Solar Lighting System

by

Mohd Hanafi Bin Iberahim

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

June 2004

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Solar Lighting System

by

Mohd Hanafi Bin Iberahim

A project dissertation submitted to the
Electrical & Electronic Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL & ELECTRONIC ENGINEERING)

Approved by,

(Mr. Zuhairi Baharudin)
Mr. Zuhairi Baharudin
Lecturer
Electrical & Electronic Engineering
Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2004

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 un specified sources or persons.

MOHD HANAFI BIN IBERAHIM

ABSTRACT

Basically this report contains the objectives of the project, problems statement, the scope of study, methodology used, results and discussion of the project.

Nowadays, solar becoming one of the energy source for human life. Solar energy from the sun can generate electricity for the daily life usage. The conversion from solar energy to electrical energy is achieved using a photovoltaic (PV) system.

For a solar system to operate, the minimum components required are the solar modules, storage system, control elements and loads. Solar modules are made from semiconductor and will convert the light energy from the sun into electricity. Storage system is used for the purpose of storing energy produced by the PV array during the day, and to supply it to the electrical loads as needed. Storage system also needed to operate the PV array near its maximum power point, to power electrical loads in stable voltages and to supply currents to electrical loads and inverters. Control elements are used to accommodate the variable nature of power from the PV modules and to avoid the malfunction of the system. Load will be any appliances that used electrical power as a supply.

ACKNOWLEDGEMENT

I am indebted to many individuals who have helped me a lot during my final year project progress. I would like to express my profound gratitude and thank to everyone involved, for his or her endless support, helps and contribution.

I would like to express my gratitude to my supervisor, Mr Zuhairi Baharudin for his strong support, for being understanding and for guiding me throughout the project. He has also performed excellent responsibilities in ensuring the accomplishment of this project.

Special thanks to all electrical lab technicians for assisting and providing the tools required for this project. I would also like to thank Final Year Project Committee for their help and assistance.

Thanks to all my fellow friends for being very understanding and lend me their handles when I need them. Deepest gratitude to my family and those who involved directly or indirectly throughout the project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, solar becoming one of the energy source for human life. Solar energy from the sun can generate electricity for the daily life usage. The demands for the solar system for appliances are increased and still continue.

Lighting is taken for granted in the industrial countries and in the most of the urban areas of the developing countries. In areas without access to main electricity, lighting is restricted to candles, kerosene lamps, or torched powered by expensive throw-away batteries.

In terms of the number of installations, lighting is presently the biggest application of photovoltaic, with tens of thousand of units installed worldwide. They are mainly used to provide lighting for domestic or community buildings, such as schools ore health centers. PV is also being increasingly used for lighting streets and tunnels, and for security lighting.

The performance of PV lighting systems has been excellent, with increasing demand for more systems in the locality where a PV light is installed.

The used of low-voltage DC fluorescent lamps, rather than filament lamps, is important for efficient use of the electricity. AC lights can be used with an inverter but this introduces electrical losses.
Even though individual PV lights are more expensive to buy than other lamps, they are generally more cost-effective over the lifetime of the installation. In addition, they provide better quality illumination.

1.2 PROBLEM STATEMENT

PV-generated power offers advantages over diesel generators, primary (one-time use) batteries, and even conventional utility power. These benefits make PV the power of choice in more and more cases every day:

- High Reliability
- Low Operating Costs
- Environmental Benefits
- Modularity
- Low Construction Costs

High Reliability
PV cells were originally developed for use in space, where repair is extremely expensive, if not impossible. PV still powers nearly every satellite circling the earth because it operates reliably for long periods of time with virtually no maintenance.

Low Operating Costs
PV cells use the energy from sunlight to produce electricity; the fuel is free. With no moving parts, the cells require little upkeep. This low-maintenance, cost-effective PV systems are ideal for supplying power to communications stations on mountain tops, navigational buoys at sea, or homes far from utility power lines.

Environmental Benefits

Since they burn no fuel and have no moving parts, PV systems are clean and silent. This is especially important where the main alternatives for obtaining power and light are from diesel generators and kerosene lanterns.

Modularity

A PV system can be constructed to any size based on energy requirements. Furthermore, a PV system can enlarge or move it if energy needs change.

Low Construction Costs

PV systems are usually placed close to where the electricity is used, requiring much shorter power lines than if power is brought in from the utility grid. In addition, using PV eliminates the need for a step-down transformer from the utility line. Less wiring means lower costs, shorter construction time, and reduced permitting paperwork, particularly in urban areas.

When come to the designing part, three factors must take into consideration:

1. Estimation of the load and load profile
2. Estimation of available solar radiation
3. Design the PV system, including area of PV panels and components selection

1.3 OBJECTIVES

The objectives of this project are as follows:

1) To learn and study the solar energy application and concept
2) To be exposed with the concept of solar system requirements
3) To do sizing for solar lighting components
4) To design a system for solar lighting

CHAPTER 2

LITERATURE AND THEORETICAL REVIEW

2.1 Solar Energy

Energy is a very important component in human life. Wind energy is used to sailing ship and for driving windmills and the force of falling water to turn water wheels. The Industrial Revolution which began with the discovery of steam engine brought about great changes. For the first time, man began to use a new source of energy, coal in large quantities. Later with the expanding finding about the engine, the new sources of energy such as fossil fuels, oil and natural gas are used extensively.

After Second World War, a new source of energy, nuclear becomes commercialized. Nuclear power is developed by fission reactions in nuclear reactors. Like water power, it is used exclusively for the generation of electricity.

In the past few years, it has become obvious that fossil fuel resources are fast depleting and that the fossil fuel era is gradually coming to an end. This is particularly true for oil and natural gas. The need of alternative energy is thus evident and considerable research and development work is already in progress in this direction.

One of the promising options is to make more extensive use of renewable energy sources of energy derived from the sun. Solar energy can be used both directly and indirectly. It can be used directly in variety of thermal applications like heating water or air, drying, distillation and cooking. The heated fluids can in turn be used for applications like power generation or refrigeration. A second way in which solar energy can be used directly is through photovoltaic effect in which it is converted to electrical energy.

Photovoltaic (or PV) systems convert light energy into electricity. The term "photo" is a stem from the Greek "phos," which means "light." "Volt" is named for Alessandro Volta (1745-1827), a pioneer in the study of electricity. "Photo-voltaics," then, could literally mean "light-electricity." Most commonly known as "solar cells," PV systems are already an important part of our lives. The simplest systems power many of the small calculators and wrist watches we use every day. More complicated systems provide electricity for pumping water, powering communications equipment, and even lighting our homes and running our appliances. In a surprising number of cases, PV power is the cheapest form of electricity for performing these tasks.

Photovoltaic cells convert light energy into electricity at the atomic level. Although first discovered in 1839, the process of producing electric current in a solid material with the aid of sunlight wasn't truly understood for more than a hundred years. Throughout the second half of the 20th century, the science has been refined and the process has been more fully explained. As a result, the cost of these devices has put them into the mainstream of modern energy producers. This was caused in part by advances in the technology, where PV conversion efficiencies have improved considerably.

2.2 Solar Lighting

Lighting is steadily growing need in the rural areas of developing countries, not only because the population is increasing but for the use in the night. An important need is for lighting for small commercial enterprises in the streets and recreational activities. Instead of that, there is an associated need for lighting for streets and public and open spaces.

In areas where there is no electricity supply, lighting for domestic and commercial applications is usually provided by kerosene lamps and candles. In general, lighting from these sources is poor quality, expensive and fire hazard.

Photovoltaic lighting systems would be an attractive alternative to those sources. The key considerations are comparative quality, reliability and cost.

2.2.1 Technical Requirement

PV lighting systems have become readily available over the last five years with manufacturers offering two basic types of unit, o ne for area lighting a nd the other for domestic applications.

Area lighting units may be used for street lighting, public open spaces and security lighting. These systems consist of PV array, battery, simple voltage regulator, timer and photosensitive switch controls and a load such as fluorescent lamp.

Domestic lighting units typically require only one or two PV modules for charging a battery which supplies from one to four fluorescent tubes, from 20W to 40W depending on the application. Some systems are portable, with a lantern unit incorporating a rechargeable battery. Larger systems can be obtained, capable of supplying other end uses such as refrigerators, radios and televisions.

Fluorescent lamps are commonly used for both area lighting and domestic lighting systems. Fluorescent lamps offer high efficiency, long life and a high reliability. They require'ballast' and a 'starter' which gives a high frequency impulse for starting, followed by much lower power and frequency for normal running. Standard AC fluorescent units may be converted for DC powering for PV systems y changing the ballast and starter components.

PV lighting systems covering a wide range of sizes and types are available as standard products. The components required for a typical domestic lighting system are listed in Table 2.1. Such a system would provide up to 200 Wh/day of useful energy for lighting given a solar input of 6.0 kWh/m^2. The 20W lamp could be used for 3 to 5 hours every night and the 7W lamp could be used for 8 to 12 hours for security. The battery provides about three days storage.

Specification	**Life (years)**
1 PV module – 40Wp	15
Battery – 12V/105Ah	4
Fluorescent lamps	2
Battery charging controller	5

Table 2.1: Typical PV lighting system for domestic use

Many of the smaller systems for domestics use are portable, which makes them particularly suitable for u se in place of kerosene lamps. The introduction of long-life rechargeable Ni-Cd batteries is an interesting development in this regard.

The battery charge controllers used for some early designs of PV lighting systems were found to be unreliable, but now fully tropicalised units are supplied which have proved very reliable in practice. The reliability and efficiency of the ballast used in commercial fluorescent units have been found to be reliable.

Small PV systems for domestic lighting are widely available and several thousands have been installed. They are simple and to operate and reliable, now that the earlier problems with battery charge regulators have been solved. PV powered fluorescent tubes provides a much higher quality of light compared to with kerosene wick or pressure lamps. The efficiency of the DC ballast used for fluorescent tube lamps is one of the factors in the design of systems.

PV powered streets lights and security lights are also available from several manufacturers. This unit generally use low pressure lamps. Some problems connected with the need to adapt standard AC units for DC operation have been experienced and there is a need for further development of suitable ballast.

2.3 Stand alone systems

There are currently many thousands of small stand-alone photovoltaic systems (as depicted in Figure 2.1) operating throughout the world for power applications. They range in size from a few watts to several tens of kilowatts, plus many millions of solar powered calculators and other consumer products. Power for remote radio, television and microwave repeater stations may in many cases be economically provided by photovoltaic generators.

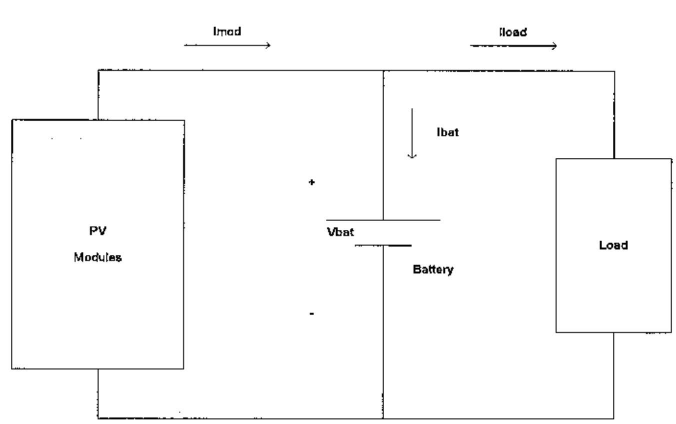


Figure 2.1: Stand-alone PV system

Various experimental and demonstration plants have been built and now this application is considered by the operating companies to be the appropriate solution on technical and economic grounds for many cases. Most photovoltaic manufacturers now offer a wide range of standards systems, for battery charging, water pumping, street lighting, domestic lighting and security equipments.

