Lebanese American University

ELE 402 – Electronics I Lab

Section 31

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Final Project Report: Solar Tracker System

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I. Introduction:

Climate change is currently one of the most concerning issue facing humanity. It is an effect of global warming which is, in return, caused by the heavy use of fossil fuels in all industries around the world. However, fossil fuels are limited resources and the most important point revolving around this resource is its toxic remains on the environment. Therefore, a more responsible and environmentally-friendly approach, that will still serve our growing dependence on electricity, is the use of renewable energy as the main source of electricity generation. This brings us to the purpose of this humble project which, if implemented on a larger scale, will help restore the environment and guarantee humanity's future. This report discusses how a simple solar tracker device is built from basic electronic devices and configurations learned throughout this course, including Light Dependent Resistors, Operational Amplifier Configurations, as well as the H-Bridge.

II. Background:

A photovoltaic or PV panel is a technology that transforms sunlight into electricity. The most basic element of a photovoltaic module is a photovoltaic cell. A PV cell is mainly made up of semiconductor material Silicon “Si” doped with a small quantity of impurity atoms, in this case Phosphorus, forming a PN-junction. This cell produces electricity when sunlight hits it. This happens because sunlight is a source of energy, in the form of photons, and when it hits the cell, photons have enough energy to free the electrons from Silicon’s outermost shells. The more electrons that are freed, the more negative DC voltage will be induced across the terminals of the PN-junction facing the sun, and a positive DC voltage across the rear end. To form a PV panel, several photovoltaic cells are interconnected together, either in series or in parallel, depending on the desired output voltage. The difference between a PV cell, panel, as well as a PV array will be discussed later. A photovoltaic cell module is packaged as follows:

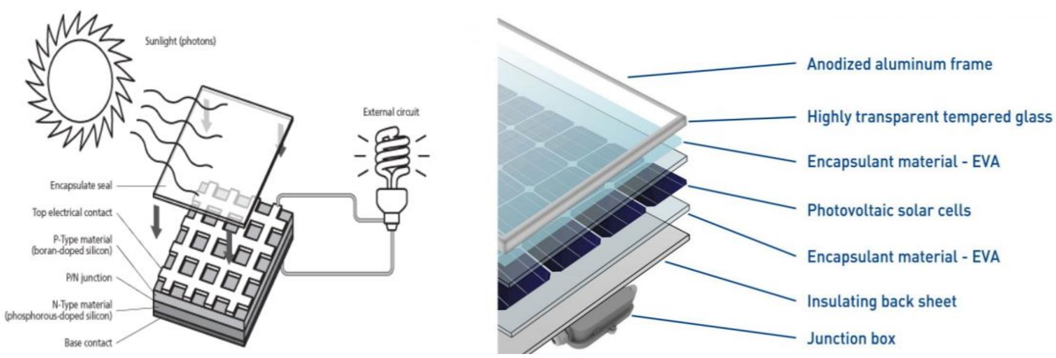

Figure 1: Structure of a Photovoltaic Cell Module.

The first part consists of the front glass, enclosed by an aluminum frame with sealant over it. This part serves as a protection layer for the PV cell, and it also makes the whole device robust. The glass is of high transparency and comes with a thickness that ranges from between 2 mm to 4 mm, depending on the type of glass chosen. The type of glass needs to be chosen according to its degree of light trapping (the greater the better), as well as its spectral transmittance and quality of hardening. The second part consists of an encapsulant material that serves as a binder between the different layers of the PV cell. This material is mainly made up of Ethylene vinyl acetate, which when deposited and cooked before and after the PV cell, holds everything together and ensures the longevity of the device. Now, for the PV cell enclosed between the encapsulant material, it has several technical characteristics including: size, color, and most importantly the conversion efficiency. Cells are regularly produced as mono or poly crystalline material, but the most common is polycrystalline due to its efficiency (typically 17.6%). The fourth part of PV module is the insulating back sheet, utilized for electrical isolation and protection from weather and moisture. The final part is the junction box which contains the necessary circuitry of the PV module, ranging from protection diodes to the connections of the PV module to different circuits (Ecoprogetti, n.d.). As mentioned before, PV cells are produced from two types of material, Monocrystalline and Polycrystalline Silicon. To begin with, monocrystalline silicon cells are made from extremely pure silicon. This silicon is extracted from a seed crystal pulled out of a mass of molten silicon, which creates a single crystal lattice structure. The structure is then mechanically sawn into wafers and impurities are added to form a basic PN-junction. An anti-reflective coating and front and rear metal contacts are added to the module, which then can be interconnected to other modules to form a panel. However, the manufacturing process of a monocrystalline silicon cell is slow and labor intensive, which makes them more expensive and sought-after than polycrystalline silicon cells. This brings us to why polycrystalline silicon cells are used more widely. This type is a single crystal structure containing small grains of crystals, which can be made by casting a cube-shaped lump from molten silicon. The only downside of polycrystalline silicon cells is that they are far less efficient than monocrystalline silicon cells (Afework, Hanania, Stenhouse, Yyelland, Donev, 2018).

