PHOTOVOLTAIC WATER PUMPING SYSTEM

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

June 2011

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.

Siti Khadhijah Zulkafli

ABSTRACT

Recent global developments appear to guarantee a market for green renewable energy. Among several sources of renewable energy currently explored, photovoltaic (PV) system appears to be promising in view of their environmentally clean nature and the advantage of direct conversion to electrical energy. The aim of this project is to design a laboratory model of solar-powered water pumping system to prove that the concept of using solar energy as electricity is possible. The system consists of solar panel, power conditioner such as charge controller and inverter, storage battery, AC Pump and DC Pump. The report will cover all theory and literature review behind this project. To design a photovoltaic water pumping system, the understanding on each system components on the operation and concept are needed. The scope of study of this project includes the photovoltaic and its operation, storage battery operation in photovoltaic system, controller circuit design and its assemblage, inverter circuit and its assemblage and prototype design and construction. The results showed that PV system would be suitable to supply electricity to both AC and DC load, without using energy from the grid.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my Final Year Project supervisor, Assoc. Prof. Irraivan a/l Elamvazuthi, for his invaluable help, advices, suggestions, and encouragement. His untiring effort has been a continuous inspiration to me.

My utmost and heartfelt thanks are to all the people who have spent time to support with me regarding the concept and methodologies of this project in order to smoothly understand and implement this project. I would like to thank the technicians, especially Mrs. Siti Hawa, Mr. Azhar, Mr. Yasin and Mr. Zuraimi for giving me their hands in constructing the prototype in order to make sure this project can be completed on time.

Most importantly, I would like to thank my parents who love me, support me and teach me to be a responsible and wise person. Their sacrifice and support throughout my life have helped me a lot in my education.

Last but not least, I would like to extend my appreciation to my classmates in Universiti Teknologi PETRONAS (UTP), who have support me throughout this project. I would also like to express my faithful thanks to all whose name had not mention, but have either directly or indirectly assist me in this project. All your helps, kindness, valuable guidance and advice will never be forgotten.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
DoA	Department of Agriculture Malaysia
AC	Alternating Current
DC	Direct Current
STC	Standard Test Conditions
Ah	Amp-hour
EWB	Electronic Workbench
DOD	Depth of Discharge

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Malaysia lies in tropical region between 1°N and 7°N, and 100°E and 119°E. The climate is hot and humid throughout the year with heavy rainfall. Rainfall range is 2032-2540 mm, temperature 21-23°C, relative humidity 80%-90%, and solar radiation 12-20 MJ/m^2. There are approximately 6 hours of sunshine per day [1].

Renewable energy plays important role in the energy supply of the developing and industrializing countries. Developing a clean and renewable energy has become one of the most important tasks assigned to modern science and engineering. Photovoltaic energy comes along as the most promising one as a future energy resource. However, the photovoltaic application is not widely been used in Malaysia despite the Malaysia's climate [2].

Improving in paddy production was one of the Department of Agriculture Malaysia (DoA) scheme since the rice price has increased. Through this plan, solar-powered water pump can be an initiative to improve the paddy production by controlling the water reservoir and paddy field water level [3].

1.2 Problem Statement

Different pumping systems have been adopted by the farmers such as manual driven pump, engine driven pump, grid powered pump, and generator driven pump. However, there are some problems have been encountered by using these systems which are [4]:

- The burning of fossil fuel produces carbon dioxide, which is one of the greenhouse gases that contribute to global warming, causing the average surface temperature of the Earth to rise in response [5].
- Most of these systems require high maintenance since they have many moving parts
- Need to install a conventional grid powered pump, which is expensive and unreliable.
- Due to the steady increase in the price of fuel for the past few years, most these systems have become expensive.

To overcome the problems, there is a need to design and construct a photovoltaic water pumping system that can be used for irrigation where it will save the money in implementation of transmission line for the rural area.

1.3 Objectives

The main objective of this project is to design and construct a laboratory model of solar-powered water pump.

1.4 Scope of Study

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

- The photovoltaic and its operation
- Battery operation in photovoltaic system
- Controller circuit design and its assemblage
- Inverter circuit and its assemblage
- Prototype design and construction

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Photovoltaic Water Pumping System

Photovoltaic water pumping system is made up of a number of components. There is a photovoltaic array which converts solar energy directly into electricity as Direct Current (DC). This electric energy then is stored in the battery. The electrical energy in the battery is used by controlling a control unit. The pump will have an electric motor to drive it. The characteristics of these components need to be matched to get the best performance. The pump motor unit will have its own optimum speed and load depending on the type and size of the pump. Solar irrigation system is shown schematically in Figure 1 [6].

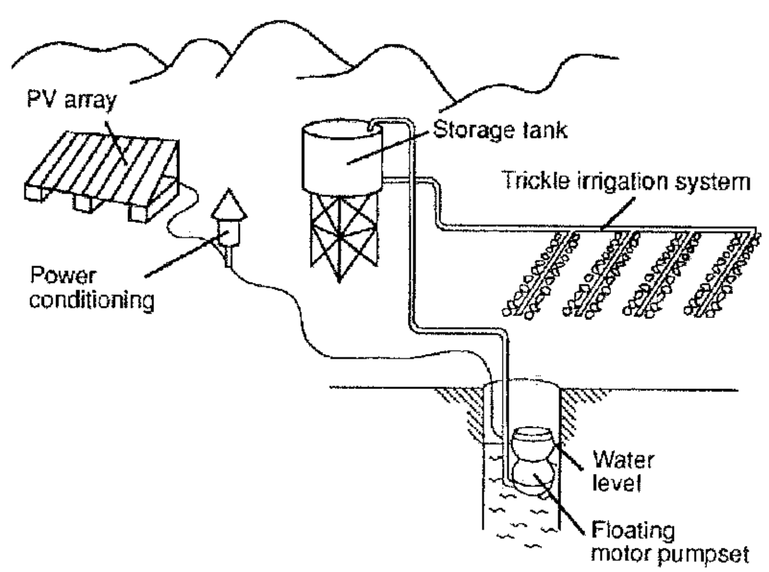

Figure 1: A Solar Irrigation System [6]

2.2 Photovoltaic Module

Figure 2: Photovoltaic array [7]

Photovoltaic array, as shown in Figure 2, are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For photovoltaic array, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current. This electricity can then be used to power a load, such as a light or a tool [7].

2.2.1 Type of Photovoltaic Cell

Photovoltaic cells are manufactured from semiconductor materials; that is, materials that act as insulators at low temperatures, but as conductors when energy or heat available. At present, most PV cells are silicon based, since this is the most mature technology. There are three general type of silicon PV cells [8]:

i. Crystalline silicon
ii. Multicrystalline silicon
iii. Amorphous silicon

2.2.1.1 Monocrystalline Silicon

Monocrystalline silicon has an ordered crystal structure, with each atom ideally lying in a pre-ordained position. It therefore allows ready application of the theories and techniques developed for crystalline material. It is, however, the most expensive type of silicon, because of the careful and slow manufacturing processes required. [8]

2.2.1.2 Multicrystalline Silicon

The techniques for production of multicrystalline are less critical and hence cheaper, than those required for crystalline silicon. The grain boundaries reduce the cell performance by blocking carriers' flows, allowing extra energy levels in the forbidden gap, thereby providing effective recombination sites and providing shunting paths for current flow across the p-n junction. [8]

2.2.1.3 Amorphous Silicon

Amorphous silicon can be produced, in principle, even more cheaply than multicrystalline. With amorphous silicon, there is no long-range order in the structural arrangement of the atoms, resulting in areas within the material containing unsatisfied bonds. These in turn result in extra energy levels within the forbidden gap, making it impossible to dope the semiconductor when pure, or to obtain reasonable current flows in a solar cell configuration. [8]

Amorphous silicon are used in many small consumer products, such as calculators and watches, and increasing also for large scale applications. In principle, thin films provide a very low cost means of cell production, although at present their efficiencies and lifetimes are lower than for crystalline products. [8]

2.2.2 Efficiency

Table 1 show typical conversion efficiencies of silicon based PV modules. A lower efficiency means more PV modules are needed for the same electricity output. [9]

A solar cell's energy conversion efficiency is the percentage of power converted (from absorbed light to electrical energy) and collected, when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, P_m, divided by the input light irradiance (E, in W/m^2) under standard test conditions (STC) and the surface area of the solar cell (A_c in m^2).

$$\eta = \frac{P_m}{E \times A_c}$$

Table 1: Comparison of efficiency of three type of photovoltaic cell silicon based

Typical efficiency	**Crystalline silicon**	**Multicrystalline silicon**	**Amorphous silicon**
Module	20 – 29%	14 - 19%	3 - 6%

2.3 Battery Storage

Battery storage is used as a back up when photovoltaic panel does not provide sufficient energy to the motor water pump. Batteries store the electrical energy generated by the photovoltaic panel during sunny periods, and deliver it whenever the panel cannot supply power.

Normally, batteries are discharged during the night or cloudy weather. But if the load exceeds the array output during the day, the batteries can supplement the energy of discharging in described as a "cycle". Ideally, the batteries are recharged to 100% capacity during the charging phase of each cycle. The batteries must not be completely discharged during each cycle.

No single component in a photovoltaic system is more affected by the size and usage of the load than storage batteries. If a charge controller is not included in the system, oversized loads or excessive use can drain the batteries' charge to the point where they are damaged and must be replaced. If a controller does not stop overcharging, the batteries can be damaged during times of low or no load usage or long periods of full sun.

For these reasons, battery systems must be sized to match the load. In addition, different types and brands of batteries have different "voltage set point windows." This refers to the range of voltage the battery has available between a fully discharged and fully charged state.

As an example, a battery may have a voltage of 14 volts when fully charged, and 11 when fully discharged. Assume the load will not operate properly below 12 volts. Therefore, there will be times when this battery cannot supply enough voltage for the load. The battery's voltage window does not match that of the load. [10]

At present, the most commonly used for stand-alone photovoltaic system is lead-acid battery.

2.3.1 Lead Acid Battery

A lead-acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again.

2.3.2 Performance

The performance of storage batteries is described two ways which are the amp-hour capacity and the depth of cycling. [10]

2.3.2.1 Amp-hour capacity

The *Amp-hour (Ah) Capacity* of a battery tries to quantify the amount of usable energy it can store at a nominal voltage. All things equal, the greater the physical volume of a battery, the larger its total storage capacity. Storage capacity is additive when batteries are wired in parallel but not if they are wired in series.

If the battery is charged or discharged at a different rate than specified, the available amp-hour capacity will increase or decrease. Generally, if the battery is discharged at a slower rate, its capacity will probably be slightly higher. More rapid rates will generally reduce the available capacity.

Typically, the amp-hour capacity of a battery is measured at a rate of discharge that will leave it empty in 20 hours (a.k.a. the C/20 rate). The more extreme the deviation from the C/20 rate, the greater the available (as opposed to total) capacity difference. [10]

2.3.2.2 Charge and discharge rates

If the battery is charged or discharged at a different rate than specified, the available amp-hour capacity will increase or decrease. Generally, if the battery is discharged at a slower rate, its capacity will probably be slightly higher. More rapid rates will generally reduce the available capacity.

The rate of charge or discharge is defined as the total capacity divided by some number. For example, a discharge rate of C/20 means the battery is being discharged at a current equal to 1/20th of its total capacity. In the case of a 400 amp-hour battery, this would mean a discharge rate of 20 amps. [10]

2.3.2.3 Temperature

Another factor influencing amp-hour capacity is the temperature of the battery and its surroundings. Batteries are rated for performance at 800F. Lower temperatures reduce amp-hour capacity significantly. Higher temperatures result in a slightly higher capacity, but this will increase water loss and decrease the number of cycles in the battery life as shown in Figure 3.

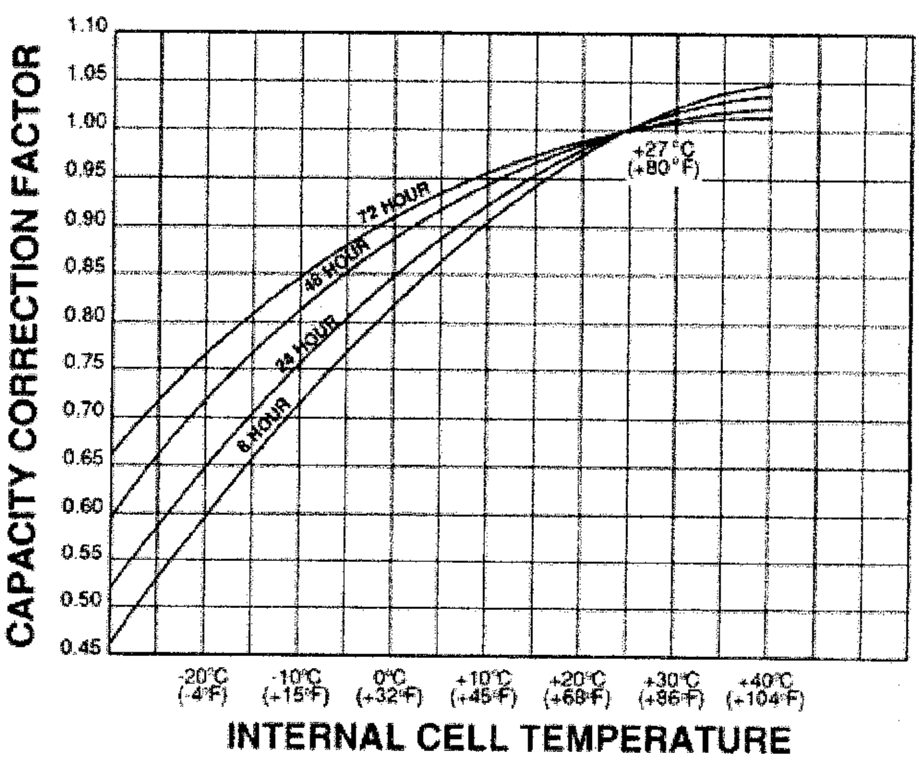

Figure 3: Battery Capacity at Different Temperatures [10]

2.3.2.4 Depth of discharge

The second description of performance is depth of discharge. This describes how much of the total amp-hour capacity of the battery is used during a charge-recharge cycle.

As an example, "shallow cycle" batteries are designed to discharge from 10% to 25% of their total amp-hour capacity during each cycle. In contrast, most "deep cycle" batteries designed for photovoltaic applications are designed to discharge up to 80% of their capacity without damage. Manufacturers of deep cycle "Ni cad" batteries claim their product can be totally discharged without damage.

Even deep cycle batteries are affected by the depth of discharge. The deeper the discharge, the smaller the number of charging cycles the battery will last. They are also affected by the rate of discharge and their temperature. [10]

2.4 Regulators

One of the fundamental difficulties in most PV systems is that battery charging can only occur while the sun is shining, which is limited period. Batteries in PV systems also experience a wide range of operating conditions, and must be properly regulated to maximize their performance and lifespan, as well as for safety purposes. Almost every PV system that uses battery requires a charge controller. Charge controllers manage battery charging within the limited charging opportunities while protecting the batteries from overcharge and overdischarge.

