# Palestine Polytechnic University

**College of Applied Sciences**
**Applied Electronics**

**Graduation Project**

## Lighting system using solar cells with automatic sun light detection system

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## Abstract

The main idea of this project is the use of solar cell in order to convert the sun light energy into electrical energy, and use this electrical energy in lamp lighting.

This idea can be achieved by using three control circuits, first circuit using a motor to control the solar cell position to the largest intensity of light, second circuit to charge a battery, third circuit to control the bulb operation.

The main reason for the work of such a project that alternative source of energy, has not been implemented, would not hurt the environment, and reduce the financial burdens of the State.

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# Chapter One

## Introduction

This chapter contains the vision of all project contents such as project goals, block diagram, solar cells, DC motors, light dependent resistor, control circuits.
While the next chapters contain more details about project parts.

### 1.1 Project goal

The aim of this project is to build an alternative source system to produce light energy.

### 1.2 project advantages

- This project is one of good implementation to renewable energy investment.
- This project enables the electrical energy company to consume with optimal electrical energy used for light at nights.

### 1.3 Block diagram

The following block diagram shows the parts of **automatic lighting system using solar cells with automatic sun light detection system** project.

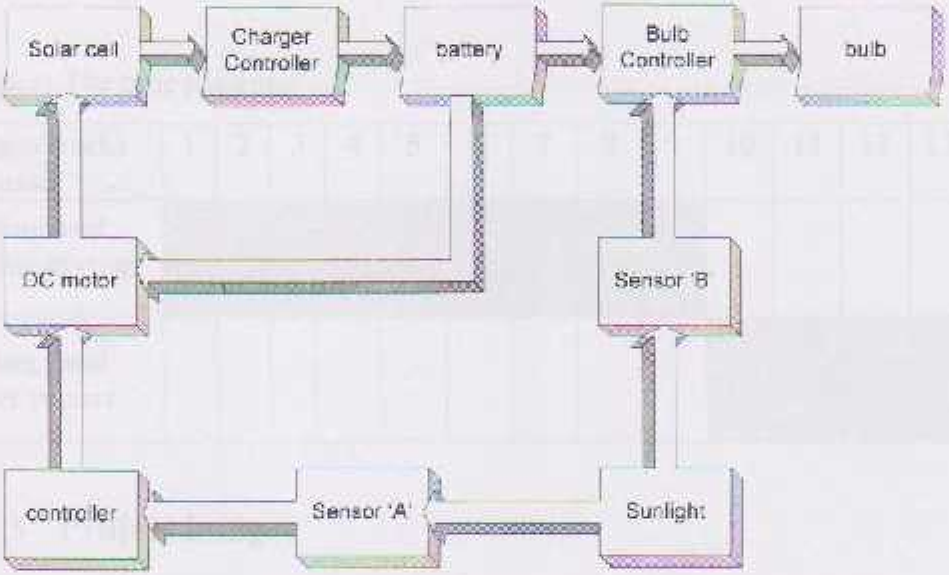


Figure 1.1: Block diagram of automatic lighting system using solar cells with automatic sun light detection system project.

The following steps summarize the work principle for the project and describe the issues of each block in the block diagram:

- *The Sun light affect the sensor 'A' (2 LDR sensors) that connected with a dc* motor motion controller.
- The DC motor rotates the solar cell into the direction of largest light intensity.
- The solar cell is connected with a battery charger to charge the battery.
- The battery is connected with the motor to supply it with the voltage needed to rotate it.
- The Sun light affect on the dark activated sensor (sensor 'B') that connected with a bulb controller.
- The bulb controller, control the operation of the bulb due to day and night.

## 1.4 time plane

Table1.1: The time planning

| Time(week) / Tasks | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building and testing the system** | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | | | | |
| **Writing final project report** | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ |

## 1.5 Project budget

Table 1.2: project budget

| Component | Cost [NIS] |
|---|---|
| solar cell | 1300 |
| Battery | 70 |
| Charger controller | 100 |
| DC bulb | 30 |
| Vat.% | 200 |
| 4 power transistors and 2N2222 transistor | 23 |
| 4 diodes | 8 |
| Resistors and potentiometers | 15 |
| Dc motor | 100 |
| Limit switch | 10 |
| 3 Relays | 24 |
| 3 LDR | 12 |
| 2 OP-amp | 8 |
| **Total cost** | **1900** |

## 1.6 solar cells

This section defines the solar cells; also will mention the types of silicon solar cell.

Silicon solar cell will used in this project; more details about it and its work principle will be mention in the next chapter.

### 1.6.1 What are Solar Cells?

Solar cells are devices which convert solar energy directly into electrical energy, either directly via the photovoltaic effect, or indirectly by first converting the solar energy to heat or chemical energy.

The most common form of solar cells are based on the photovoltaic (PV) effect in which light falling on a two layer semi-conductor device produces a photovoltage or potential difference between the layers. This voltage is capable of driving a current through an external circuit and thereby producing useful work.

### 1.6.2 Types of silicon solar cells

There are different types of silicon solar cells; the following points describe these types:

- Single crystal silicon solar cells.

- Polycrystalline silicon solar cells.
- Amorphous silicon cells.

## 1.7 DC motor

This section mentions and describes the types of dc motors.
More details about it will be mentioned in the next chapter.

### 1.7.1 Types of DC motors

Permanent magnet dc motor is used in this project.
More details about it will be mentioned in the next chapter.
There are many types of dc motors; some of these types are mentioned below:

1. The separately excited dc motor.
2. The shunt dc motor.
3. The series dc motor.
4. The compounded dc motor.
5. The permanent-magnet dc motor (PMDC): PMDC motor is a dc motor whose poles are made of permanent magnets.

This type of motors applied in low power systems.

**Advantages of the permanent-magnet dc motors**

There are many advantages to PMDC, some of these advantages are describe below:

- Since the PMDC motors do not require an external field circuit, they do not have the field circuit copper losses associated with other dc motors.
- Because no field windings are required in PMDC motors, they can be smaller than other dc motors.

**Disadvantages of the permanent-magnet dc motors**

There are a one disadvantages to PMDC motors mentioned below:

- Permanent magnets cannot produce as high a flux as an externally supplied shunt field, so a PMDC motor will have a lower induced torque per ampere of armature current than a shunt motor of the same size and construction. But in this project the lower induced torque is not a problem.

### 1.7.2 Conclusion

After this vision of DC motor types; in this project we will use a PMDC motor because it has the minimum losses and small enough so it doesn't take a wide space.

## 1.8 Light dependent resistor (LDR)

An LDR is an input transducer (sensor) which converts brightness (light) to resistance. It is made from cadmium sulfide (CdS) and the resistance decreases as the brighiness of light falling on the LDR increases. The LDR picture shown in Fig 1.2

Typical values for a standard LDR:

- Darkness: maximum resistance, about 1MΩ.
- Very bright light: minimum resistance about 100Ω.

Figure 1.2: LDR picture

More details about LDR will be mentioned in the next chapter, where the project team makes an experiment about the characteristics for LDR.

## 1.9 Control Circuits

This project has many control circuits, these circuits are describe below:

1. **Controller circuit**: convert the light energy coming from sun to an electrical energy in order to charge the battery and then light a bulb.

   To see this circuit go to page 47

2. **Solar tracking system circuit**: control the dc motor rotation that will rotate the solar cell to the direction of largest intensity light.

   To see this circuit go to page 43

3. **Bulb control circuit**: control the operation of the bulb.

   To see this circuit go to page 49

# Chapter Two

## Solar cells and Light dependent resistor

This chapter has tow parts, the first one will talk about the basic information of solar cells and its types. The second one will talk about the light dependent resistor (LDR) and its circuits.

### 2.1 Introduction to solar cells

The alternative energy sources are not free of pollution in general. There is many options that have less environmental damage than the conventional energy sources.[1]

The best techniques that harness the sun's energy, by using solar cells that directly convert solar radiation into electrical energy. Its energy source is free and inexhaustible, clean and remnants or without notice.[1]

Solar cells convert sunlight energy directly into electrical energy and are made of semiconducting materials. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electrical current. This process of converting light energy (photons) to electrical energy (voltage) is called the *photovoltaic* (PV) effect.[1]

## 2.2 Solar cell history

Although practical solar cells have only been available since the mid 1950s, scientific investigation of the photovoltaic effect started in 1839, when the French scientist, Henri Becquerel discovered that an electric current could be produced by shining a light onto certain chemical solutions.[2]

The effect was first observed in a solid material (in this case the metal selenium) in 1877. This material was used for many years for light meters, which only required very small amounts of power. A deeper understanding of the scientific principles, provided by Einstein in 1905 and Schottky in 1930, was required before efficient solar cells could be made. In 1954 Chapin, Pearson and Fuller developed a silicon solar cell that converted 6% of sunlight falling onto it into electrical energy, and this kind of cell was used in specialized applications such as orbiting space satellites from 1958.[2]

Today's commercially available silicon solar cells have efficiencies of converting about 18% of the sunlight falling onto them into electrical energy, at a fraction of the price of thirty years ago. There is now a variety of methods for the practical production of silicon solar cells (single crystal, polycrystalline, amorphous), as well as solar cells made from other materials (copper indium diselenide, cadmium telluride, etc).[2]

## 2.3 Solar cell working principle

To understand the operation of a PV cell, it is important to consider both the nature of the material and the nature of sunlight. Solar cells consist of two types of material, often p-type silicon and n-type silicon. Light of certain wavelengths is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charges ("holes") from the negative charges (electrons) within the photovoltaic device. The holes are swept into the positive or p-layer and the electrons are swept into the negative or n-layer. Although these opposite charges are attracted to each other, most of them can only recombine by passing through an external circuit outside the material because of the internal potential energy barrier. Therefore, if a circuit is made, power can be produced from the cells under illumination as shown in Fig 2.1, since the free electrons have to pass through the load to recombine with the positive holes.[3]

A typical solar cell consists of a glass or plastic cover, an antireflective layer, a front contact to allow electrons to enter a circuit, a back contact to allow them to complete the circuit, and the semiconductor layers where the electrons begin and complete their journey[3], as shown in Fig 2.1

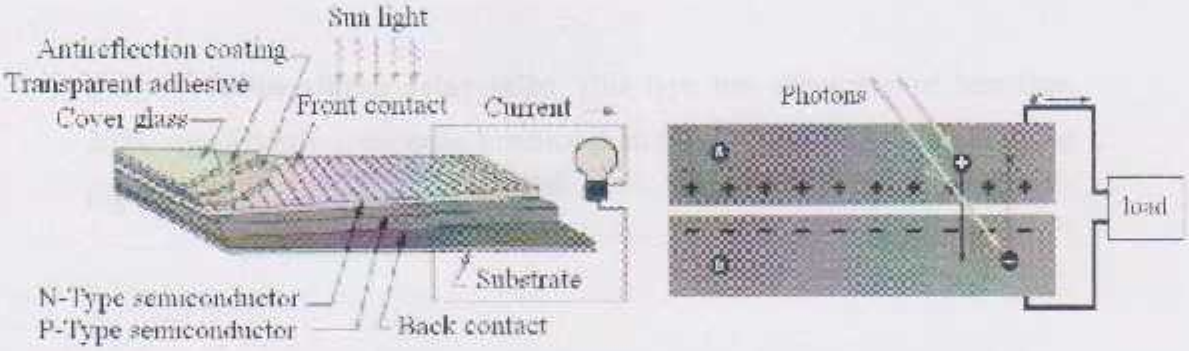


Figure 2.1: The Photovoltaic Effect in a Solar Cell

## 2.4 Silicon solar cell types

Solar cell could be distinguished into three cell types according to the type of crystal: monocrystalline, polycrystalline and amorphous:

- **Single crystal silicon solar cells (monocrystalline):** This type cannot currently convert more than 25% of the solar energy into electrical energy, because the radiation in the infrared region of the electromagnetic spectrum does not have enough energy to separate the positive and negative charges in the material, as shown in Fig 2.2 [4]

Figure 2.2 Single crystal solar cells

- **Polycrystalline silicon solar cells:** This type has efficiency of less than 20%, significantly cheaper to produce than single crystal cells, as shown in Fig 2.3 [4]

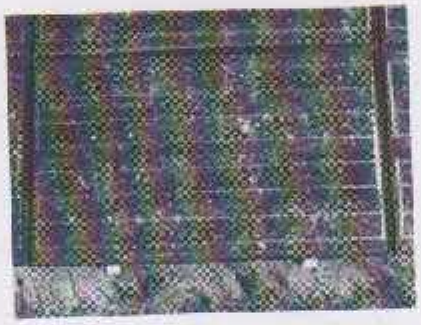


Figure2.3: Polycrystalline solar cells

- **Amorphous silicon cells:** This type made by depositing silicon onto a glass substrate from a reactive gas such as silane ($SiH_4$). Since amorphous silicon cells have no crystal structure at all, their efficiencies are presently only about 10% due to significant internal energy losses, as shown in Fig 2.4 [4]

Figure2.4: Amorphous solar cells

An important feature of PV cells is that the voltage of the cell does not depend on its size, because remains fairly constant with changing light intensity. However, the current in a device is almost directly proportional to light intensity and size. Therefore, when people want to compare different sized cells, they record the current density, or Amperes per Square Centimeter of cell area, as shown in Fig 2.5 [4]

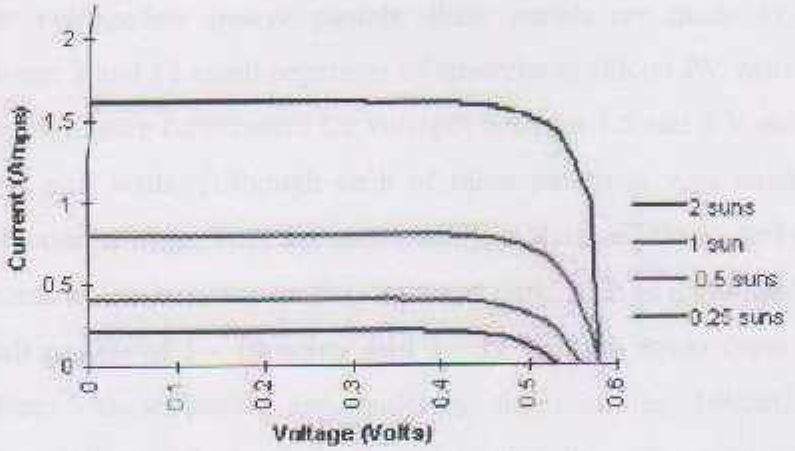


Figure2.5: Single-junction solar cell current (I)/voltage (V) curves

The power output of a solar cell can be increased quite effectively by using a tracking mechanism to keep the PV device directly facing the sun, or by concentrating the sunlight using lenses or mirrors. However, there are limits to this process, due to the complexity of the mechanisms, and the need to cool the cells. The current output is relatively stable at higher temperatures, but the voltage is reduced, leading to a drop in power as the cell temperature is increased. [5]

## 2.5 PV Panels

As single PV cells have a working voltage of about 0.5 V, they are usually connected together in series (positive to negative) to provide larger voltages. Panels are made in a wide range of sizes for different purposes. They generally fall into one of three basic categories:

- **Low voltage/low power panels**: these panels are made by connecting between 3 and 12 small segments of amorphous silicon PV with a total area of a few square centimeters for voltages between 1.5 and 6 V and outputs of a few mill watts. Although each of these panels is very small, the total production is large. They are used mainly in watches, clocks and calculators, cameras and devices for sensing light and dark, such as night lights.
- **Small panels of 1 - 10 watts and 3 - 12 V, with areas from 100cm$^2$ to 1000cm$^2$**: these panels are made by either cutting 100cm2 single or polycrystalline cells into pieces and joining them in series, or by using amorphous silicon panels. The main uses are for radios, toys, small pumps, electric fences and trickle charging of batteries.
- **Large panels, ranging from 10 to 60 watts, and generally either 6 or 12 volts, with areas of 1000cm$^2$ to 5000cm$^2$**: these panels are usually made by connecting from 10 to 36 full-sized cells in series. They are used either separately for small pumps and caravan power (lights and refrigeration) or in arrays to provide power for houses, communications pumping and remote area power supplies (RAPS).

## 2.6 PV Panel Selection

The selection of the PV panel took according to the available budget.

A 40 watt KC40 PV multicrystal panel from Kyocera was chosen. At a conservative output of 28 watts, the panel, over a period of 8 hours will provide 224 watts to the battery.

This is sufficient to fully recharge the battery daily and make up for days of low solar irradiance. A conversion rating sof 70% (40 -> 28) is conservative for design purposes.

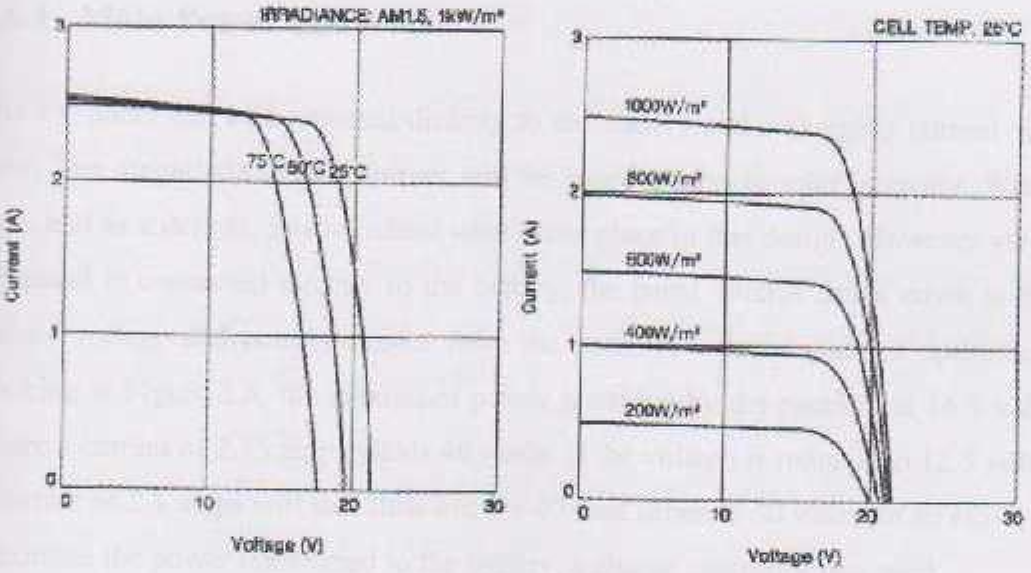


Figure 2.6: KC40 Electrical Characteristics

The PV panel is a simple electrical device and given any two of three variables, the third variable can be derived using the graphs in Figure 2.6. The three variables are panel temperature, panel voltage, and output current. The peak power current varies with solar isolation and thus using the panel output current in a maximal power point tracking (MPPT) algorithm would require sensing solar irradiance. This can be done, but would require mounting multiple sensors on the panel to accurately measure the irradiance onto the panel and would unnecessarily complicate the feedback controller.

The maximal power voltage, unlike the current, is constant regardless of irradiance. As shown on the right of Figure 2.6, the "knee" of each curve occurs at 16.9 volts. At that point, a rectangle drawn by extending a line from the point to either axes has the maximum area. The area is I * V which is power. The peak power voltage changes with panel temperature. The ambient temperature does not vary nearly as fast as solar ambience (clouds moving) and serves as a stable parameter for the controller.

### 2.6.1 Main Power Converter

The PV panel can be connected directly to the battery and a charging current will flow. The magnitude of that current will be based solely on solar intensity. Worst case, and as a default, this is indeed what takes place in this design. However when the panel is connected directly to the battery, the panel voltage drops down to the battery voltage and power transfer from the panel is reduced and not optimized. Looking at Figure 2.6, the maximum power provided by the panel is at 16.9 volts where a current of 2.35 amps yields 40 watts. If the voltage is reduced to 12.5 volts, a current of 2.4 amps will still flow but the 40 watt drops to 30 watts. In an effort to maximize the power transferred to the battery, a charge controller was used.

## 2.7 Conclusion

After the previous vision of solar cell working principle and silicon solar cell types; this project will use the multicrystal silicon solar cell because its high efficiency, suitability and availability.

## 2.8 LDR Structure

The LDR is made from a crystal structure material and utilizes its photoconductive properties. The most common crystal is Cadmium Sulfide.

### 2.8.1 Introduction to light structure

This discussion of photoelectric phenomena requires a basic knowledge of the properties of light. [6]

Light Response means that the white light is a "mixture" of light rays combined together. Each of these rays has its own wavelength and it is their wavelengths variation that performs the rainbow colors. [6]

The light, as the sound, is a combination of tones varying in wide range of frequencies. Each tone has its own frequency. In the same way, the light can be describe as mixture of colors, tones, as each one can be define by his own wavelength. [6]

Comparing two white light sources, for example- a regular incandescent lamp and a fluorescent lamp, shows that their visible light color in not the same. The explanation for this result is that the combination of color tones of each source differ, another color tone is more dominant. [6]

From now, we can use the terminology "Light Wavelength" or "Light frequency" instead of "Tone".