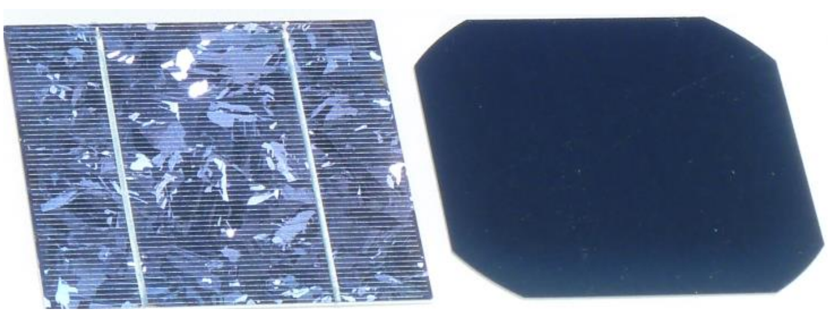

Figure 2: Polycrystalline Silicon Cell (left) VS Monocrystalline Silicon Cell (right).

A PV cell can be equated with an equivalent circuit connected to an active load as shown below:

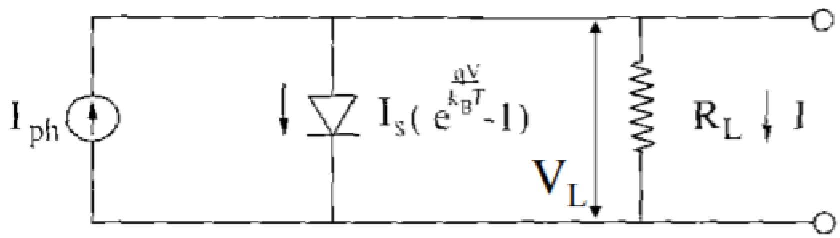

Figure 3: Equivalent Circuit of a PV cell connected to an Active Load.

The current passing through the load can be expressed as a function of I_{ph} (which is the photocurrent due to the photons effect on the PN-junction) and I passing through the diode (KCL) [3].

$$I = I_s\left(e^{\frac{qV}{kT}} - 1\right) - I_{ph}$$

We previously mentioned that there are differences between a PV cell, module, and array. A PV cell forms the basic element of photovoltaic system, and it is made in a way where its edges are cut, so it could be interconnected to other cells to form a PV panel or module. The latter is formed from several PV cell packaged and sealed together as described in previous paragraphs. According to the desired output voltage, PV modules are wired together in series or in parallel to form PV arrays. As an example, to achieve a 12 V panel or module, 36 cells must be connected together in series (Samlex Solar, n.d).

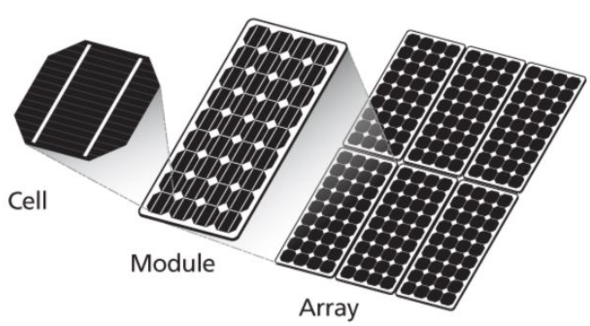

Figure 4: PV Cell, PV Module, and PV Array.