A charge controller is a device that regulates battery charge by controlling the charging voltage from a DC power source, such as PV array. A charge controller in a PV system maintains a battery at its highest possible state of charge while protecting the battery from overcharge by the array and overdischarge by system loads. This maximizes available capacity and cycle life. [11]

2.5 AC and DC Power

Direct Current (DC) is electrical current that flows in one direction, either positive or negative. DC power may be constant or variable, but must maintains one direction.

If voltage and current signals are either always positive or always negative, they are DC waveforms. If the signals switch between positive and negative, they are AC waveforms as shown in Figure 4.

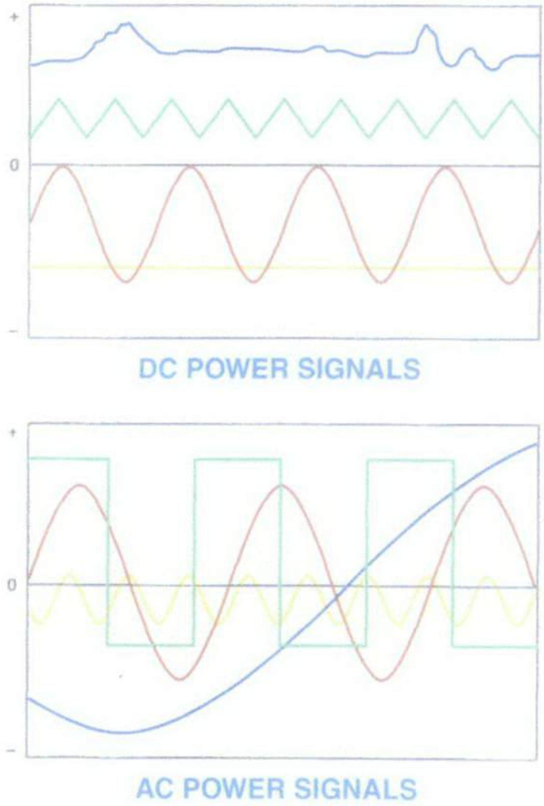

Figure 4: AC and DC power signals [11]

PV modules produce variable Direct Current (DC) power. However, most electrical loads operate using AC power, so DC power usually must be transformed into AC power in order to be useful. Alternating Current (AC) is electrical current that changes between positive and negative directions. AC power is characterized by waveform shape, frequency, and magnitude.

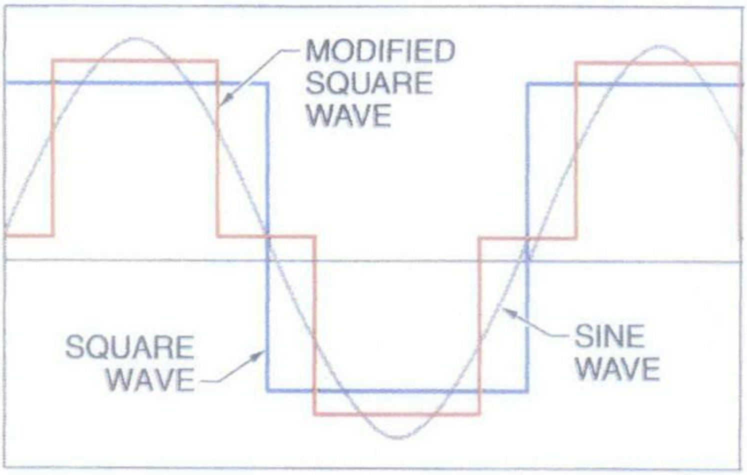

Figure 5: AC waveform [11]

The rotating generators that provide most of the electrical power on the utility grid naturally produce sine waves, so most loads are designed to operate using sinusoidal AC power. Therefore interactive inverters produce sine waves for utility synchronization. Other waveforms may damage loads.

Square waves and modified square waves are non-sinusoidal waveforms. A square wave is an alternating current waveform that switches between maximum positive and negative values every half period. Square waves are inefficient and are not common inverter output, but are the basis for the improved modified square wave.

A modified square wave is a synthesized, stepped waveform that approximates a sine wave. Also called a modified sine wave or a quasi sine wave, this type of waveform is the typical AC output of many stand-alone inverters. In terms of power quality, a modified square wave is a substantial improvement over a simple square wave. Compared to square wave inverters, modified square wave inverters have lower harmonic distortion, higher peak voltage, higher efficiency, and better surge current capability. [11]

2.6 Inverter

When AC loads and appliances are to be used in a PV system, an inverter is required to convert DC power to AC power. An inverter is a device that converts DC power to AC power; the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

As they became available with adequate power ratings, transistors and various other types of semiconductor switches have been incorporated into inverter circuit designs. [12]

2.7 Solar Radiation in Malaysia

A heavy rainfall, constantly high temperature and relative humidity characterize the Malaysian climate. Generally, chances of rain falling in the afternoon or early evening are high compared with that in the morning. The country experiences more than 170 rainy days. Average ambient temperature are between 26°C – 32°C . Most locations have a relative humidity of 80 – 88%, rising to nearly 90 % in the highland areas, and never falling below 60%.

The monthly average daily solar radiation in Malaysia is 4000 - 5000 Whr/m2, with the monthly average daily sunshine duration ranging from 4 hours to 8 hours [13]. It also estimated that the solar energy received in a year is 16 times the Malaysian annual conventional energy requirement.

In Figure 6, it shows most places in Peninsular Malaysia recorded solar radiation ranging from 14 to 20 MJm^{-2} per day whereas the whole Sabah and Sarawak recorded 16 MJm^{-2} to 23 MJm^{-2} per day. [14]

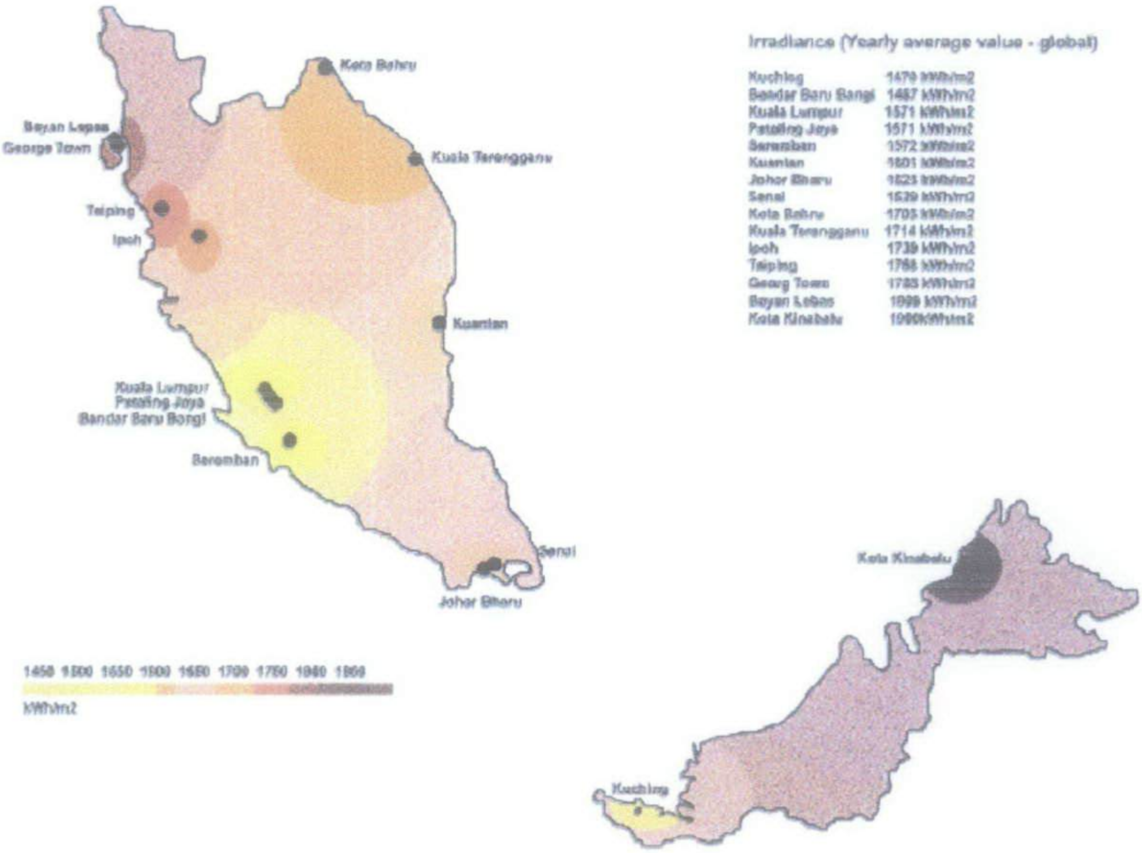

Figure 6: Estimates of the Annual Average Daily Global Solar Irradiation [14]

2.7.1 Solar Radiation Characteristic

A photovoltaic module would generate DC electricity whenever it is exposed to direct sunshine. The amount of power generated is proportional to the intensity of the solar radiation, but it could be affected by ambient temperature. A $100W_p$ solar photovoltaic module would produce $100W_{d.c.}$ power at Standard Test Condition (STC), for example at direct exposure to $1000W/m^2$ of solar radiation and the photovoltaic temperature is at 25°C. However, this ideal condition is hard to achieve.

In tropical climate country such as Malaysia, the maximum solar radiation is typically between $800W/m^2$ to $1000W/m^2$, but the ambient temperature could be as high as 40°C at noon, resulting in a 60°C photovoltaic cell temperature. Hence, the $100W_p$ photovoltaic would only produce a maximum of $80W_{d.c.}$ power at times. [15]

2.7.2 Solar Radiation in Tronoh

Mohd Zulhilmie bin Mat Kana (2010) has conducted an experiment on solar radiations in Tronoh. The data of solar radiation below were taken from Universiti Teknologi PETRONAS Solar Lab on 3rd March 2010 by pyranometer. The X-axis is the time of the day while the Y-axis is the solar radiation value in W/m^2. [16]

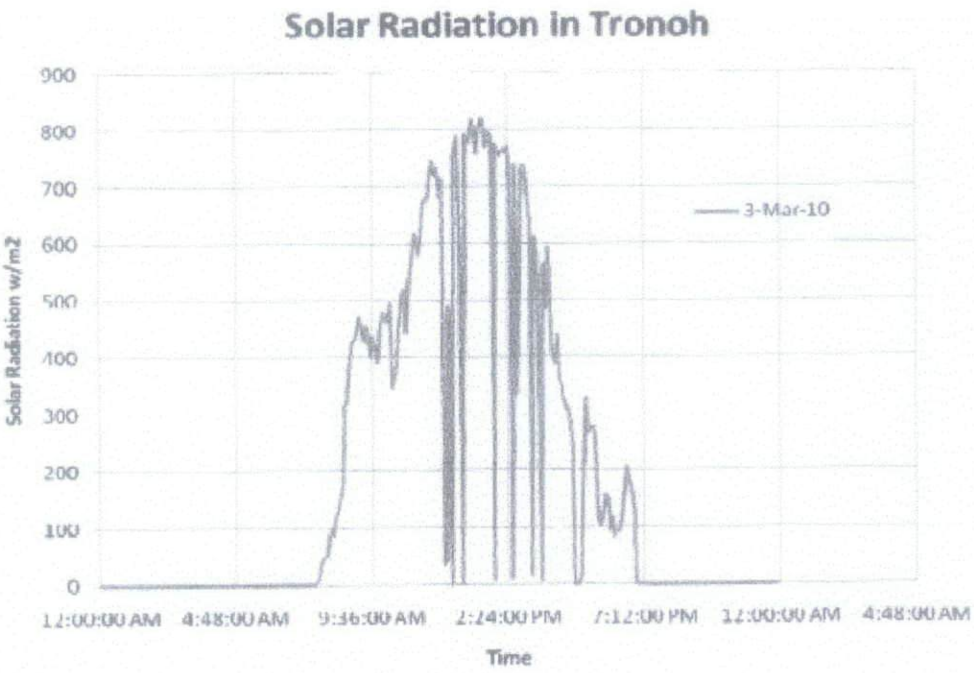

Figure 7: Solar radiation in Tronoh [16]

Based on this result, it is safe to assume that Malaysia climate and weather are suitable for the implementation of photovoltaic systems. Average of solar hours in Malaysia is around 6 hours. Although the daytime is almost constant throughout the year, the global radiation on any particular day cannot be predicted. This is typical for any location situated in the equatorial climate.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

Methodology in this project can be divided into three stages, which are research, design and implementation of the project. Research and design was done in the first semester while the implementation of the project will be done in second semester.

In the first stage, it covers fundamental and theories related to the project such as photovoltaic panel, battery, motor and water pump. The studies were completed by doing researches from the website, books, and journals. For these few topics, the concepts behind them should be clearly understood and comprehensive enough since this will be helpful when completing the project.

All the photovoltaic panels and water pumps available in the market are identified and selection of the most appropriate type of photovoltaic panel and water pump project was done. The selection was basically done by referring and comparing all the important properties that suitable for building a prototype for this system. The conceptual design also has been done and the next step is to prepare a detail design to construct the prototype.

The charge controller circuit has been designed and constructed and it is working as expected. The last prototyping part to complete the project is done by using inverter. The inverter is used to produce AC supply to AC load (AC pump).

The process flow of conducting the project is as shown in Figure 8.

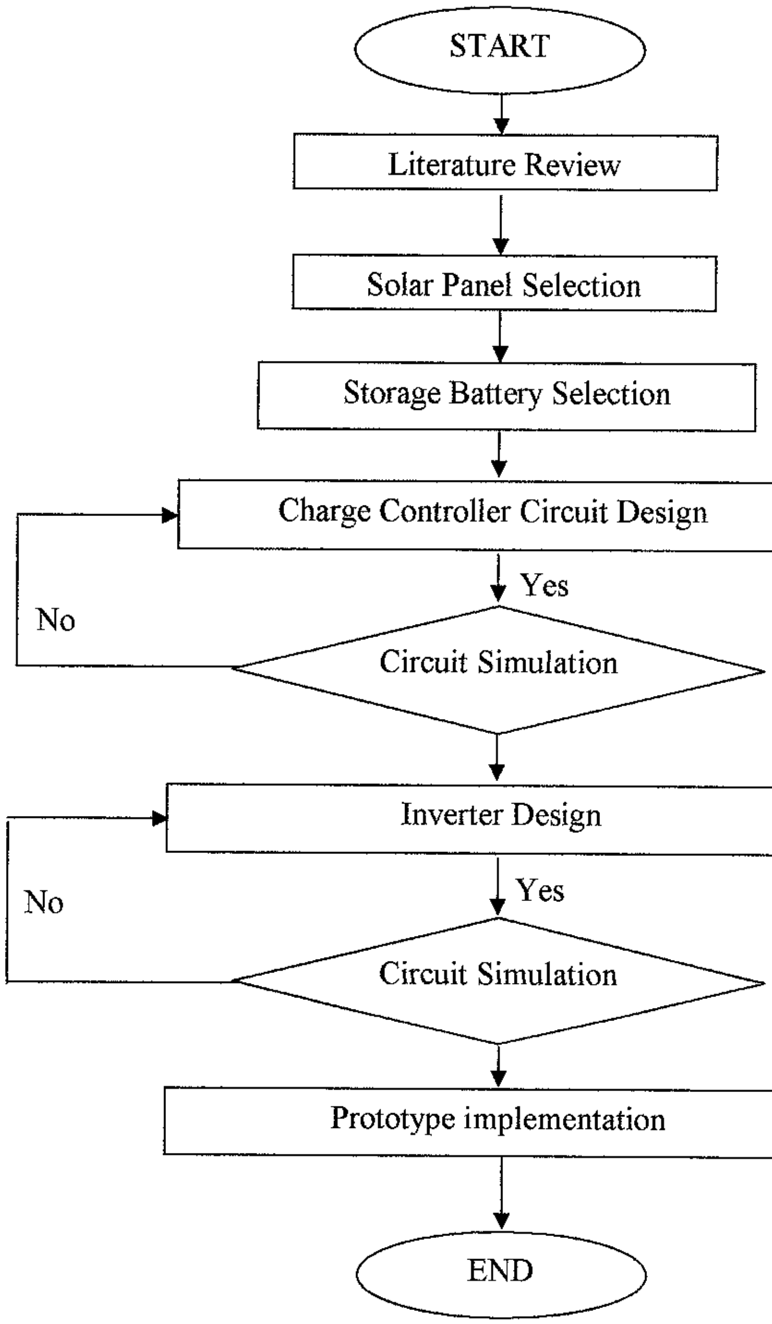

Figure 8: Flow Chart

A Gantt Chart as per **APPENDIX I** has been done to make sure the project can be completed within one year.