The wavelength is specified as a function of frequency according to its relation to light velocity and is given by the following equation:

$\lambda = C/F$

Where:

λ= light wavelength

C= light velocity in space (300,000 km/second)

F = light frequency

The light can be divided, according to its wavelength, into three categories:

1. Ultraviolet light- below 0.4μm.
2. Visible light- between 0.4 μm to 0.7 μm.
3. Infrared light- over 0.7 μm.

Light wave shorter than violet light or longer than red light waves, do not register in the human eye. Of the various types of LDRs in use, the most sensitive to visible light rays are the cadmium sulfide (CdS) photoconductive LDR. [6]

### 2.8.2 The LDR Features

The principle of LDR work is that the Resistance varying as function of Illumination and Doping. [6]

In LDR devices, the crystal is treated or doped with impurity. Its photoconductivity is obtained as function of the carriers (electrons) energized by the light falling on the sensitive surface of the **LDR**. [6]

At darkness, without illumination falling on the **LDR**, the carriers are not energized which mean- high resistance. Under illumination, the light energizes the carriers, which means – lower resistance. [6]

Project team makes an experiment on LDR, by connecting a circuit as shown in Figure 2.7

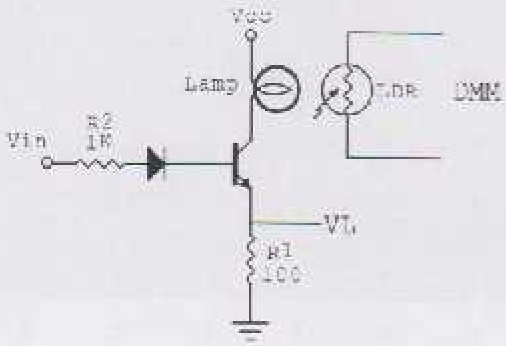


Figure 2.7: LDR resistance

The lamp and LDR are connected internally in the same box. So by changing input voltage ($V_{in}$), the voltage ($V_L$) across R1 will change. At different values of $V_L$ calculate the current through R1 ($I_L$) by using the following equation:

$I_L = V_L / R1$

This current $I_L$ is equal to the lamp current. Now by using a digital multimeter connected with the LDR; its resistance can be taken. [6]

The results of the experiment shown below:

Table 2.1: Measurement of LDR resistance

| **$V_L$ (v)** | **0.25** | **0.5** | **0.75** | **1.00** | **1.25** | **1.50** | **1.75** | **2.00** | **2.25** |
|---|---|---|---|---|---|---|---|---|---|
| **$I_L$(mA)** | 0.217 | 0.735 | 1 | 2 | 3 | 4 | 6 | 7 | 9 |
| **R (Ω)** | 1150 | 680 | 503 | 406 | 348 | 310 | 283 | 265.5 | 249.5 |

The LDR resistance may vary from material to material, but in general, the curves shape will always remain the same (as shown in figure 2.8). [6]

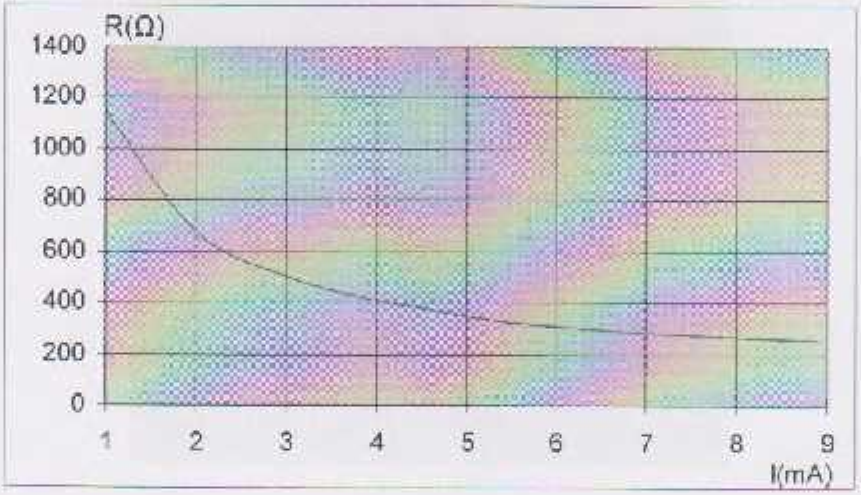


Figure2.8: Resistance/light intensity characteristic of the LDR

In electronics circuits when LDR is used, its symbol will appear as shown in Fig 2.9, and its picture as used in devices shown in Fig 2.10 [7]

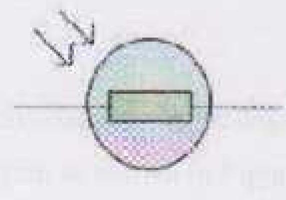


Figure2.9: LDR symbol

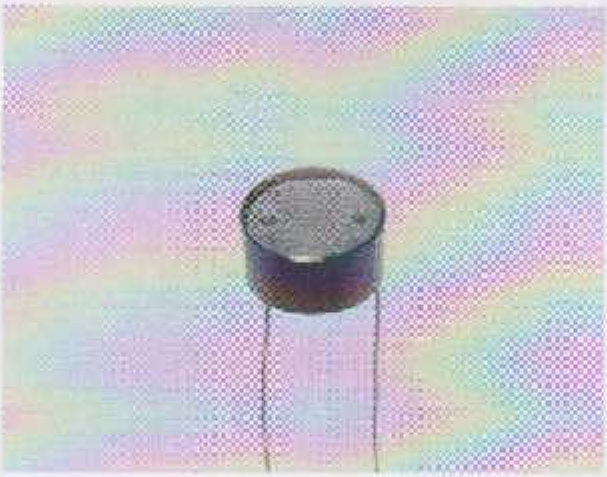


Figure 2.10: LDR picture

### 2.8.3 LDR circuits

There are just two ways of constructing the voltage divider, with the LDR at the top, or with the LDR at the bottom as shown in Figure 2.11:

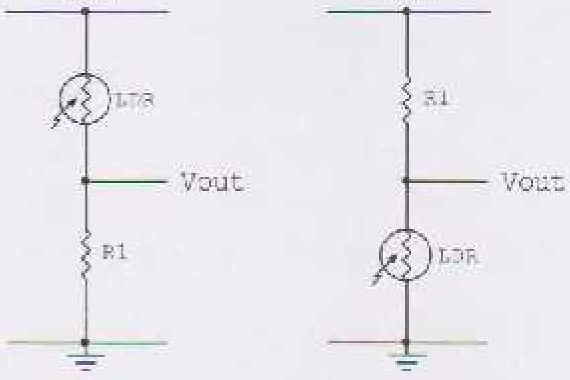


Fig 2.11: LDR circuits

Now find out how to choose a sensible value for the fixed resistor in a voltage divider circuit. [7]

Remember the formula for calculating $V_{out}$:

$$Vout = V_{in} \times \frac{R_{bottom}}{R_{bottom+}R_{top}}$$

### 2.8.4 Summary of the LDR features

The sensitivity of the LDR depends on several factors such as: photoconductive material, reception area of the incident light, wavelength distribution of the incident light and the impurity level. The main disadvantage of the LDR is its slow response. The rise time of a typical LDR is of approximately 0.1 second, which is too slow for many applications, such as computers and digital communications. But in this project the slow rise time is not a problem. [6]

# Chapter Three

# DC motors

## 3.1 Introduction

The direct current (DC) motor is one of the first machines devised to convert electrical energy to mechanical energy, The DC Motor has many advantages over other motors which are generally the reason for its choice; Firstly the simple torque control . Then the fact that the power supply of a DC motor connects directly to the armature of the motor allows for precise voltage control, which is necessary with torque control applications. [8]

DC motors perform better than other motors on most traction equipment. They are also used for mobile equipment like carts; DC motors are conveniently portable and well suited to special applications, such as industrial. [8]

Permanent magnetic (PMDC) convert electrical energy into mechanical energy through the interaction of two magnetic fields. A permanent magnetic assembly produces one field; an electrical current flowing in the motor windings produces the other field. These two fields result in a torque which to rotate the rotor. As the rotor turns, the current in the windings is commutated to produce a continuous torque output. [8]

The field is supplied by PM motor, as its name implies. In operation, the PM motor stator flux is always constant. In practice, this means that the speed-torque and speed-armature voltage curves are linear. [8]

One major advantage of PMDC motors is that they require no field current. This fact means that there will be a considerable saving in energy over equivalent wound-pole machines during a typical machine life time. Although permanent-magnet materials tend to be expensive, the size of a permanent-magnet field pole may be much less than that of the equivalent wound pole. This means that the overall size of the machine is reduced. The reduction in the cost of other materials compensates, at least in part, for the magnet cost. In small machines there is a definite cost advantage in permanent magnet field poles. [8]

The magnetic field of (PM) motors is generated by permanent magnets so no power is used to create the magnetic field structure. The "stator" magnetic flux remains essentially constant at all levels of armature current and, therefore, the speed versus torque curve of the PM motor is linear over an extended range. In general the PMDC motor is characterized by the following: [8]

- The DC motor is easier than other motors in control processes.
- They produce their maximum torque at zero speed.
- They produce zero torque at their maximum speed.
- They develop their maximum power at 50% of their maximum speed.
- At 50% of maximum speed, they produce 50% of their maximum torque.
- At maximum power, they are no more than 50% efficient.
- They require no field current and saving energy during the life time.

## 3.2 Electrical Model

Electrically, permanent magnet brushed DC motors can be modeled as a series of three basic electrical components: a resistor, an inductor, and a source of electromotive force (EMF), or voltage (Figure 3.1).

This voltage source is commonly called the "**back-EMF**" or "**counter EMF.**" The origins of the resistive and inductive components are easy to see. The resistor in the model is a result of the finite resistance per unit length of wire used to construct the coils in the armature. The inductor is a result of coils of wire that make up the armature windings. All coils of wire act as inductors.

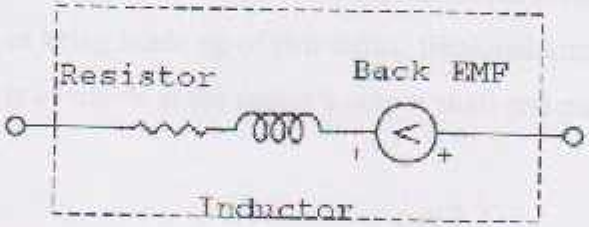


Figure 3.1: Electrical Model of a Permanent Magnet Brushed DC Motor

## 3.3 Characteristic Constants for Permanent Magnet Brushed DC Motors

As a motor turns faster, more back-EMF is generated since the coils in the armature are moving faster through the stator's magnetic field. The magnitude of the back-EMF is related to the rotational speed through a constant $K_e$, called the **speed constant** or **voltage constant**.

$E = K_e \omega$ equ.3.1

Where E = back-EMF

$K_e$ = speed constant $\left[\frac{V}{rad/s}\right]$

$\omega$ = rotational speed $[rad/s]$

Quantities like the motor's physical dimensions, the number of turns in the coil windings, and the magnetic flux density of the stator all contribute to the value of $K_e$.

In this development, we will ignore, for the moment, the non-ideal mechanical and electrical losses associated with the motor/generator operation. The largest of the effects we will assume are negligible in this discussion is the torque required to overcome friction in the motor. Because of friction, the torque generated by the motor may be treated as being made up of two terms: frictional torque and usable torque (or torque that is available at the motor's output shaft and may be used to drive a load):

$$T_M = T_L + T_f \qquad \text{equ.3.2}$$

For now, we assume $T_f \approx 0$. For most motors this is a reasonable first approximation. If the losses are negligible, then the mechanical power into the generator, $T\omega$, will equal the electrical power out, EI

$$P = EI = T\omega \qquad \text{equ.3.3}$$

We can combine Eq.3.1 with Eq.3.3 to yield:

$$K_e \omega I = T\omega \qquad \text{equ.3.4}$$

Which can be simplified to:

$$T = K_e I \qquad \text{equ.3.5}$$

The constant can be expressed equivalently with units of

$$\left[\frac{volts}{radians/second}\right] \text{Or} \left[\frac{Newton \bullet meter}{Ampere}\right]$$

To minimize confusion, we treat the constant in Eq.3.5 as different and call it $K_T$, the **torque constant**.

The motor's physical dimensions, the number of turns in the coil windings, and the magnetic flux density of the stator all contribute to the value of $K_T$, just as they did with $K_e$. With the substitution of $K_T$ for $K_e$, Eq.3.5 takes on its more common form:

$T = K_T I$ equ.3.6

Where: T = torque $[N \bullet m]$

$K_T$ = torque constant $\left[\frac{N \bullet m}{A}\right]$

I= current $[A]$

This distinction between $K_T$ and $K_e$ is particularly useful in that numerically $K_T$ = $K_e$ when compatible units are used (e.g., $\left[\frac{volts}{radians/_{second}}\right]$ and $\left[\frac{Newton \bullet meter}{Ampere}\right]$).

## 3.4 Characteristic Equations for Constant Voltage

To more fully understand the torque and speed characteristics of a motor we can start by examining what goes on when we place the motor into a circuit with a driving voltage as shown in figure 3.2.

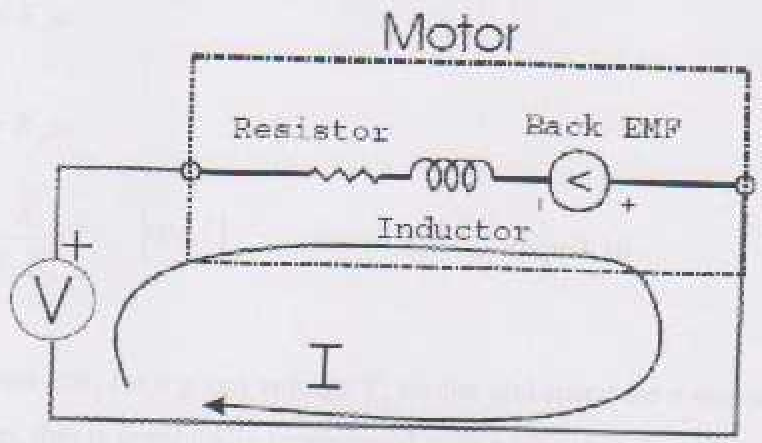


Figure 3.2: DC Motor circuit with driving voltage

We can use Kirchoff's laws to write a loop equation to describe the steady-state current flow in this circuit.

$V = IR + K_e\omega$ equ.3.9

Where: V = voltage $[V]$

I = current $[A]$

R = resistor of motor coils $[\Omega]$

$K_e$ = voltage constant $\left[\frac{V}{rad/s}\right]$

ω = rotational speed $[rad/s]$

The voltage drop across the motor's coils has an IR term, as you would normally expect, plus the effects of the back-EMF generated by spinning the motor, expressed in the term $K_e\omega$.

By substituting Eq. 3.6 into Eq. 3.9, we can develop an expression relating torque to speed.

$$V = \frac{T}{K_T} R + K_e \omega$$

$$V - \frac{T}{K_T} R = K_e \omega$$

$$\omega = \frac{V}{K_e} - \frac{R}{K_T K_e} T \quad \left[ {rad}/{s} \right] \qquad \text{equ.3.10}$$

Eq. 3.10 shows that, for a given voltage V, torque and speed for a motor are linearly related. Often, this is graphically represented with a plot showing a family of lines relating T vs. ω for several constant values of voltage, V. Figure 3.3 shows a typical example.

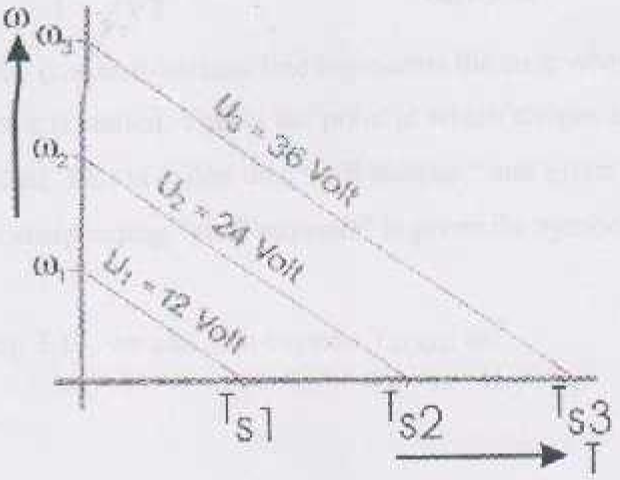


Figure 3.3: Typical Torque vs. ω Curves for a Permanent Magnet Brushed DC Motor

There are a few aspects of Figure 3.3 that we should identify and label. The first is the y-intercept of each line. This is the maximum speed that the motor can achieve for a given voltage, which occurs for the idealized case where there is no torque generated. This is called the "**no-load speed**," written as $\omega_{NL}$, and is the $\frac{V}{K_e}$ term in Eq. 3.10. Thus, for a permanent magnet brushed DC motor:

$$\omega_{NL} = \frac{V}{K_e} \quad \left[{rad}/{s}\right] \qquad \text{equ.3.11}$$

The slope of the line given by Eq. 3.10 is the multiplier on T, which is $\frac{R}{K_T K_e}$. The slope term is also given it own symbol, $R_M$, and is called the "**speed regulation constant**":

$$R_M = \frac{R}{K_t K_e} \quad \left[\frac{rad/s}{N \bullet m}\right] \qquad \text{equ.3.12}$$

By substituting $\omega_{NL}$ and $R_M$ into Eq. 3.10 we get an expression that is more easily identified as that of a straight line:

$$\omega = \omega_{NL} - R_M T \quad \left[{rad}/{s}\right] \qquad \text{equ.3.13}$$

The x-intercept of the constant-voltage line represents the case where $\omega = 0$, which occurs when the motor is stalled. This is the point at which torque, and therefore current, are maximized. This is called the "**stall torque**," and given the symbol $T_{STALL}$ or $T_S$. The corresponding "**stall current**" is given the symbol $I_{STALL}$ or $I_S$.

If we set $\omega = 0$ in Eq. 3.13, we can also express $T_{STALL}$ as:

$$0 = \omega_{NL} - R_M T_{STALL}$$

$$T_{STALL} = \frac{\omega_{NL}}{R_M}$$

Recalling from Eq. 3.11 that $\omega_{NL} = \frac{V}{K_e}$ :

$$T_{STALL} = \frac{V}{R_M K_e} \qquad [N \bullet m] \qquad \text{equ.3.14}$$

Then, recalling from Eq. 3.12 that $R_M = \frac{R}{K_T K_e}$ and then simplifying gives:

$$T_{STALL} = \frac{K_T V}{R} \qquad [N \bullet m] \qquad \text{equ.3.15}$$

Simplifying further using Ohm's Law, we once again obtain Eq. 3.6:

$$T = K_T I \qquad [N \bullet m] \qquad \text{equ.3.6}$$

## 3.5 Power Characteristics

For the purposes of this discussion, mechanical power is defined as $P = T\omega$. Recall from Eq. 3.2 that overall motor torque is made up of a friction torque term and a usable torque term, so the full expression for motor power output becomes:

$$P = T\omega = (T_f + T_L)\omega \qquad [W] \qquad \text{equ.3.16}$$

For this discussion, we will assume that the friction torque is relatively small and may be safely neglected. Again, for most motors this is a reasonable first approximation. However, for any of these discussions, the effects of frictional torque may be explored by carrying the $T_f$ term in the equations through and redeveloping the results.

As with the relationship between torque and speed, a motor's torque and power characteristics are usually presented graphically for lines of constant voltage, and drawn as a family of curves. Figure 3.4 shows a typical family of curves for a representative motor. The power output characteristic is parabolic in shape, having a maximum at ½$T_{STALL}$ for a given voltage.

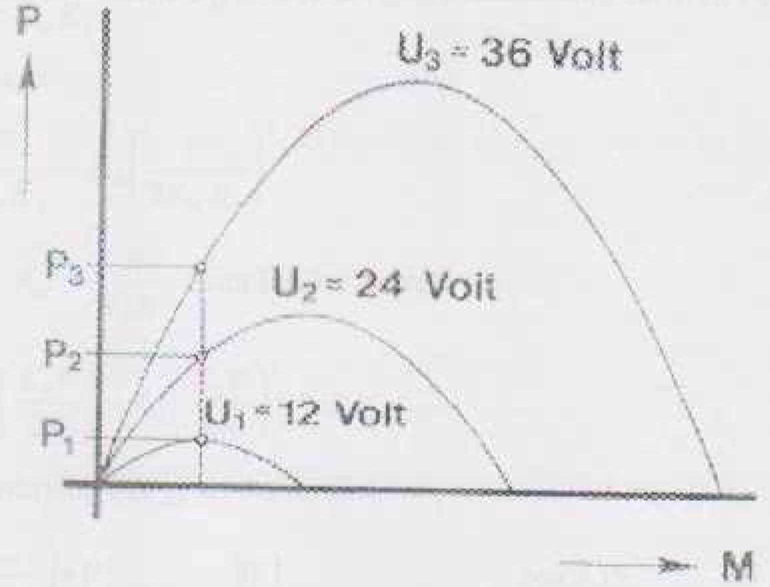


Figure 3.4: Typical Torque vs. Power Output Curves for a Permanent Magnet Brushed DC Motor

To understand the shape of the curve and the position of the peak value, start from the statement that $P = T\omega$ .By substituting Eq. 3.13 for ω, this can be rewritten as:

$$P = T(\omega_{NL} - R_M T) \qquad [W] \qquad \text{equ.3.17}$$

Then, by combining terms and substituting $\omega_{NL} = \frac{V}{K_E}$ from Eq. 3.11, we arrive at an expression relating power to torque:

$$P = \frac{VT}{K_E} - R_M T^2 \qquad [W] \qquad \text{equ.3.18}$$

Taking the derivative of Eq. 3.18 with respect to torque and setting the results equal to 0 yields the point of **maximum power**. The results of that exercise are that maximum power output for a permanent magnet brushed DC motor occurs when

$T = \frac{1}{2} T_{STALL}$.