It is important to stress that a stand-alone photovoltaic generator for a given application should not be considered merely as a substitute for a battery or diesel generator. All components interact and the objective of good system design must be to obtain the most cost-effective and reliable combination of components, taking into account the expected variation in incident solar radiation and the requirement of the end user.

2.4 System Components

2.4.1 Solar Cells

The devices used in photovoltaic conversion are called solar cells. When solar radiation falls on these devices, it is converted directly into dc electricity. The principal advantages associated with solar cells are that they have no moving parts, require little maintenance and work quit satisfactorily with beam or diffusion radiation. Also they are readily adapted by varying power requirements because a cell is like a 'building block'. The main factors limiting their use that they are still rather costly and that there is very little economy associated with the magnitude of power generated in an installation.

However significant developments have been obtained for the last few years. New types of cell have been developed, innovative manufacturing processes introduced, conversion efficiencies of existing type increased, costs reduced and the volume of production steadily increased. As a result for the development, solar cells are now being used extensively in many consumer products and appliances.

Many different solar cells are available on the market, and yet more are under development. Crystalline silicon cells hold the largest part of the market. To reduce the cost, these cells are now often made from multi-crystalline, rather than from the more expensive single crystal. Crystalline silicon cell technology is well established. The modules have a long lifetime (20 years or more).

Cheaper (but also less efficient) types of silicon cells, made in the form of amorphous thin films, are used to power a variety of consumer products such as solar-powered watches and calculators. Beside of these small modules, larger amorphous silicon solar modules also available.

A variety of compound semiconductors can also be used to manufacture thin-film cells (for example, cadmium telluride or copper indium diselenide). These modules are now beginning to appear on the market and hold the promise of combining low cost with acceptable conversion efficiencies.

A particular class of high –efficiency solar cells from single crystal silicon or compound semiconductors (for example gallium arsenide) are used in specialized applications, such as to power satellites or in a system which operate under high-intensity concentrated sunlight.

2.4.1.1 Thin Film Solar Cells

Thin film technology holds the promise of reducing the module costs through lower material and energy requirements of the manufacturing process. In addition, integrally connected modules are produced directly without the costly individual cell handling and interconnections.

Four types of thin-film solar cells have emerged to be likely commercial important in the next few years. These are amorphous silicon cell, most probably in a double-junction structure, thin multi-crystalline silicon films on a low cost substrate, the copper indium diselenide and cadmium sulphide heterojunction cell.

2.4.1.2 Single Crystal Silicon Cell

Silicon is the material generally used for making solar cells. Single crystal silicon cells (Figure 2.2) are thin wafers about 300μm in thickness, sliced from a single crystal of p-type doped silicon. A shallow junction is formed at one end by diffusion of the n-type impurity. Metal electrodes made from a Ti-Ag solder are attached to the front and back side of the cell. On the front side, the electrode is in the form of a metal grid with fingers which permit the sunlight to go through, while on the backside, the electrode completely covers the surface. An anti-reflection coating of SiO, having a thickness of about 0.1μm, and a thin transparent encapsulating sheet are also put on the top surface to complete the assembly. A typical cell develops a voltage of 0.5-1 V and a current density of 20-40 mA/cm^2.

In order to obtain higher voltage and currents, individual cells are fixed side by side on a suitable back-up board and connected in series and parallel to form a module. In turn, a number of modules are interconnected to form an array.

Earlier the cells used to be circular in shape with diameters ranging from 6 to 15 cm. Now they are rectangular in shape, resulting in more compact modules.

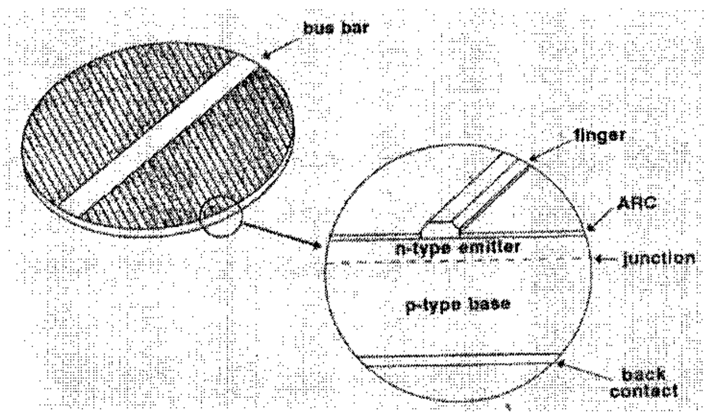


Figure 2.2: The silicon solar cell

2.4.1.3 The Principle Working Of Solar Cell

The principle of working of a solar cell can be describes using two steps:

1. Creation of pairs of positive and negative charges(called electron-hole pairs) in the solar cell by absorbed solar radiation
2. Separation of the positive and negative charges by a potential gradient within the cell

For the first step to occur, the cell must be made of a material which can absorb the energy associated with the photons of sunlight. The only materials suitable for absorbing the energy of the photons of the sunlight are semiconductors like silicon, cadmium sulphide, gallium arsenide etc.

In a semiconductor, the electrons occupy one of two energy bands- the valence band and the conduction band. The valence band has electrons at a lower energy level and is fully occupied, while the conduction band has electrons at a higher energy level and is not fully occupied. The difference between the energy levels of the electrons in the two bands is called the band energy gap *Eg* (Figure2.3). Photons of sunlight having energy E greater than the band gap energy *Eg* are absorbed in the cell material and excite some of the electrons. These electrons jump across the band gap from the valence band to the conduction band leaving behind holes in the valence band. Thus electron-hole pairs are created.

The electrons in the conduction band and the holes in the valence are mobile. They can be separated and made to flow through an external circuit (thereby executing the second step of the photovoltaic effect) if a potential gradient exist within the cell. In the case of silicon, the potential gradient is obtained by making the cell as sandwich of two types of silicon, p-type and n-type. Silicon of p-type is silicon 'doped' with some atoms of boron. While silicon of n-type is silicon 'doped' with some atoms of phosphorus. The energy levels of the conduction and valence bands in p-type silicon are slightly higher than the corresponding levels in n-type silicon. Thus when a composite of the two types of silicon is formed, a jump in energy levels occurs at the junction interface (Figure 2.3). This potential gradient is adequate to separate the electrons and holes, and cause a direct electric current to flow in an external load.

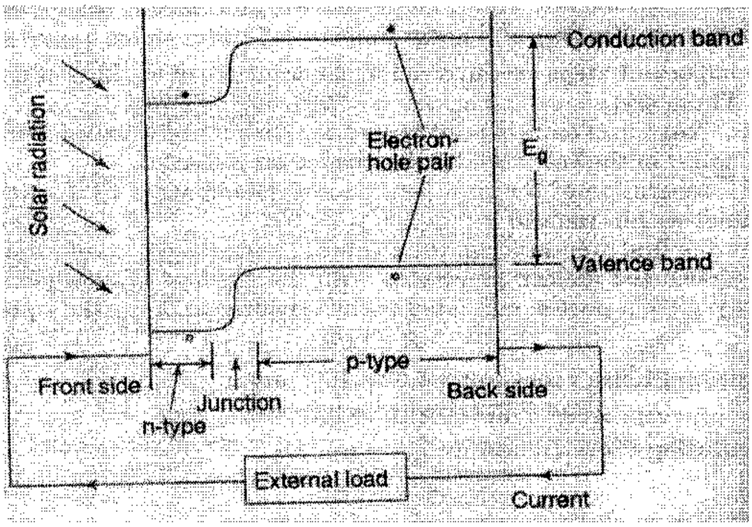


Figure 2.3: Principle working of a solar cell

In a silicon cell, the junction is the thin region separating the n-type and p-type portions. Since the basic material is al silicon, such a junction is more specifically called a homojunction. Solar cells can also be made from dissimilar materials. For example, in one type a layer of copper sulphide is deposited ion a layer of c admium sulphide, the junction being formed along the contact between the two materials. Such a junction is called heterojunctions.

2.4.2 Storage

Since the solar energy supply is intrinsically variable in time, stand alone photovoltaic systems usually make a provision for energy storage. Table 2.2 below shows some energy storage systems that are widely used:

Energy Stored	**Technology**
Mechanical	Pumped water Compressed air Flywheel
Electromagnetic	Electric current in superconducting ring
Chemical	Batteries Hydrogen production

Table 2.2: Energy storage systems

Nickel cadmium batteries have become wider use for a storage system for photovoltaic. Nickel cadmium batteries are used in some smaller applications where their ruggedness, both mechanical and electrical is considered essential.

Batteries in PV systems operate under specific conditions which must be allowed for in the system design, as they affect both battery life and the efficiency of the battery operation. The most prominent feature is cycling with various cycle of different degree of regularity (Figure 2.4). During the daily cycle, the battery is charged during the day and discharge by the night-time load. The depth of discharge in the daily cycle for systems without backup is always fairly shallow. Superimposed on the daily cycle is the climatic cycle, due to the variable climatic conditions. This cycle occurs anytime when the daily load exceeds the average supply from the PV generator.

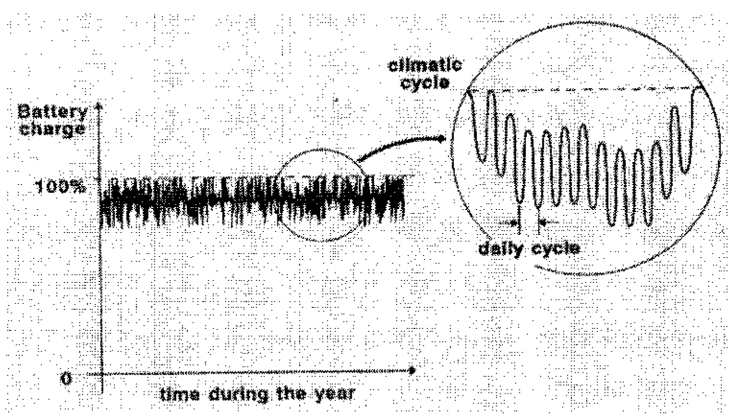
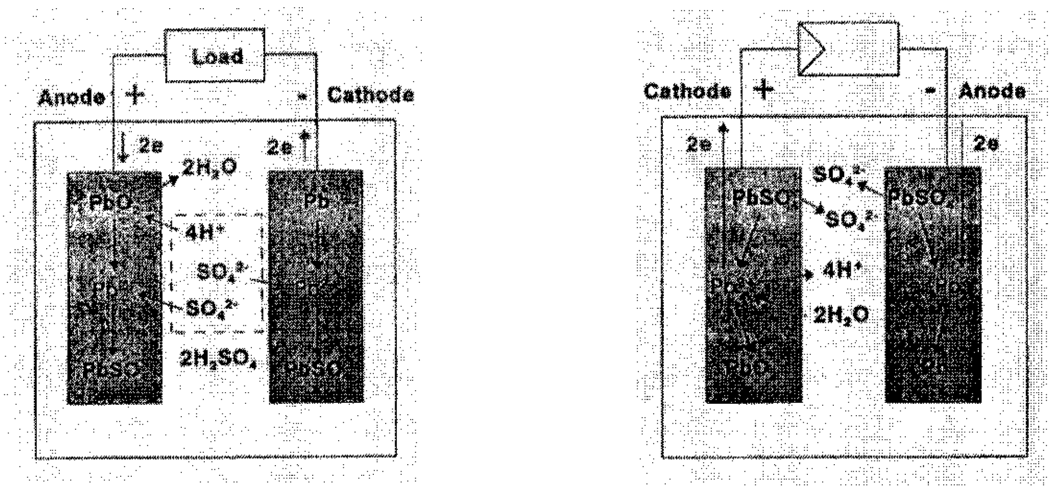


Figure2.4: The cyclic operation of battery in PV system

The lead-acid battery comprises two electrodes of lead and lead dioxide, and the electrolyte of sulphuric acid diluted with water. In practical construction, the electrodes are formed by a lead grid carrying the active material in the form of porous structure that offers a large surface are for chemical reactions with the electrolyte.