3.2 Tools and Equipments

3.2.1 Hardware

The components that will be used in constructing a prototype for photovoltaic water pumping system is photovoltaic panel, storage battery, charge controller, inverter, DC motor water pump and AC motor water pump.

3.2.2 Software

The software required to implement this project are as follows:

- PSPICE and Electronic Workbench (EWB) - to simulate the circuit
- Microsoft Office such as Microsoft Word and Microsoft Excel – for documentation purposes.

3.3 System Configuration

Figure 9 shows the block diagram of the photovoltaic water pumping system. It consists of Photovoltaic Panel, Charge Controller, Inverter, Storage Battery, AC Load and DC Load.

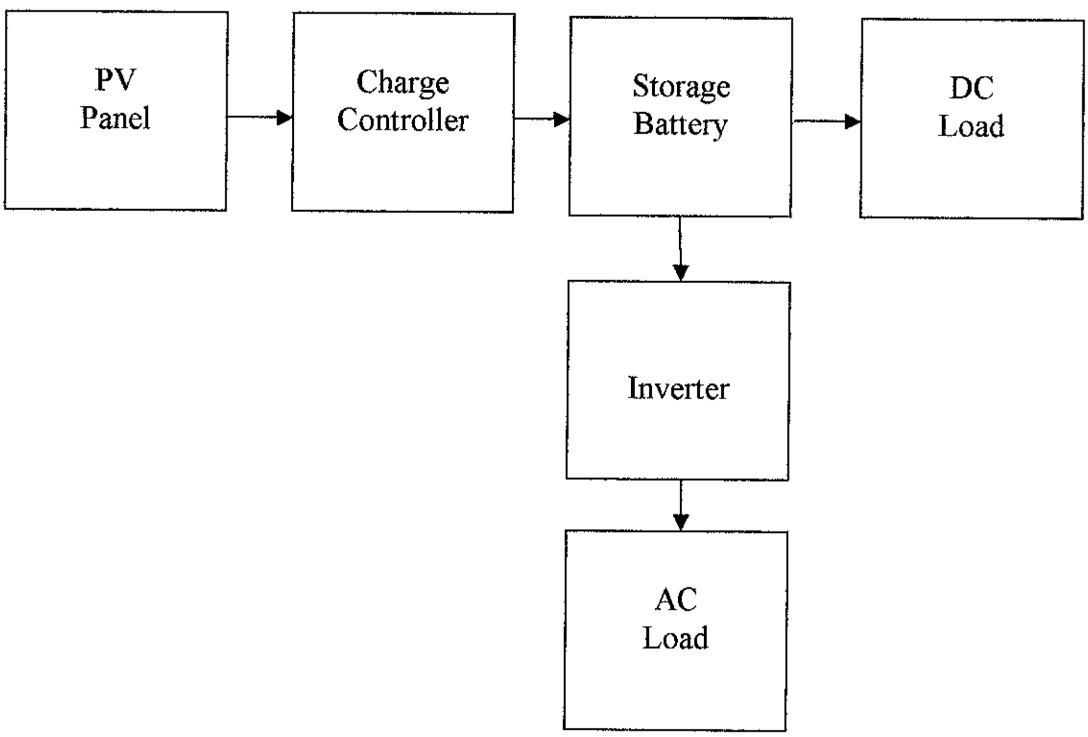

Figure 9: Block diagram

The solar energy is collected through Photovoltaic Cell. Since the solar energy only available during daytime, a storage battery has been used to store the energy and will provide energy to the load when the photovoltaic panel cannot provide enough power or during at night. The storage battery converts electrical energy from the sun into chemical energy when charging and vice-versa when discharging. Most importantly, batteries establish a relatively stable system operating voltage, at which the array and loads both operate. A stable system voltage allows electrical loads or inverters to operate at their rated voltage, avoiding damage from high voltages or reduced performance from low voltages. A battery system also establishes the operating voltage of the array, which can optimized to deliver maximum power.

Power conditioning equipment, such as inverters and charge controllers, converts, controls, or otherwise processes the DC power produced by an array to make the power compatible with other equipment or loads.

Nearly every PV system that uses a battery requires a charge controller. A charge controller is a device that regulates battery charge by controlling the charging voltage from a DC power source, such as a PV array. Charge controller protects the battery from overcharge and overdischarge, improving system performance and prolonging battery life. An inverter is a device that converts DC power from the battery systems to utility-grade AC power for AC loads.

Since a PV array produces DC power, DC loads are used to avoid having to invert the power to AC. This simplifies the design and installation and reduces costs. AC loads are powered from inverters and operate at normal service voltage at specific phase and frequency. Most residential and commercial loads are AC loads. AC loads are more widely available and usually less expensive than comparable DC loads. For this project, both AC and DC load have been used in this project to prove that the energy from the solar panel can be used for both loads and to give choices to consumer to use either DC or AC load as both loads have their pros and cons.

3.4 Circuit Design

3.4.1 Charge Controller Circuit

Charge controller is a device that regulates battery charge by controlling the charging voltage from solar panel. The purpose of this circuit is to ensure that the voltage output never goes above 14V (a good 12V battery charging rule of thumb) and that current never travels back from the battery into the solar panel. This regulator circuit achieves 3 things:

- Battery cannot discharge into the panel
- Panel voltage can never goes above 14.3V
- Even when the panel voltage output is low as 6-7 volts it is still capable of charging a 12V battery.

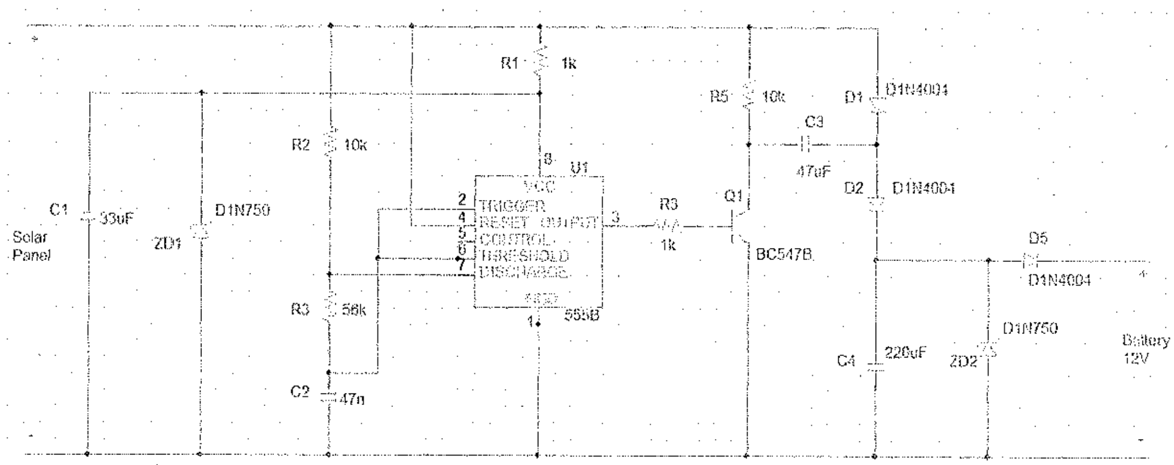

Figure 10: Charge controller circuit

The operations of the circuit are as below:

- D3 stops current from flowing out of the battery and back into the circuit. It cost a continuous 0.7V off the top of the operating voltage (from using a diode).
- ZD2 clamps the voltage at 14.3V (since D3 use 0.7V from 15V). If the batteries are fully charged the solar panel will try to bring them above 14.3V.
- The IC 555 hard switches Q1 at T=(R2+R3)*C2=3.1 kHz.
- Looking at the arrangement of C3, D1, D2 and C4, we can see when Q1 is on the negative plate of C3 is held close to ground and thus charges up to close to VCC via D1.
- C4 also charges up to close to VCC. Now when Q1 turns off the negative plate of C3 is forced to VCC through R5 but it still has a charge of VCC across it.
- Since D1 does not allow current back to VCC, c4 now has 2xVCC across it, and thus the voltage is doubled. It is find a stable level at the battery voltage but you can see that if VCC drops to 6V - 7V (cloud goes across the panel) the output on the battery is still 12V - 14V.

3.4.2 Inverter Circuit

Figure 11 shows the inverter circuit. It will produce a 240V AC power from the input of 12V DC power. This inverter can produced up to 15 Watts. The frequency is about 50 Hz.

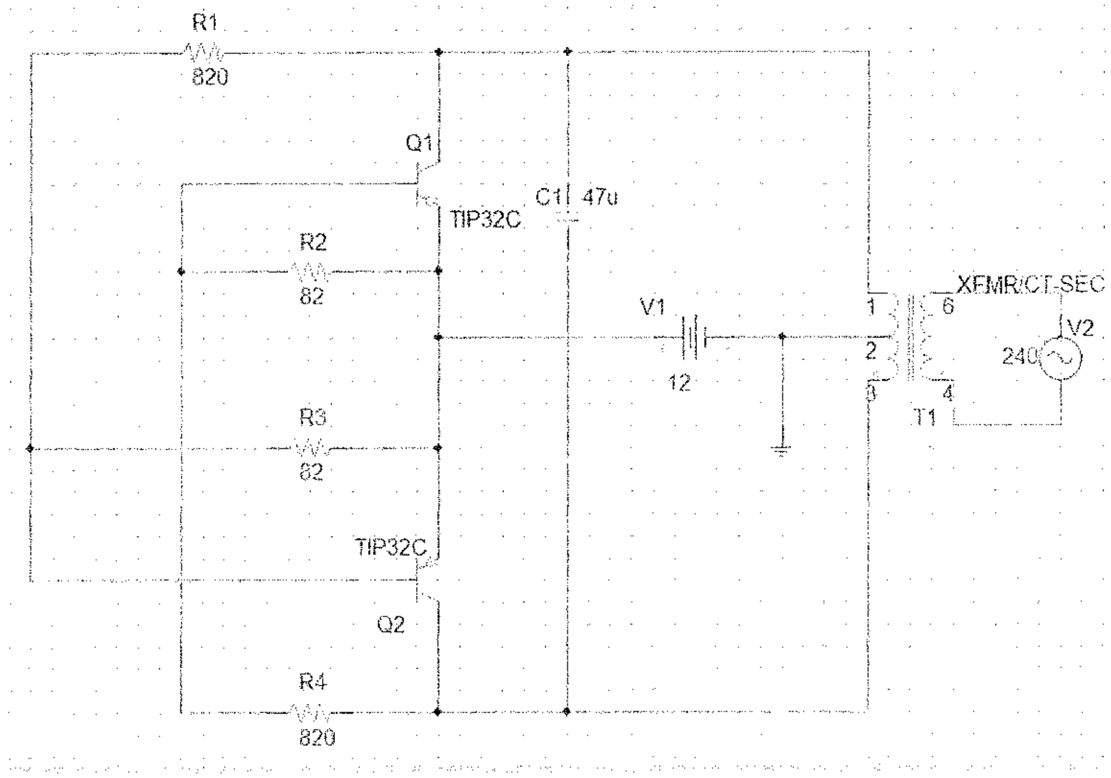

Figure 11: Inverter Circuit

In this circuit, R2 and R3 form a simple voltage divider to bias the transistors to conduction before the oscillation starts. The transistor is switched back and forth to produce alternating current. Then it is transformed, filtered, stepped to get an acceptable output waveform (sine wave or square wave). The transformer is used to step up 12VAC to 240VAC.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 System Sizing

When describing PV systems, it is logical to follow the energy flow from the array side to the loads. However, when sizing a PV system, it is necessary to consider the energy demand before considering the supply. Therefore, PV system sizing starts at the load side and proceeds backward to the array. See Figure 12. The objective is to determine the size of inverter, storage battery, and array that will be able to meet the requirements.

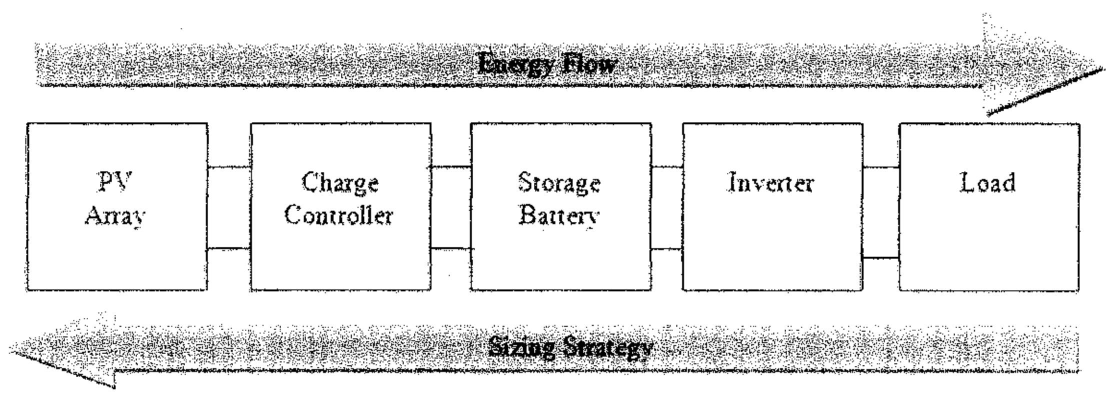

Figure 12: Sizing strategy starts at the load side and proceed backward to the array

Sizing PV systems for stand-alone operations involve four sets of calculations. First, a load analysis determines the electrical load requirements. Then, monthly load requirements are compared to the local insolation data to determine the critical design month. Next, the storage battery is sized to be able to independently supply the loads for a length of time if cloudy weather reduces array output. Finally, the PV array is sized to fully charge the storage battery under the critical conditions.

4.1.1 Load Analysis

Analyzing the electrical loads is the first and most important step in PV-system sizing. The energy consumption and power demand dictate the amount electricity that must be produced.

All existing and potential future loads must be considered. DC loads should be listed separately from AC loads. This is because energy for AC loads goes through the inverter, resulting in losses that must be accounted for separately.

Table 2: Load Analysis

Load Description	**Power Rating (W)**	**Operating Time (hr/day)**	**Energy Consumption (Wh/day)**
AC Pump	15 W	6	90
DC Pump	6 W	6	36

Electrical energy consumption is based on the power demand over time. Load rarely operate continuously, so each load's operating time must be determined.