We can make use of this by starting with Eq. 3.18, and substituting $T = \frac{1}{2} T_{STALL}$ and $T_{STALL} = \frac{V}{R_M K_n}$ from Eq. 3.14 to develop a relationship between $P_{MAX}$ and applied voltage:

$$P_{MAX} = \frac{V^2}{2 R_M K_E} - R_M \left( \frac{V}{2 R_M K_e} \right)^2$$

Substituting $R_M = \frac{R}{K_T K_e}$ from Eq. 3.12 gives:

$$P_{MAX} = \frac{V}{K_E} \left( \frac{K_T V}{2R} \right) - R_M \left( \frac{K_T V}{2R} \right)^2$$

Finally, simplifying this gives the result:

$$P_{MAX} = \left( \frac{K_T}{4 K_e R} \right) \bullet V^2 \qquad [W] \qquad \text{equ.3.19}$$

These results show that $P_{MAX}$ is proportional to $V^2$, since the term $\left( \frac{K_T}{4 K_e R} \right)$ is a constant for a given motor.

This is an important result: the mechanical power output of permanent magnet brushed DC motors changes as the square of the applied voltage. Changes in voltage have a substantial impact on a motor's power output.

## 3.6 DC Motor Efficiency

An additional quantity of great interest is that of **motor efficiency**, η. In this analysis, efficiency is defined as the ratio of mechanical power produced by the motor to electrical power consumed by the motor:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{T_L \omega}{VI} = \frac{(T_M - T_f)\omega}{VI} \qquad \text{equ.3.20}$$

The general equation for motor efficiency is stated above in Eq.3.20. We can restate V using Ohm's Law as follows:

$$V = I_S R \quad [V] \qquad \text{equ.3.21}$$

Since V, $I_S$ and R are all constants. Substituting this back into the $P_{IN}$ term of Eq. 3.20 gives:

$$\eta = \frac{(T_M - T_f)\omega}{I_S IR}$$

Substituting the expression for ω from Eq.3.10 gives:

$$\eta = \frac{(T_M - T_f)\left(\frac{V}{K_e} - \frac{RT_M}{K_e K_T}\right)}{I_S IR}$$

And replacing total motor torque produced $T_M = K_T I$ (eq.3.6) and $V = I_S R$ (eq.3.21) gives:

$$\eta = \frac{(K_T I - T_f)\left(\frac{I_S R}{K_e} - \frac{K_T IR}{K_e K_T}\right)}{I_S IR}$$

Simplifying this gives:

$$\eta = \frac{(K_T I - T_f)\left(\frac{I_S R - IR}{K_e}\right)}{I_S IR}$$

The frictional torque term, $T_F$, may also be expressed as:

$$T_f = K_t I_{NL} \quad [N \bullet m] \qquad \text{equ.3.22}$$

Since the no-load current, $I_{NL}$, is the amount of current required to overcome the force of friction only, without generating any additional useful torque – the definition of the no-load condition. Substituting this into our expression for efficiency results in the following:

$$\eta = \frac{(K_t I - K_T I_{NL})\left(\frac{I_S R - IR}{K_e}\right)}{I_S IR}$$

Finally, since K$_T$ = K$_e$ in consistent units, efficiency can be expressed as:

$$\eta = \frac{(I - I_{NL})(I_S R - IR)}{I_S IR}$$

$$\eta = \frac{(I - I_{NL})(I_S - I)}{I_S I}$$

$$\eta = 1 - \frac{I}{I_S} - \frac{I_{NL}}{I} + \frac{I_{NL}}{I_S} \qquad \text{equ.3.23}$$

$$\eta = \left(1 - \frac{I_{NL}}{I}\right)\left(1 - \frac{I}{I_S}\right) \qquad \text{equ.3.24}$$

With Eq.3.23 and Eq.3.24, we have expressions for efficiency only as functions of motor current (I), no-load current (I$_{NL}$), and stall current (I$_S$). In order to find the current that results in the operating point of maximum efficiency, take the derivative of Eq.3.23 with respect to current (I), set the results equal to 0 and solve for I.

$$\frac{\partial \eta}{\partial I} = \frac{\partial}{\partial I}\left(1 - \frac{I}{I_S} - \frac{I_{NL}}{I} + \frac{I_{NL}}{I_S}\right) = 0$$

$$\frac{I_{NL}}{I^2} - \frac{1}{I_S} = 0$$

$$I = \sqrt{I_{NL} I_S} \qquad \text{equ.3.25}$$

Substituting the result in Eq.3.25 back into Eq.3.24 gives us the expression for maximum efficiency we were after:

$$\eta_{MAX} = \left(1 - \frac{I_{NL}}{\sqrt{I_{NL} I_S}}\right)\left(1 - \frac{\sqrt{I_{NL} I_S}}{I_S}\right)$$

Simplifying this gives the more compact result:

$$\eta_{MAX} = \left(1 - \sqrt{\frac{I_{NL}}{I_S}}\right)^2 \qquad \text{equ.3.26}$$

Recalling from Eq.3.22 that $T_f = K_T I_{NL}$ and $V = I_S R$ from Eq.3.21, we can rewrite 3.24 in terms that will allow us to draw a few additional conclusions:

$$\eta_{MAX} = \left(1 - \sqrt{\frac{T_f R}{K_T V}}\right)^2 \qquad \text{equ.3.27}$$

This expression for maximum efficiency shows that increases in friction decrease efficiency, as do increases in resistance.

## 3.7 Conclusion

The PMDC motor used in this project; because it has high stability in position control. Also its smaller size and lower losses.

# Chapter four

# Batteries

## 4.1 Introduction

In science and technology, a battery is a device that stores chemical energy and makes it available in an electrical form. Batteries consist of electrochemical devices such as one or more galvanic cells. [9]

## 4.2 Battery concepts

It consists of one or more voltaic cells, each of which is composed of two half cells connected in series by the conductive electrolyte. The battery consists of one or more voltaic cells in series, each cell has a positive terminal and a negative terminal, and these do not touch each other but are immersed in a solid or liquid electrolyte. [9]

The electrolyte is a conductor which connects the half-cells together. It also contains ions which can react with chemicals of the electrodes. Chemical energy is converted into electrical energy by chemical reactions that transfer charge between the electrode and the electrolyte at their interface. Such reactions are called faradaic, and are responsible for current flow through the cell. Ordinary, non-charge-transferring (non-faradaic) reactions also occur at the electrode-electrolyte interfaces. Non-faradaic reactions are one reason that voltaic cells (particularly the lead-acid cell of ordinary car batteries) "run down" when sitting unused. [9]

Voltaic cells, and batteries of voltaic cells, are rated in volts, the SI unit of electromotive force. The voltage across the terminals of a battery is known as its terminal voltage. The terminal voltage of a battery that is neither charging nor discharging (the open-circuit voltage) equals its electromotive force (emf). The terminal voltage of a battery that is discharging is less than the emf, and that of a battery that is charging is greater than the emf. [9]

The simplest characterization of a battery would give its emf (voltage), its internal resistance, and its capacity. In principle, the energy stored by a battery equals the product of its emf and its capacity. [9]

## 4.3 Battery capacity

Since the voltage of a battery is relatively constant, the capacity of a battery to store energy is often expressed in terms of the total amount of charge able to pass through the device. This is expressed in ampere hours, where one A·h equals 3600 coulombs. If a battery can pump charges for one hour at a rate of one coulomb/sec or one ampere (1 A), it has a capacity of 1 A·h. The more electrolyte and electrode material in the cell, the greater the capacity of the cell. Thus a tiny cell has much less capacity than a much larger cell, even if both rely on the same chemical reactions (e.g. alkaline cells), which produce the same terminal voltage. Because of the chemical reactions within the cells, the capacity of a battery depends on the discharge conditions such as the magnitude of the current, the duration of the current, the allowable terminal voltage of the battery, temperature, and other factors. [9]

Battery manufacturers use a standard method to determine how to rate their batteries. The battery is discharged at a constant rate of current over a fixed period of time, such as 10 hours or 20 hours, down to a set terminal voltage per cell. So a 100 ampere-hour battery is rated to provide 5 A for 20 hours at room temperature. The efficiency of a battery is different at different discharge rates. When discharging at low rate, the battery's energy is delivered more efficiently than at higher discharge rates. This is known as Peukert's Law. [9]

## 4.4 Electrical component for cell versus battery

The cells in a battery can be connected in parallel, series, or in both. A parallel combination of cells has the same voltage as a single cell, but can supply a higher current (the sum of the currents from all the cells). A series combination has the same current rating as a single cell but its voltage is the sum of the voltages of all the cells. Most practical electrochemical batteries, such as 9 volt flashlight (torch) batteries and 12 V automobile (car) batteries, have several cells connected in series inside the casing. Parallel arrangements suffer from the problem that, if one cell discharges faster than its neighbor, current will flow from the full cell to the empty cell, wasting power and possibly causing overheating. Even worse, if one cell becomes short-circuited due to an internal fault, its neighbor will be forced to discharge its maximum current into the faulty cell, leading to overheating and possibly explosion. Cells in parallel are therefore usually fitted with an electronic circuit to protect them against these problems. In both series and parallel types, the energy stored in the battery is equal to the sum of the energies stored in all the cells. [9]

A battery can be simply modeled as a perfect voltage source (i.e. one with zero internal resistance) in series with a resistor. The voltage source depends mainly on the chemistry of the battery, not on whether it is empty or full. When a battery runs down, its internal resistance increases. When the battery is connected to a load (e.g. a light bulb), which has its own resistance, the resulting voltage across the load depends on the ratio of the battery's internal resistance to the resistance of the load. When the battery is fresh, its internal resistance is low, so the voltage across the load is almost equal to that of the battery's internal voltage source. As the battery runs down and its internal resistance increases, the voltage drop across its internal resistance increases, so the voltage at its terminals decreases, and the battery's ability to deliver power to the load decreases. [9]

# Chapter Five

## Control circuits

### 5.1 Introduction

There are many control circuits can be used in all the part of this project. Each circuit used in this project shown in next sections with details.

### 5.2 Solar tracking system circuit

This circuit contains many electronic components (as shown in Fig 5.1) such as:

- Light dependent resistor (LDR).

R1, R2

- Operational Amplifier (op-amp 741)

U1, U2

- NPN Transistors (BD243) Q1, Q3
- PNP Transistors (BD244) Q2, Q4
- Resistors (R3, R4, P1, P2).
- Diodes (D1, D2, D3, D4).
- H-Bridge.

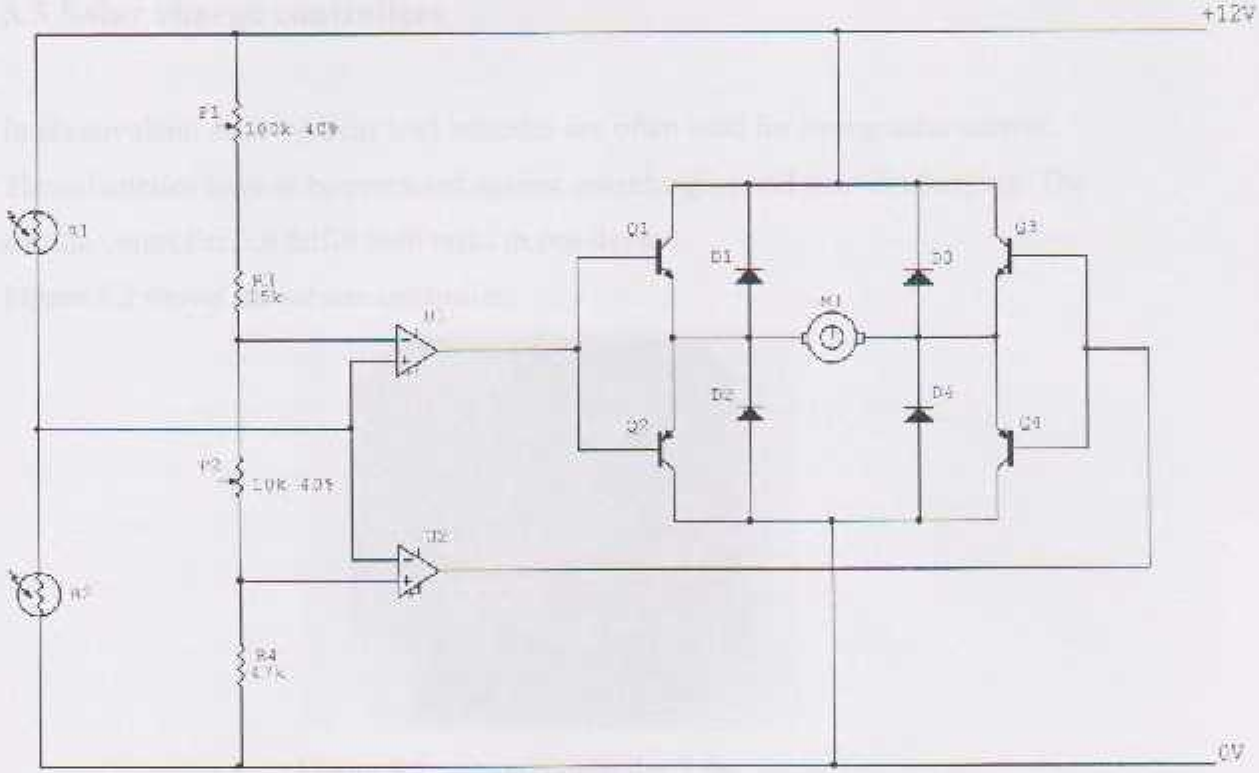


Figure 5.1: solar tracking system

The DC motor connected to the solar cell in order to rotate it to the largest intensity of light.

When there is the same illumination light on the two LDRs then the output voltage from the two comparators is the same, so that the motor stay without rotations.

But when the sun moves, then the illumination light will be different on the two LDRs, so that the output voltage of the comparators will change causing the motor to rotate clock-wise or counter clock-wise.

P1, P2 used to control the sensitivity in order to make the motor without rotation when the illumination lights the same on R1 and R2.

If there is an illumination light on R1 more than R2, then the output voltage on U1 will rise and Q1-Q4 will work causing the motor to rotate.

And if there is an illumination light on R2 more than R1, then the output voltage on U2 will rise and Q2-Q3 will work causing the motor to rotate in the other direction.

## 5.3 Solar charge controllers

In photovoltaic solar systems lead batteries are often used for strong solar current. These batteries have to be protected against overcharging and over discharging. The solsum controller 5.0 fulfill both tasks in one device.

Figure 5.2 shows the solsum controller.

Figure 5.2: solsum controller 5.0x

### 5.3.1 Overcharge protection

When the battery exceeds the final charge voltage, it starts to gas. As this process is temperature dependent, the final charge voltage is adapted automatically to the ambient temperature by a built-in sensor. Strong gassing leads to an electrolyte loss and finally to the destruction of the battery. The battery is however not charged completely when the final charge voltage is reached, so that the current flow should not be interrupted. The charge controller therefore reduces the current flow into the battery just as much as that the final charge voltage is not exceeded. This procedure is called "IU-charging" which is considered to be especially fast and gentle. The reduction of current flow is effected by very quick, temporary short-circuiting (pulse width modulation) of the solar generator.

### 5.3.2 Over discharge protection

The batteries have to be protected from over discharge, as it would be destroyed otherwise. Therefore the charge controller protects the battery from over discharge by disconnecting the loads when the voltage falls below the final charge voltage. After the battery has been recharged by the solar generator and the reconnection voltage is reached, the users are again reconnection.
Wear-resistant MOSFET transistors are used for the over discharge protection in this charge controllers.

### 5.3.3 Displays

The controller contains a green and a LED which can change its color from red via yellow to green in ten different colors. The green LED is on as soon as there is energy from the module. When the controller starts to limit the charge current, this LED is flashing. The LED which can change its color shows the voltage by its color. Before the load is switched off, this LED starts to flash fast. When the load is switched off, this LED flashes slowly.

### 5.3.4 Sources of errors

1. Inversion of battery polarity: the fuse blows, it has to be replaced by the same type.
2. Inversion of module polarity: this is to be avoided.
3. Inversion of the polarity of the load: the users (lights, radio etc.) can be damaged before the fuse blows. A huge energy quantity is stored in the

battery. In the case of a short circuit, this energy can be set free within a short time and a fire at the place of the short circuit can be caused because of heat.

### 5.3.5 Safety Features

- Over voltage protection by integrated varistor.
- Wrong polarity protection at Battery and Module.
- Built-in fuse.
- Electronically short circuit protected.
- Voltage-display by changing color

| | |
|---|---|
| red | 11,8 V |
| yellow to red-yellow | 12,3 V |
| green | 12,8 V |

### 5.3.6 Charging Functions

- Shunt regulator - fast and gentle charging.
- Time-delayed over discharge protection.
- Temperature compensation by built-in sensor.
- Automatic voltage adaptation.
- Schottky diode.
- MOSFET switch.
- LED- display of charging function.

Table 5.1 shows the technical specifications of the charger controller ( solsum 5.0) which used in this project.

Table 5.1: technical specifications for the solsum charger controller

| Technical Specifications | Solsum 5.0* |
|---|---|
| **Max. Charge Current at 50° C** | 5 A |
| **Load Current at 50° C** | - |
| **Connection Terminal (fine/single wire)** | 2,5 mm ² |
| **Weight** | 108 g |
| **Protection** | IP 22 |
| **Dimensions** | 85x98x34 mm |
| **Ambient Temperature** | -25° C bis 50° C |
| **System Voltage** | 12/24 V |

For 24 V Systems voltages are to be doubled!* No load disconnection. Only fused with 6,3A

The circuit here contains many electronic components that charge a battery (as shown in Fig 5.3) such as:

- Integrated circuit **atonic** ( programmed IC)
- Resistors
- Battery
- Solar cell
- Bulb ( as a load)
- MOSFET switches (T1 and T2)

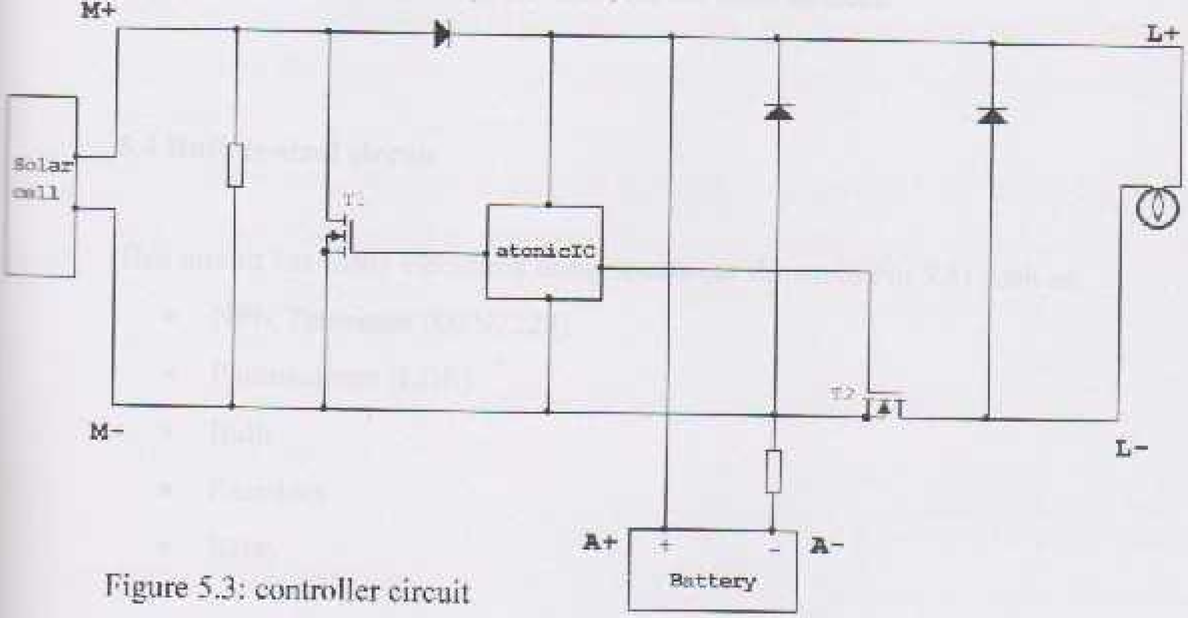


Figure 5.3: controller circuit

The solar cell give an output voltage, this voltage enter to the controller to charge the battery with a constant voltage and to turn on the bulb. The controller here protect the battery from over discharging by using a Wear-resistant MOSFET transistors, also protect the battery from over charging by using a pulse-width-modulated shunt controller which guarantees quick and gentle charging of the battery.