A PV panel is again a form of solar energy transmutation into electricity, as it also produces power. Power is measured in Watts (W: Joules/second) and can be described as the rate at which energy is produced or consumed. We can now introduce the unit Watt-hour (Wh) which is a unit of energy. Electricity supplier companies typically charge households and other institutions by the Kilowatt-hour (kWh), which is equivalent to 1,000 Watt-hours. The Watt-hour is another way of measuring the amount of work performed or generated from household appliances, for example. As a recap, we can say that watt measures the rate of power at one moment in time (one second), while the watt-hour equates the amount of energy for a specific period of time. It is important to be aware of these units and how one can compute the amount of energy consumed for the sake of monitoring it and saving as much energy as possible, this will then raise environmental awareness (Enphase Energy, n.d.). Energy monitoring is not that crucial however when it comes to solar energy production. In this case, the use of PV modules needs the Watt-Peak (Wp) unit as the basic unit for energy production measurement. The watt-peak or the peak power specifies the value of the output power of a PV module under full solar radiation (under Standard Test Conditions). Standard conditions are defined as the solar radiation of 1,000 Watts per square meter (Solar Mango, n.d.).

As mentioned before, a PV panel takes sunlight as input and produces a DC potential difference at its PN-junction. But most real-life appliances and applications require an AC voltage to function. So, in order for a PV panel to be fully functional, its DC output must be converted to an AC output, through what are called “Inverters”. A simple inverter’s functionality can be illustrated by approximating a sine wave, for example, as a combination of pulses.

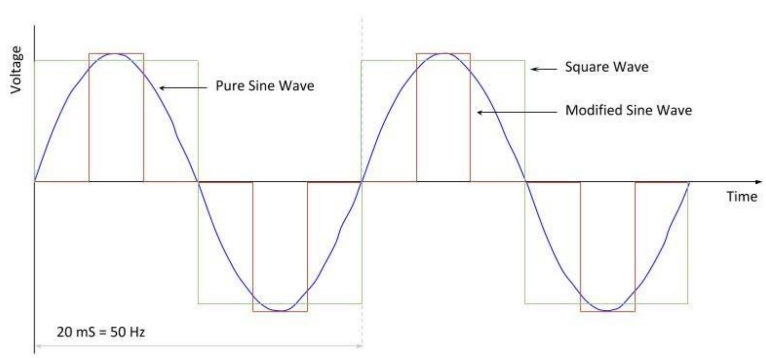

Figure 5: Square, Modified Sine, and Pure Sine Waves.

An inverter's output quality is classified into 3 types: Square Wave Inverter, Modified Sine Wave Inverter, and Pure Sine Wave Inverter. As mentioned above, a pulse is a square wave which can be generated by rapidly switching a DC power supply between positive and negative. Then, we can use Pulse Width Modulation (PWM) coupled with filters to achieve a closely refined sine wave. In PWM, the width of each pulse is varied in order to get an overall match of a sine wave.

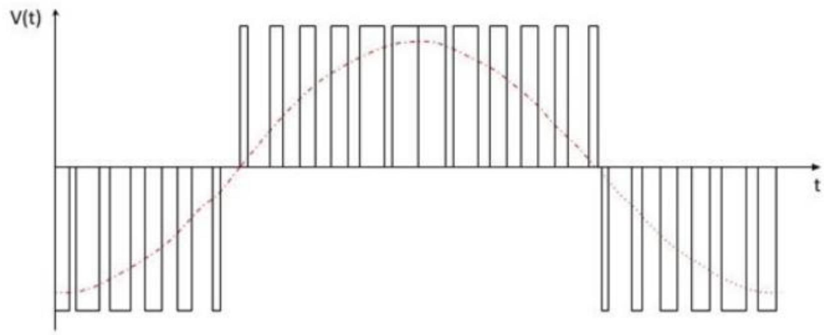

Figure 6: Pulse Width Modulation Example.

Pulse Width Modulation (specifically multi-level) is a technique used by inverters to mimic an alternating waveform. The more levels employed, the more accurate the sine wave will be.