Load-operating time data is also used to size of the storage battery. The battery discharge rate will then change as various loads turn on and off during the day. In this case, a weighted average operating time is calculated using the following formula:

$$t_{op} = \frac{(B_1 \times t_1) + (B_2 \times t_2)}{B_1 + B_2}$$

Where

t_{op} = weighted average operating time (in hr/day)

B_1 = energy required for load 1 (in Wh/day)

t_1 = operating time for load 1 (in hr/day)

B_2 = energy required for load 2 (in Wh/day)

t_2 = operating time for load 2 (in hr/day)

Therefore, taking data from table 3,

$$t_{op} = \frac{(B_1 \times t_1) + (B_2 \times t_2)}{B_1 + B_2}$$

$$t_{op} = \frac{(90 \times 6) + (36 \times 6)}{90 + 36}$$

$$t_{op} = 6\, hr/day$$

The two loads have a combined effect of a single load operating for 6 hr/day

4.1.2 Inverter Design Consideration

Several factors must be considered when designing the inverter. First, the inverter must have a maximum continuous power output rating at least as great as the total AC power demand. A slightly oversized inverter is usually recommended to account for potential future load additions.

Voltage output is another consideration. Most stand-alone inverters produce either 120V single-phase output or 120/240V split phase output. The inverter DC-input voltage must also correspond with either the array voltage or storage battery.

Inverters are not 100% efficient. Some power is lost in the process converting DC energy to AC energy. Therefore, more DC energy is required to produce a certain amount of AC energy. Both the AC and DC energy requirements from the load analysis are used to determine how much total DC energy will be required. The total amount of DC energy required by the loads is calculated using following formula:

$$E_{SDC} = \frac{E_{AC}}{\eta_{inv}} + E_{DC}$$

Where

E_{SDC} = required daily system DC electrical energy (in Wh/day)

E_{AC} = AC energy consumed by loads (in Wh/day)

η_{inv} = inverter efficiency

E_{DC} = DC energy consumed by loads (in Wh/day)

Since the load analysis determines that the system required 90 Wh/day for the AC load and 36 Wh/day for the DC load and the inverter efficiency is 90%, therefore,

$$E_{SDC} = \frac{E_{AC}}{\eta_{inv}} + E_{DC}$$

$$E_{SDC} = \frac{90}{0.9} + 36$$

$$E_{SDC} = 136\ Wh/day$$

Inverter efficiency is typically between 80% and 95%. Also, an inverter's efficiency varies with its power output, though usually not more about 5% over most of its power range.

4.1.3 Storage Battery Sizing

Batteries store excess energy the array produces during periods of high insolation, and supply power to the system loads at nighttime and during period of low insolation. They also establish the system DC operating voltage and supply surge currents to electrical loads and inverters.

Batteries for stand-alone PV systems are sized to store enough energy to meet the system loads for desired length of autonomy without any further charge or energy contributions from the PV array. The amount of battery capacity required depends on the load requirements and desired autonomy. The required storage battery capacity is calculated using the following formula:

$$B_{out} = \frac{E_{SDC} \times t_a}{V_{SDC}}$$

Where,

B_{out} = required storage battery output (in A-h)

E_{SDC} = required daily system DC electrical energy (in Wh/day)

t_a = autonomy (in days)

V_{SDC} = nominal DC system voltage (in V)

This system required 136 Wh of energy daily and the nominal DC-system voltage is 12V. Assuming the system requires 3 days of autonomy. Therefore,

$$B_{out} = \frac{E_{SDC} \times t_a}{V_{SDC}}$$

$$B_{out} = \frac{136 \times 3}{12}$$

$$B_{out} = 34\, A - h$$

Therefore, the storage battery will need to supply 34 A-h to the system loads. However, the total of the nameplate rating of the storage battery must be higher than this, because the useful capacity of a battery is generally less that its rated capacity.

4.1.4 Storage Battery Capacity

The average discharge rate is determined from the total operating time over the period of autonomy, taking the allowable depth of discharge into account. Using the daily operating time calculated in the load analysis, the average discharge rate is calculated using the following formula:

$$r_d = \frac{t_{op} \times t_a}{DOD_a}$$

Where

r_d = average discharge rate (in hr)

t_{op} = weighted average operating time (in hr/day)

t_a = autonomy (in days)

DOD_a = allowable depth of discharge

Assuming the daily operating time for system loads is 4 hour over an autonomy period of 3 days, and the allowable depth of discharge is 80%, therefore,

$$r_d = \frac{t_{op} \times t_a}{DOD_a}$$

$$r_d = \frac{4 \times 3}{0.8}$$

$$r_d = 15\, hr$$

The storage battery will discharge at a rate that would completely discharge the battery in 15 hour. Therefore the battery average discharge rate is C/15.

4.1.5 Array Sizing

The array must be sized to produce enough electrical energy to meet the load requirements while accounting for normal system losses. This ensures that the battery will always be properly charged and that system availability is high throughput the year.

First, the required array current is calculated from the load requirement, and the nominal DC-system voltage. However, because battery efficiency is less than 100%, more current must be supplied to charge a battery than is withdrawn on discharge. A battery-system charging efficiency factor increases the required array output to a slightly higher value. A value between 0.85 and 0.95 is appropriate for most batteries. The required array current is calculated using following formula:

$$I_{array} = \frac{E_{SDC}}{\eta_{batt} \times V_{SDC} \times t_{PSH}}$$

Where,

I_{array} = required array maximum-power current (in A)

E_{SDC} = required daily system DC electrical energy (in Wh/day)

η_{batt}= battery system charging efficiency

V_{SDC} = nominal DC system voltage (in V)

t_{PSH}= peak sun hours (in hr/day)

Consider a nominal 12V system in a location with 4.9 peak sun hours that must supply 136 Wh per day. The battery system charging efficiency is estimated at 0.90. Therefore,

$$I_{array} = \frac{E_{SDC}}{\eta_{batt} \times V_{SDC} \times t_{PSH}}$$

$$I_{array} = \frac{136}{0.90 \times 12 \times 4.9}$$

$$I_{array} = 2.57\,A$$

Array Rated Output. Just as with storage battery, certain factors reduce the array output from the factory ratings to actual output values. Therefore, these factors are applied to the required array output to determine the necessary increase in array ratings for sizing and module selection.

$$I_{rated} = \frac{I_{array}}{C_s}$$

Where,

I_{rated}= rated array maximum-power current (in A)

I_{array}= required array maximum-power current (in A)

C_s= soling derating factor

In addition, the array voltage must be higher that the storage battery voltage in order to charge the battery. A 12V array will not charge a nominal 12V battery because the actual voltage of a nearly charged battery is about 14.5V. The array must be at least 14.5V to charge a nominal 12V battery. Therefore, the rated array voltage is multiplied by 1.2 to ensure that the maximum-power voltage is sufficient to charge a storage battery.

The rated array maximum-power voltage is calculated using the following formula:

$$V_{rated} = 1.2 \times V_{SDC} \times \{1 + [C_{\%V} \times (T_{max} - T_{ref})]\}$$

Where

V_{rated}= rated array in maximum-power voltage (in V)

V_{SDC} = nominal DC system voltage (in V)

$C_{\%V}$= Temperature coefficient for voltage (in/°C)

T_{max}= maximum expected module temperature (in °C)

T_{ref}= reference (or rating) temperature (in °C)

In this project, an array for a nominal 12V DC system must output 2.57 A. The soiling conditions are expected to be light and the maximum module temperature is estimated at 50°C. Therefore,

$$I_{rated} = \frac{I_{array}}{C_s}$$

$$I_{rated} = \frac{2.57\,A}{0.95}$$

$$I_{rated} = 2.71\,A$$

$$V_{rated} = 1.2 \times V_{SDC} \times \{1 + [C_{\%V} \times (T_{max} - T_{ref})]\}$$

$$V_{rated} = 1.2 \times 12\,V \times \{1 + [0.0045 \times (50 - 25)]\}$$

$$V_{rated} = 16.02\,V$$

4.2 Experiment on the solar panel

18.7 Watts Amorphous cells were used in this experiment. A series of experiments have been conducted and Table 3 shows the data for a single day that have been collected throughout the experiment while Figure 13 show the power output of solar panel versus time.

Table 3: Experiment Results of Solar Panel

Time	Condition	Voltage V	Current mA	Power W	Temperature C
7:00	sunrise	0.42	0.1	4.2×10^{-5}	20
8:00	-	19.87	51.2	1.017	21
9:00	-	20.99	260.1	5.460	24
10:00	-	19.83	307	6.088	28
11:00	-	19.09	324.7	6.200	34
12:00	-	18.39	316.0	5.811	38
13:00	-	18.49	299.8	5.543	38
14:00	-	18.29	174.3	3.188	38
15:00	cloudy	17.24	56.5	0.974	25
16:00	cloudy	17.58	31.71	0.557	31
17:00	cloudy	18.06	34.14	0.617	28
18:00	cloudy	13.24	5.32	0.070	26
19:00	sunset	1.58	0.01	1.58×10^{-5}	25
20:00	-	0.315	0.01	3.15×10^{-6}	23

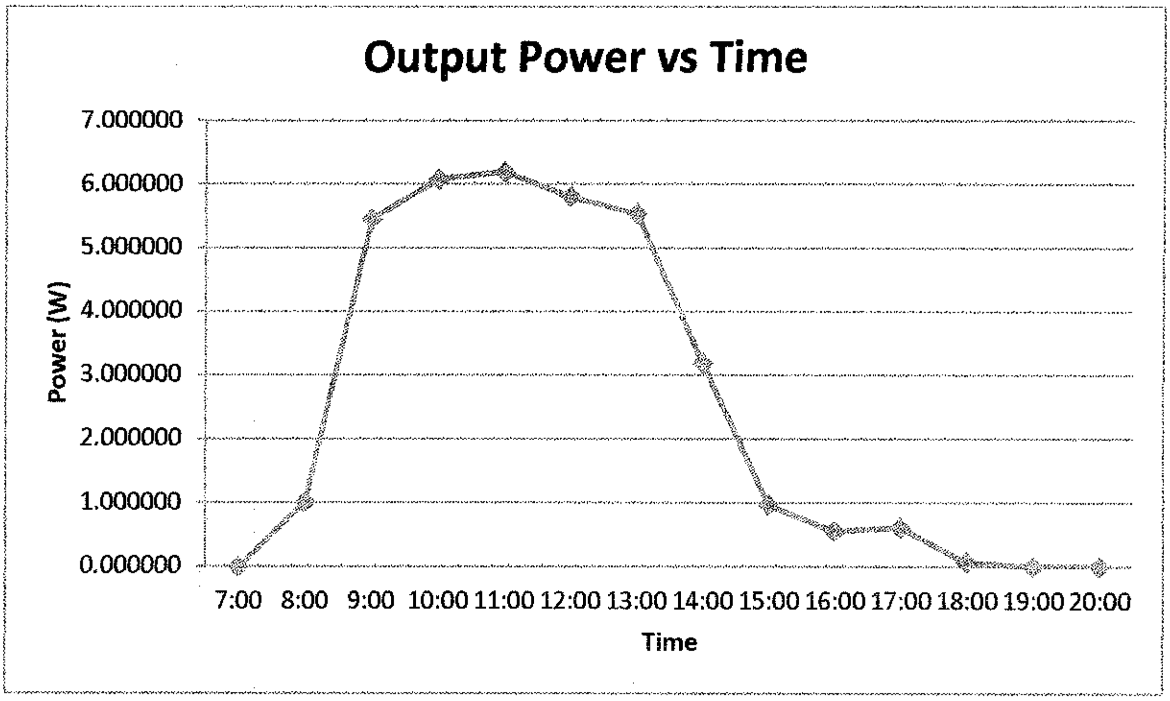

Figure 13: Power output of solar panel versus time

From the graph, it can be seen that the output power in the morning is the highest, since the solar panel was faced towards the East. The highest power that the solar panel can supplied is 6.2 Watts. It is hard to achieve 18.7 Watts, since it is affected by ambient temperature. Hence, the amount of power generated is proportional to the intensity of the solar radiation, but it could be affected by ambient temperature.

Table 4 shows the tabulation of voltage and current that will be produce by solar panel during sunny and cloudy day.

Table 4: Voltage and current tabulation

Condition	Voltage	Current
Sunny	19 V	200 mA
Cloudy	17 V	30 mA

From the experiment that has been done, the average voltage and current that the solar panel can be produce during normal sunny day are $\pm 19V$ and $\pm 200mA$ while during cloudy day are $\pm 17V$ and $\pm 30mA$. The solar panel that has been used in this experiment is Amorphous silicon, which has a low efficiency of 5% - 8%. The higher the efficiency of the solar panel, the more voltage and current it will produce.

4.3 Prototype Construction

The photovoltaic water pumping system consists of Photovoltaic Panel, Charge Controller, Inverter, Storage Battery, AC Water Pump and DC water Pump. Figure 14 shows the photovoltaic panel and Figure 15 shows the storage battery that has been used in this project.

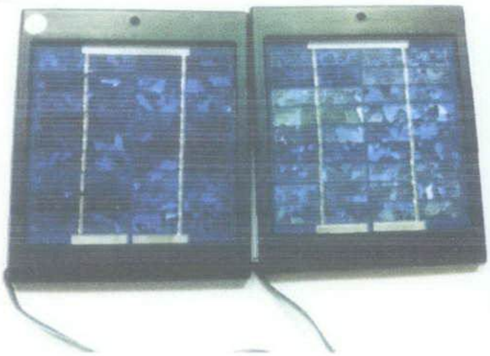

Figure 14: Photovoltaic Panel

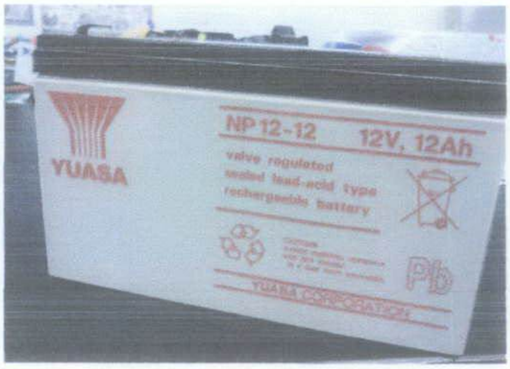

Figure 15: Storage Battery

The solar energy is collected through Photovoltaic Cell. Since the solar energy only available during daytime, a storage battery has been used to store the energy and will provide energy to the load when the photovoltaic panel cannot provide enough power or during at night.

Figure 16 shows the charge controller circuit and the inverter circuit can be seen in Figure 17. Both circuits have been constructed into a veroboard. Charge Controller circuit is a simple circuit that can achieve three things; battery cannot discharge into the panel, voltage can never go beyond 14.3V and even the panel voltage output is as low as 6V-7V it is still capable of charging a 12V battery.