For installation the controller see figure 5.4

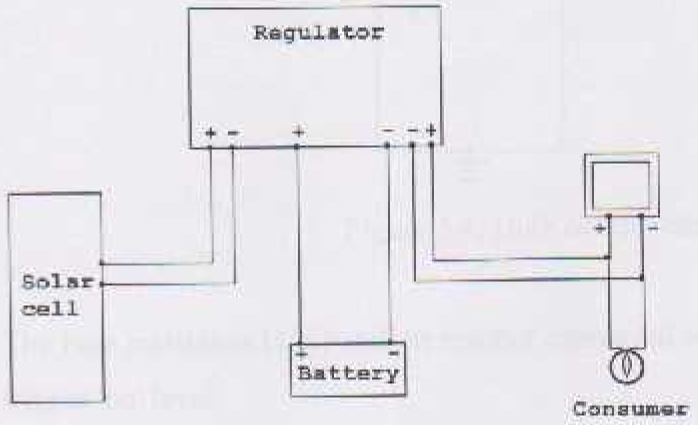


Figure 5.4: connection of the solsum with the other devices.

## 5.4 Bulb control circuit

This circuit has many electronic components (as shown in Fig 5.5) such as:

- NPN Transistor (Q2N2222)
- Photoresistor (LDR)
- Bulb
- Resistors
- Relay

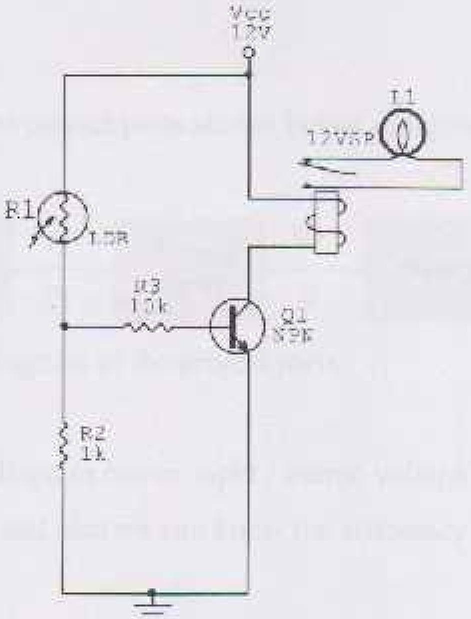


Figure 5.4: Bulb control circuit

The base resistance (10k) and the resistor connected with the ground adjust the trigger 'on' level.

When there is illumination light on the LDR, its resistance will be small, so that the base voltage will be enough to turn the transistor 'on', according to that the collector current will change the state of relay from normally close to open, now the bulb become 'off'.

When there is no illumination light on the LDR, its resistance will become big, so that the base voltage will be not enough (small), therefore the transistor will turn off and the collector current will be small, so that the relay back to normally close state, thus make the light 'on'.

Voltage divider rule:

$$V_{base} = \frac{Vcc^{*}\,R\,(LDR)}{R\,(LDR) + (R3//R2)}$$

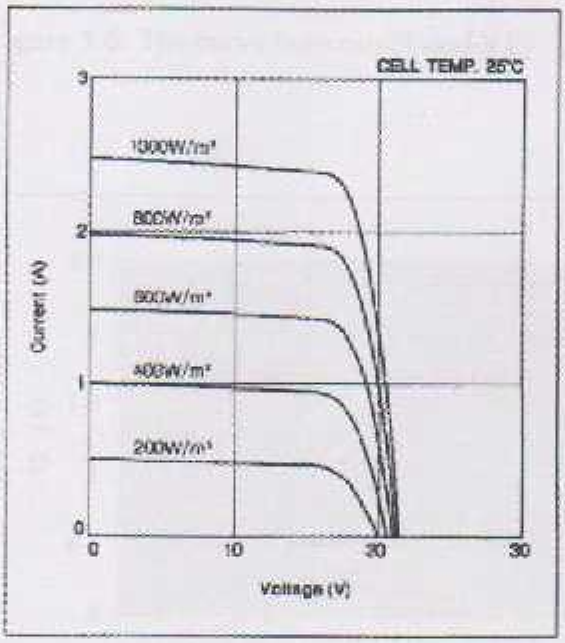
## 5.5 Simulation

The block diagram of the project parts shown below in figure 5.5:

Figure 5.5: block diagram of the project parts

Each part of this block diagram has an input / output voltage and current, so the power can be measured and also we can know the efficiency of each part.

The first of all is the solar cell, so according to the following characteristic curve we can get the current (I1), voltage (V1), power (P1) and efficiency.



According to practical simulation, we get the following simulation characteristics:

- When there is an irradiance equal 1000w/m$^2$ on the solar cells:

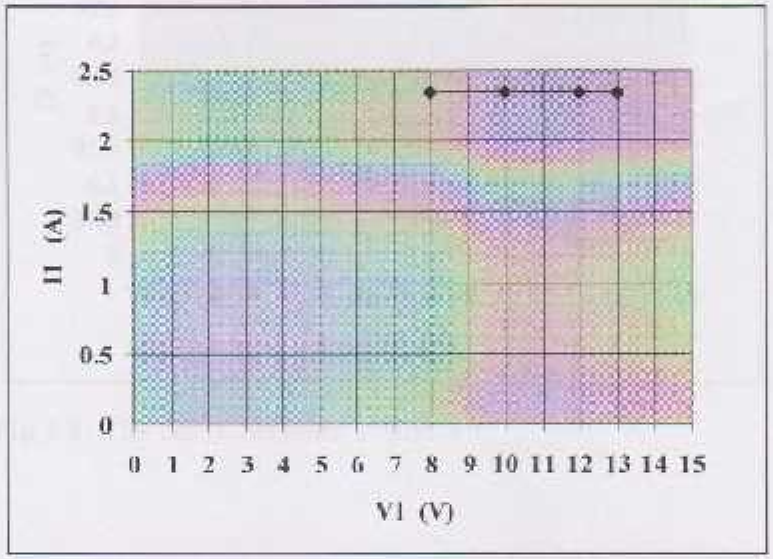


Figure 5.6: The curve between I1 and V1

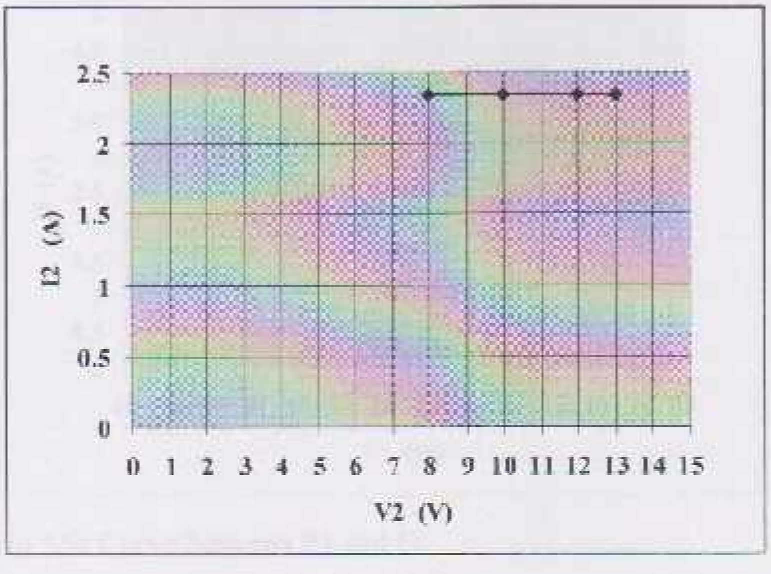


Fig 5.7: The curve between I2 and V2

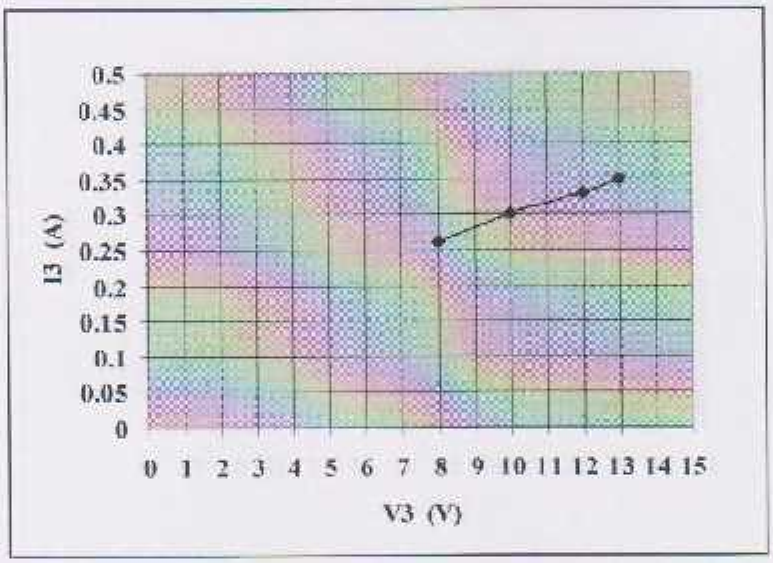


Fig 5.8: The curve between I3 and V3

From these curves, power curves can be obtained as shown below:

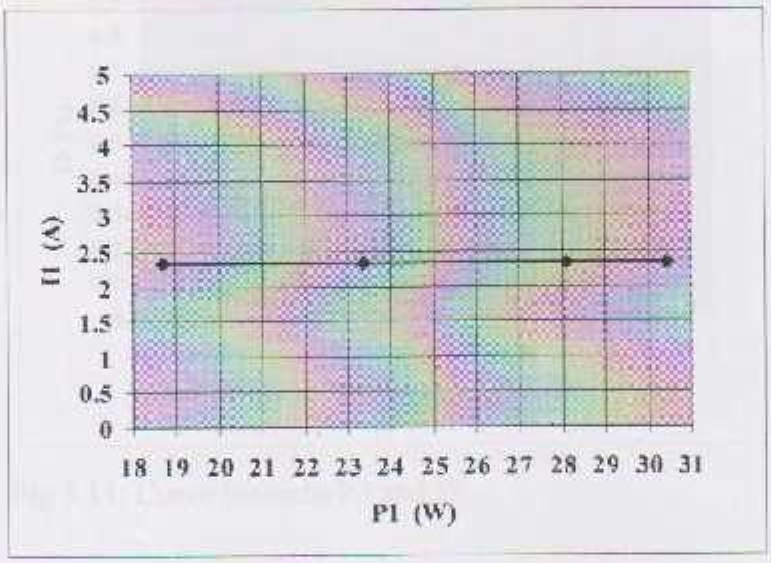


Fig 5.9: Curve between P1 and I1

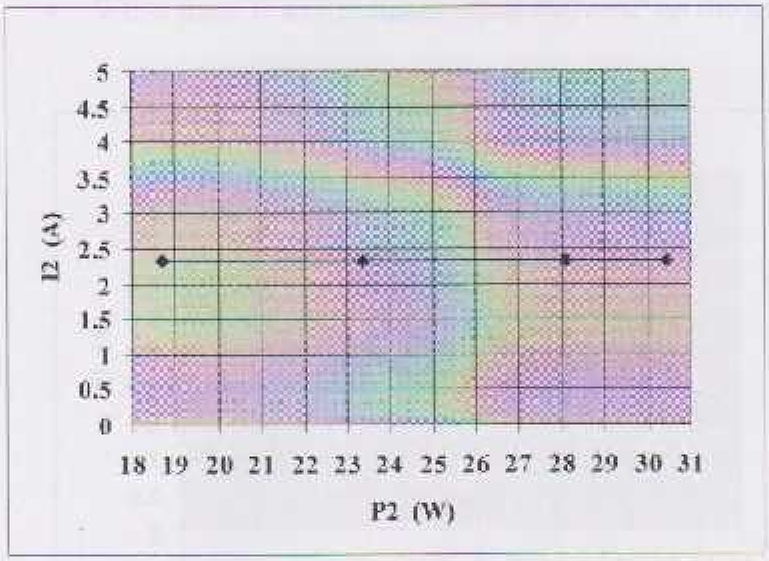


Fig 5.10: Curve between P2 and I2

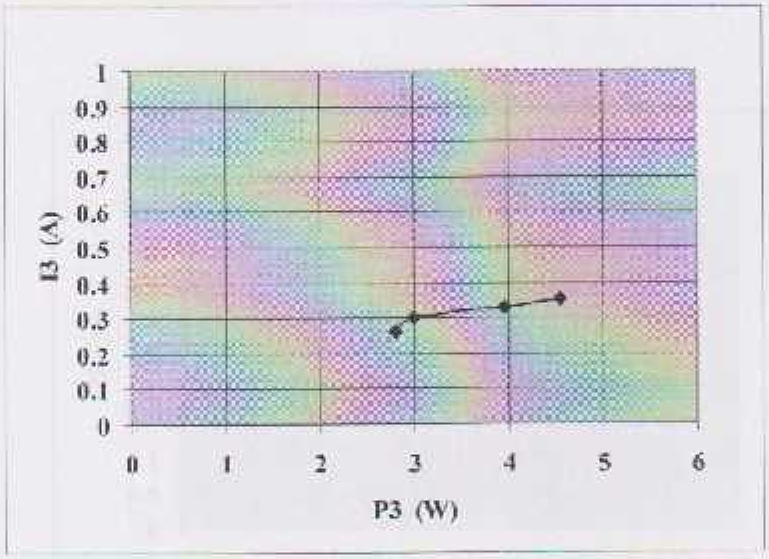


Fig 5.11: Curve between P3 and I3

- When there is an irradiance equal 800w/m$^2$ on the solar cells:

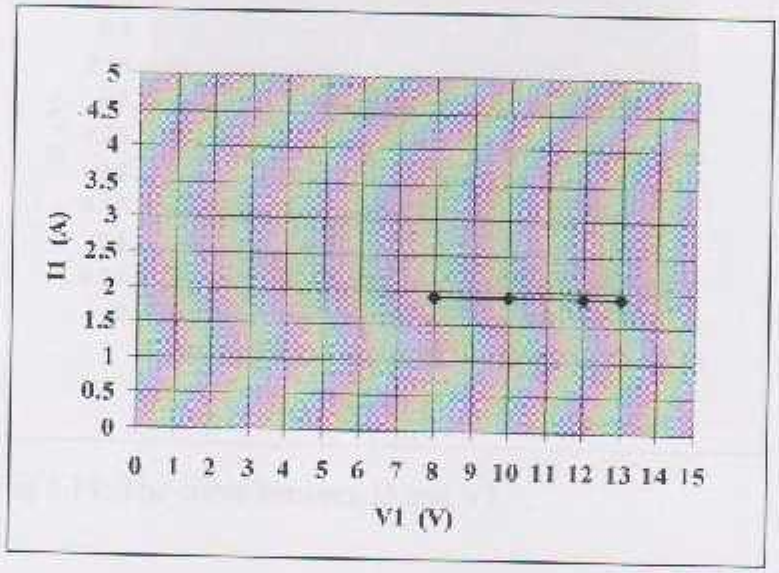


Fig 5.12: The curve between I1 and V1

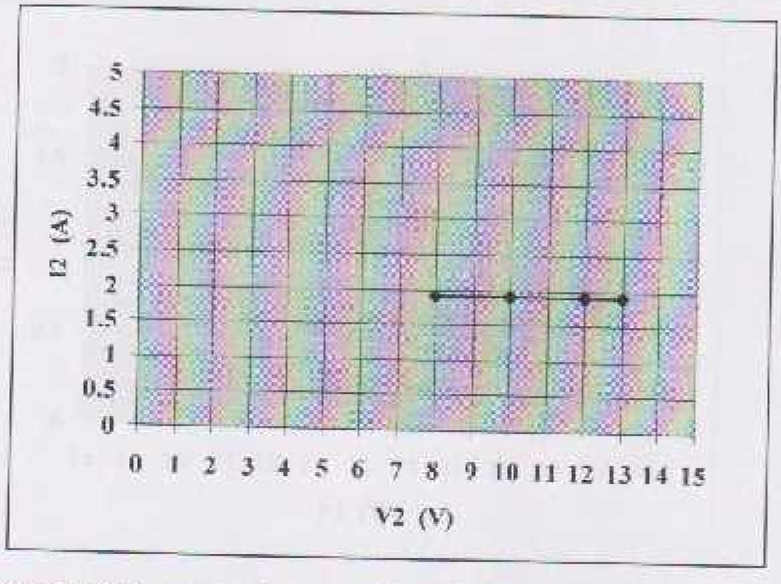


Fig 5.13: The curve between I2 and V2

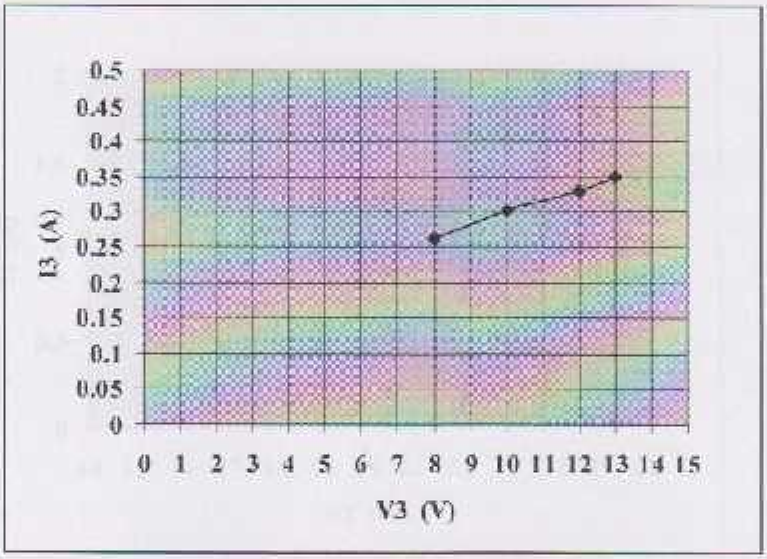


Fig 5.14: The curve between I3 and V3

From these curves, power curves can be obtained as shown below:

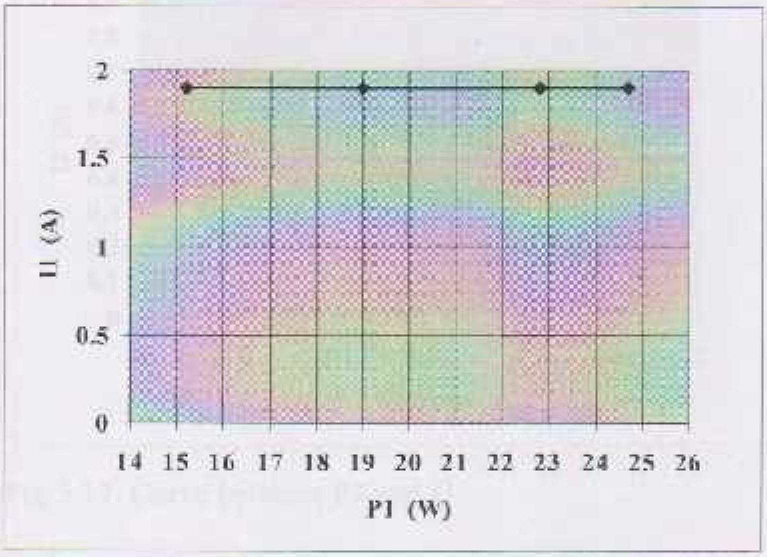


Fig 5.15: Curve between P1 and I1

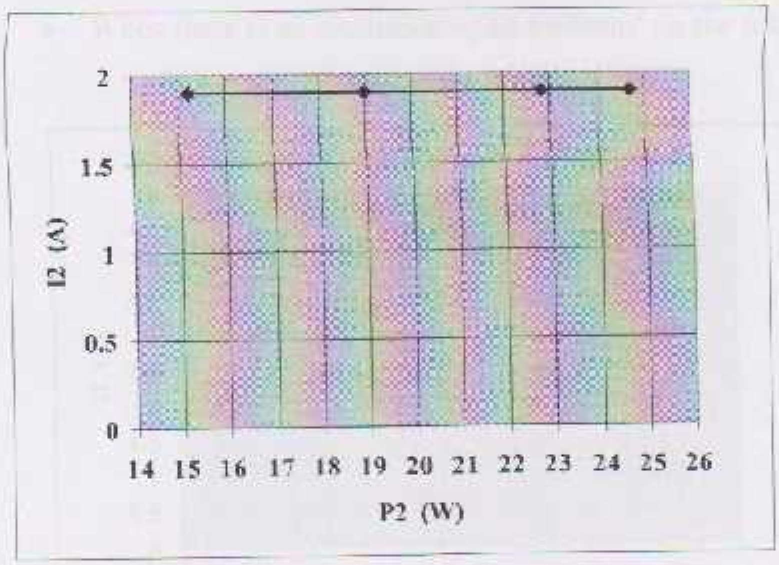


Fig 5.16: Curve between P2 and I2

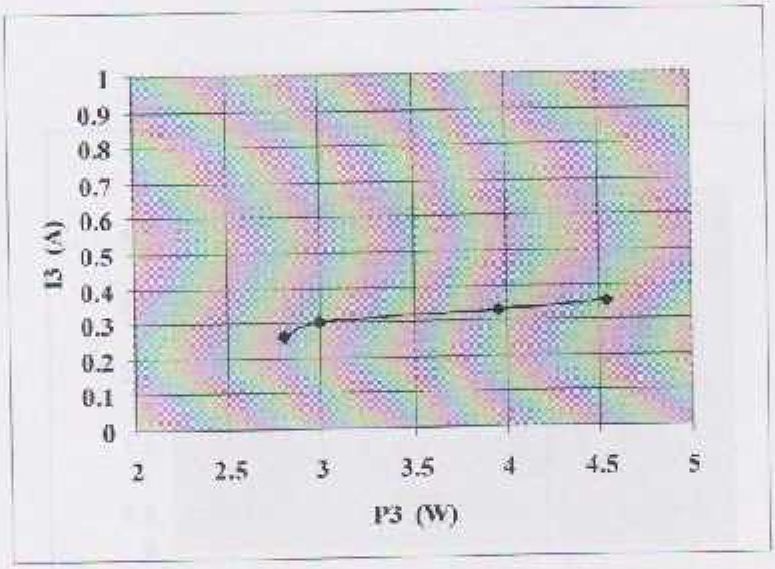


Fig 5.17: Curve between P3 and I3

- When there is an irradiance equal $600 w/m^2$ on the solar cells:

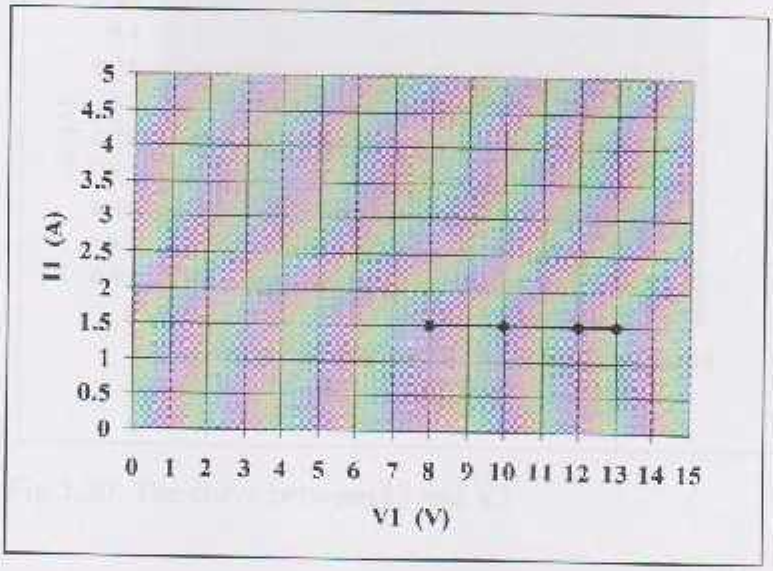


Fig 5.18: The curve between I1 and V1

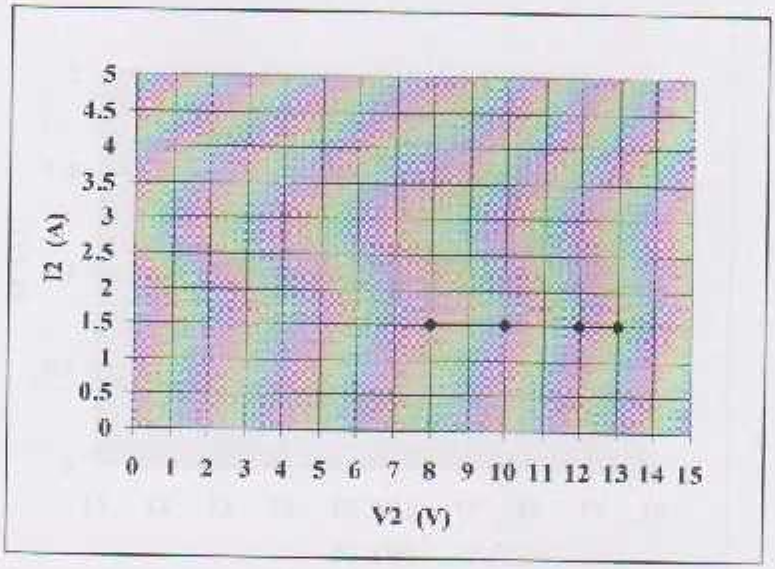


Fig 5.19: The curve between I2 and V2

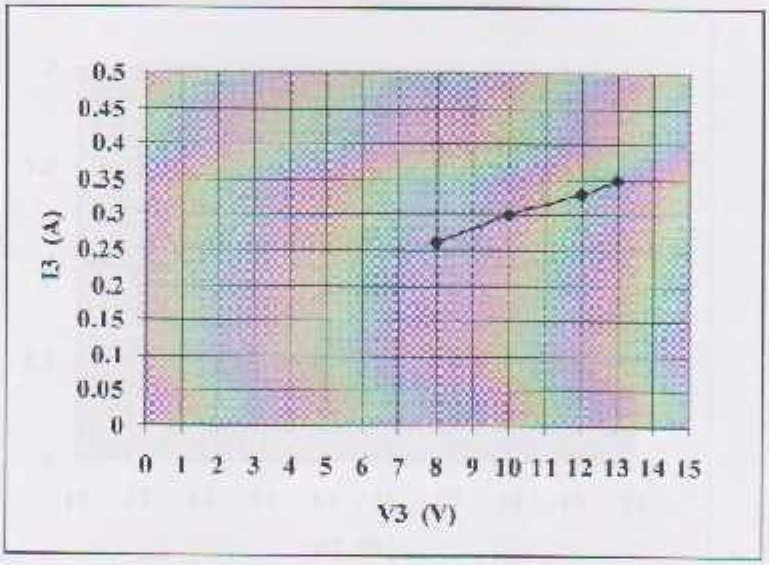


Fig 5.20: The curve between I3 and V3

From these curves, power curves can be obtained as shown below:

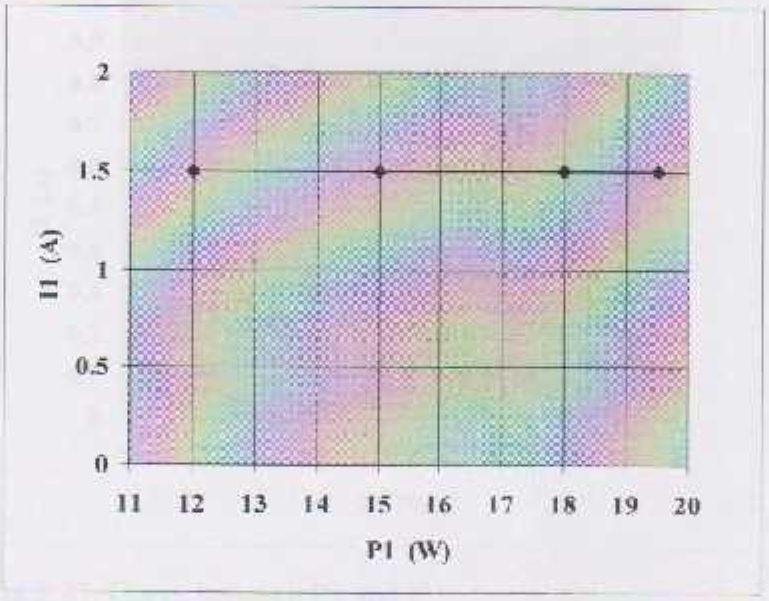


Fig 5.21: Curve between P1 and I1

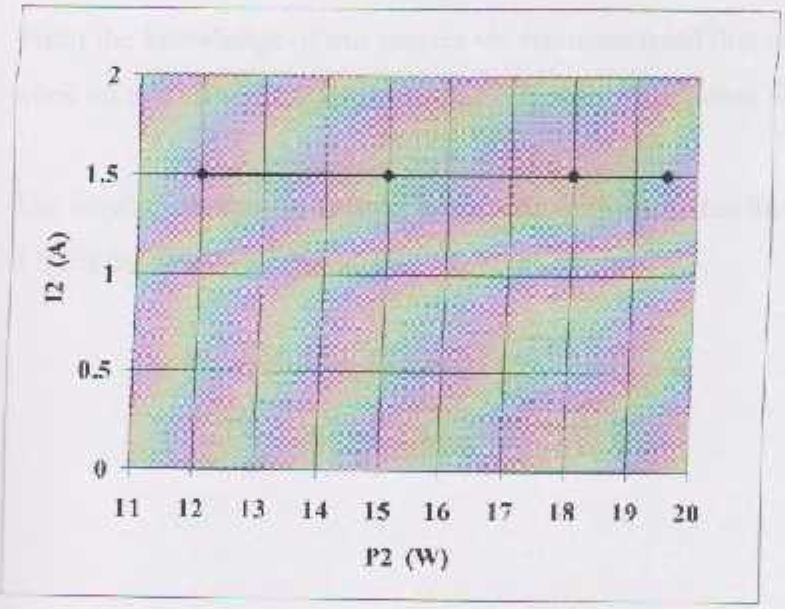


Fig 5.22: Curve between P2 and I2

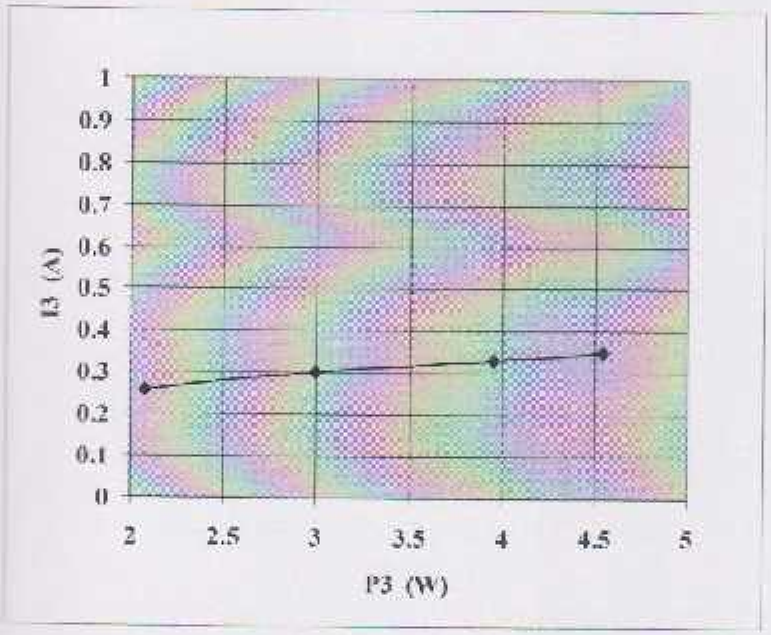


Fig 5.23: Curve between P3 and I3

## 5.6 Recommendations

From the knowledge of our project we recommended that any other team want to work on this idea to try to get a solar cell with more better features like the power.

The irradiance must be known, so we recommended that the other team must know it from the weather department.

## References

1. Research submitted by Brother: Osama Ibrahim Alzalok
   Nasser weapons University Department of Mechanical Engineering

2. http://www.solarbotics.net/starting/200202_solar_cells/200202_solar_cells.html /2006

3. http://www.solarbotics.net/starting/200202_solar_cells/200202_solar_cell_physics.html /2006

4. http://www.solarbotics.net/starting/200202_solar_cells/200202_solar_cell_types.html /2006

5. http://www.solarbotics.net/starting/200202_solar_cells/200202_solar_cell_use.html /2006

6. lap

7. http://library.thinkquest.org/26776/ldr.htm /2006

8. project

9. http://en.wikipedia.org/wiki/Battery_(electricity)#Battery_concepts / 2006

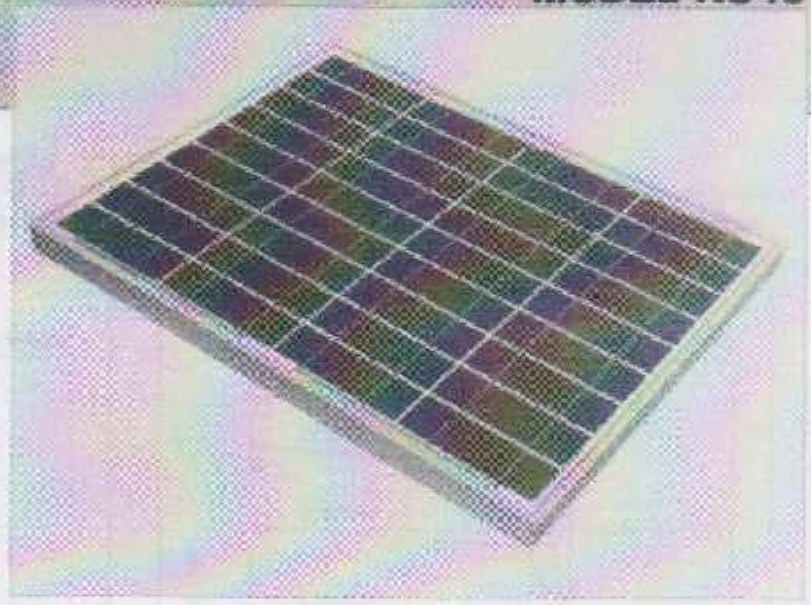
10. Tom Markvart and Luis Castañer, Practical Handbook of Photovoltaics: Fundamentals and Applications.

# Appendix

# Datasheets

**KYOCERA**

**MODEL KC40**



# KC40

## HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

TYPICAL OUTPUT 40 Wp

## HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES

Kyocera's advanced cell processing technology and automated production facilities have produced a highly efficient multicrystal photovoltaic modules.
The conversion efficiency of the Kyocera solar cell is over 14%.
These cells are encapsulated between a tempered glass cover and an EVA pottant with PVF back sheet to provide maximum protection from the severest environmental conditions.
The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.

## APPLICATIONS

- Microwave/Radio repeater stations
- Electrification of villages in remote areas
- Medical facilities in rural areas
- Power source for summer vacation homes
- Emergency communication systems
- Water quality and environmental data monitoring systems
- Navigation lighthouses, and ocean buoys
- Pumping systems for irrigation, rural water supplies and livestock watering
- Aviation obstruction lights
- Cathodic protection systems
- Desalination systems
- Recreational vehicles
- Railroad signals
- Sailboat charging systems

## SPECIFICATIONS

### Electrical Specifications

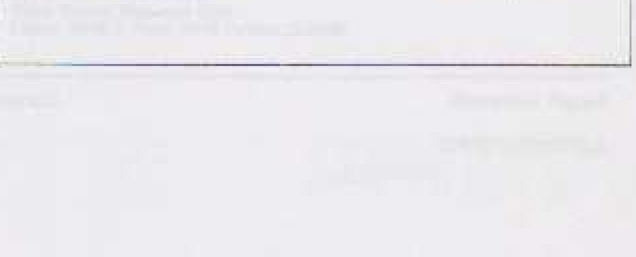
| MODEL | KC40 |
|---|---|
| Maximum Power | 40 Watts |
| Maximum Power Voltage | 16.9 Volts |
| Maximum Power Current | 2.34 Amps |
| Open Circuit Voltage | 21.5 Volts |
| Short-Circuit Current | 2.48 Amps |
| Length | 526mm (20.7in.) |
| Width | 652mm (25.7in.) |
| Depth | 52mm (2.0in.) |
| Weight | 6.0kg (13.2lbs.) |

Note: The electrical specifications are under test conditions of irradiance of 1kW/m², Spectrum of 1.5 air mass and cell temperature of 25°C

Kyocera reserves the right to modify these specifications without notice.

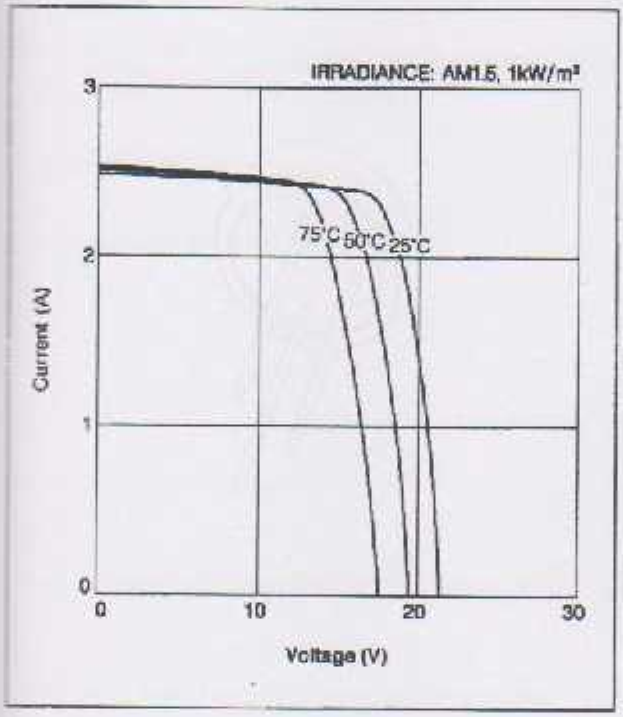
### Physical Specifications

(Unit: mm)

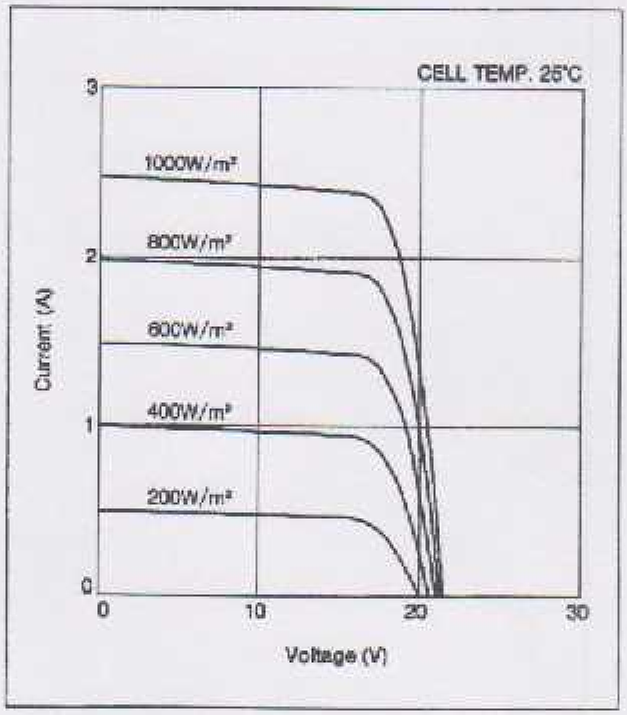


## ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics of Photovoltaic Module KC40 at various cell temperatures



Current-Voltage characteristics of Photovoltaic Module KC40 at various irradiance levels



## QUALITY ASSURANCE

Kyocera multicrystal photovoltaic modules exceed government specifications for the following tests.

- Thermal cycling test
- Thermal shock test
- Thermal/Freezing and high humidity cycling test
- Electrical isolation test
- Hail impact test
- Mechanical, wind and twist loading test
- Salt mist test
- Light and water-exposure test
- Field exposure test

Please contact our office to obtain details without hesitation.

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CAT5T9604YS(J)

**DISCRETE SEMICONDUCTORS**

# DATA SHEET

# 2N2222; 2N2222A
## NPN switching transistors

Product specification
Supersedes data of September 1994
File under Discrete Semiconductors, SC04

1997 May 29

**Philips**
**Semiconductors**

**PHILIPS**

## FEATURES

- High current (max. 800 mA)
- Low voltage (max. 40 V).

## APPLICATIONS

- Linear amplification and switching.

## DESCRIPTION

NPN switching transistor in a TO-18 metal package.
PNP complement: 2N2907A.

## PINNING

| PIN | DESCRIPTION |
|---|---|
| 1 | emitter |
| 2 | base |
| 3 | collector, connected to case |

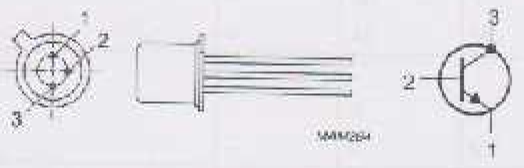


Fig.1 Simplified outline (TO-18) and symbol.