The chemical reactions for the discharging and charging of the batteries are shown by Figure 2.5. During the charging process, lead oxide is formed at the anode, pure lead is formed at the cathode, and sulphuric is liberated in the electrode. During discharge, lead sulphate is formed at both electrodes and sulphur acid is removed from the electrolyte.



Discharge to load **Charging by PV**

Figure2.5: Charging and Discharging of Battery

Figure2.6 shows the voltage behavior during charging of lead-acids battery. After a relatively slow increase up to about 2.35 per element, there is a steep voltage rise accompanied by gassing. Gassing is the generation of hydrogen and oxygen at the electrodes.

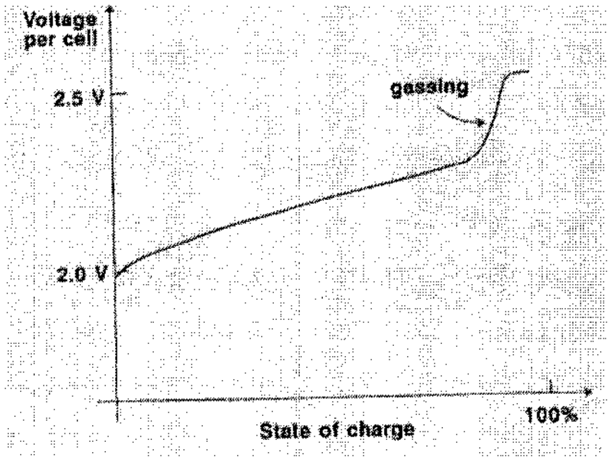


Figure2.6: Battery charging characteristic

Figure2.7 shows a typical behavior during the discharge process of the battery. It can be seen that the battery capacity decreases markedly when it is discharged at high rate. A battery with nominal capacity specified at 10h discharge rate can markedly increase its capacity under 100 h discharges.

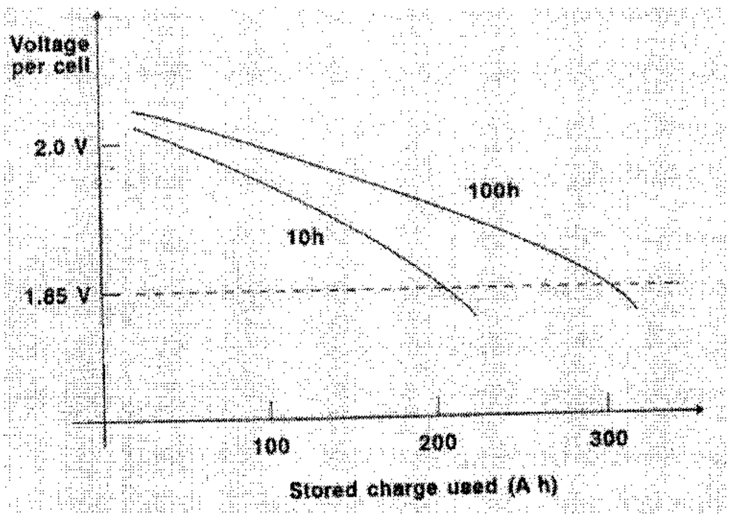


Figure2.7: Battery discharge characteristic

2.4.3 Loads

Photovoltaic systems can be used to power up the electrical based-systems and equipments. The loads for this system include:

- Lighting elements
- AC/DC Motors
- Home appliances
- Battery

The load data give detailed information about the appliances or equipment to be powered: their number, their nominal operating voltages and the number of hours of operation in a typical day.

2.4.4 Charge Regulator

Various electronic devices are used to accommodate the variable nature of power output from the PV generator, to avoid the malfunction of the system or to convert the DC power produced by the PV generator into AC output. Charge regulator is a device for preventing excessive charge or overcharge of batteries.

Excessive discharge is avoided by monitoring the battery voltage and disconnecting the load from the battery if the voltage falls below a pre-set minimum value. The regulator will not connect the load until the battery voltage has risen to a value significantly higher than this minimum value. This is necessary to ensure that the load is not reconnected until some charge has been returned to the battery.

While power is being supplied by the PV array the main role of the regulator is to limit the maximum battery voltage to prevent excessive gassing and to prevent overcharging the battery. Unless a very large array is used with a very small battery, it is not normally necessary to limit the peak current during the bulk charge phase, when the battery voltage is below the limiting value. The voltage regulation may be achieved by the use of either shunt regulator or series regulator.

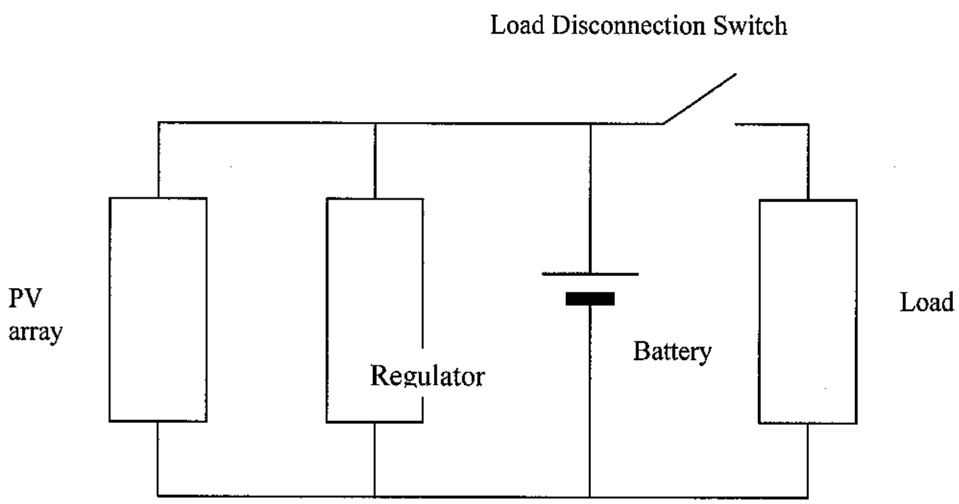


Figure 2.8: Shunt Regulator

A shunt regulator (Figure 2.8) has a variable resistance element in parallel with the battery. As the resistance is reduced more of the current from the PV array is diverted through the resistor and less through the battery. The variable resistance element will generally be a transistor. The disadvantage of the shunt regulator is that it may dissipate a large amount of power.

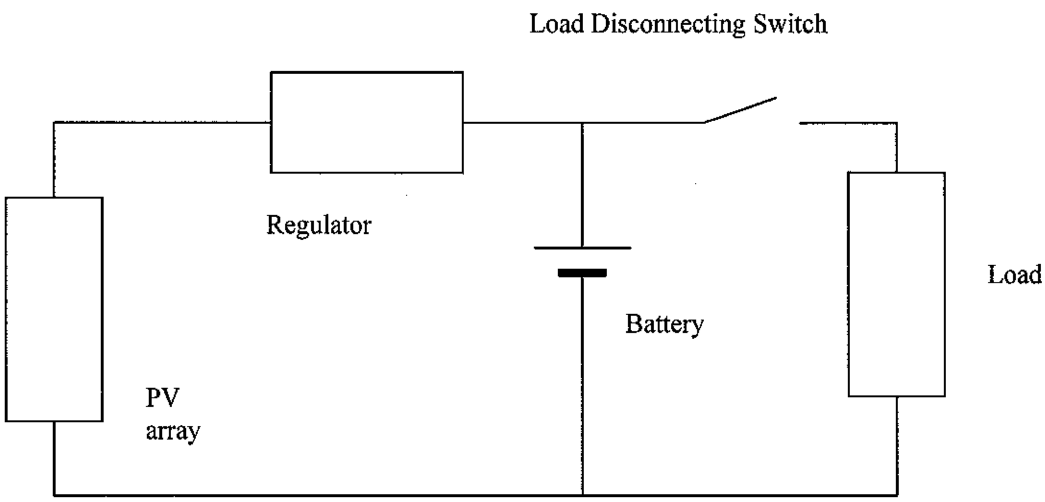


Figure 2.9: Series Regulator

A series regulator (Figure 2.9) is an alternative for the shunt regulator. It variable resistance element is included in series with the PV array and the battery. As the battery is charged and its voltage raises the series resistance is increased to reduce the battery voltage and current. This arrangement dissipates little power in the resistive element before the regulator starts to operate and little power when the battery is fully charged. The series regulator thus dissipates much less power than the shunt regulator, provided the array open-circuit voltage is chosen correctly.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

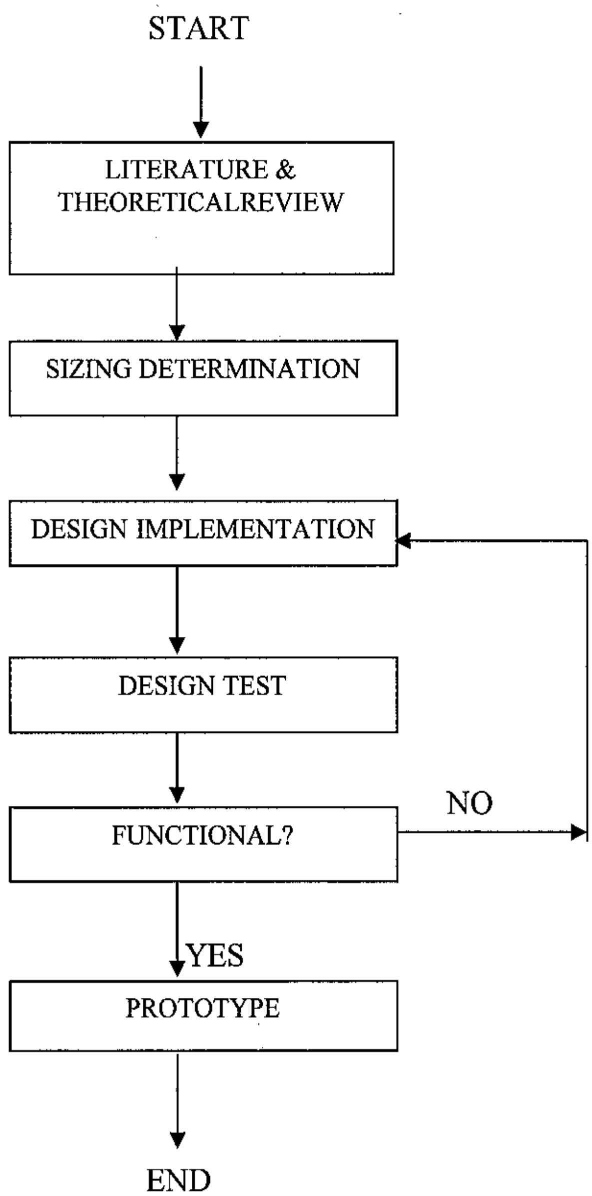


Figure 3.1: Project Flow

3.1 Literature And Theoretical Review

Literature and theoretical review phase provides the essential knowledge's needed by the author before proceeding with design phase. Author has done research on the current and existing technology related to the project. From this literature review, the author will enable to explore and evaluate every possible solution in achieving the project objectives.