Figure 16: Charge Controller Circuit

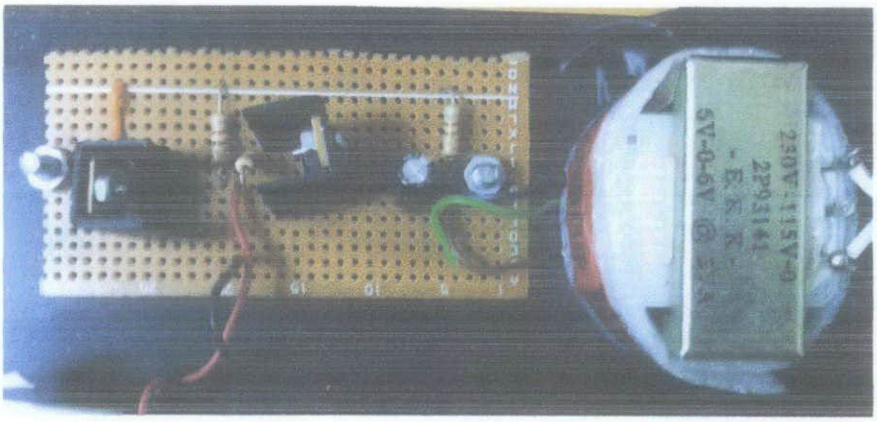

Figure 17: Inverter Circuit

The inverter circuit has been designed to produce power up to 15 watts. The transformer is used to step up 12VAC to 240VAC. The output from the transformer is a sine wave, as shown in Figure 15. Alternating Current (AC) is electrical current that changes between positive and negative directions. AC power is characterized by waveform shape, frequency, and magnitude.

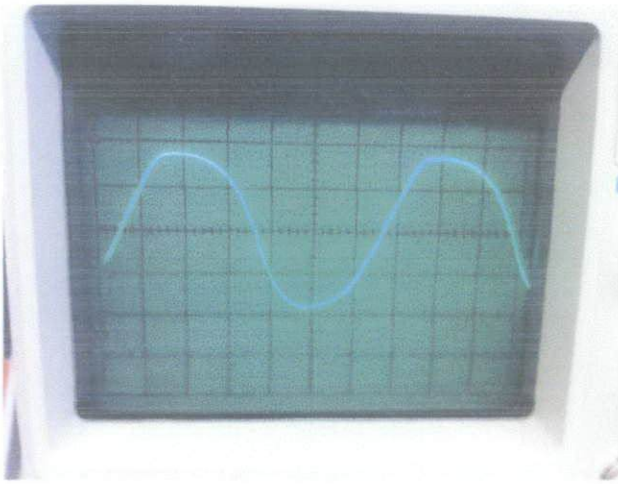

Figure 18: Waveform of AC power

Figure 19 shows DC Water Pump and Figure 20 shows AC Water Pump that has been used in this project. Table 5 shows the specification for both pumps.

Figure 19: DC Water Pump

Figure 20: AC Water Pump

Table 5: Specification for AC and DC water pump

	Voltage	**Power**
AC Water Pump	240VAC	15 Watts
DC Water Pump	12VDC	6 Watts

Since a PV array produces DC power, DC loads are used to avoid having to invert the power to AC. This simplifies the design and installation and reduces costs. AC loads are powered from inverters and operate at normal service voltage at specific phase and frequency. Most residential and commercial loads are AC loads. AC loads are more widely available and usually less expensive than comparable DC loads. For this project, both AC and DC load have been used in this project to prove that the energy from the solar panel can be used for both loads and the user have an option selecting either DC or AC load as both loads have their pros and cons.

Figure 21 shows the completed prototype and Figure 22 shows the components inside the casing which are battery storage, charge controller and inverter.

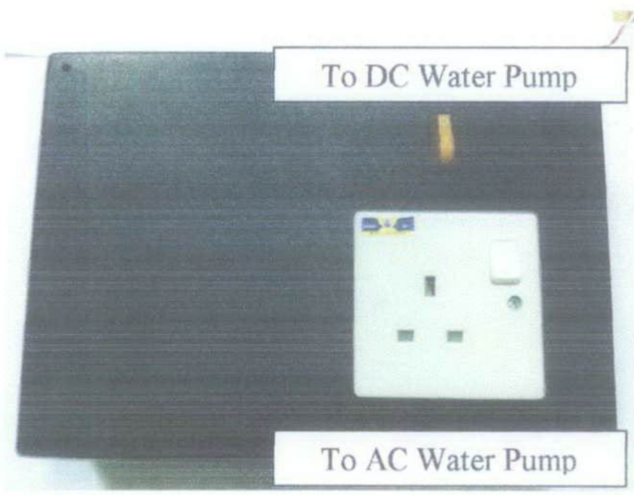

Figure 21: The prototype

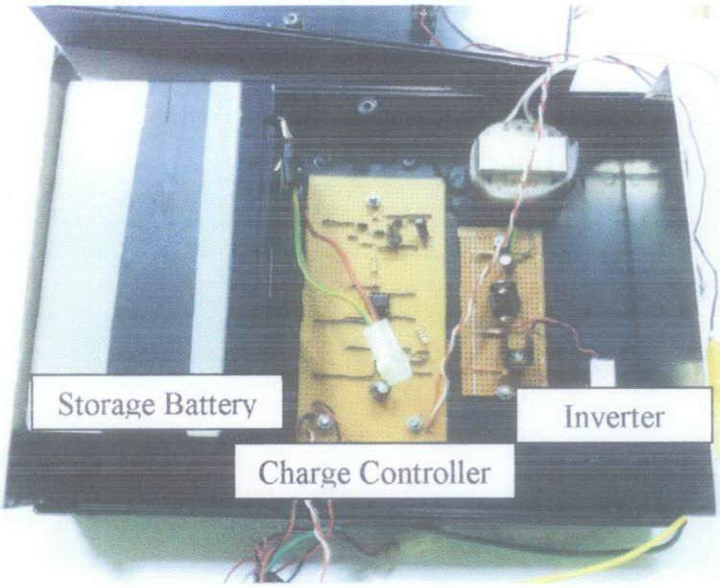

Figure 22: Inside the casing

The prototype of the project is installed and the testing of the prototype is successful. The system is working and can run both DC water pump and AC water pump, as expected. The AC water pump can pump the water at approximately 8 litres per minute while the DC water pump can pump the water at approximately 6 litres per minute.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Overall, most of the works are successfully done within the time frame. The charge controller and inverter circuit has been designed and the working laboratory model for Photovoltaic Water Pumping has been successfully constructed. Several experiments on the solar panel and storage battery also have been done to give more understanding on the subject matter. The results showed that PV system would be suitable to supply electricity to both AC and DC load, without using energy from the grid.

This report provides an overview on how the research of the project progressed throughout the first semester. It serves as a framework, which will enhance students' skills in the process of applying knowledge, expanding thoughts, solving problems independently and presenting findings.

5.2 Recommendations

Since this is the laboratory model of Photovoltaic Water Pumping System to prove that the concept of using Solar Panel as an alternative source is possible. Therefore there is a need to test it in a real environment. Another improvement that can be done is to upgrade this system to meet the industrial specification.

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APPENDIX A

GANTT CHART

NO	SCOPE OF WORK	MONTH											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Determination of Functional Requirement Specification												
2	Conceptual Design												
3	Detail Design												
4	Fabrication/Procrurement Component												
5	Assembly and Integration of System												
6	Testing												
7	Modication of System												
8	Demostration and Documentation												

SOLAR VOLTAIC
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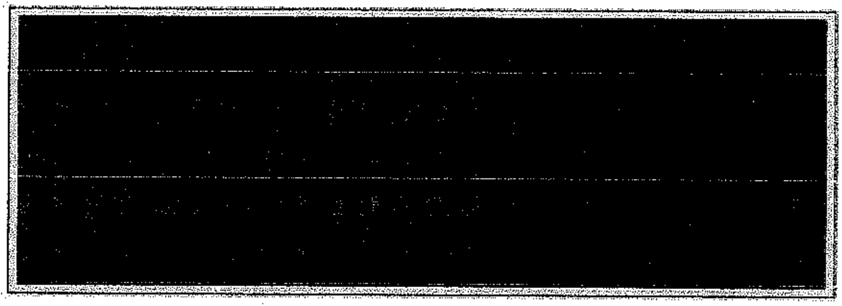
SOLAR VOLTAIC™ : Thin-film PV Modules

Thin Film, Amorphous, the High Temperature photovoltaic modules.
Our photovoltaic panels output from 18 Watts Peak to 10 Kilowatts Peak, the most **cost efficient,** CE certification photovoltaic panels, on the market.

Front of Module



Performance per Modular section (Any number of modules may be used)

Rated power (Pmax)	12 Watts
Annual Energy Yield (Tropical)	1.3 Kilo Watt hours, per rated Watt Peak
Nominal Voltage	17.3 V
Limited Warranty	15 years

Configuration

Any number of Modules, may be mounted to a Single Frame, to give any size you require. Example of 1 module and 10 module size, specified below:

Electrical Characteristics per	Single module	Array of 10 Modules
Maximum power (Pmax)	18.75 W/P (12 Watts)	187.50 W/P (120 Watts)
Voltage at Pmax (Vmp)	16 V	16 V
Current at Pmax	800 mA	8 Amps
Warranted minimum Pmax	11 W	110 W
Short-circuit current (Isc)	1.2 Amps	12 Amps
Open circuit voltage (Voc)	22 V	22 V
Temperature coefficient of Isc	0 % per degree Centigrade	
Temperature coefficient of Voc	- 0 V per degree Centigrade	
Temperature coefficient of power	- 0 % per degree Centigrade	
NOCT	60°C	
Maximum system voltage	1,000 V insulation (Safety 48 V)	

Mechanical Characteristics per Single Module

(Any number of modules may be used in an array.)

Dimensions : Length: 925mm Width: 325mm Depth: 22mm

Weight : 3.0 Kg (6.61 Pounds)

Solar Cells : 29 cells (10mm x 915mm) Thin Film Deposition

Connections : Male and Female Parallel Connectors. 10 amp RCA. No screws. Polarity protected. Never comes loose and never needs Tightening. Corrosion proof. Can only fit the correct way round and prevents problems of Wrong Connections, Completely.

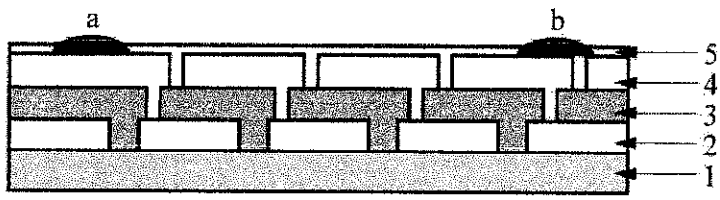
Diodes : Schottky reverse protection diode 30 V

Construction : 4mm Glass Substrate fused directly to cell structure at 550 degrees Centigrade. Coated by evaporation of Aluminium as collector. Final electrical insulation and backing, of spray coated, Heat Conductive Polymer, to remove Heat.

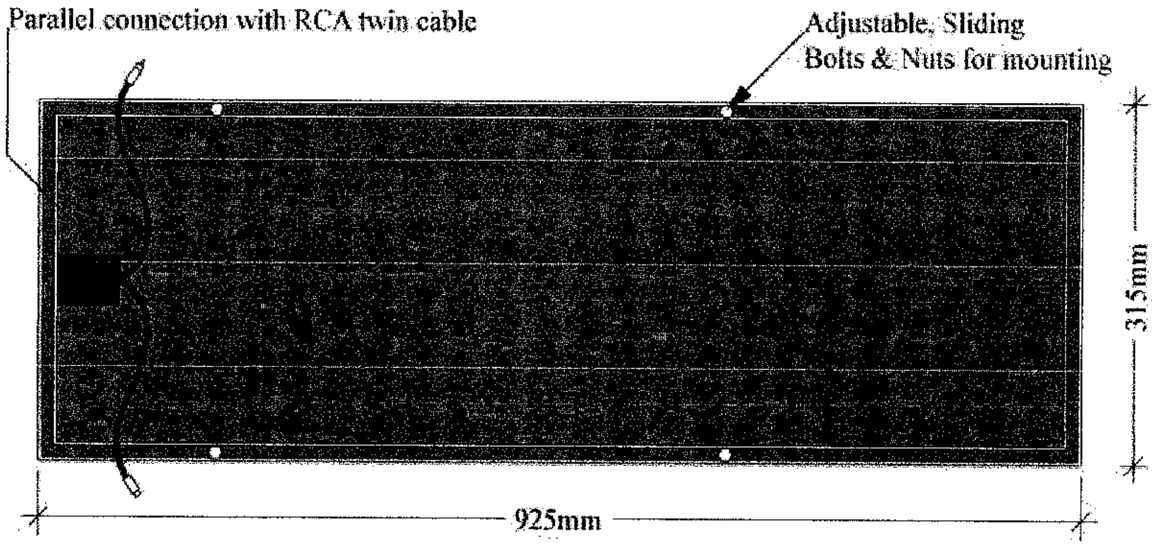
Frame : Anodized Aluminum alloy, colour: Silver. Adjustable, Sliding, Bolt Head, connection to allow for fitting, to any size of support Frame.
Multiple mounting Rack included, for easy mounting of any number of Modules.

Module Diagram

Solar Cell Structure

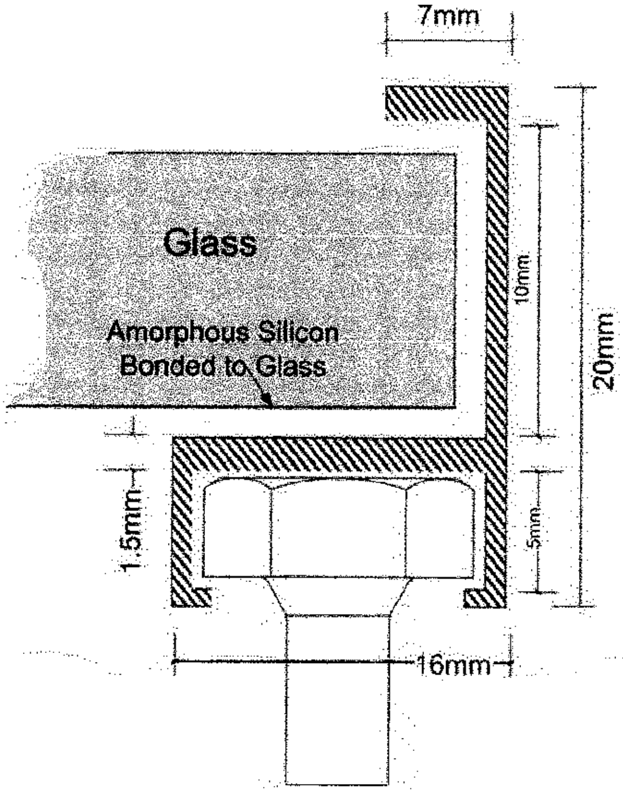


a - Positive point.
b - Negative point.
1 - Glass.
2 - SnO2 layer (cell positive layer, transparent).
3 - Amorpous Si Film (laminated by P, I, N junction).
4 - Aluminium layer (cell negative layer).
5 - UV coating (cut off with air), and backing.