## QUICK REFERENCE DATA

| SYMBOL | PARAMETER | CONDITIONS | MIN. | MAX. | UNIT |
|---|---|---|---|---|---|
| $V_{CBO}$ | collector-base voltage | open emitter | | | |
| | 2N2222 | | – | 60 | V |
| | 2N2222A | | – | 75 | V |
| $V_{CEO}$ | collector-emitter voltage | open base | | | |
| | 2N2222 | | – | 30 | V |
| | 2N2222A | | – | 40 | V |
| $I_C$ | collector current (DC) | | – | 800 | mA |
| $P_{tot}$ | total power dissipation | $T_{amb} \leq 25$ °C | – | 500 | mW |
| $h_{FE}$ | DC current gain | $I_C = 10$ mA; $V_{CE} = 10$ V | 75 | – | |
| $f_T$ | transition frequency | $I_C = 20$ mA; $V_{CE} = 20$ V; f = 100 MHz | | | |
| | 2N2222 | | 250 | – | MHz |
| | 2N2222A | | 300 | – | MHz |
| $t_{off}$ | turn-off time | $I_{Con} = 150$ mA; $I_{Bon} = 15$ mA; $I_{Boff} = -15$ mA | – | 250 | ns |

## LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

| SYMBOL | PARAMETER | CONDITIONS | MIN. | MAX. | UNIT |
|---|---|---|---|---|---|
| $V_{CBO}$ | collector-base voltage | open emitter | | | |
| | 2N2222 | | – | 60 | V |
| | 2N2222A | | – | 75 | V |
| $V_{CEO}$ | collector-emitter voltage | open base | | | |
| | 2N2222 | | – | 30 | V |
| | 2N2222A | | – | 40 | V |
| $V_{EBO}$ | emitter-base voltage | open collector | | | |
| | 2N2222 | | – | 5 | V |
| | 2N2222A | | – | 6 | V |
| $I_C$ | collector current (DC) | | – | 800 | mA |
| $I_{CM}$ | peak collector current | | – | 800 | mA |
| $I_{BM}$ | peak base current | | – | 200 | mA |
| $P_{tot}$ | total power dissipation | $T_{amb} \leq 25$ °C | – | 500 | mW |
| | | $T_{case} \leq 25$ °C | – | 1.2 | W |
| $T_{stg}$ | storage temperature | | −65 | +150 | °C |
| $T_j$ | junction temperature | | – | 200 | °C |
| $T_{amb}$ | operating ambient temperature | | −65 | +150 | °C |

## THERMAL CHARACTERISTICS

| SYMBOL | PARAMETER | CONDITIONS | VALUE | UNIT |
|---|---|---|---|---|
| $R_{th\ j\text{-}a}$ | thermal resistance from junction to ambient | in free air | 350 | K/W |
| $R_{th\ j\text{-}c}$ | thermal resistance from junction to case | | 146 | K/W |

## CHARACTERISTICS

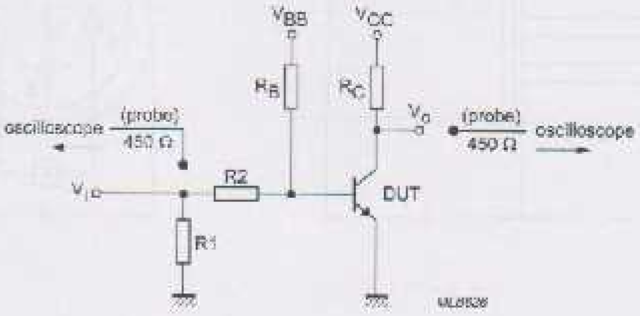
$T_j = 25$ °C unless otherwise specified.

| SYMBOL | PARAMETER | CONDITIONS | MIN. | MAX. | UNIT |
|---|---|---|---|---|---|
| $I_{CBO}$ | collector cut-off current<br>2N2222 | $I_E = 0$; $V_{CB} = 50$ V | – | 10 | nA |
| | | $I_E = 0$; $V_{CB} = 50$ V; $T_{amb} = 150$ °C | – | 10 | µA |
| $I_{CBO}$ | collector cut-off current<br>2N2222A | $I_E = 0$; $V_{CB} = 60$ V | – | 10 | nA |
| | | $I_E = 0$; $V_{CB} = 60$ V; $T_{amb} = 150$ °C | – | 10 | µA |
| $I_{EBO}$ | emitter cut-off current | $I_C = 0$; $V_{EB} = 3$ V | – | 10 | nA |
| $h_{FE}$ | DC current gain | $I_C = 0.1$ mA; $V_{CE} = 10$ V | 35 | – | |
| | | $I_C = 1$ mA; $V_{CE} = 10$ V | 50 | – | |
| | | $I_C = 10$ mA; $V_{CE} = 10$ V | 75 | – | |
| | | $I_C = 150$ mA; $V_{CE} = 1$ V; note 1 | 50 | – | |
| | | $I_C = 150$ mA; $V_{CE} = 10$ V; note 1 | 100 | 300 | |
| $h_{FE}$ | DC current gain<br>2N2222A | $I_C = 10$ mA; $V_{CE} = 10$ V; $T_{amb} = -55$ °C | 35 | – | |
| $h_{FE}$ | DC current gain<br>2N2222<br>2N2222A | $I_C = 500$ mA; $V_{CE} = 10$ V; note 1 | 30<br>40 | –<br>– | |
| $V_{CEsat}$ | collector-emitter saturation voltage<br>2N2222 | $I_C = 150$ mA; $I_B = 15$ mA; note 1 | – | 400 | mV |
| | | $I_C = 500$ mA; $I_B = 50$ mA; note 1 | – | 1.6 | V |
| $V_{CEsat}$ | collector-emitter saturation voltage<br>2N2222A | $I_C = 150$ mA; $I_B = 15$ mA; note 1 | – | 300 | mV |
| | | $I_C = 500$ mA; $I_B = 50$ mA; note 1 | – | 1 | V |
| $V_{BEsat}$ | base-emitter saturation voltage<br>2N2222 | $I_C = 150$ mA; $I_B = 15$ mA; note 1 | – | 1.3 | V |
| | | $I_C = 500$ mA; $I_B = 50$ mA; note 1 | – | 2.6 | V |
| $V_{BEsat}$ | base-emitter saturation voltage<br>2N2222A | $I_C = 150$ mA; $I_B = 15$ mA; note 1 | 0.6 | 1.2 | V |
| | | $I_C = 500$ mA; $I_B = 50$ mA; note 1 | – | 2 | V |
| $C_c$ | collector capacitance | $I_E = i_e = 0$; $V_{CB} = 10$ V; f = 1 MHz | – | 8 | pF |
| $C_e$ | emitter capacitance<br>2N2222A | $I_C = i_c = 0$; $V_{EB} = 500$ mV; f = 1 MHz | – | 25 | pF |
| $f_T$ | transition frequency<br>2N2222<br>2N2222A | $I_C = 20$ mA; $V_{CE} = 20$ V; f = 100 MHz | 250<br>300 | –<br>– | MHz<br>MHz |
| F | noise figure<br>2N2222A | $I_C = 200$ µA; $V_{CE} = 5$ V; $R_S = 2$ kΩ;<br>f = 1 kHz; B = 200 Hz | – | 4 | dB |

| SYMBOL | PARAMETER | CONDITIONS | MIN. | MAX. | UNIT |
|---|---|---|---|---|---|
| **Switching times (between 10% and 90% levels)**; see Fig.2 | | | | | |
| $t_{on}$ | turn-on time | $I_{Con}$ = 150 mA; $I_{Bon}$ = 15 mA; $I_{Boff}$ = −15 mA | – | 35 | ns |
| $t_d$ | delay time | | – | 10 | ns |
| $t_r$ | rise time | | – | 25 | ns |
| $t_{off}$ | turn-off time | | – | 250 | ns |
| $t_s$ | storage time | | – | 200 | ns |
| $t_f$ | fall time | | – | 60 | ns |

**Note**

1. Pulse test: $t_p \leq 300$ μs; $\delta \leq 0.02$.

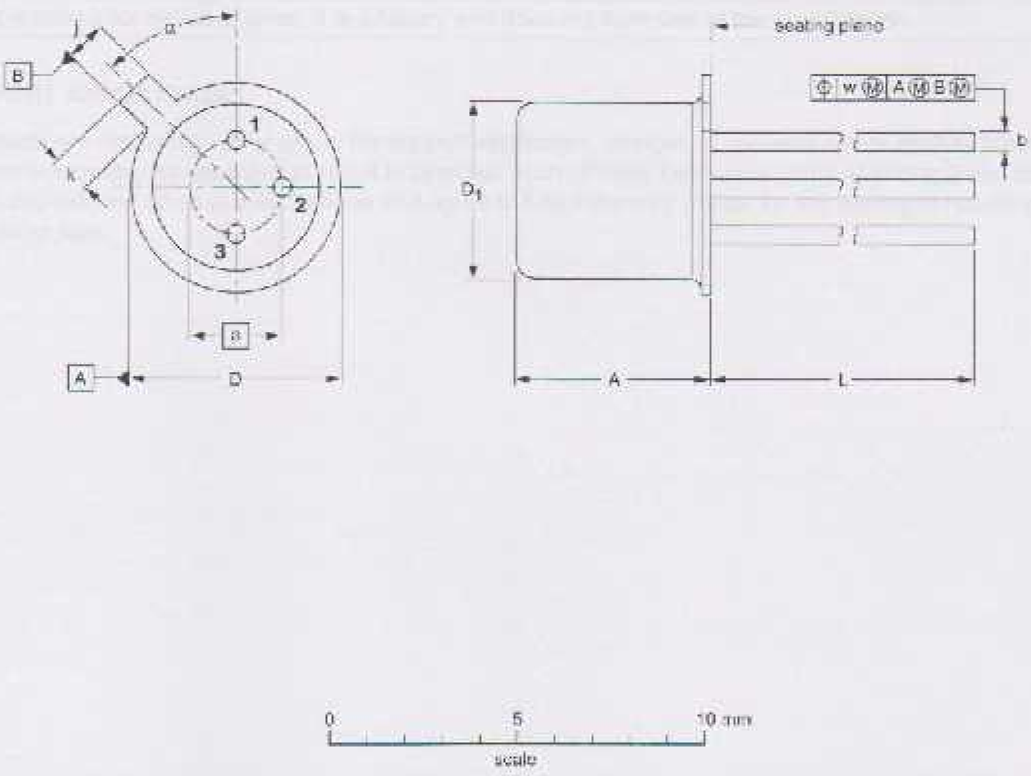


$V_i$ = 9.5 V; T = 500 μs; $t_p$ = 10 μs; $t_r = t_f \leq 3$ ns.
R1 = 68 Ω; R2 = 325 Ω; $R_B$ = 325 Ω; $R_C$ = 160 Ω.
$V_{BB}$ = −3.5 V; $V_{CC}$ = 29.5 V.
Oscilloscope input impedance $Z_i$ = 50 Ω.

Fig.2 Test circuit for switching times.

## PACKAGE OUTLINE

**Metal-can cylindrical single-ended package; 3 leads** **SOT18/13**



DIMENSIONS (millimetre dimensions are derived from the original inch dimensions)

| UNIT | A | a | b | D | $D_1$ | j | k | L | w | α |
|---|---|---|---|---|---|---|---|---|---|---|
| mm | 5.31<br>4.74 | 2.54 | 0.47<br>0.41 | 5.45<br>5.30 | 4.70<br>4.55 | 1.03<br>0.94 | 1.1<br>0.9 | 15.0<br>12.7 | 0.40 | 45° |

| OUTLINE VERSION | REFERENCES | | | | EUROPEAN PROJECTION | ISSUE DATE |
|---|---|---|---|---|---|---|
| | IEC | JEDEC | EIAJ | | | |
| SOT18/13 | B11/C7 type 3 | TO-18 | | | | 97-04-18 |

## DEFINITIONS

| **Data sheet status** | |
|---|---|
| Objective specification | This data sheet contains target or goal specifications for product development. |
| Preliminary specification | This data sheet contains preliminary data; supplementary data may be published later. |
| Product specification | This data sheet contains final product specifications. |
| **Limiting values** | |
| Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability. | |
| **Application information** | |
| Where application information is given, it is advisory and does not form part of the specification. | |

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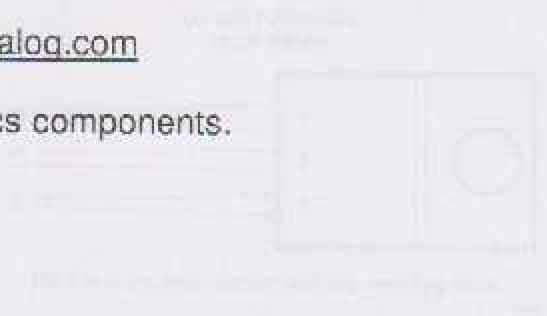
# BD243, BD243A, BD243B, BD243C
# NPN SILICON POWER TRANSISTORS

- Designed for Complementary Use with the BD244 Series
- 65 W at 25°C Case Temperature
- 6 A Continuous Collector Current
- 10 A Peak Collector Current
- Customer-Specified Selections Available



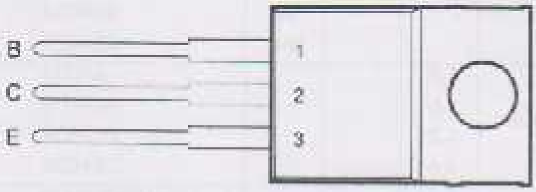
## absolute maximum ratings at 25°C case temperature (unless otherwise noted)

# BD243, BD243A, BD243B, BD243C
# NPN SILICON POWER TRANSISTORS

JUNE 1973 - REVISED MARCH 1997

- **Designed for Complementary Use with the BD244 Series**
- **65 W at 25°C Case Temperature**
- **6 A Continuous Collector Current**
- **10 A Peak Collector Current**
- **Customer-Specified Selections Available**

**TO-220 PACKAGE**
**(TOP VIEW)**



Pin 2 is in electrical contact with the mounting base

MDTRACA

## absolute maximum ratings at 25°C case temperature (unless otherwise noted)

| RATING | | SYMBOL | VALUE | UNIT |
|---|---|---|---|---|
| Collector-emitter voltage ($R_{BE}$ = 100 Ω) | BD243<br>BD243A<br>BD243B<br>BD243C | $V_{CER}$ | 55<br>70<br>90<br>115 | V |
| Collector-emitter voltage ($I_C$ = 30 mA) | BD243<br>BD243A<br>BD243B<br>BD243C | $V_{CEO}$ | 45<br>60<br>80<br>100 | V |
| Emitter-base voltage | | $V_{EBO}$ | 5 | V |
| Continuous collector current | | $I_C$ | 6 | A |
| Peak collector current (see Note 1) | | $I_{CM}$ | 10 | A |
| Continuous base current | | $I_B$ | 3 | A |
| Continuous device dissipation at (or below) 25°C case temperature (see Note 2) | | $P_{tot}$ | 65 | W |
| Continuous device dissipation at (or below) 25°C free air temperature (see Note 3) | | $P_{tot}$ | 2 | W |
| Unclamped inductive load energy (see Note 4) | | $½LI_C^2$ | 62.5 | mJ |
| Operating junction temperature range | | $T_j$ | -65 to +150 | °C |
| Storage temperature range | | $T_{stg}$ | -65 to +150 | °C |
| Lead temperature 3.2 mm from case for 10 seconds | | $T_L$ | 250 | °C |

NOTES:
1. This value applies for $t_p \leq 0.3$ ms, duty cycle ≤ 10%.
2. Derate linearly to 150°C case temperature at the rate of 0.52 W/°C.
3. Derate linearly to 150°C free air temperature at the rate of 16 mW/°C.
4. This rating is based on the capability of the transistor to operate safely in a circuit of: L = 20 mH, $I_{B(on)}$ = 0.4 A, $R_{BE}$ = 100 Ω, $V_{BE(off)}$ = 0, $R_S$ = 0.1 Ω, $V_{CC}$ = 20 V.

## ectrical characteristics at 25°C case temperature

| PARAMETER | | TEST CONDITIONS | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|---|
| $V_{(BR)CEO}$ | Collector-emitter breakdown voltage | $I_C$ = 30 mA<br>(see Note 5) | $I_B$ = 0 | BD243<br>BD243A<br>BD243B<br>BD243C | 45<br>60<br>80<br>100 | | | V |
| $I_{CES}$ | Collector emitter cut-off current | $V_{CE}$ = 55 V<br>$V_{CE}$ = 70 V<br>$V_{CE}$ = 90 V<br>$V_{CE}$ = 115 V | $V_{BE}$ = 0<br>$V_{BE}$ = 0<br>$V_{BE}$ = 0<br>$V_{BE}$ = 0 | BD243<br>BD243A<br>BD243B<br>BD243C | | | 0.4<br>0.4<br>0.4<br>0.4 | mA |
| $I_{CEO}$ | Collector cut-off current | $V_{CE}$ = 30 V<br>$V_{CE}$ = 60 V | $I_B$ = 0<br>$I_B$ = 0 | BD243/243A<br>BD243B/243C | | | 0.7<br>0.7 | mA |
| $I_{EBO}$ | Emitter cut-off current | $V_{EB}$ = 5 V | $I_C$ = 0 | | | | 1 | mA |
| $h_{FE}$ | Forward current transfer ratio | $V_{CE}$ = 4 V<br>$V_{CE}$ = 4 V | $I_C$ = 0.3 A<br>$I_C$ = 3 A | (see Notes 5 and 6) | 30<br>15 | | | |
| $V_{CE(sat)}$ | Collector-emitter saturation voltage | $I_B$ = 1 A | $I_C$ = 6 A | (see Notes 5 and 6) | | | 1.5 | V |
| $V_{BE}$ | Base-emitter voltage | $V_{CE}$ = 4 V | $I_C$ = 6 A | (see Notes 5 and 6) | | | 2 | V |
| $h_{fe}$ | Small signal forward current transfer ratio | $V_{CE}$ = 10 V | $I_C$ = 0.5 A | f = 1 kHz | 20 | | | |
| $\|h_{fe}\|$ | Small signal forward current transfer ratio | $V_{CE}$ = 10 V | $I_C$ = 0.5 A | f = 1 MHz | 3 | | | |

TES: 5. These parameters must be measured using pulse techniques, $t_p$ = 300 µs, duty cycle ≤ 2%.
6. These parameters must be measured using voltage-sensing contacts, separate from the current carrying contacts.

## hermal characteristics

| PARAMETER | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| $R_{θJC}$ | Junction to case thermal resistance | | | 1.92 | °C/W |
| $R_{θJA}$ | Junction to free air thermal resistance | | | 62.5 | °C/W |

## sistive-load-switching characteristics at 25°C case temperature

| PARAMETER | | TEST CONDITIONS † | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|---|
| $t_{on}$ | Turn-on time | $I_C$ = 1 A | $I_{B(on)}$ = 0.1 A | $I_{B(off)}$ = -0.1 A | | 0.3 | | µs |
| $t_{off}$ | Turn-off time | $V_{BE(off)}$ = -3.7 V | $R_L$ = 20 Ω | $t_p$ = 20 µs, dc ≤ 2% | | 1 | | µs |

† Voltage and current values shown are nominal; exact values vary slightly with transistor parameters.

## TYPICAL CHARACTERISTICS

### TYPICAL DC CURRENT GAIN vs COLLECTOR CURRENT

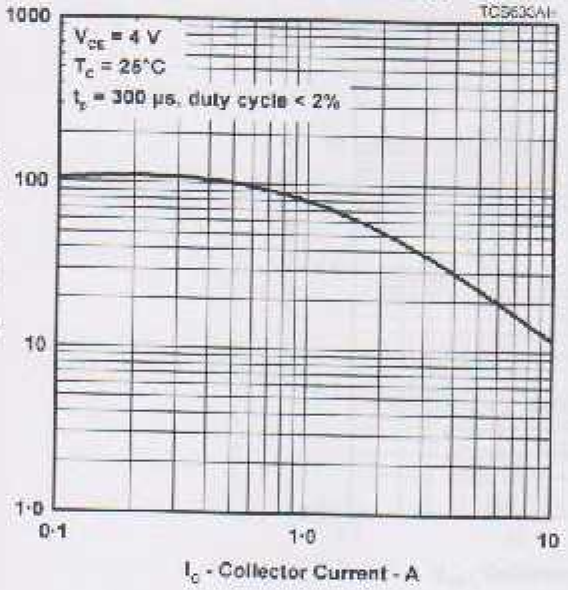


Figure 1.