3.2 Sizing And Designing

Photovoltaic system sizing consists of working out the cheapest combination of array size and storage capacity that will meet the anticipated load requirements with the minimum acceptable level of security. By security is meant the probability that the system will always satisfied the load. The minimum acceptable level has very important influence on cost. For example, for standalone household system in rural areas, a security level of 95% may be considered sufficient but for telecommunication systems, a level of 99.99% ore more is generally required. If the system is grid-connected or has some other back-up, a lower security level will be acceptable. The final design always compromises between cost and security. The following input data are required for system sizing:

1) The daily or hourly load requirements during a typical year
2) The required security of supply
3) The mean daily irradiation in the plane of the array at the chosen site
4) The maximum number of consecutive sunless days likely to be experienced
5) The mean daily ambient temperature for every month
6) The estimated cell temperature rise above ambient of the modules in the array
7) Typical current-voltage characteristics of the selected types of module
8) The selected dc voltage
9) The maximum allowable depth of discharge of the battery

10) The estimated energy losses in the battery, power conditioning equipment and control system
11) The estimated losses in the array from module mismatch, cable and voltage drop
12) The estimated losses from dust and shading

CHAPTER 4

RESULT AND DISCUSSION

4.1 Sizing of the System

Lamp: 7W System: 12V

With the assumption that lamp work 8hrs/day or 56hrs/week:

$$Average\_daily\_Ah = \frac{7W}{12V} \times \frac{56hrs/week}{7days/week}$$

$$= 4.67\,Ah/day$$

Due to voltage drop in wiring system about 2%, the new voltage drawn by the lamp:

$$\frac{4.67\,Ah}{98\%efficiency}$$

$$= 4.765\,Ah$$

The discharging and charging of batteries is taken as 10%, the corrected average daily of the lamp:

$$\frac{4.765}{90\% efficiency}$$

$$= 5.29 Ah$$

Battery sizing:

$$Ah = \left(\frac{Ah}{day}\right)\left(\frac{days}{D_T D_{CH}(depth\_of\_discharge)}\right)$$

where D_T = temperature derating factor and D_{CH} = charge/discharge derating factor

By neglecting D_T and D_{CH} and taking depth of discharge of 40%, the storage battery size is:

$$Ah = \frac{5.29 Ah / days}{40\% / days}$$

$$= 13.23 Ah$$

PV Sizing

The PV sizing is determined by the number of series and parallel of the modules. Number of series-connected modules N_S is governed by equation below:

$$N_S = \frac{V_{DC}}{V_m} \qquad (3.1)$$

The DC operating bus bar voltage V_{DC} is specified and is usually taken to be multiple of nominal battery voltage of 12V whereby V_m is the operating voltage of one module and should be taken as 12V for a module of 36 cells.

The number of parallel modules is directly related to the current requirement of the load. The load current is:

$$I_L(A) = \frac{E_L}{24V_{DC}} \tag{3.2}$$

where E_L is the typical power requirement of the load in Wh/day.

$$E_L(Wh/day) = PSH \times I_{PV} \times V_{DC} \tag{3.3}$$

where I_{PV} is the nominal current when PV generator is irradiated by the standard AM 1.5 at 1 kW/m^2 and PSH is peak sun hour- equal to the number of the hours of the standard irradiance (1kW/m^2) which will produce the same irradiance. Thus,

$$I_{PV} = \frac{24I_L}{PSH} \tag{3.4}$$

and

$$N_P = (SF)\frac{I_{PV}}{I_{SC}} \tag{3.5}$$

Where

SP = sizing factor

I_{PV} = nominal current when PV generator is irradiated by the standard AM 1.5 at 1 kW/m$^{2.}$

I_{SC} = short circuit current supplied by PV module when illuminated under standard conditions.

4.2 Charge Controller

In implementing charge controller, analogue device such as Op-Amp can be used. Basically, Op-Amp is a very high gain differential amplifier with high input impedance and v ery l ow o utput i mpedance. T his d evice i s u sed i n m any a pplications t o p rovide voltage amplitude changes such as, oscillators, filter circuits and instrumentation circuits.

Figure 4.1 shows the comparator circuit with independent hysteresis and adjustment reference voltage. This circuit constitutes a main part of Battery-Charge Control Circuit. The main component in that circuit is an Op-Amp which acts as a voltage comparator. It senses the battery voltage and compares it with adjustable reference voltage.

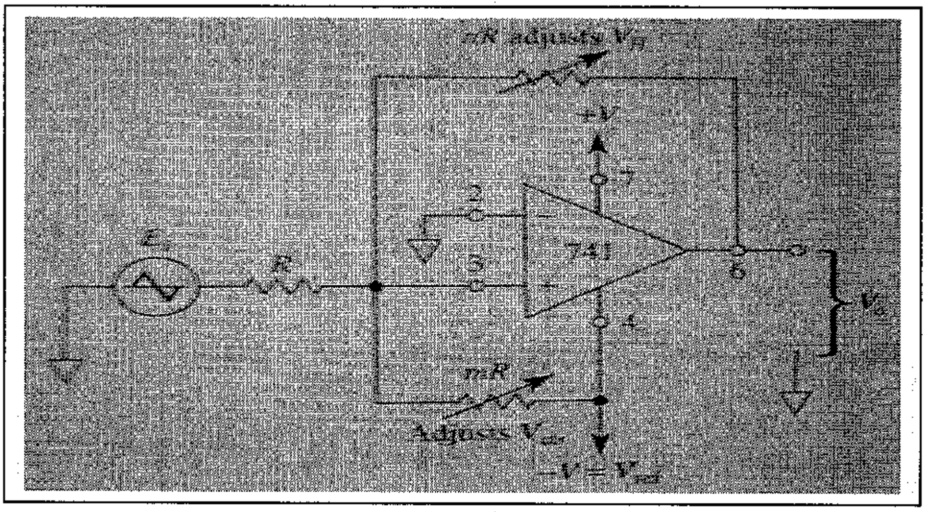


Figure 4.1: Comparator with independent adjustments for hysteresis and reference voltage

The whole circuit is a non-inverting voltage detector with independent adjustment of hysteresis and centre voltage. The centre voltage, V_{ctr} is determined by the values of *m*R and reference voltage, V_{ref} and V_H can be adjusted independently by changing the variable resistor *n*R.

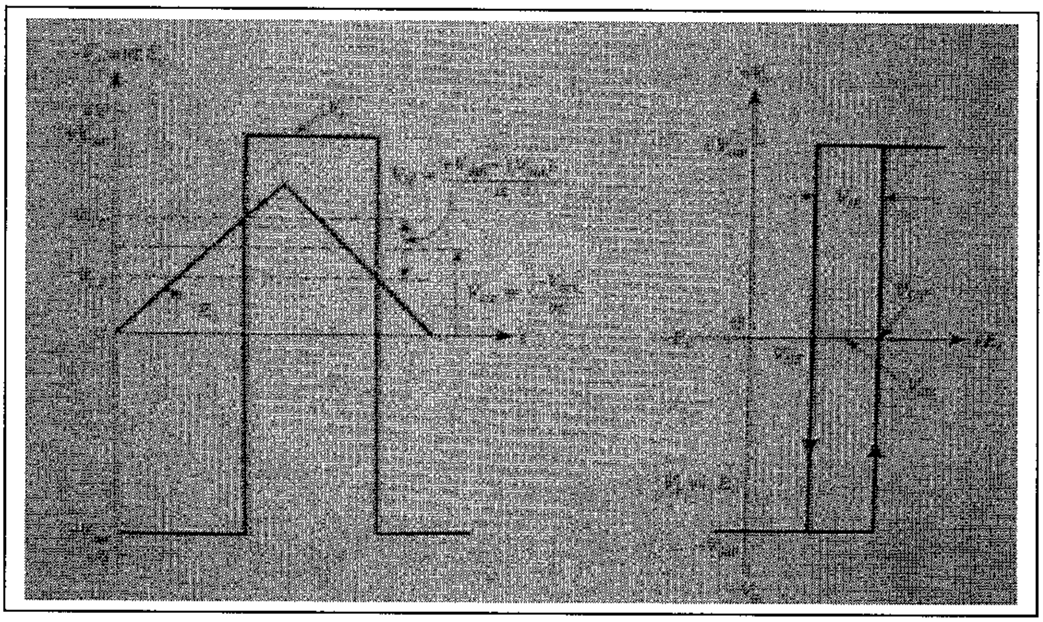


Figure 4.2: Hysteresis voltage V_H

Resistor mR and supply voltage $-V$ establish the centre voltage V_{ctr}. Resistor nR allows independent adjustment of the hysteresis voltage V_H symmetrically around Vctr.

The value of resistor, R is taken arbitrarily. The design parameters can be calculated by using these mathematical equations,

$$V_{UT} = -\frac{-V_{sat}}{n} - \frac{V_{ref}}{m}$$

$$V_{LT} = -\frac{-V_{ref}}{m} - \frac{+V_{sat}}{n}$$

$$V_H = V_{UT} - V_{LT} = \frac{(+V_{sat}) - (-V_{sat})}{n}$$

$$V_{ctr} = \frac{V_{UT} + V_{LT}}{2} = -\frac{V_{ref}}{m} - \frac{+V_{sat} + (-V_{sat})}{2n}$$

where

V_{UT} = minimum voltage level of the battery that needs to be monitored

V_{LT} = maximum voltage level of the battery that needs to be monitored

$+V_{sat}$ = positive saturation voltage of comparator output

$-V_{sat}$ = negative saturation voltage of comparator output

V_H = hysteresis voltage

V_{ctr} = center voltage

Calculation to determine the resistance value for circuit in Figure 4.3:

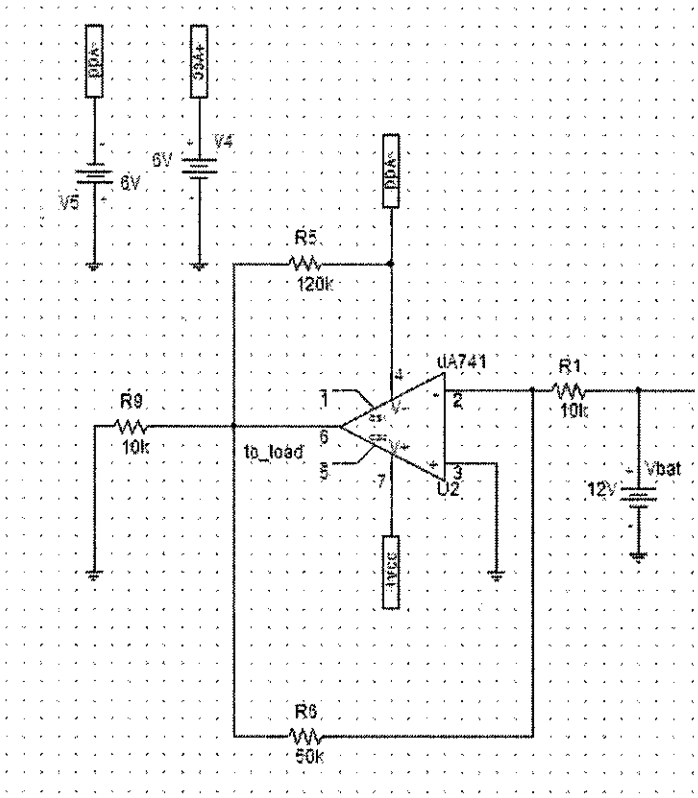


Figure 4.3: Battery charge controller to load

$V_{LT} = 7V$

$V_{UT} = 9.5V$

$-V_{supply} = V_{nett} = -6V$

$\pm V_{SAT} = \pm 15V$

$V_H = V_{UT} - V_{LT}$

$V_H = 9.5V - 7V = 2.5V$

$$V_{CTR} = \frac{V_{UT} + V_{LT}}{2}$$

$$V_{CTR} = \frac{9.5V + 7V}{2} = 8.25V$$

Let R=10KΩ,

$$A = \frac{-V_{nett}}{V_{CTR}}$$

$$A = \frac{-(-6V)}{8.25V} = 0.727$$

$$AR = (0.727)(10K\Omega) = 7.27K\Omega$$

This will obtained a resistance value for R6. So R6 is set to 7.27K Ω.

$$B = \frac{+V_{SAT} - (-V_{SAT})}{V_H}$$

$$B = \frac{15V + 15V}{2.5V} = 12$$

$$BR = (12)(10K\Omega) = 120K\Omega$$

The value of resistor, R5 in Figure 4.3 is set 120K Ω.

Calculation to determine resistance value for circuit in Figure 4.4:

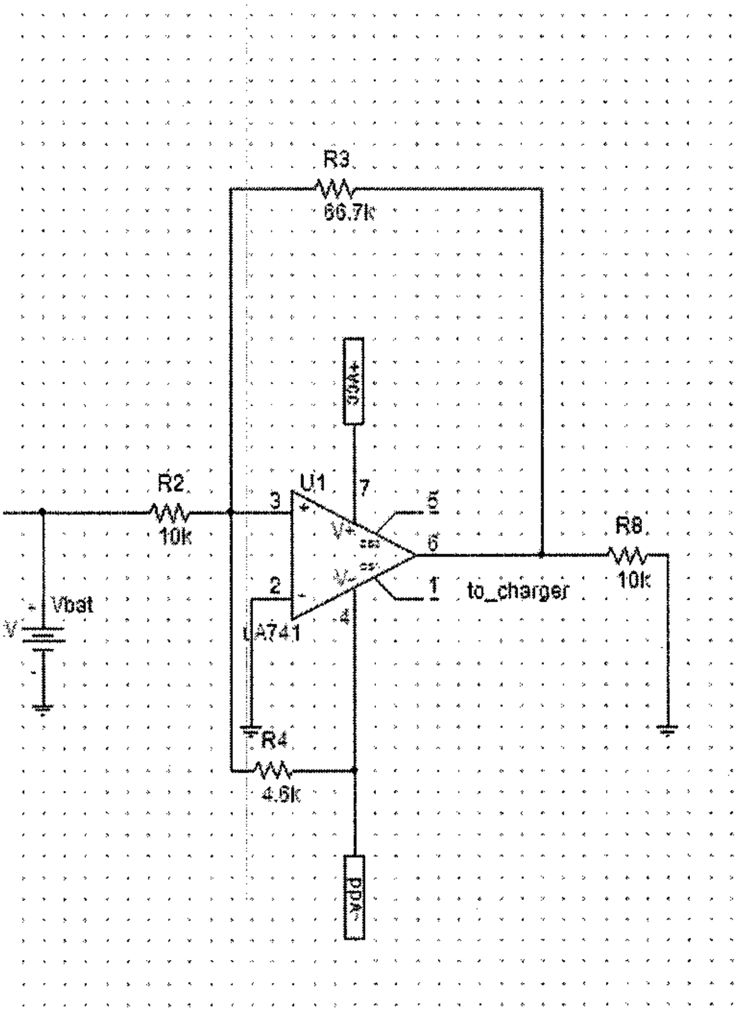


Figure 4.4: Battery charge controller to charger (PV cell)

$V_{LT} = 11V$

$V_{UT} = 15.5V$

$V_{Supply} = V_{nett} = -6V$

$V_{sat} = \pm 15V$

$V_H = 15.5V - 11 = 4.5\ V$

$$V_{CTR} = \frac{V_{UT} + V_{LT}}{2}$$

$$V_{CTR} = \frac{15.5 + 11}{2} = 13.25V$$

Let R=10KΩ

$$m = -\frac{V_{nett}}{V_{CTR}}$$

$$m = -\frac{-6V}{13.25V} = 0.453$$

$$mR = (0.453)(10K) = 4.6K\Omega$$

So the value of R4 in Figure 4.4 is change to 4.6KΩ.

$$n = \frac{+V_{SAT} - (-V_{SAT})}{V_H}$$

$$n = \frac{15V + 15V}{4.5V} = 6.6667$$

$$nR = (6.667)(10K\Omega) = 66.67K\Omega$$

The value for R3 is set to 66.67K Ω.

4.3 Circuit Simulation And Discussion

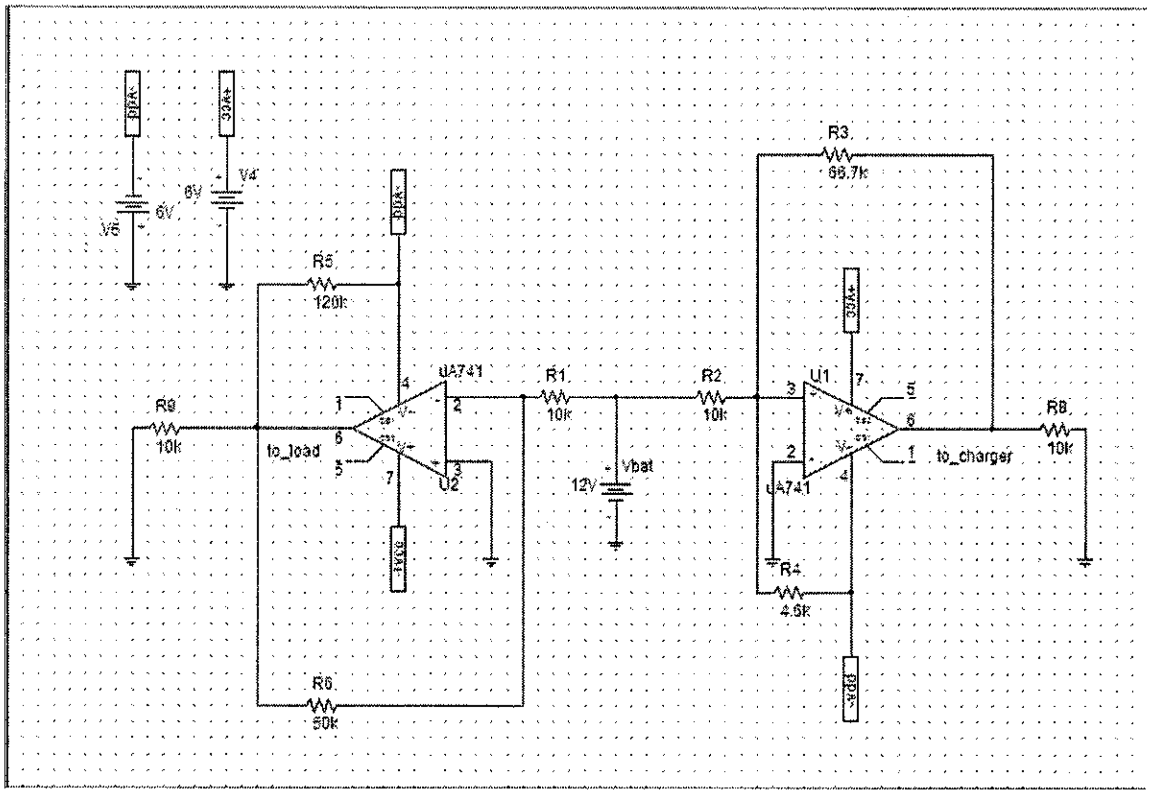


Figure 4.5 Circuit Simulation

By combining Figure 4.3 and Figure 4.4, the main circuit for the charge controller is complete (Figure 4.5). From the designed circuit, a simulation is made using the PSpice software to obtain the characteristics of the charge controller circuit. From simulation, two graphs are obtained; lower and upper limit of the battery as depicted in Appendix A1 and Appendix A2 respectively.

Appendix A1 shows the Op-Amp output is triggered to Logic 1 at nearly 14V. From calculation, the V_{ctr} is 13.25V and when the $V_{battery}$ is exceeding the Vctr, the normally close (NC) relay will energizes and thus disconnecting the battery from the charger. The disconnection will avoid the battery over-discharge and prevent the damaged to the battery.

Appendix A2 shows the Op-Amp output that connected to the load. The value for V_{ctr} is calculated to be 8.25V. When $V_{battery}$ is greater than 8.25V, the Op-Amp is triggered to Logic 1 and thus connecting the battery to the load for operation. When the battery is less than this limit, this relay will de-energize and disconnect the battery from the load.

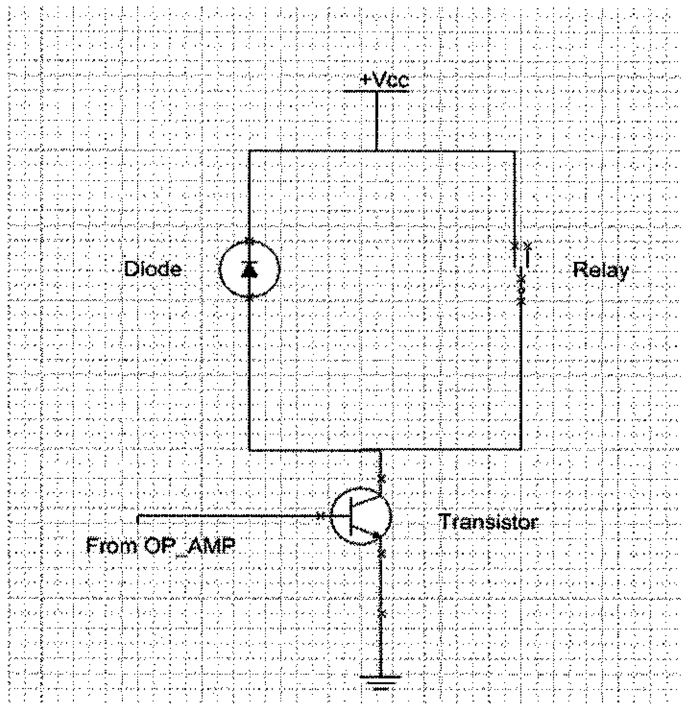


Figure 4.6: Relay Circuit

The relay circuit in Figure 4.6 is the connection from the Op-Amp to the charger (PV) and the load. Two relay circuits are needed to complete the charge controller circuit.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The photovoltaic system usually consists of a number of subsystems. In addition to the photovoltaic cell, provision is usually made for energy storage and control elements.