Back of Module

Frame cross section

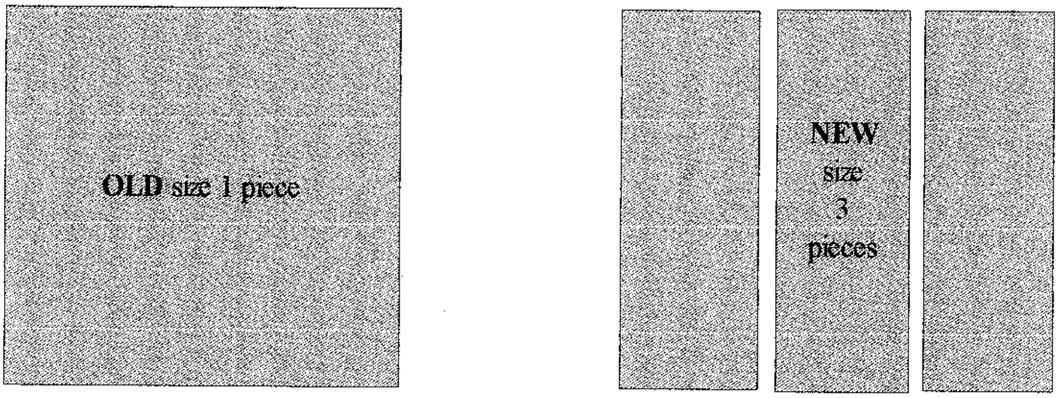


Note : This publication summarizes product warranty and specifications, which are subject to change without prior notice. Should you need further information, please give us a call at +60(3)7980 5419 or e-mail us at solarcon@tm.net.my

SOLAR VOLTAIC™

"SPLIT PANEL" design, for ease of use.

The original panel size was very large. Difficult to handle and very heavy.



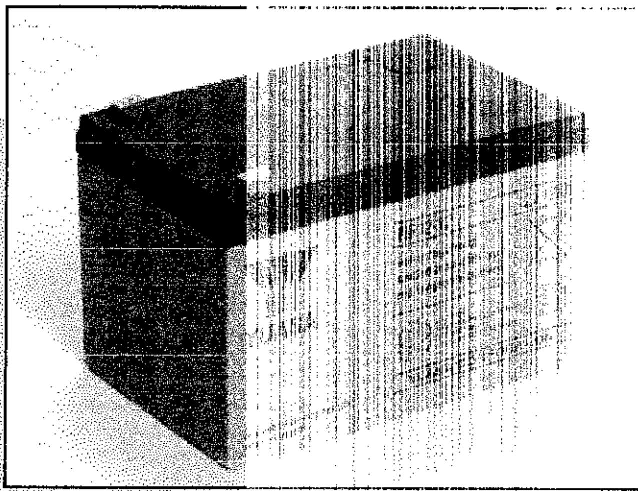
The new **"SPLIT PANEL"** size is still 1 square Metre, BUT is now split into 3 pieces. Still the same power output, still the same surface area but many advantages.

OLD 1 piece design 56 Watts Peak	NEW "SPLIT DESIGN" 56 Watts Peak
Total 21 **Kg with frame.** *Very Heavy 1 piece.* *Glass must be 6mm Thick at this size to be strong.* *Frame must be thicker to hold the extra weight.*	Total of 3 pieces is only 9**Kg with frame.** *Slimline design in 3 pieces.* *Needs only 3mm Glass for strength.* *Each piece is 3Kg.*
Difficult to carry. *Needs 2 people to carry the big panel.*	Easy to carry. *1 person can carry 3 pieces, under 1 arm, easily.*
A Big panel has HIGH Wind resistance. *Pole blows down in a storm easily.*	Small panels have LOW Wind resistance. *3 pieces can be mounted side by side, with an Air Gap between each panel. This allows the Wind to blow THROUGH the gaps and does not blow down the pole.*
NO ADAPTABILITY. *That means you can have only 56wp **or** 112wp.*	Gives you more ADAPTABILITY, to get the size most suitable for your requirements. *You can have just the single 18wp **or** 36wp **or** 56wp **or** 72wp **or** 112wp **or** 130wp, etc...*
High cost. *If you need 70wp, you must buy 2 big panels, of 112wp.*	**Cost saving** from buying only the amount you need. *If you need 70wp, you only need to buy 72wp.* *Saving the cost of 40wp, that you do not need.*
High cost of loss from Damage. *Loss of Total 56wp panel.*	**Low cost** of loss from Damage. *If 1 x 18Wp piece is damaged. One third of the loss of a big panel.*
System integrity is compromised if the big 56wp panel is broken. **100% loss of power.**	56wp is split into 3 pieces. If one piece is broken, the other 2 still produce two thirds of the power. System remains intact. **33% loss of power.**
High cost of heavy mounting structure to hold 21Kg panels with High Wind resistance..	**Low cost**, Lightweight structure to hold 9kg panels with Low Wind resistance.

;ERIES - **NP 12-12**

ɔility is your Security

| the latest advance design Oxygen
ɔination Technology, Yuasa have applied
years experience in the lead acid battery
ɔroduce the optimum design of Sealed
:id batteries.



IRES

ɔ recovery from deep discharge.
olyte suspension system.
lecombination.
urpose: Float or Cyclic use.
: in any orientation.
ior energy density.
:alcium grids for extended life.
'actured World wide.
ation specific designs.

cal Features

Construction
ıique construction and sealing technique
ı electrolyte leakage from case or terminals.

yte Suspension System
eries utilize Yuasa's unique electrolyte suspension
ɔrporating a microfine glass mat to retain the
ımount of electrolyte in the cells. The electrolyte is
the separator material and there is no free
to escape from the cells. No gels or other
ıts are added.

of Gas Generation
of Yuasa's NP batteries incorporates the very latest
ombination technology to effectively control the
of gas during normal use.

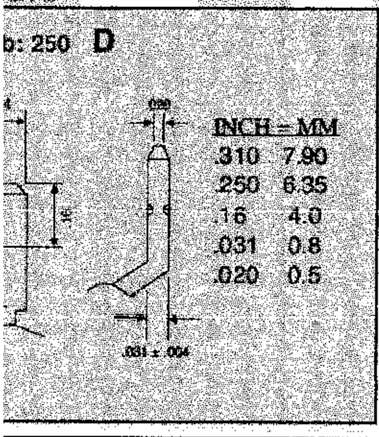
intenance Operation
perfectly sealed construction and the
on of gasses within the cell, the battery is almost
ce free.

Terminals
NP batteries are manufactured using a range of terminals which vary in size and type. Please refer to details as shown.

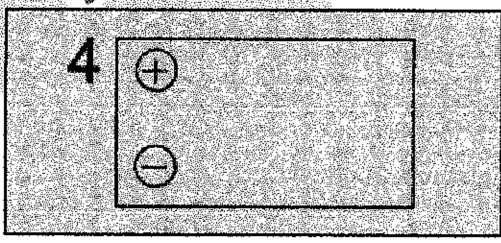
Operation in any Orientation
The combination of sealed construction and Yuasa's unique electrolyte suspension system allows operation in any orientation, with no loss of performance or fear of electrolyte leakage.

Valve Regulated Design
The batteries are equipped with a simple, safe, low pressure venting system which releases excess gas and automatically reseals should there be a build up of gas within the battery due to severe overcharge. Note: On no account should the battery be charged in a sealed container.

als



Layout



General Specifications

Nominal Capacity (Ah)	NP12-12
20hr to 1.75vpc 30°C	12
10hr to 1.75vpc 20°C	11.1
5hr to 1.70vpc 20°C	10
1 hr to 1.60vpc 20°C	7.2
Voltage	12
Energy Density (Wh.L 20hr)	1.04
Specific Energy (Wh.kg 20hr)	36
Int. Resistance (m.Ohms)	1.6
Maximum discharge (A)	75
Short Circuit current (A)	360
Dimensions (mm)	
Length	151
Width	98
Height overall	97.5
Weight (Kg)	4.05
Terminal	D
Layout	4
Terminal Torque Nm	-

:RIES - NP 12-12

cium Grids

ity lead calcium alloy grids provide an extra margin
ce and life in both cyclic and float applications and
eled recovery from deep discharge.

:le Service Life

oon the average depth of discharge, over a
scharge/charge cycles can be expected.

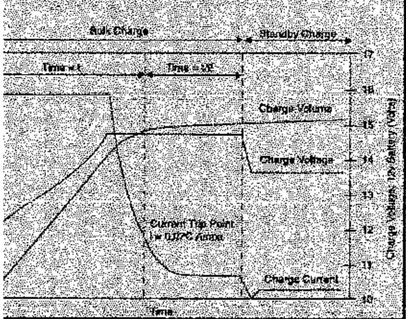
'vice Life

l service life is five years in float standby

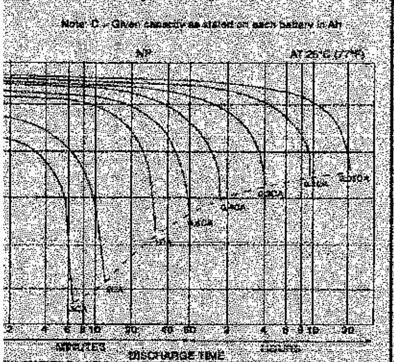
'rs

e special separator material provides a very efficient
ween plates preventing inter-plate short circuits
ng the shedding of active materials.

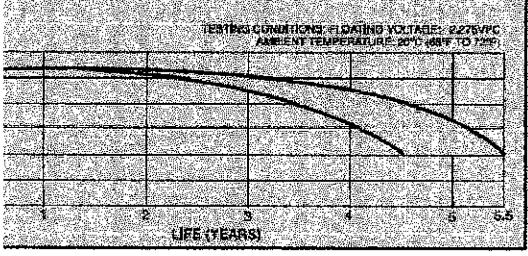
RECHARGE REGIME



:HARGE CHARACTERISTICS
5 AT 25°C (77°F)



T SERVICE LIFE NP RANGE



Long shelf Life

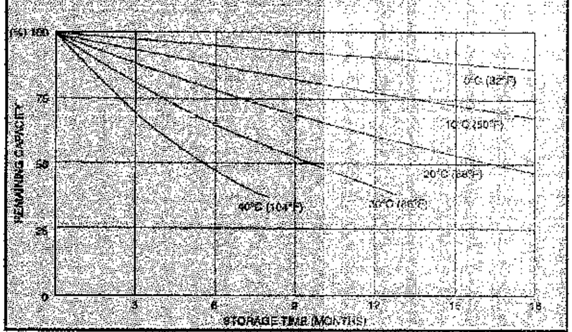
The extremely low self discharge rate allows the battery to be stored for extended periods up to one year at normal ambient temperatures with no permanent loss of capacity.

Operating Temperature Range

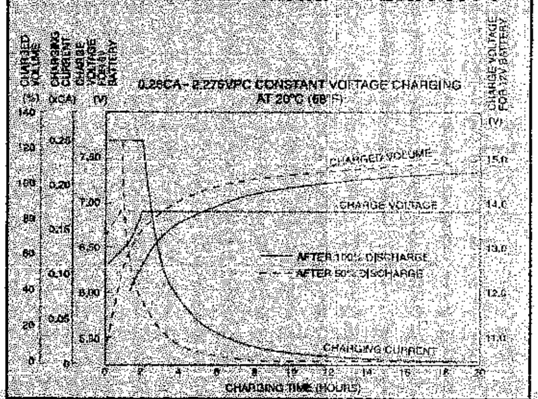
The batteries can be used over a broad temperature range permitting considerable flexibility in system design and location.

Charge – 15°C to 50°C
Discharge – 20°C to 60°C
Storage – 20°C to 50°C (fully charged battery)

SELF DISCHARGE CHARACTERISTICS

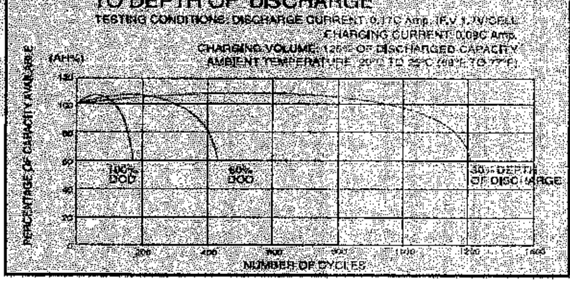


FLOAT CHARGE CHARACTERISTICS



TYPICAL DISCHARGE CHARACTERISTICS NP RANGE

CYCLE SERVICE LIFE IN RELATION TO DEPTH OF DISCHARGE



Yuasa Battery Inc.
2901 Montrose Ave
Laureldale, PA 19605
www.yuasabatteries.com

Registered number 1548820

Cat. No.	NP 12-12 March 09

Distributed by

National Semiconductor

July 2006

LM555
Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200mA or drive TTL circuits.

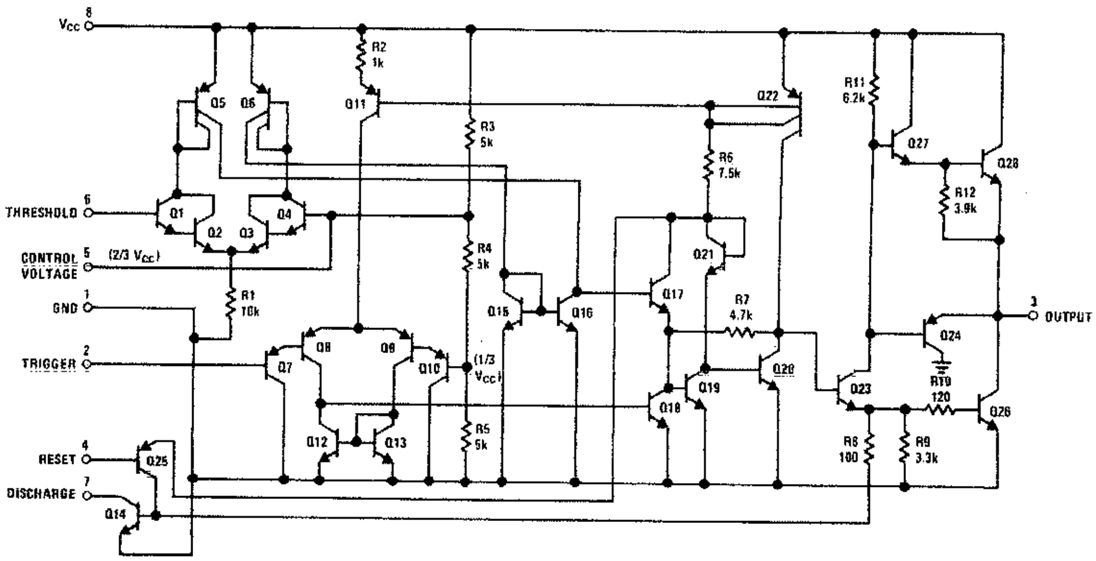
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output
- Available in 8-pin MSOP package

Applications

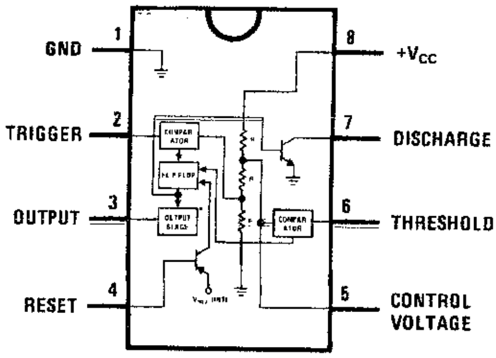
- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram



Connection Diagram

Dual-In-Line, Small Outline and Molded Mini Small Outline Packages



00785103

Top View

Ordering Information

Package	Part Number	Package Marking	Media Transport	NSC Drawing
8-Pin SOIC	LM555CM	LM555CM	Rails	M08A
	LM555CMX	LM555CM	2.5k Units Tape and Reel	
8-Pin MSOP	LM555CMM	Z55	1k Units Tape and Reel	MUA08A
	LM555CMMX	Z55	3.5k Units Tape and Reel	
8-Pin MDIP	LM555CN	LM555CN	Rails	N08E

solute Maximum Ratings (Note 2)

ilitary/Aerospace specified devices are required, se contact the National Semiconductor Sales Office/ ibutors for availability and specifications.