### COLLECTOR-EMITTER SATURATION VOLTAGE vs BASE CURRENT

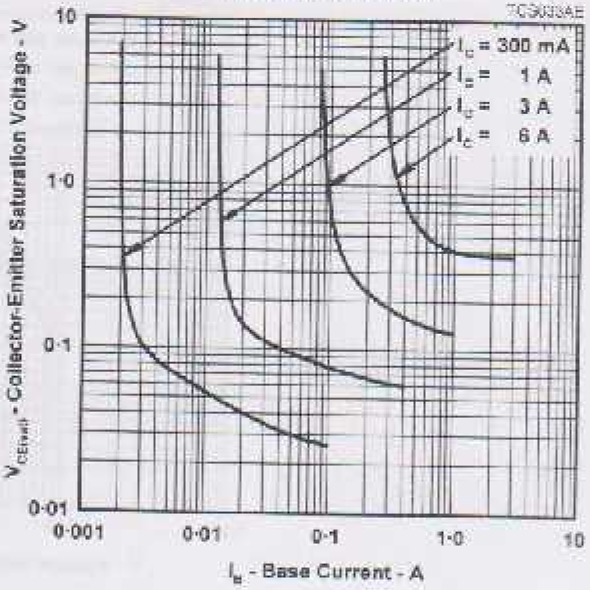


Figure 2.

### BASE-EMITTER VOLTAGE vs COLLECTOR CURRENT

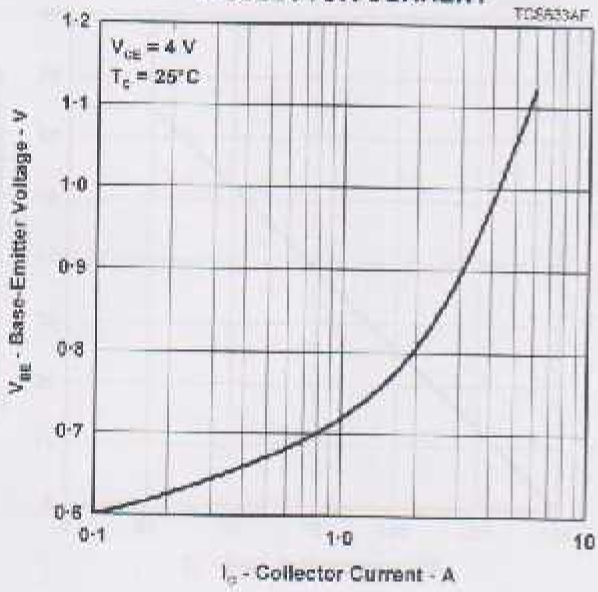


Figure 3.

## MAXIMUM SAFE OPERATING REGIONS

### MAXIMUM FORWARD-BIAS SAFE OPERATING AREA

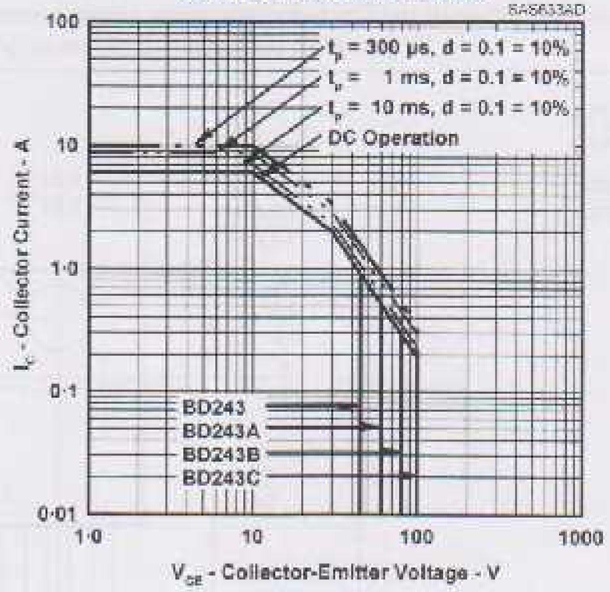


Figure 4.

## THERMAL INFORMATION

### MAXIMUM POWER DISSIPATION vs CASE TEMPERATURE

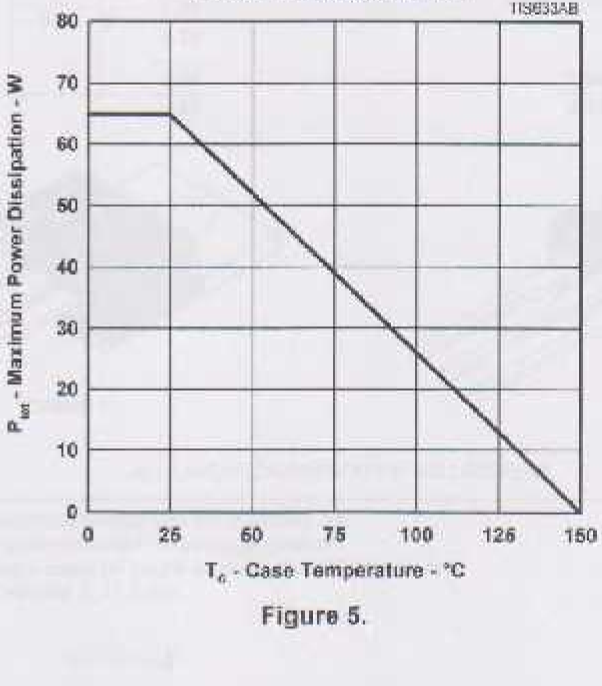
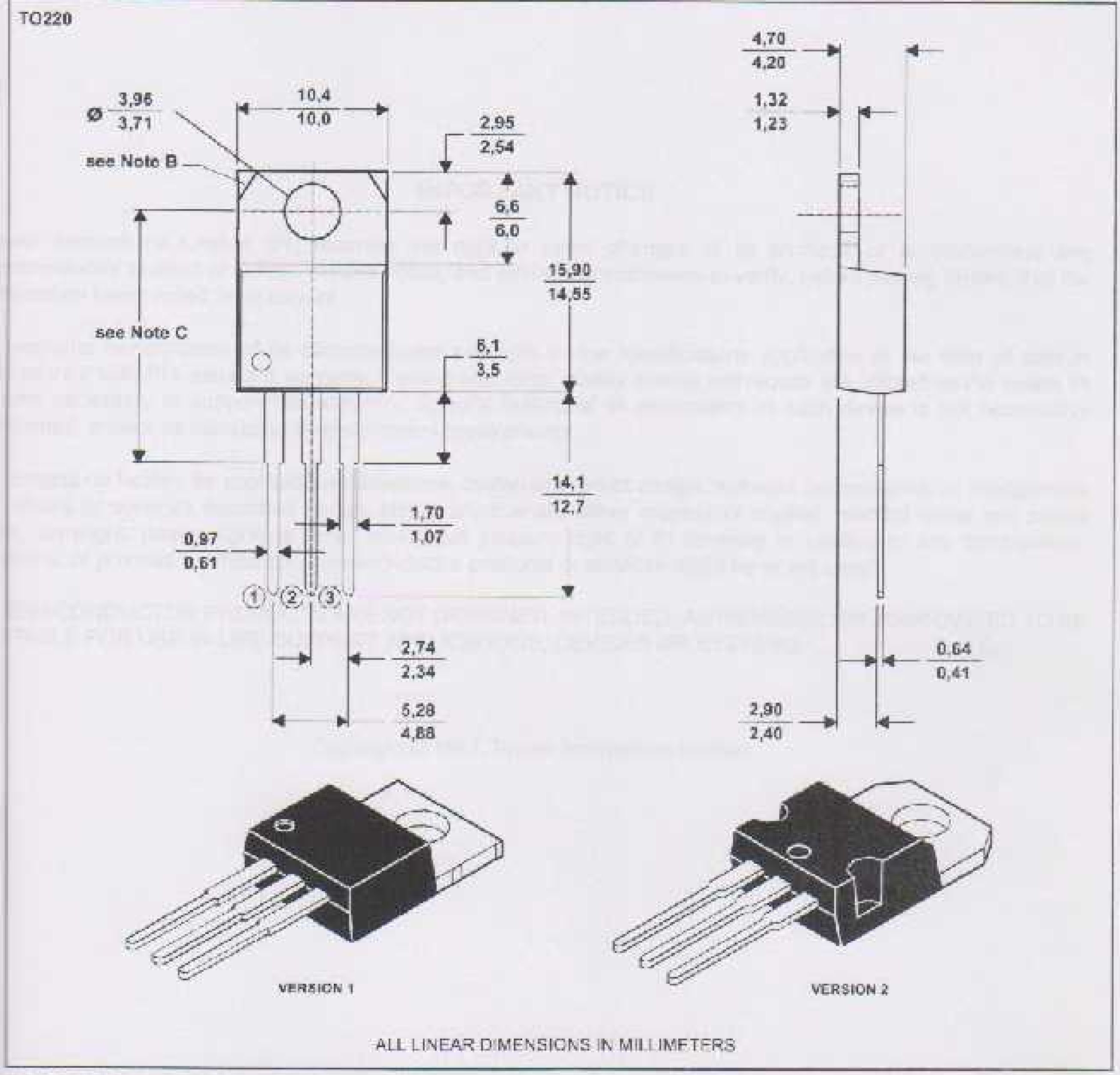


Figure 5.

## MECHANICAL DATA

### TO-220
### 3-pin plastic flange-mount package

This single-in-line package consists of a circuit mounted on a lead frame and encapsulated within a plastic compound. The compound will withstand soldering temperature with no deformation, and circuit performance characteristics will remain stable when operated in high humidity conditions. Leads require no additional cleaning or processing when used in soldered assembly.



ALL LINEAR DIMENSIONS IN MILLIMETERS

NOTES: A. The centre pin is in electrical contact with the mounting tab.
B. Mounting tab corner profile according to package version.
C. Typical fixing hole centre stand off height according to package version.
Version 1, 18.0 mm. Version 2, 17.6 mm.

MDXXBE

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# BD244/A/B/C

## Medium Power Linear and Switching Applications

- Complement to BD243, BD243A, BD243B and BD243C respectively

1.Base 2.Collector 3.Emitter

## PNP Epitaxial Silicon Transistor

### Absolute Maximum Ratings $T_C$=25°C unless otherwise noted

| Symbol | Parameter | Value | Units |
|---|---|---|---|
| $V_{CBO}$ | Collector-Base Voltage<br>: BD244<br>: BD244A<br>: BD244B<br>: BD244C | <br>- 45<br>- 60<br>- 80<br>- 100 | <br>V<br>V<br>V<br>V |
| $V_{CEO}$ | Collector-Emitter Voltage<br>: BD244<br>: BD244A<br>: BD244B<br>: BD244C | <br>- 45<br>- 60<br>- 80<br>- 100 | <br>V<br>V<br>V<br>V |
| $V_{EBO}$ | Emitter-Base Voltage | - 5 | V |
| $I_C$ | Collector Current (DC) | - 6 | A |
| $I_{CP}$ | *Collector Current (Pulse) | - 10 | A |
| $I_B$ | Base Current | - 2 | A |
| $P_C$ | Collector Dissipation ($T_C$=25°C) | 65 | W |
| $T_J$ | Junction Temperature | 150 | °C |
| $T_{STG}$ | Storage Temperature | - 65 ~ 150 | °C |

### Electrical Characteristics $T_C$=25°C unless otherwise noted

| Symbol | Parameter | Test Condition | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|
| $V_{CEO}$(sus) | * Collector-Emitter Sustaining Voltage<br>: BD244<br>: BD244A<br>: BD244B<br>: BD244C | $I_C$ = - 30mA, $I_B$ = 0 | <br>- 45<br>- 60<br>- 80<br>- 100 | | | <br>V<br>V<br>V<br>V |
| $I_{CBO}$ | Collector Cut-off Current : BD244/244A<br>: BD244B/244C | $V_{CB}$ = - 30V, $I_E$ = 0<br>$V_{CB}$ = - 60V, $I_E$ = 0 | | | - 0.7<br>- 0.7 | mA<br>mA |
| $I_{CES}$ | Collector Cut-off Current : BD244<br>: BD244A<br>: BD244B<br>: BD244C | $V_{CE}$ = - 45V, $V_{BE}$ = 0<br>$V_{CE}$ = - 60V, $V_{BE}$ = 0<br>$V_{CE}$ = - 80V, $V_{BE}$ = 0<br>$V_{CE}$ = - 100V, $V_{BE}$ = 0 | | | - 0.4<br>- 0.4<br>- 0.4<br>- 0.4 | mA<br>mA<br>mA<br>mA |
| $I_{EBO}$ | Emitter Cut-off Current | $V_{EB}$ = - 5V, $I_C$ = 0 | | | - 1 | mA |
| $h_{FE}$ | * DC Current Gain | $V_{CE}$ = - 4V, $I_C$ = - 0.3A<br>$V_{CE}$ = - 4V, $I_C$ = - 3A | 30<br>15 | | | |
| $V_{CE}$(sat) | * Collector-Emitter Saturation Voltage | $I_C$ = - 6A, $I_B$ = - 1A | | | - 1.5 | V |
| $V_{BE}$(on) | * Base-Emitter ON Voltage | $V_{CE}$ = - 4V, $I_C$ = - 6A | | | - 2 | V |

* Pulse Test: PW=300μs, duty Cycle=2% Pulsed

## Typical Characteristics

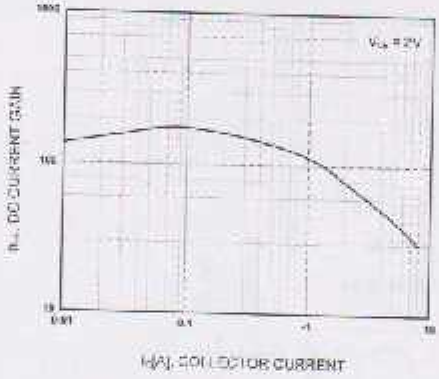


Figure 1. DC current Gain

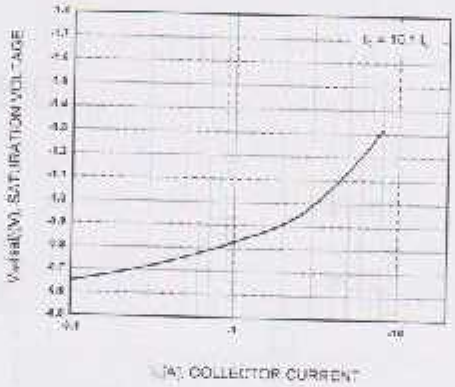


Figure 2. Base-Emitter Saturation Voltage

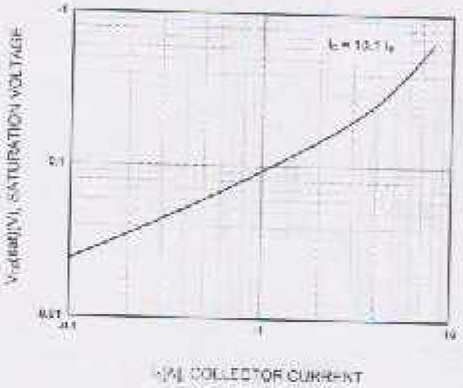


Figure 3. Collector-Emitter Saturation Voltage

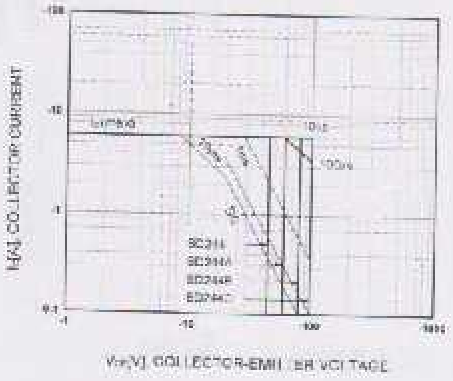


Figure 4. Safe Operating Area

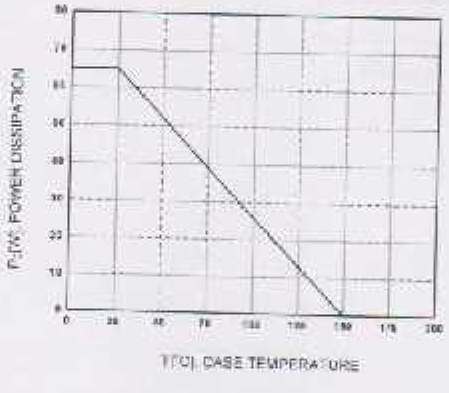
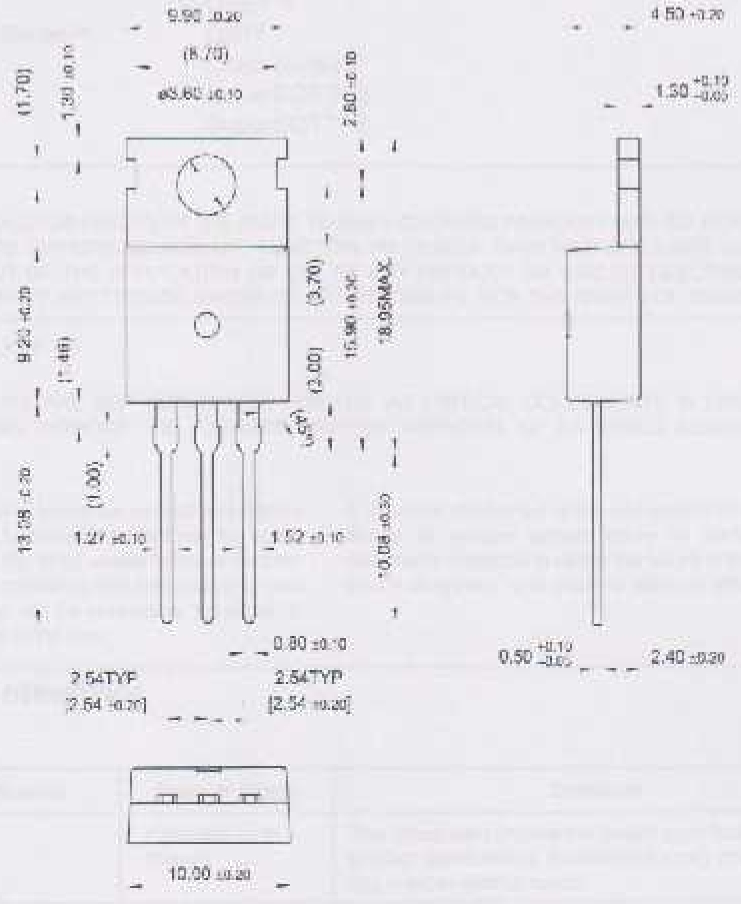


Figure 5. Power Derating

## Package Demensions

TO-220



Dimensions in Millimeters

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FAIRCHILD

# LM741

## Single Operation

## Features

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

## Description

[illegible]

## Internal Block Diagram

# LM741

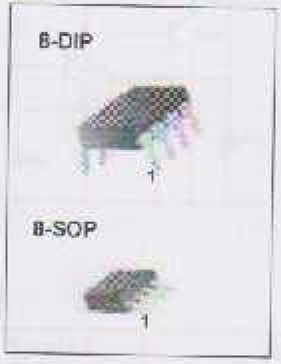
## Single Operational Amplifier

### Features

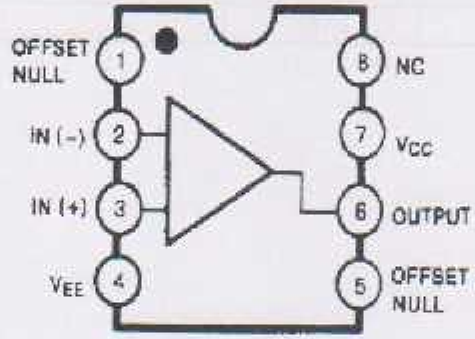
- Short circuit protection
- Excellent temperature stability
- Internal frequency compensation
- High Input voltage range
- Null of offset

### Description

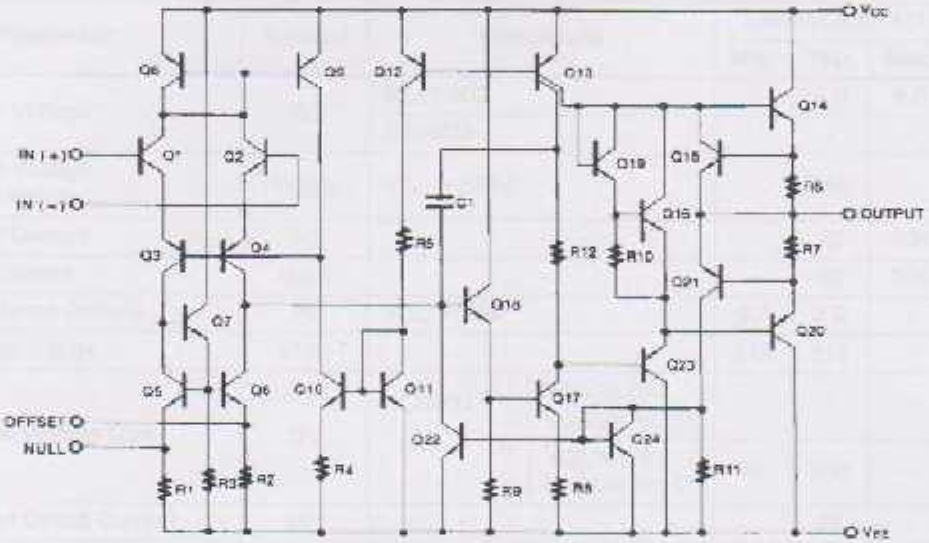
The LM741 series are general purpose operational amplifiers. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback applications.



