconductors and Semimetals, Volume 70: Recent Trends in Thermoelectric Materials Research, Part Two (2000)
- Semiconductors and Semimetals, Volume 71: Recent Trends in Thermoelectric Materials Research: Part Three (2000)
- Thermoelectric Materials - New Directions & Approaches (1997)

Additional information that may be important to you may include:

- Module Specifications
- Module Prices
- Module Overview
- How A TEC Works

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Specifications, drawings and data are subject to change without notice.

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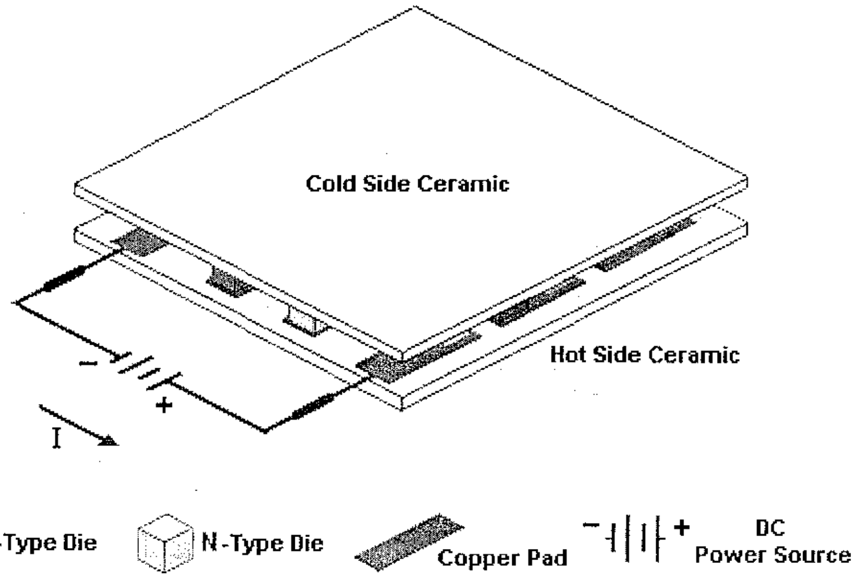

A typical thermoelectric module is composed of two ceramic substrates that serve as a foundation and insulation for P-type and N-type Bismuth Telluride dice that are connected electrically in series and the parallel between the ceramics. The ceramics also serve as insulation between the modules internal ele elements and a heat sink that must be in contact with the hot side as well as an object against the cold An electrically conductive material, usually copper pads attached to the ceramics, maintain electrical co inside the module. Solder is most commonly used at the connection joints to enhance the electrical cor hold the module together.

Most modules have and even number of P-type and N-type dice and one of each sharing an electrical interconnection is known as, "a couple." The above module would be described as an 11-couple modu

While both P-type and N-type materials are alloys of Bismuth and Tellurium, both have different free el densities at the same temperature. P-type dice are composed of material having a deficiency of electro type has an excess of electrons. As current (Amperage) flows up and down through the module it atter establish a new equilibrium within the materials. The current treats the P-type material as a hot junctior be cooled and the N-type as a cold junction needing to be heated. Since the material is actually at the : temperature, the result is that the hot side becomes hotter while the cold side becomes colder. The dir current will determine if a particular die will cool down or heat up. In short, reversing the polarity will sw and cold sides.

Leads to the modules are attached to pads on the hot side ceramic. If the module is sealed you can de hot side without applying power. With the module on a flat surface, point the leads toward you with the usually in red wire insulation, on the right. The bottom surface will be the hot side.

Material researchers are investigating the use of other materials to improve the efficiency of thermoele but Bismuth Telluride remains the most economical material for cooling modules used in ambient temp applications. However, at low temperature (around minus 110 degrees Celsius) this material stops bec semiconductor and performance is severely diminished. Typically, the highest temperature that module operate is the melting point of the solder inside, usually + 150 or 200 °C (302 or 392° F).