Sizing is an important part of the system design, particularly for standalone systems. The sizing procedure uses the radiation and load data to recommend the sizes of the array and battery storage, subject to the required reliability of power supply. It is also allows the system cost to be minimized.

Photovoltaic is expensive to produce because of the high cost of semiconducting materials. Cost reductions can be achieved by reducing manufacturing costs. As manufacturing capacity increases, costs of manufacturing decrease.

This project has enhanced the understanding on knowledge in several areas especially in system sizing for solar powered systems. The implementation of this project had given really good skills in handling hardware and software tools.

5.2 Recommendations

The recommendations on the enhancement of this project in the future are as follows:

i. For this project, the load that used is a direct current (DC) source type. It would be more interesting if the load can be change to the alternating current (AC) appliances.

ii. In this project, the solar cell generated a supply for a 7W bulb only. In the future, this system could be upgraded to supply a bigger load for a higher power appliance.

iii. As it is proven; in the long run, this system is very cost-effective. It is recommended that UTP use this system as a long term investment to save its power supply cost.

REFERENCES

[1] *Solar Energy – Principles of Thermal Collection and Storage*, Tata McGraw-Hill 2nd Edition, S P Sukhatme

[2] *Solar Electricity*, John Wiley and Sons, Tomas Markvart

[3] *Applications of Photovoltaics*, Adam Hilger, Edited by R Hill

[4] *Generating Electricity From The Sun*, Pergammon Press, Edited by Fred C Treble

[5] *Operational Amplifier and Linear Integrated Circuits*,Robert F. Coughlin & Fredrick F. Driscoll, 2001,6th Edition, Prentice Hall, New Jersey, USA

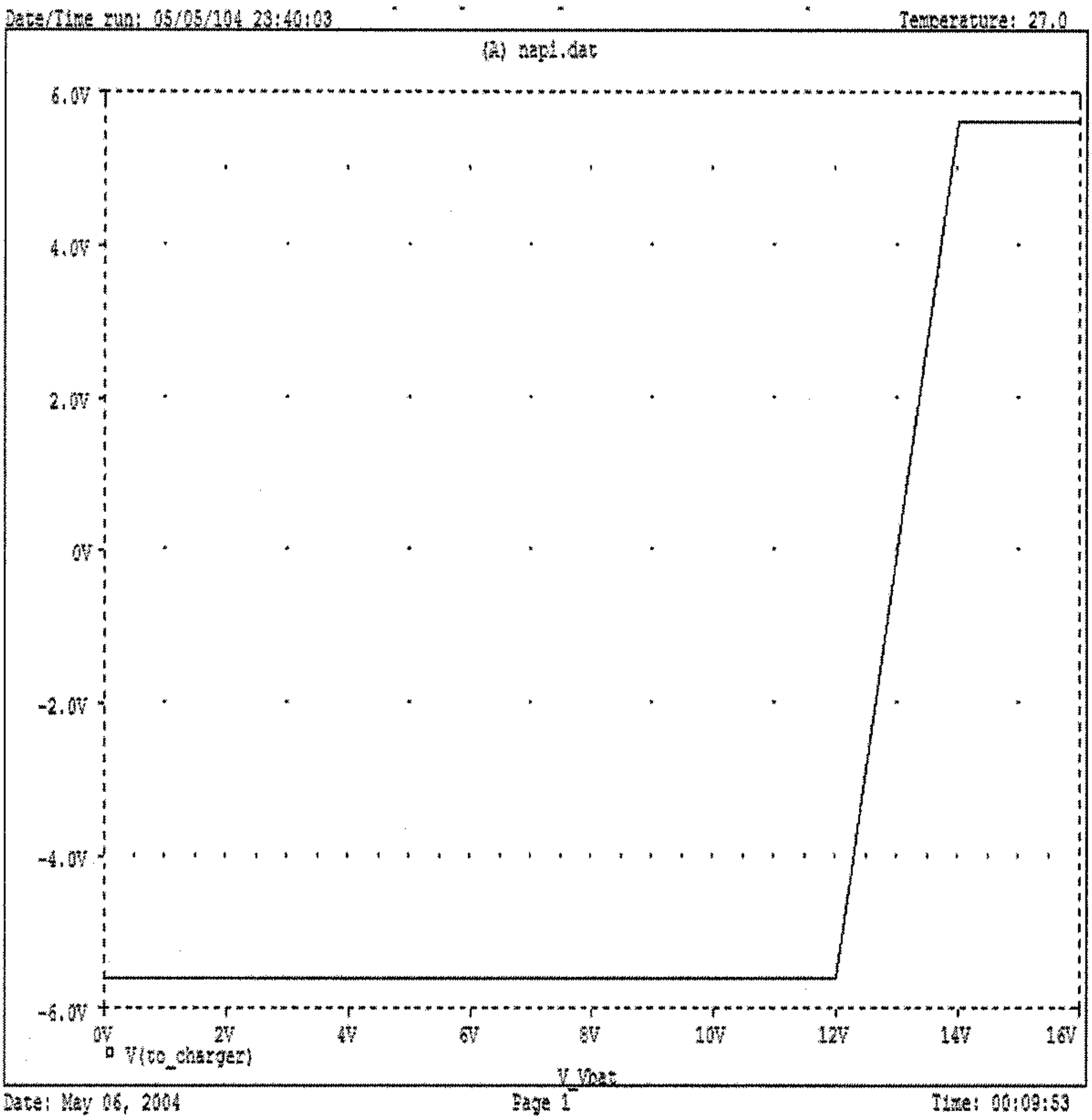
http://www.history.rochester.edu/class/solar/cells.htm [6]

http://www.eere.energy.gov/erec/factsheets/pvbasics.html [7]

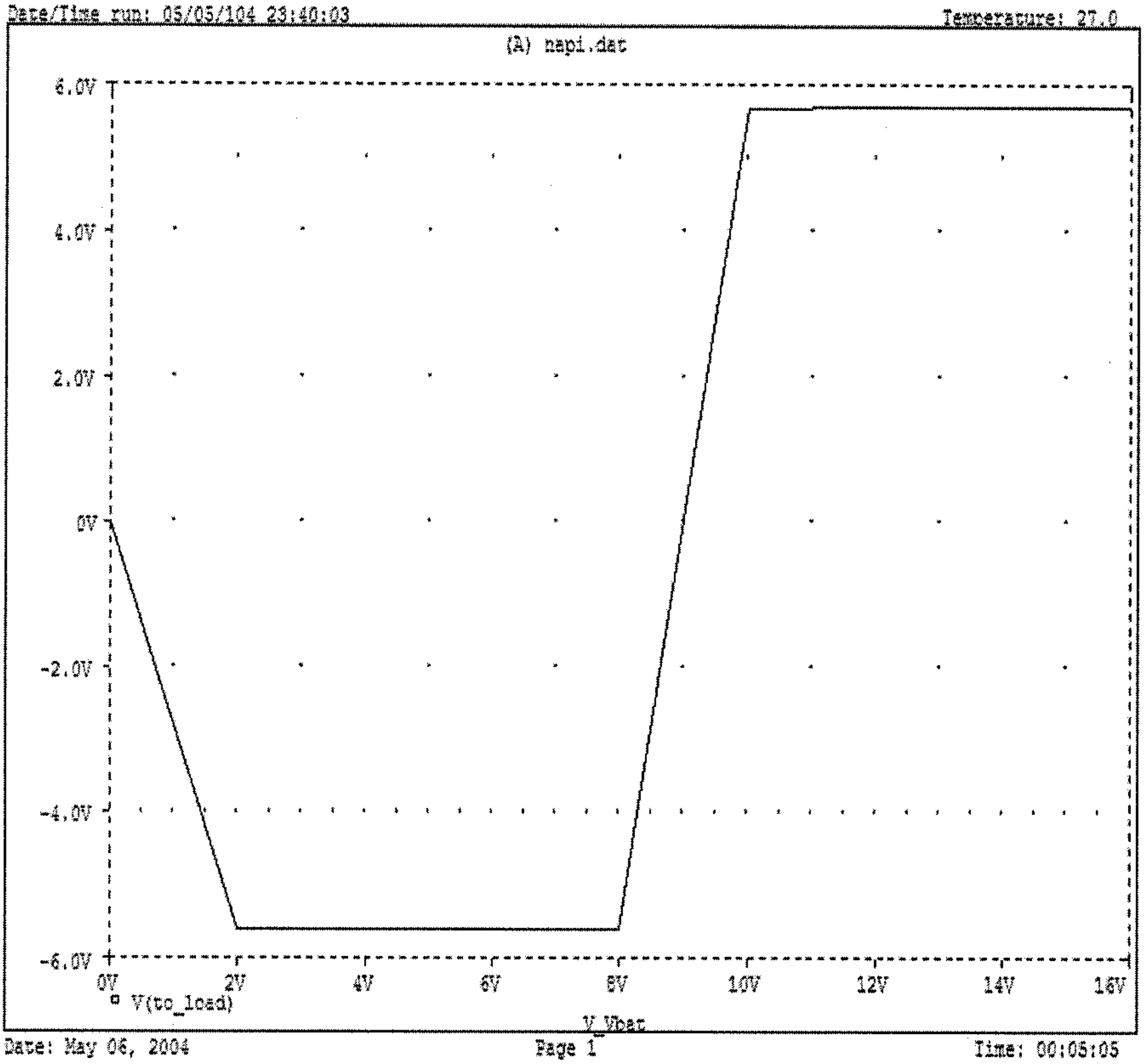
http://www.eere.energy.gov [8]

http://www.pvinsider.com [9]