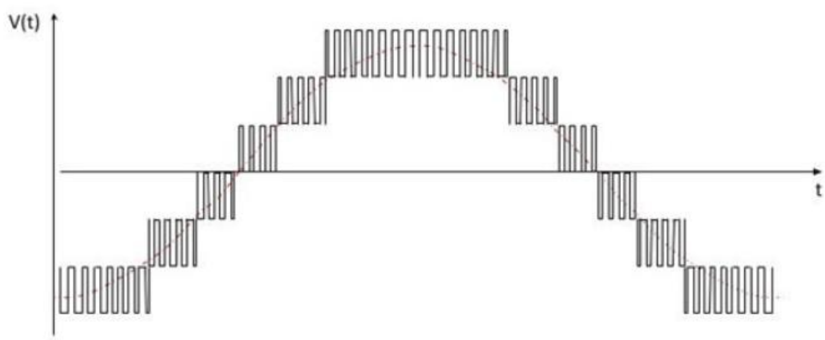

Figure 7: Three-Level PWM Waveform.

One DC voltage is switched on and off using an H-bridge to achieve the pulse waveform. According to the figure below:

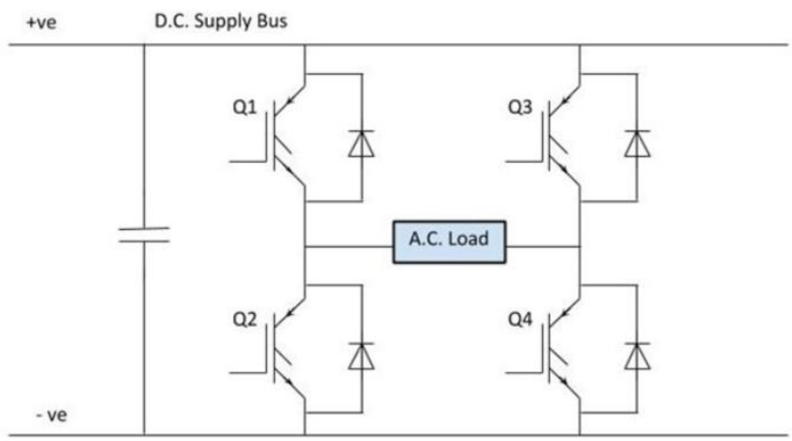

Figure 8: H-Bridge using IGBTs.

Each transistor acts as a switch (turns on when a signal is applied to it, and off when that signal is removed). By closing Q1 and Q4, a positive DC voltage is going to be applied to the load. And when Q2 and Q3 are closed, this will result in a negative DC voltage across the load. This switching mechanism produces several pulses that, when modulated, can imitate a sine wave (McFadyen, 2014).

An important issue revolving around current PV modules is their immobility. This key point reduces the amount energy production of a module, since it will only produce the greatest amount of energy at noon when the sun is at its highest point and directly facing the panel. As mentioned before, standard test conditions (on a clear day) of a PV module are defined as the solar radiation of 1,000 Watts per square meter, a panel temperature of 25°C, and a spectral distribution of air mass: 1.5. The graph below shows the I-V characteristics of a PV module under experimental measurement (Equipment used: Portable I-V curve data system – Pyranometer or Irradiance Sensor – Temperature Sensor). The conditions are as follows: Solar radiation was 715.4 W/m^2 and the panel temperature was 38.6°C. Conversion to Standard Test Conditions is a necessary second step done through the normalization of the results.

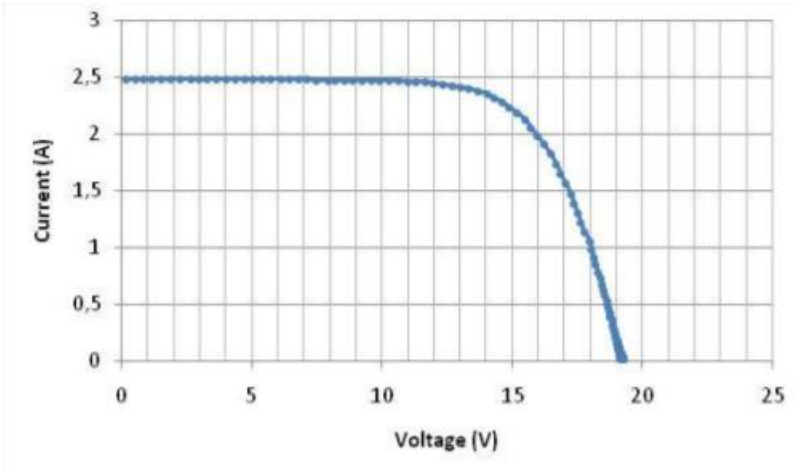

Figure 9: I-V Characteristics of a PV Module (Kaplani, 2012).