### Internal Block Diagram



## Schematic Diagram



## Absolute Maximum Ratings ($T_A$ = 25°C)

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | ±18 | V |
| Differential Input Voltage | $V_{I(DIFF)}$ | 30 | V |
| Input Voltage | $V_I$ | ±15 | V |
| Output Short Circuit Duration | - | Indefinite | - |
| Power Dissipation | $P_D$ | 500 | mW |
| Operating Temperature Range<br>LM741C<br>LM741I | $T_{OPR}$ | 0 ~ + 70<br>-40 ~ +85 | °C |
| Storage Temperature Range | $T_{STG}$ | -65 ~ + 150 | °C |

## Electrical Characteristics

($V_{CC}$ = 15V, $V_{EE}$ = - 15V. $T_A$ = 25 °C, unless otherwise specified)

| Parameter | | Symbol | Conditions | | LM741C/LM741I | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min. | Typ. | Max. | |
| Input Offset Voltage | | $V_{IO}$ | $R_S \le 10K\Omega$ | | - | 2.0 | 6.0 | mV |
| | | | $R_S \le 50\Omega$ | | - | - | - | |
| Input Offset Voltage Adjustment Range | | $V_{IO(R)}$ | $V_{CC}$ = ±20V | | - | ±15 | - | mV |
| Input Offset Current | | $I_{IO}$ | - | | - | 20 | 200 | nA |
| Input Bias Current | | $I_{BIAS}$ | - | | - | 80 | 500 | nA |
| Input Resistance (Note1) | | $R_I$ | $V_{CC}$ =±20V | | 0.3 | 2.0 | - | MΩ |
| Input Voltage Range | | $V_{I(R)}$ | - | | ±12 | ±13 | - | V |
| Large Signal Voltage Gain | | $G_V$ | $R_L \ge 2K\Omega$ | $V_{CC}$ =±20V,<br>$V_{O(P-P)}$ =±15V | - | - | - | V/mV |
| | | | | $V_{CC}$ =±15V,<br>$V_{O(P-P)}$ =±10V | 20 | 200 | - | |
| Output Short Circuit Current | | $I_{SC}$ | - | | - | 25 | - | mA |
| Output Voltage Swing | | $V_{O(P-P)}$ | $V_{CC}$ = ±20V | $R_L \ge 10K\Omega$ | - | - | - | V |
| | | | | $R_L \ge 2K\Omega$ | - | - | - | |
| | | | $V_{CC}$ = ±15V | $R_L \ge 10K\Omega$ | ±12 | ±14 | - | |
| | | | | $R_L \ge 2K\Omega$ | ±10 | ±13 | - | |
| Common Mode Rejection Ratio | | CMRR | $R_S$<10KΩ, $V_{CM}$ = +12V | | 70 | 90 | - | dB |
| | | | $R_S \le 50\Omega$, $V_{CM}$ = ±12V | | - | - | - | |
| Power Supply Rejection Ratio | | PSRR | $V_{CC}$ = ±15V to $V_{CC}$ = ±15V<br>$R_S \le 50\Omega$ | | - | - | - | dB |
| | | | $V_{CC}$ = ±15V to $V_{CC}$ = ±15V<br>$R_S$<10KΩ | | 77 | 96 | - | |
| Transient Response | Rise Time | $T_R$ | Unity Gain | | - | 0.3 | - | µs |
| | Overshoot | OS | | | - | 10 | - | % |
| Bandwidth | | BW | - | | - | - | - | MHz |
| Slew Rate | | SR | Unity Gain | | - | 0.5 | - | V/µs |
| Supply Current | | $I_{CC}$ | $R_L$= ∞Ω | | - | 1.5 | 2.8 | mA |
| Power Consumption | | $P_C$ | $V_{CC}$ = ±20V | | - | - | - | mW |
| | | | $V_{CC}$ = ±15V | | - | 50 | 85 | |

Note:

1. Guaranteed by design.

## Electrical Characteristics

( 0°C ≤$T_A$≤70 °C $V_{CC}$ = ±15V, unless otherwise specified)
The following specification apply over the range of 0°C ≤ $T_A$ ≤ +70 °C for the LM741C; and the -40°C ≤ $T_A$ ≤ +85 °C for the LM741I

| Parameter | Symbol | Conditions | | LM741C/LM741I | | | Unit |
|---|---|---|---|---|---|---|---|
| | | | | Min. | Typ. | Max. | |
| Input Offset Voltage | $V_{IO}$ | $R_S$≤50Ω | | - | - | - | mV |
| | | $R_S$≤10KΩ | | - | - | 7.5 | |
| Input Offset Voltage Drift | $\Delta V_{IO}/\Delta T$ | - | | - | - | | μV/°C |
| Input Offset Current | $I_{IO}$ | - | | - | - | 300 | nA |
| Input Offset Current Drift | $\Delta I_{IO}/\Delta T$ | - | | - | - | | nA/°C |
| Input Bias Current | $I_{BIAS}$ | - | | - | - | 0.8 | μA |
| Input Resistance (Note1) | $R_I$ | $V_{CC}$ = ±20V | | - | - | - | MΩ |
| Input Voltage Range | $V_{I(R)}$ | - | | ±12 | ±13 | - | V |
| Output Voltage Swing | $V_{O(P-P)}$ | $V_{CC}$ =±20V | $R_S$≥10KΩ | - | - | - | V |
| | | | $R_S$≥2KΩ | - | - | - | |
| | | $V_{CC}$ =±15V | $R_S$≥10KΩ | ±12 | ±14 | - | |
| | | | $R_S$≥2KΩ | ±10 | ±13 | - | |
| Output Short Circuit Current | $I_{SC}$ | - | | 10 | - | 40 | mA |
| Common Mode Rejection Ratio | CMRR | $R_S$≤10KΩ, $V_{CM}$ = ±12V | | 70 | 90 | - | dB |
| | | $R_S$≤50Ω, $V_{CM}$ = ±12V | | - | - | - | |
| Power Supply Rejection Ratio | PSRR | $V_{CC}$ = ±20V to ±5V | $R_S$≤50Ω | - | - | - | dB |
| | | | $R_S$≤10KΩ | 77 | 96 | - | |
| Large Signal Voltage Gain | $G_V$ | $R_S$≥2KΩ | $V_{CC}$ = ±20V, $V_{O(P-P)}$ = ±15V | - | - | - | V/mV |
| | | | $V_{CC}$ = ±15V, $V_{O(P-P)}$ = ±10V | 15 | - | - | |
| | | | $V_{CC}$ = ±15V, $V_{O(P-P)}$ = ±2V | - | - | - | |

Note :
1. Guaranteed by design.

## Typical Performance Characteristics

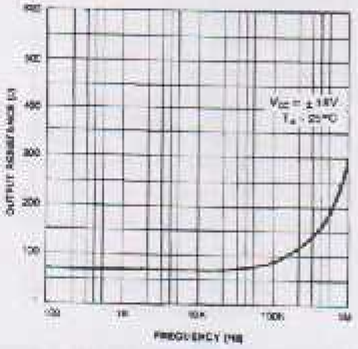


Figure 1. Output Resistance vs Frequency

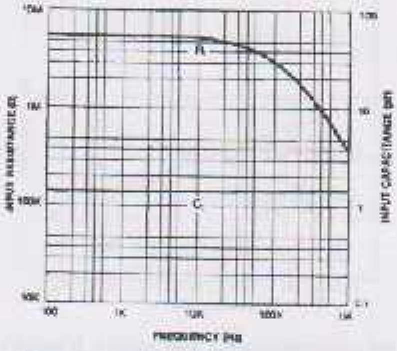


Figure 2. Input Resistance and Input Capacitance vs Frequency

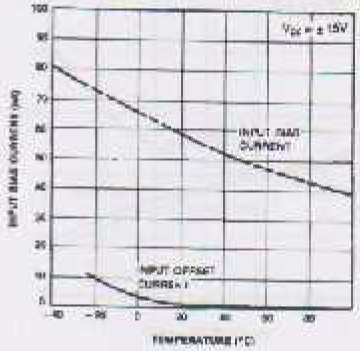


Figure 3. Input Bias Current vs Ambient Temperature

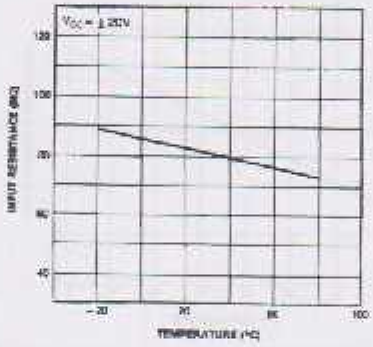


Figure 4. Power Consumption vs Ambient Temperature

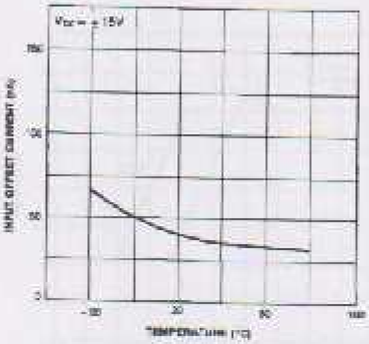


Figure 5. Input Offset Current vs Ambient Temperature

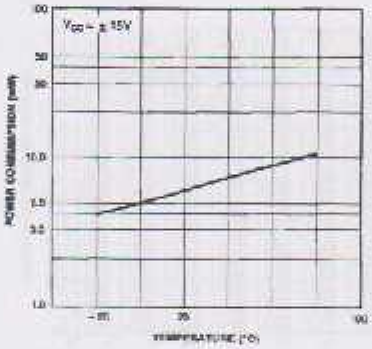


Figure 6. Input Resistance vs Ambient Temperature

## Typical Performance Characteristics (continued)

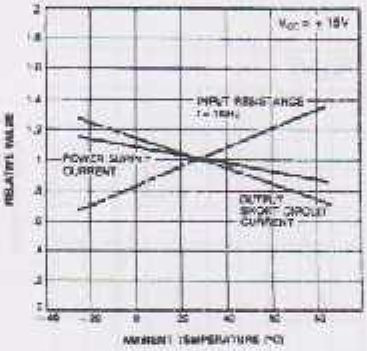


Figure 7. Normalized DC Parameters vs Ambient Temperature

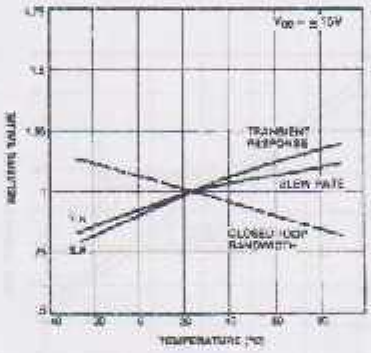


Figure 8. Frequency Characteristics vs Ambient Temperature

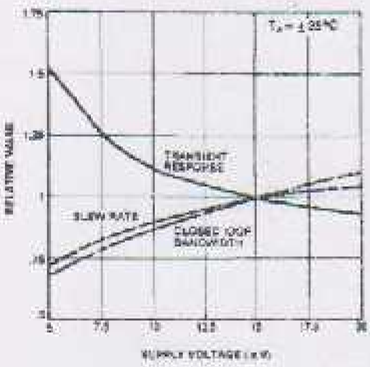


Figure 9. Frequency Characteristics vs Supply Voltage

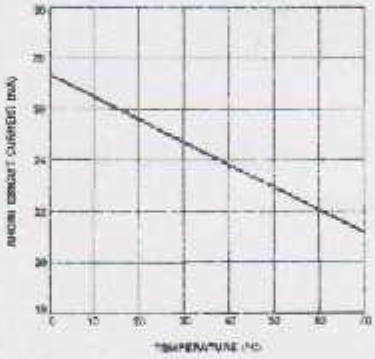


Figure 10. Output Short Circuit Current vs Ambient Temperature

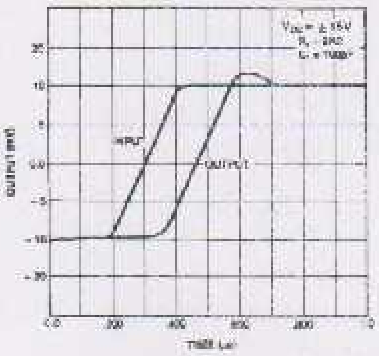


Figure 11. Transient Response

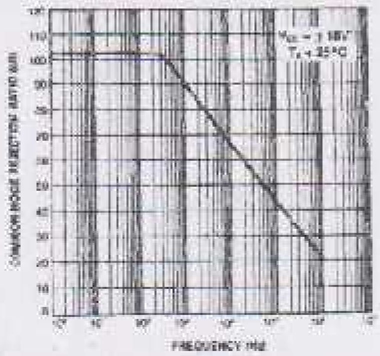


Figure 12. Common-Mode Rejection Ratio vs Frequency

## Typical Performance Characteristics (continued)

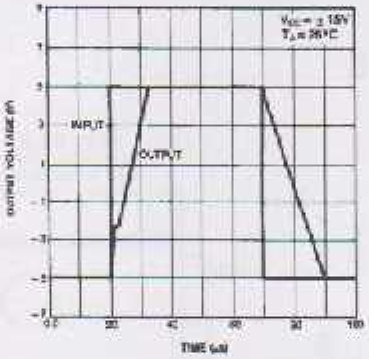


Figure 13. Voltage Follower Large Signal Pulse Response

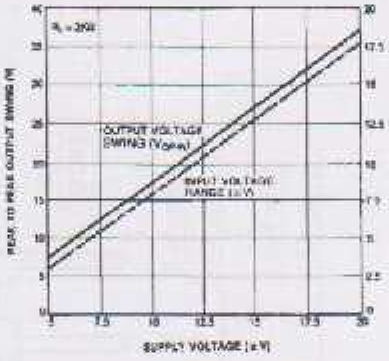
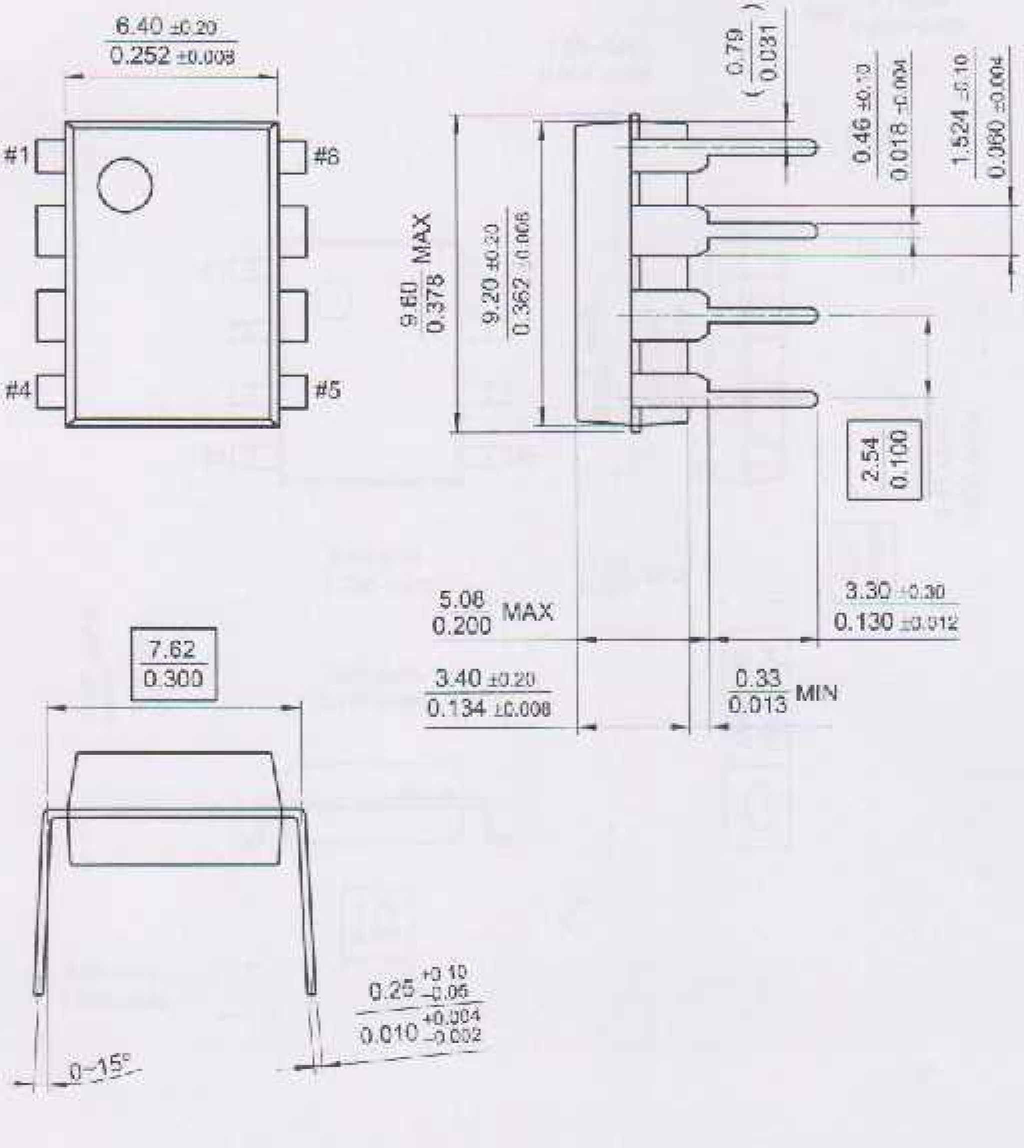


Figure 14. Output Swing and Input Range vs Supply Voltage

## Mechanical Dimensions

### Package

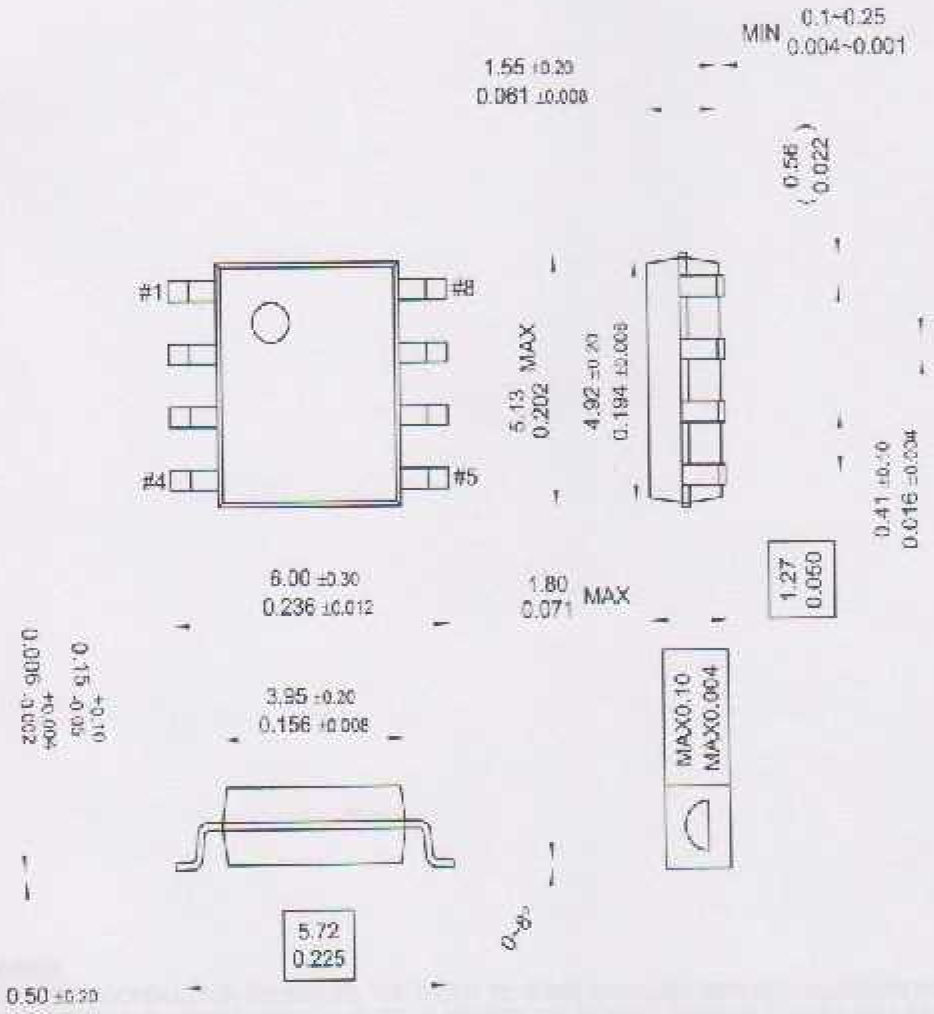
### 8-DIP



## Mechanical Dimensions (Continued)

**Package**

### 8-SOP



## Ordering Information

| Product Number | Package | Operating Temperature |
|---|---|---|
| LM741CN | 8-DIP | 0 ~ + 70°C |
| LM741CM | 8-SOP | |
| LM741IN | 8-DIP | -40 ~ + 85°C |

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