ɔly Voltage	+18V
er Dissipation (Note 3)	
/1555CM, LM555CN	1180 mW
/1555CMM	613 mW
rating Temperature Ranges	
/1555C	0°C to +70°C
age Temperature Range	−65°C to +150°C

Soldering Information	
Dual-In-Line Package	
Soldering (10 Seconds)	260°C
Small Outline Packages	
(SOIC and MSOP)	
Vapor Phase (60 Seconds)	215°C
Infrared (15 Seconds)	220°C

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

ctrical Characteristics (Notes 1, 2)

= 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits			Units
		LM555C			
		Min	Typ	Max	
ıly Voltage		4.5		16	V
Supply Current	V_{CC} = 5V, $R_L = \infty$ V_{CC} = 15V, $R_L = \infty$ (Low State) (Note 4)		3 10	6 15	mA
ıg Error, Monostable					
ial Accuracy			1		%
ft with Temperature	R_A = 1k to 100kΩ, C = 0.1µF, (Note 5)		50		ppm/°C
curacy over Temperature			1.5		%
ft with Supply			0.1		%/V
ıg Error, Astable					
ial Accuracy			2.25		%
ft with Temperature	R_A, R_B = 1k to 100kΩ, C = 0.1µF, (Note 5)		150		ppm/°C
ɔuracy over Temperature			3.0		%
ft with Supply			0.30		%/V
ɜhold Voltage			0.667		x V_{CC}
er Voltage	V_{CC} = 15V V_{CC} = 5V		5 1.67		V V
er Current			0.5	0.9	µA
t Voltage		0.4	0.5	1	V
t Current			0.1	0.4	mA
ɜhold Current	(Note 6)		0.1	0.25	µA
Control Voltage Level	V_{CC} = 15V V_{CC} = 5V	9 2.6	10 3.33	11 4	V
Leakage Output High			1	100	nA
Sat (Note 7)					
ıput Low	V_{CC} = 15V, I_7 = 15mA		180		mV
ıput Low	V_{CC} = 4.5V, I_7 = 4.5mA		80	200	mV

Electrical Characteristics (Notes 1, 2) (Continued)

(T_A = 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits			Units
		LM555C			
		Min	Typ	Max	
Output Voltage Drop (Low)	V_{CC} = 15V				
	I_{SINK} = 10mA		0.1	0.25	V
	I_{SINK} = 50mA		0.4	0.75	V
	I_{SINK} = 100mA		2	2.5	V
	I_{SINK} = 200mA		2.5		V
	V_{CC} = 5V				
	I_{SINK} = 8mA				V
	I_{SINK} = 5mA		0.25	0.35	V
Output Voltage Drop (High)	I_{SOURCE} = 200mA, V_{CC} = 15V		12.5		V
	I_{SOURCE} = 100mA, V_{CC} = 15V	12.75	13.3		V
	V_{CC} = 5V	2.75	3.3		V
Rise Time of Output			100		ns
Fall Time of Output			100		ns

Note 1: All voltages are measured with respect to the ground pin, unless otherwise specified.

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 state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: For operating at elevated temperatures the device must be derated above 25°C based on a +150°C maximum junction temperature and a thermal resistance of 106°C/W (DIP), 170°C/W (S0-8), and 204°C/W (MSOP) junction to ambient.

Note 4: Supply current when output high typically 1 mA less at V_{CC} = 5V.

Note 5: Tested at V_{CC} = 5V and V_{CC} = 15V.

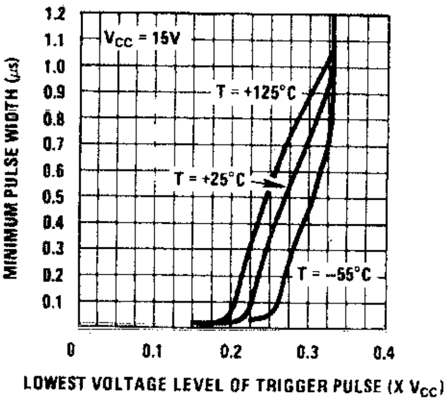
Note 6: This will determine the maximum value of $R_A + R_B$ for 15V operation. The maximum total ($R_A + R_B$) is 20MΩ.

Note 7: No protection against excessive pin 7 current is necessary providing the package dissipation rating will not be exceeded.

Note 8: Refer to RETS555X drawing of military LM555H and LM555J versions for specifications.

ɔical Performance Characteristics

Minimuim Pulse Width Required for Triggering



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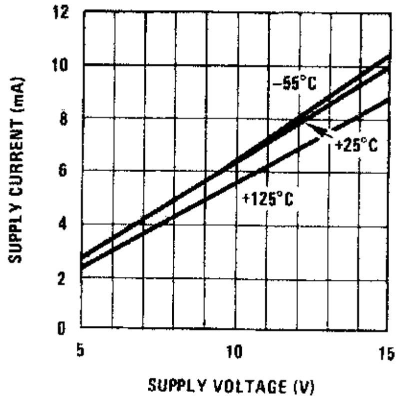
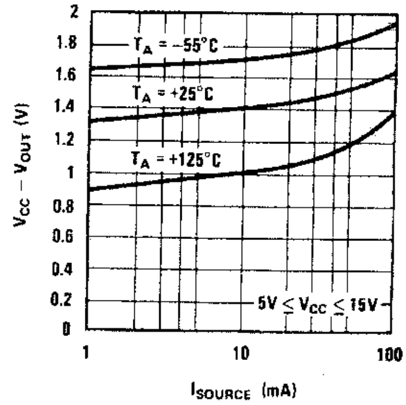
Supply Current vs. Supply Voltage



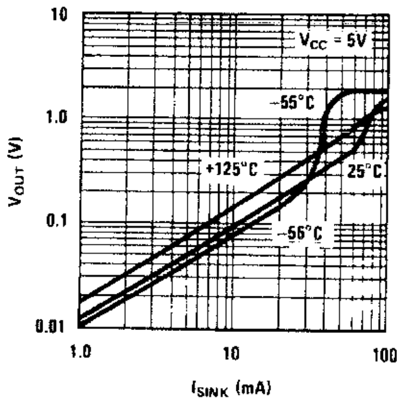
00785119

High Output Voltage vs. Output Source Current



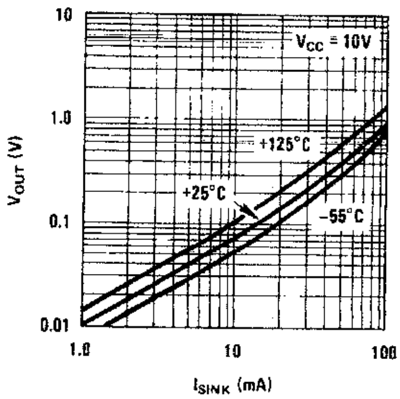
00785120

Low Output Voltage vs. Output Sink Current



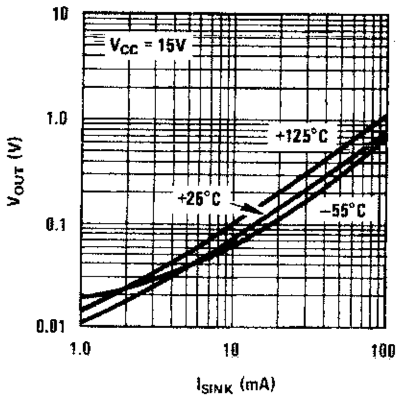
00785121

Low Output Voltage vs. Output Sink Current



00785122

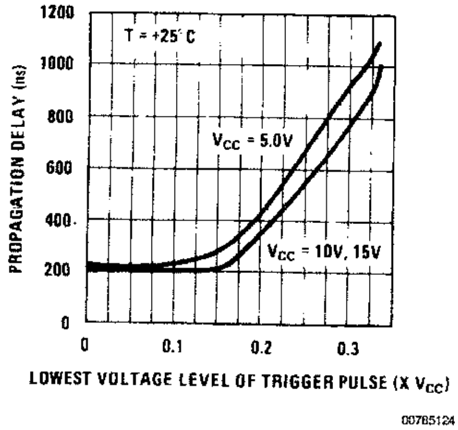
Low Output Voltage vs. Output Sink Current



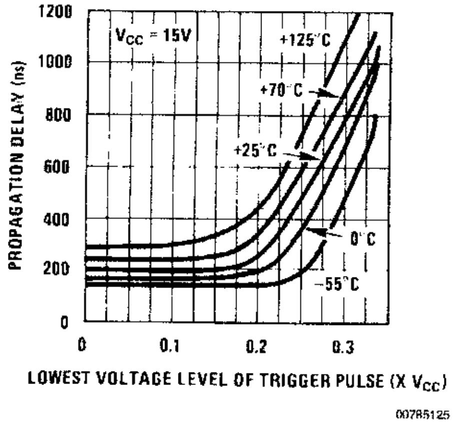
00785123

Typical Performance Characteristics (Continued)

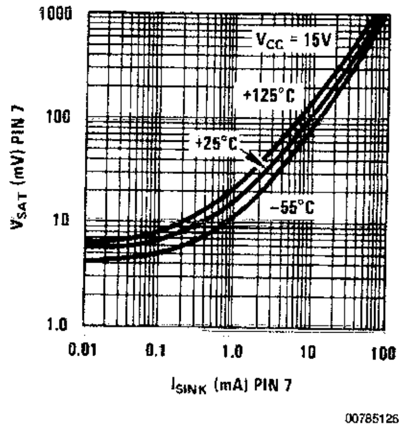
Output Propagation Delay vs. Voltage Level of Trigger Pulse



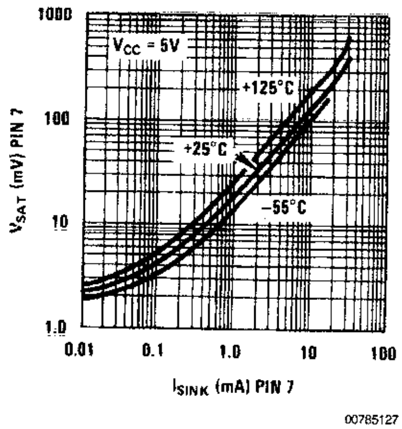
Output Propagation Delay vs. Voltage Level of Trigger Pulse



Discharge Transistor (Pin 7) Voltage vs. Sink Current



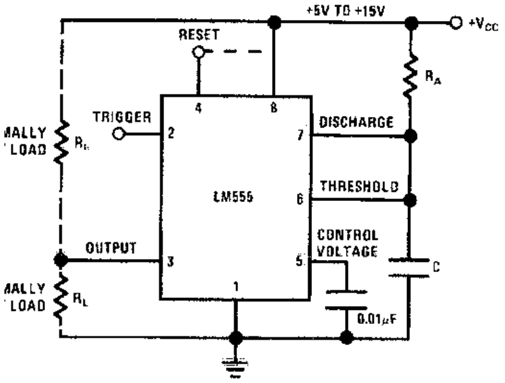
Discharge Transistor (Pin 7) Voltage vs. Sink Current



plications Information

OSTABLE OPERATION

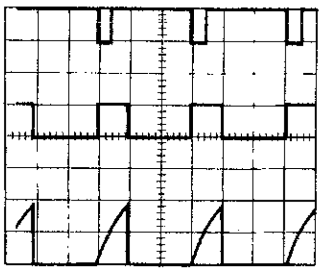
s mode of operation, the timer functions as a one-shot *re 1*). The external capacitor is initially held discharged transistor inside the timer. Upon application of a nega- 'igger pulse of less than 1/3 V_{CC} to pin 2, the flip-flop is hich both releases the short circuit across the capacitor lrives the output high.



00785105

FIGURE 1. Monostable

'oltage across the capacitor then increases exponen- or a period of t = 1.1 R_A C, at the end of which time the ıe equals 2/3 V_{CC}. The comparator then resets the ıp which in turn discharges the capacitor and drives the t to its low state. *Figure 2* shows the waveforms gen- 1 in this mode of operation. Since the charge and the ıold level of the comparator are both directly propor- to supply voltage, the timing interval is independent of /.



00785106

;V Top Trace: Input 5V/Div.
0.1 ms/DIV. Middle Trace: Output 5V/Div.
1kΩ Bottom Trace: Capacitor Voltage 2V/Div.
1μF

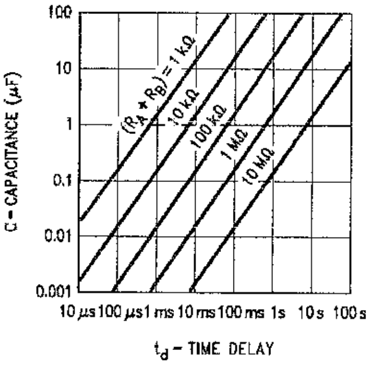
FIGURE 2. Monostable Waveforms

ı the timing cycle when the output is high, the further ıtion of a trigger pulse will not effect the circuit so long trigger input is returned high at least 10μs before the the timing interval. However the circuit can be reset during this time by the application of a negative pulse to the reset terminal (pin 4). The output will then remain in the low state until a trigger pulse is again applied.

When the reset function is not in use, it is recommended that it be connected to V_{CC} to avoid any possibility of false triggering.

Figure 3 is a nomograph for easy determination of R, C values for various time delays.

NOTE: In monostable operation, the trigger should be driven high before the end of timing cycle.

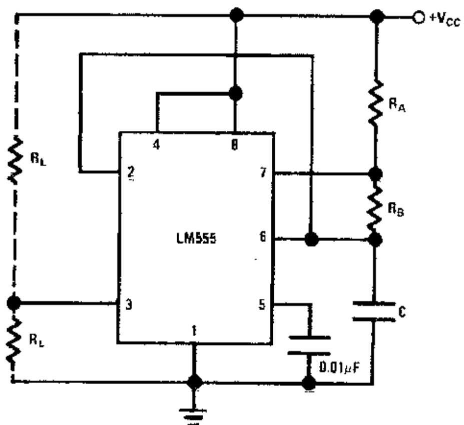


00785107

FIGURE 3. Time Delay

ASTABLE OPERATION

If the circuit is connected as shown in *Figure 4* (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through R_A + R_B and discharges through R_B. Thus the duty cycle may be precisely set by the ratio of these two resistors.



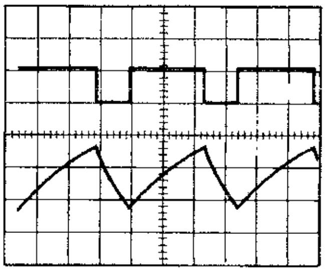
00785108

FIGURE 4. Astable

In this mode of operation, the capacitor charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

Applications Information (Continued)

Figure 5 shows the waveforms generated in this mode of operation.