These experiment results are, as a matter of fact, prone to a degree of error. One of the causes of this error is the shading phenomenon. The experimental results after partial shading are shown in red in the figure below:

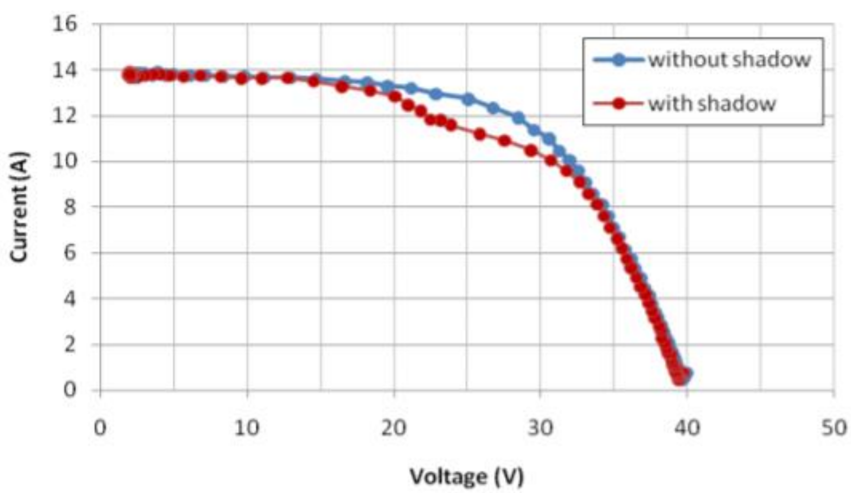

Figure 10: I-V Characteristics of a PV Module with and without Partial Shading (Kaplani, 2012).

Shading of a couple PV cells causes the output power to substantially drop. In the case of a PV array, as the number of shaded PV modules increases, the amount of output power will decrease (Kaplani, 2012).

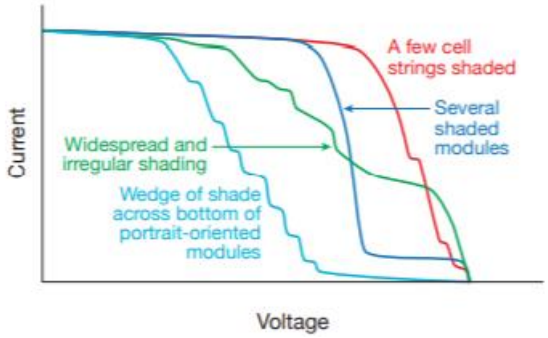

Figure 11: Rough Graph of a PV Array with a Varying Number of Shaded Modules (Hernday, 2014) [9].

One solution to the problem of immobile PV modules is creating a moving PV module. This type of device will be able to follow the sun as it moves throughout the day, which brings us to the purpose of this project where we illustrate and explain how a solar tracker system is built and how it functions. To start off, in order to build an efficient solar tracker, we first need to understand the sun path during different seasons of the year, as well as at different times of the day. It is safe to say that, during the day, the sun rises from the east and sets in the west (reaches its highest point during one season at noon). And since the Earth is rotating on its axis and around the sun, sunlight rays will hit the Earth at a varying angle, relatively changing how high or low it appears. On the winter solstice (December 21st), the sun appears to be relatively low in the sky (lies at the most south of the celestial equator). Meanwhile, during the summer solstice (June 21st), the sun is at its highest point in the sky (lies at the most north of the celestial equator). During late March and late September, the sun's path will directly follow the celestial equator.