APPENDIX A

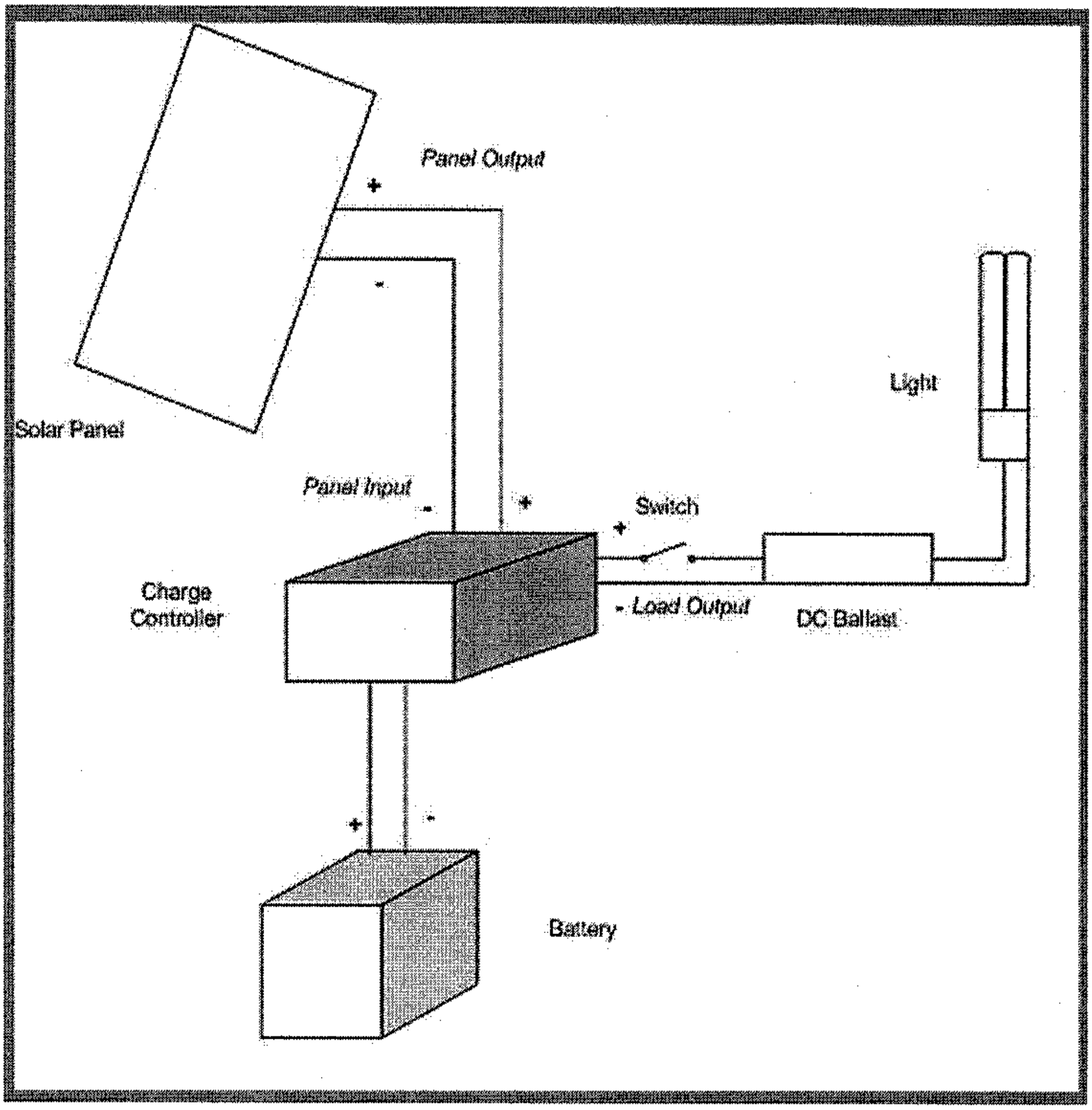


Appendix A1: OP-Amp Output to the PV cell



Appendix A2: OP-Amp Output to the Load

APPENDIX B



Appendix B: Solar Lighting System

APPENDIX C

(LM741 Operational Amplifier Datasheets)

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

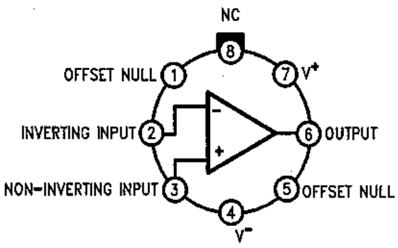
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

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

Connection Diagrams

Metal Can Package

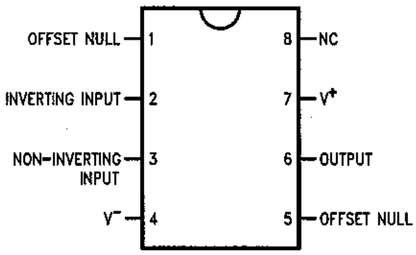


DS009341-2

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

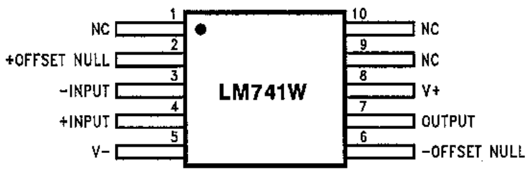
Dual-In-Line or S.O. Package



DS009341-3

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

Ceramic Flatpak

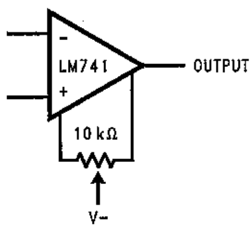


DS009341-6

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



DS009341-7

Absolute Maximum Ratings (Note 2)

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

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55˚C to +125˚C	−55˚C to +125˚C	0˚C to +70˚C
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C	−65˚C to +150˚C
Junction Temperature	150˚C	150˚C	100˚C
Soldering Information			
N-Package (10 seconds)	260˚C	260˚C	260˚C
J- or H-Package (10 seconds)	300˚C	300˚C	300˚C
M-Package			
Vapor Phase (60 seconds)	215˚C	215˚C	215˚C
Infrared (15 seconds)	215˚C	215˚C	215˚C

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

ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25˚C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/˚C
Input Offset Voltage Adjustment Range	$T_A = 25˚C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25˚C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/˚C
Input Bias Current	$T_A = 25˚C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25˚C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25˚C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	T_A = 25°C, $R_L \geq 2$ kΩ										
	V_S = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$R_L \geq 2$ kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
Output Voltage Swing	V_S = ±20V										
	$R_L \geq 10$ kΩ	±16									V
	$R_L \geq 2$ kΩ	±15									V
	V_S = ±15V										
	$R_L \geq 10$ kΩ				±12	±14		±12	±14		V
	$R_L \geq 2$ kΩ				±10	±13		±10	±13		V
Output Short Circuit	T_A = 25°C	10	25	35		25			25		mA
Current	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
Rejection Ratio	$R_S \leq 10$ kΩ, V_{CM} = ±12V				70	90		70	90		dB
	$R_S \leq 50\Omega$, V_{CM} = ±12V	80	95								dB
Supply Voltage Rejection	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
Ratio	V_S = ±20V to V_S = ±5V										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10$ kΩ				77	96		77	96		dB
Transient Response	T_A = 25°C, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		μs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	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 = ±20V		80	150							mW
	V_S = ±15V					50	85		50	85	mW
LM741A	V_S = ±20V										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741	V_S = ±15V										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Electrical Characteristics (Note 5) (Continued)

Note 3: 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 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

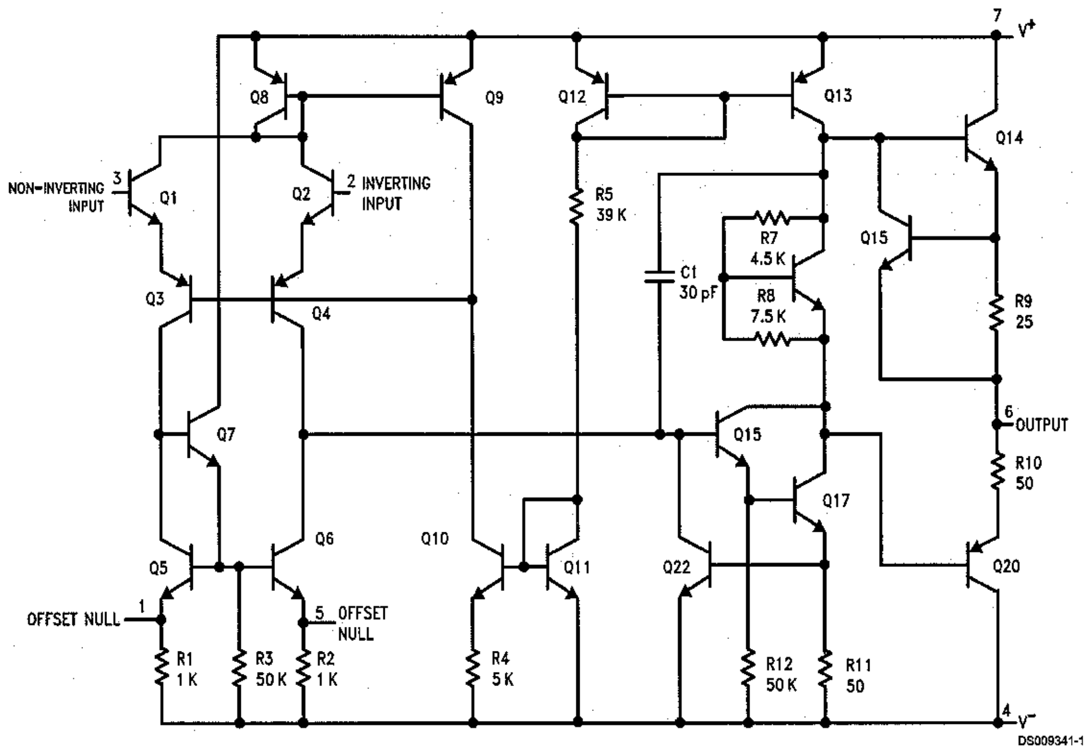
Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(μs).

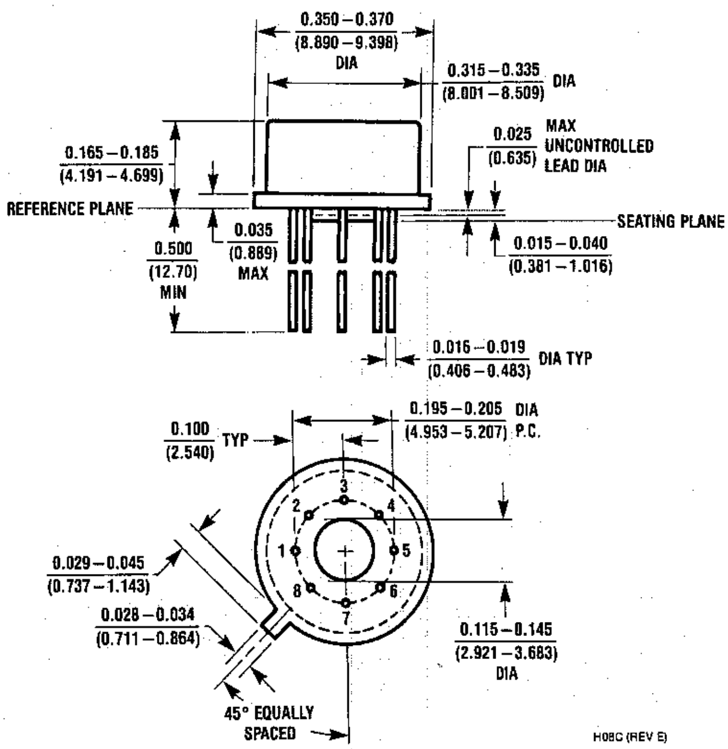
Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