Some Bismuth Telluride based modules for power generation applications are fabricated with high mel temperature solder or without solder entirely that can be used at temperatures up to + 400 °C. Hi-Z Te Inc. has some interesting and helpful information on this subject and manufactures modules of this typ

If you would like to learn more, we highly recommend:

- DARPA/ONR/DOE High Efficiency Thermoelectric Workshop (March 2002)

- CRC Handbook of Thermoelectrics (1995)
- Principles of Thermoelectrics: Basics and New Materials Development (2001)
- Thermoelectric Materials 2000 - The Next Generation Materials for Small-Scale Refrigeration ar Generation (2001)
- Semiconductors and Semimetals, Volume 69: Recent Trends in Thermoelectric Materials Rese One (2000)
- Semiconductors and Semimetals, Volume 70: Recent Trends in Thermoelectric Materials Rese Two (2000)
- Semiconductors and Semimetals, Volume 71: Recent Trends in Thermoelectric Materials Rese Three (2000)
- Thermoelectric Materials - New Directions & Approaches (1997)

Click here to return to our ***Fundamental Thermoelectrics*** page.

Additional information that may be important to you may include:

- Module Specifications
- Module Prices
- Module Overview
- DC Power Supplies

ADVANCED THERMOELECTRIC

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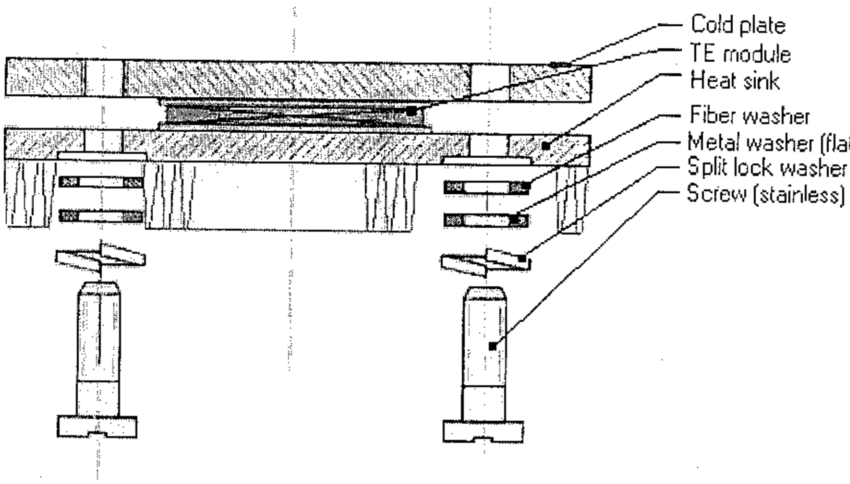
How to Install a Thermoelectric Module

Installing a TE module is relatively simple. Carefully following these guidelines will ensure that modules optimally and are not damaged. Noncompliance with these guidelines may result in a decrease in mod efficiency or failure.

Typically it is recommended that a module/s be compressed between two clean, flat and parallel surfac thermoelectric module contains somewhat fragile semiconductor material however, most modules are strong in compression. Good interfaces (low thermal resistance) between the module and components contact with it will optimize performance. With few exceptions, a module should not be used as a supp member because a shear force may force a module open.

If two or more modules are installed in an assembly, their thickness should not vary by more than 0.05 Should you require a very uniform thickness, select our "Lapped" option, which ensures a close height of ± 0.01 mm.

It is common to "clamp" a module between a cold plate, or other object to be cooled, and a heat sink. A example of the recommended configuration and components is pictured here.

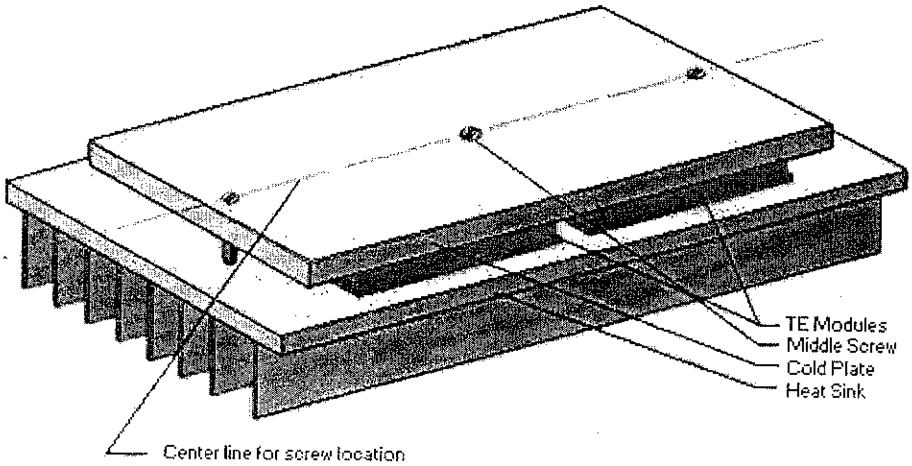


To install the module/s, follow these directions:

1.) Spread a thin layer of thermally conductive grease (i.e. AOS 52022 or Dow Corning G340) in the lo where the module will be seated on the heat sink. Place the module on the heat sink and gently move module back and forth to squeeze out any excess grease.