00785109

V_{CC} = 5V
TIME = 20µs/DIV.
R_A = 3.9kΩ
R_B = 3kΩ
C = 0.01µF

Top Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

FIGURE 5. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693\,(R_A + R_B)\,C$$

And the discharge time (output low) by:

$$t_2 = 0.693\,(R_B)\,C$$

Thus the total period is:

$$T = t_1 + t_2 = 0.693\,(R_A + 2R_B)\,C$$

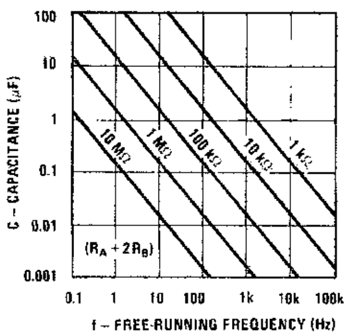
The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2\,R_B)\,C}$$

Figure 6 may be used for quick determination of these RC values.

The duty cycle is:

$$D = \frac{R_B}{R_A + 2R_B}$$

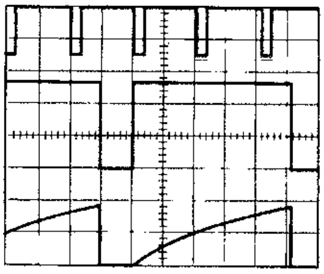


00785110

FIGURE 6. Free Running Frequency

FREQUENCY DIVIDER

The monostable circuit of *Figure 1* can be used as a frequency divider by adjusting the length of the timing cycle. *Figure 7* shows the waveforms generated in a divide by three circuit.



00785111

V_{CC} = 5V
TIME = 20µs/DIV.
R_A = 9.1kΩ
C = 0.01µF

Top Trace: Input 4V/Div.
Middle Trace: Output 2V/Div.
Bottom Trace: Capacitor 2V/Div.

FIGURE 7. Frequency Divider

PULSE WIDTH MODULATOR

When the timer is connected in the monostable mode and triggered with a continuous pulse train, the output pulse width can be modulated by a signal applied to pin 5. *Figure 8* shows the circuit, and in *Figure 9* are some waveform examples.

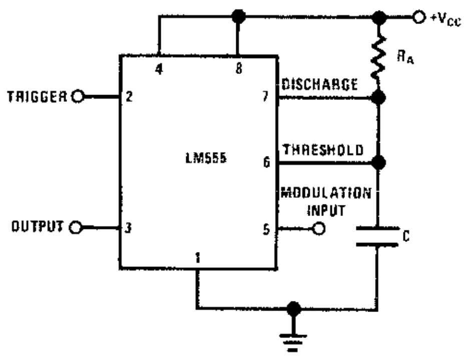


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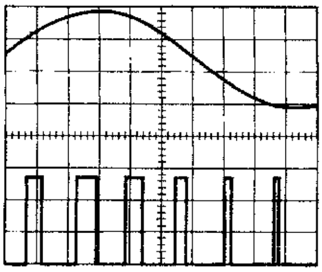
FIGURE 8. Pulse Width Modulator



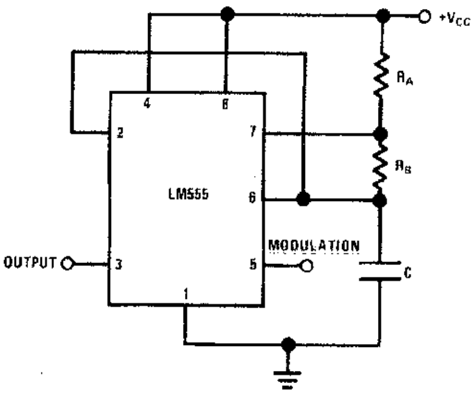
00785113

= 5V Top Trace: Modulation 1V/Div.
= 0.2 ms/DIV. Bottom Trace: Output Voltage 2V/Div.
9.1kΩ
ı.01µF

FIGURE 9. Pulse Width Modulator

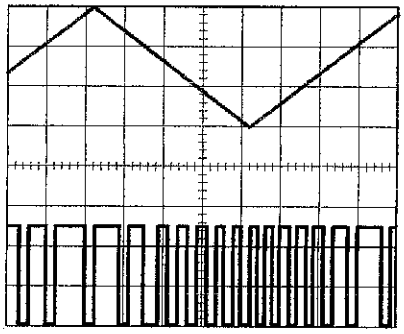
SE POSITION MODULATOR

application uses the timer connected for astable opera- as in *Figure 10*, with a modulating signal again applied e control voltage terminal. The pulse position varies with nodulating signal, since the threshold voltage and hence ime delay is varied. *Figure 11* shows the waveforms ırated for a triangle wave modulation signal.



00785114

FIGURE 10. Pulse Position Modulator



00785115

V_{CC} = 5V Top Trace: Modulation Input 1V/Div.
TIME = 0.1 ms/DIV. Bottom Trace: Output 2V/Div.
R_A = 3.9kΩ
R_B = 3kΩ
C = 0.01µF

FIGURE 11. Pulse Position Modulator

LINEAR RAMP

When the pullup resistor, R_A, in the monostable circuit is replaced by a constant current source, a linear ramp is generated. *Figure 12* shows a circuit configuration that will perform this function.

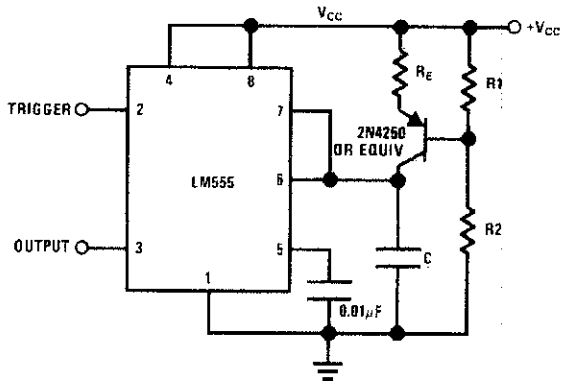


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FIGURE 12.

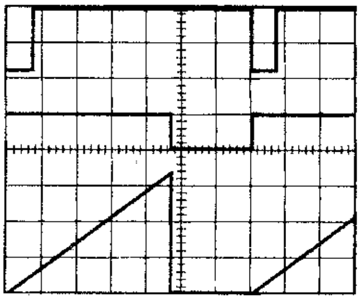
Figure 13 shows waveforms generated by the linear ramp. The time interval is given by:

$$T = \frac{2/3\, V_{CC}\, R_E\, (R_1 + R_2)\, C}{R_1\, V_{CC} - V_{BE}\, (R_1 + R_2)}$$

$$V_{BE} \cong 0.6V$$

$$V_{BE} \approx 0.6V$$

Applications Information (Continued)



V_{CC} = 5V   Top Trace: Input 3V/Div.
TIME = 20µs/DIV.   Middle Trace: Output 5V/Div.
R_1 = 47kΩ   Bottom Trace: Capacitor Voltage 1V/Div.
R_2 = 100kΩ
R_E = 2.7 kΩ
C = 0.01 µF

FIGURE 13. Linear Ramp

50% DUTY CYCLE OSCILLATOR

For a 50% duty cycle, the resistors R_A and R_B may be connected as in *Figure 14*. The time period for the output high is the same as previous, $t_1 = 0.693\ R_A\ C$. For the output low it is t_2 =

$$\left[(R_A R_B)/(R_A + R_B)\right] C\ \ell n \left[\frac{R_B - 2R_A}{2R_B - R_A}\right]$$

Thus the frequency of oscillation is

$$f = \frac{1}{t_1 + t_2}$$

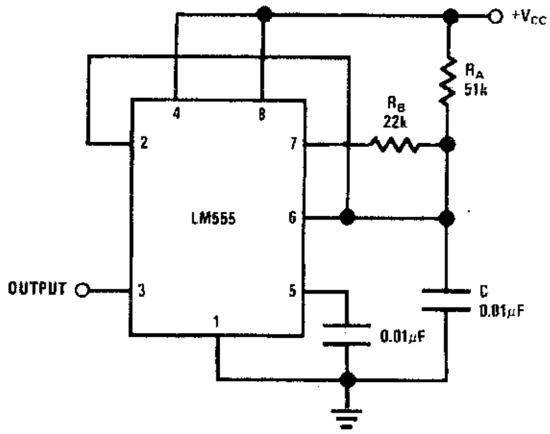


FIGURE 14. 50% Duty Cycle Oscillator

Note that this circuit will not oscillate if R_B is greater than 1/2 R_A because the junction of R_A and R_B cannot bring pin 2 down to 1/3 V_{CC} and trigger the lower comparator.

ADDITIONAL INFORMATION

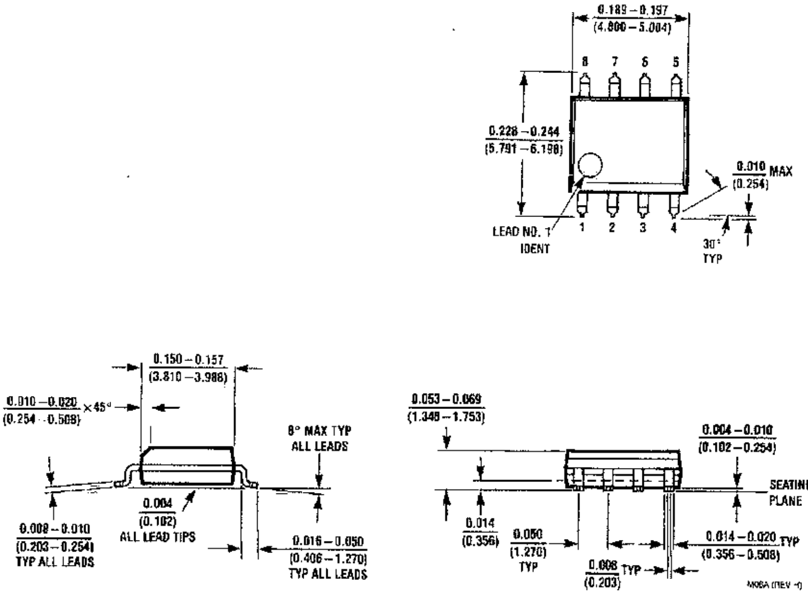
Adequate power supply bypassing is necessary to protect associated circuitry. Minimum recommended is 0.1µF in parallel with 1µF electrolytic.

Lower comparator storage time can be as long as 10µs when pin 2 is driven fully to ground for triggering. This limits the monostable pulse width to 10µs minimum.

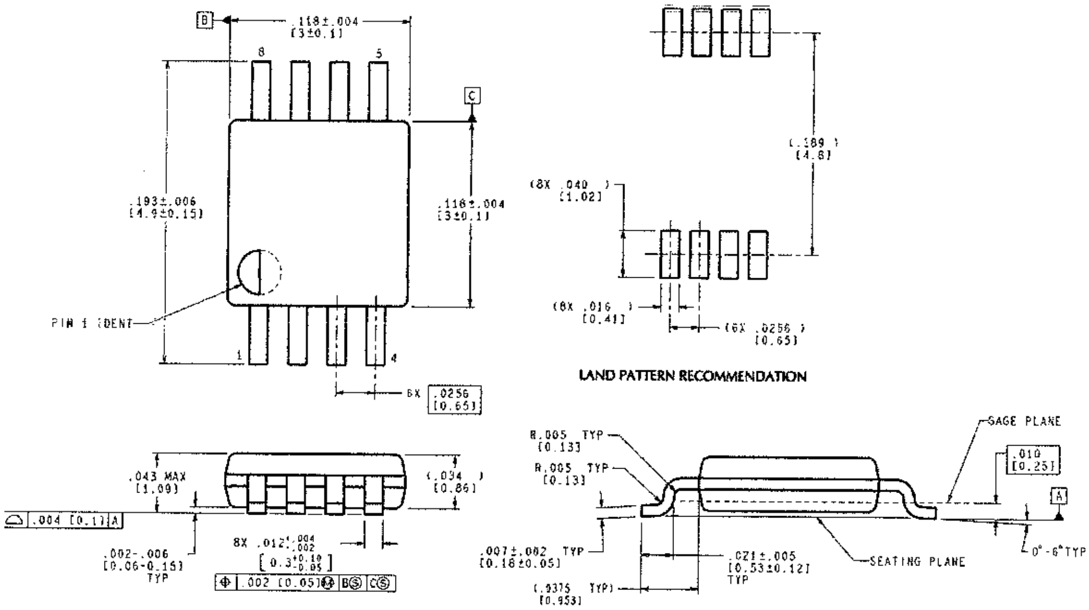
Delay time reset to output is 0.47µs typical. Minimum reset pulse width must be 0.3µs, typical.

Pin 7 current switches within 30ns of the output (pin 3) voltage.

ysical Dimensions inches (millimeters) unless otherwise noted



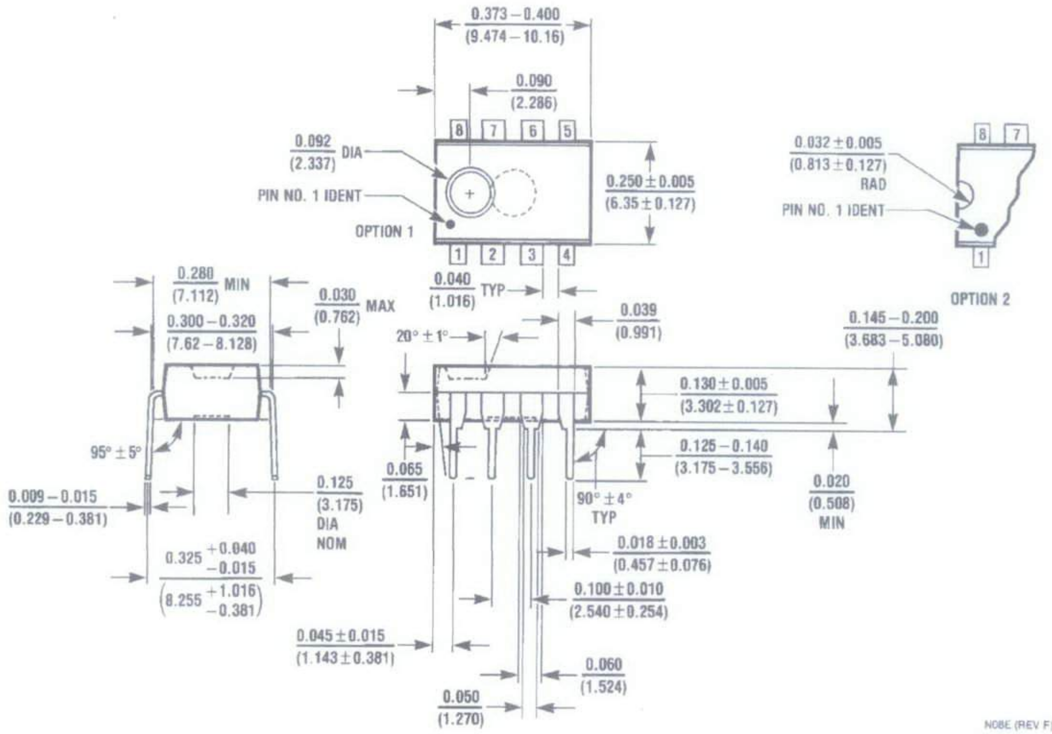
Small Outline Package (M)
NS Package Number M08A



MUA08A (Rev E)

8-Lead (0.118" Wide) Molded Mini Small Outline Package
NS Package Number MUA08A

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



Molded Dual-In-Line Package (N)
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