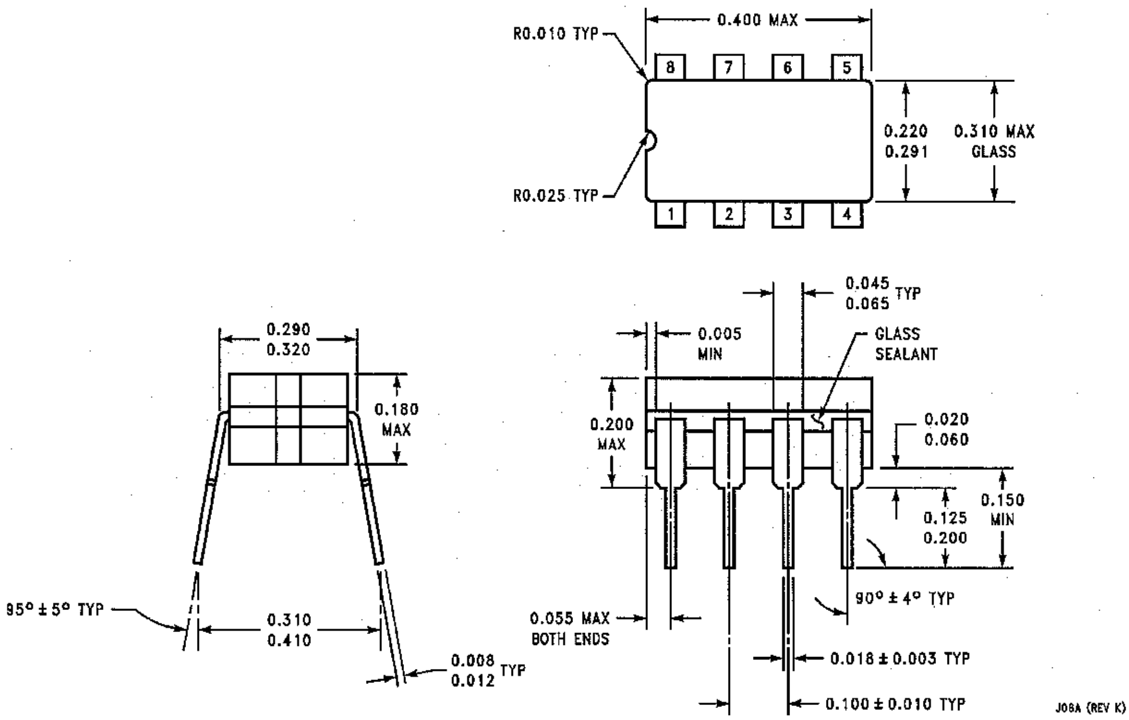
Schematic Diagram



Physical Dimensions inches (millimeters) unless otherwise noted

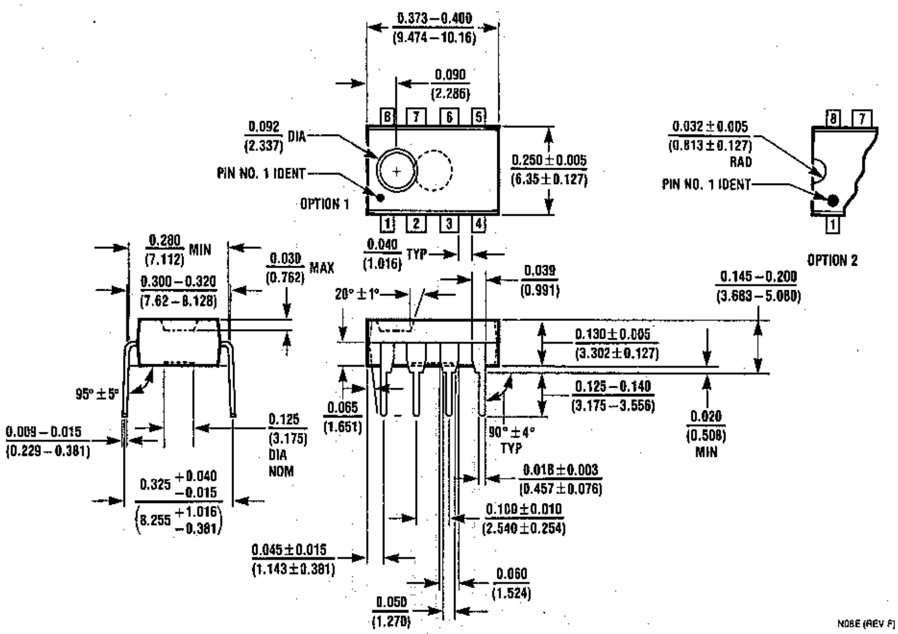


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741AH-MIL or LM741CH
NS Package Number H08C

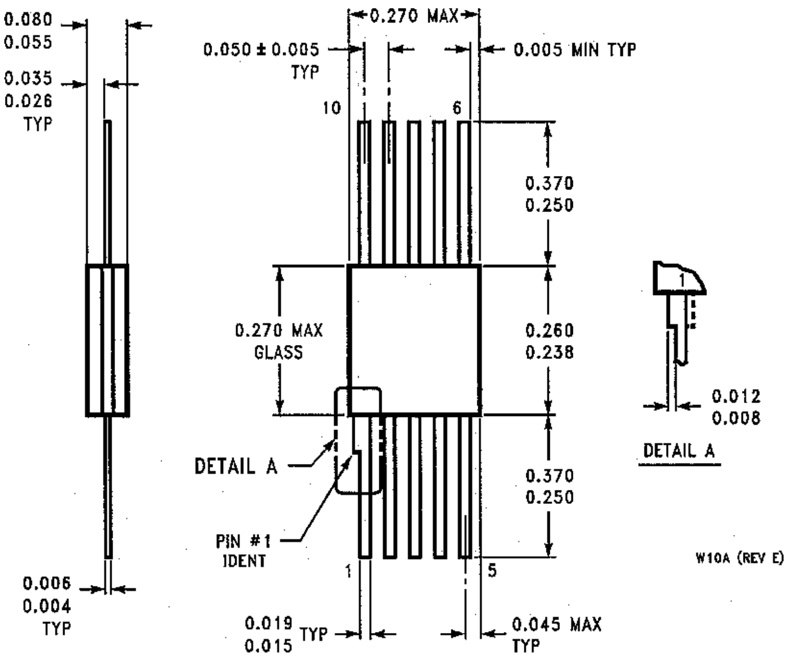


Ceramic Dual-In-Line Package (J)
Order Number LM741J/883
NS Package Number J08A

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



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



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883, LM741WG-MPR or LM741WG/883
NS Package Number W10A

Notes

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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

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

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

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

APPENDIX D

(2N2219 Silicon NPN Transistor Datasheets)

SEMICOA
SEMICONDUCTORS

2N2219

Silicon NPN Transistor

Data Sheet

Description

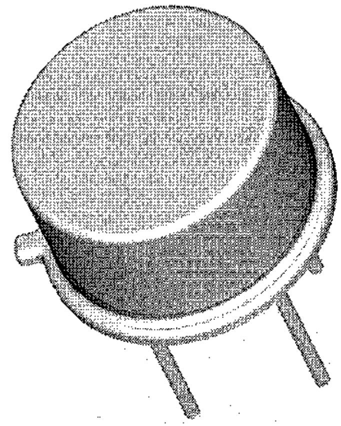
Semicoa Semiconductors offers:

- Screening and processing per MIL-PRF-19500 Appendix E
- JAN level (2N2219J)
- JANTX level (2N2219JX)
- JANTXV level (2N2219JV)
- JANS level (2N2219JS)
- QCI to the applicable level
- 100% die visual inspection per MIL-STD-750 method 2072 for JANTXV and JANS
- Radiation testing (total dose) upon request

Please contact Semicoa for special configurations
www.*SEMICOA*.com or (714) 979-1900

Applications

- General purpose
- Low power
- NPN silicon transistor



Features

- Hermetically sealed TO-39 metal can
- Also available in chip configuration
- Chip geometry 0400
- Reference document: MIL-PRF-19500/251

Benefits

- Qualification Levels: JAN, JANTX, JANTXV and JANS
- Radiation testing available

Absolute Maximum Ratings

T_C = 25°C unless otherwise specified

Parameter	Symbol	Rating	Unit
Collector-Emitter Voltage	V_{CEO}	30	Volts
Collector-Base Voltage	V_{CBO}	60	Volts
Emitter-Base Voltage	V_{EBO}	5	Volts
Collector Current, Continuous	I_C	800	mA
Power Dissipation, $T_A = 25^oC$ Derate linearly above 25^oC	P_T	0.8 4.6	W mW/°C
Power Dissipation, $T_C = 25^oC$ Derate linearly above 25^oC	P_T	3.0 17.0	W mW/°C
Operating Junction Temperature	T_J	-55 to +200	°C
Storage Temperature	T_{STG}	-55 to +200	°C

ELECTRICAL CHARACTERISTICS

characteristics specified at $T_A = 25°C$

Off Characteristics

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$	$I_C = 10$ mA	30			Volts
Collector-Base Cutoff Current	I_{CBO1}	$V_{CB} = 60$ Volts			10	μA
Collector-Base Cutoff Current	I_{CBO2}	$V_{CB} = 50$ Volts			10	nA
Collector-Base Cutoff Current	I_{CBO3}	$V_{CB} = 50$ Volts, $T_A = 150^oC$			10	μA
Collector-Emitter Cutoff Current	I_{CES}	$V_{CE} = 30$ Volts			10	nA
Emitter-Base Cutoff Current	I_{EBO1}	$V_{EB} = 5$ Volts			10	μA
Emitter-Base Cutoff Current	I_{EBO2}	$V_{EB} = 4$ Volts			10	nA

On Characteristics

Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
DC Current Gain	h_{FE1} h_{FE2} h_{FE3} h_{FE4} h_{FE5} h_{FE6}	$I_C = 0.1$ mA, $V_{CE} = 10$ Volts $I_C = 1.0$ mA, $V_{CE} = 10$ Volts $I_C = 10$ mA, $V_{CE} = 10$ Volts $I_C = 150$ mA, $V_{CE} = 10$ Volts $I_C = 500$ mA, $V_{CE} = 10$ Volts $I_C = 10$ mA, $V_{CE} = 10$ Volts $T_A = -55^oC$	35 50 75 100 30 15		325 300	
Base-Emitter Saturation Voltage	V_{BEsat1} V_{BEsat2}	$I_C = 150$ mA, $I_B = 15$ mA $I_C = 500$ mA, $I_B = 50$ mA	0.6		1.3 2.6	Volts
Collector-Emitter Saturation Voltage	V_{CEsat1} V_{CEsat2}	$I_C = 150$ mA, $I_B = 15$ mA $I_C = 500$ mA, $I_B = 50$ mA			0.4 1.6	Volts

Dynamic Characteristics

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Magnitude – Common Emitter, Short Circuit Forward Current Transfer Ratio	$\|h_{FE}\|$	$V_{CE} = 20$ Volts, $I_C = 20$ mA, f = 100 MHz	2.5		12	
Small Signal Short Circuit Forward Current Transfer Ratio	h_{FE}	$V_{CE} = 10$ Volts, $I_C = 1$ mA, f = 1 kHz	50			
Open Circuit Output Capacitance	C_{OBO}	$V_{CB} = 10$ Volts, $I_E = 0$ mA, 100 kHZ < f < 1 MHz			8	pF
Open Circuit Input Capacitance	C_{IBO}	$V_{EB} = 0.5$ Volts, $I_C = 0$ mA, 100 kHZ < f < 1 MHz			25	pF

Switching Characteristics

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Saturated Turn-On Time	t_{ON}				40	ns
Saturated Turn-Off Time	t_{OFF}				250	ns

Semicoa Semiconductors, Inc.
333 McCormick Avenue, Costa Mesa, California 92626 714.979.1900, FAX 714.557.4541
www.SEMICOA.com