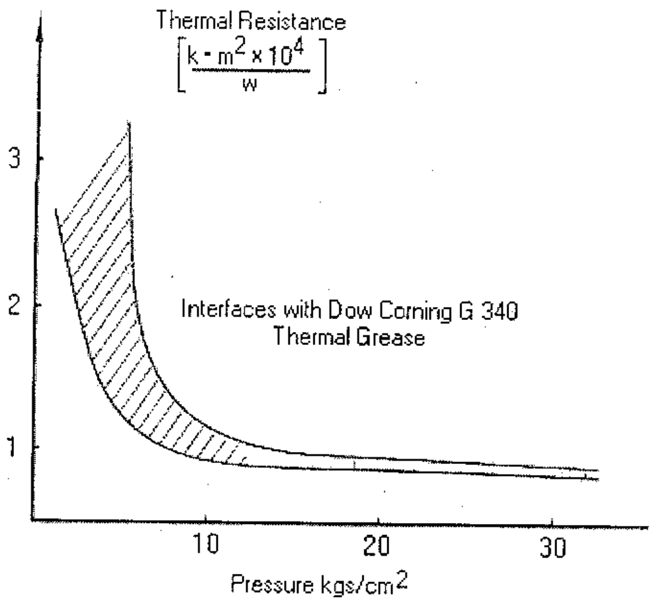
2.) Spread a thin layer of thermal grease in the appropriate location of the cold plate, or object to be co place this onto the module (and heat sink). As above, gently remove any excess grease.

3.) Place all connecting hardware loosely into the sub-assembly. Beginning at the center evenly tighter connecting hardware by hand or until you meet slight resistance. In this example, you would begin with middle screw located between modules on the module center line.



4.) Using a torque-limiting wrench, begin tightening in small increments from the center bolt outward.

5.) As shown in the following figure (data by Dr. J.G. Stockholm) the thermal resistance and dispersion thermal grease depends upon the pressure against the module ceramics and reaches a relatively low \ pressure of 10 kgf/cm2. It is sufficient to provide pressure in the 10 - 15 kgf/cm2 range for acceptable ε thermal contact. The torque per clamping screw (Type 4 - 40, 6 - 32 manufactured from stainless steel be no more than 0.11 kgm for modules having and area of 40 x 40 mm.



6.) After reaching the desired torque value, leave the assembly for one hour. Check torque and re-tight necessary.

Design Recommendations

Both the heat sink and cold plate should be sufficiently rigid to prevent any bowing or deformation whe clamping your assembly together. If components are not sufficiently rigid, modules will not perform opti may be damaged. Aluminum components should not be less than 6 mm thick and copper components less than 4 mm. Clamping screws should only be located on the module/s center line. We recommend clearance between module edges and bolt holes be 3 mm. If space does not allow this, you may increa distance but not exceed 12 mm.

Finally, If your finished product will be operating at temperatures near the dew point, or if the equipmer routinely turned off, condensation from components may become water which can enter the module. T moisture can cause corrosion leading to performance deterioration or an electrical short. Adequate car be taken to seal modules from moisture. If you prefer, order moisture protected modules that have bee "potted" to prevent the long term problems associated with electro-corrosion within the module ("P" suf number) or order Epoxy sealed modules that have a bead of epoxy aircraft grade around the perimeter module and sufficiently far down the leads to prevent wicking ("E" suffix in part number). Together thes exceptional protection from condensation however Epoxy sealing is recommended in most applications only potting.

Additional information that may be important to you may include:

- Module Specifications
- Module Prices
- Module Overview
- Basic Thermoelectrics
- How A TEC Works

If you have a question please feel free to contact us:

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