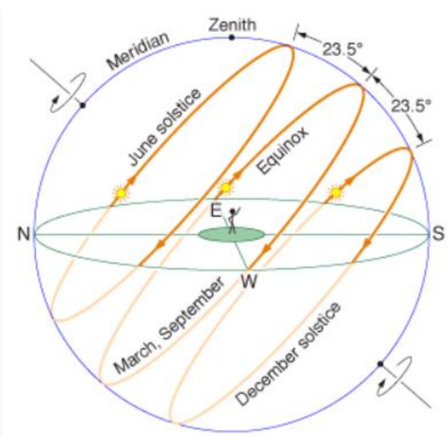

Figure 12: The Sun Path during Different Months.

The figure below shows a generic way of how the sun rays appear during winter and summer. The intensity of sunlight here is dependent on the angle at which the sun is at in the sky. When the sun is at a low angle as opposed to a high angle, the same amount of energy is spread but over a larger area of ground (Schroeder, 2011):

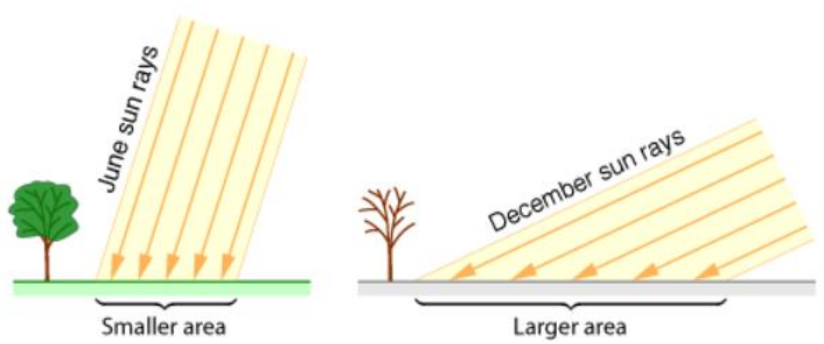

Figure 13: Sun Rays During Summer (left) and Winter (right).

Using this knowledge on how the sun path is, we can develop a tracker system that is capable of following up with the movement of the sun, at different times during the day and seasons. This will generate far more amounts of energy than a static PV module. Current solar trackers are able to direct solar panels or modules toward the sun. The tracker needs to be positioned in a way where it can minimize the angle of incidence between the rays of the sun and the panel, this will increase the produced energy at the output. One type of solar trackers includes a single-axis solar tracker which can rotate horizontally, vertically, tilted, or polar aligned. This type allows the tracker to rotate on one axis, moving back and forth in a single direction. Another type of solar tracker is a Dual-axis tracker, capable of moving in two different directions and continually facing the sun. Dual-axis trackers include tip-tilt and azimuth-altitude. These trackers are able to maximize solar energy generation since they follow the sun vertically and horizontally. The mechanism of how a solar tracker moves is based on a compressed gas fluid driven to one side or the opposite. In addition, motors and gear trains direct active solar trackers through a controller that get feedback from the sun's direction and acts accordingly. Single-axis solar trackers are used in large scale projects, while dual-axis trackers can be found in residents and locations with high government Feed-In-Tariffs. Some of the disadvantages of solar trackers include the need for maintenance or replacement of broken parts (there is more equipment in a solar tracker as opposed to a static PV module). Also, trackers are more prone to be damaged in a storm than a normal PV module (Zipp, 2013).

Our project consists of a prototype of what a basic solar tracker is, and how we can build one using components and configurations studied throughout the Electronics Course and its complimentary Lab.

III. Implementation on a Solderless Breadboard:

The equipment used in this phase constituted of the following:

- 2 BD136-16 PNP transistors,
- 2 KN2222 NPN transistors,
- 4 1N4007 Diodes,
- 2 µa741 Operational amplifiers,
- Resistors (value = 10 kΩ, number = 2; value = 1 kΩ, number = 5; value = 330 Ω, number = 2),
- 1 DC Motor (3 V nominal voltage, 75 rpm),
- 1 ceramic capacitor (0.1 µf),
- 2 potentiometers (value = 10 kΩ),
- Jump wires,
- 1 battery (value = 6 V),
- 1 DC power supply (set to ±10 V),
- 2 Light Dependent Resistors (LDR).
- A piece of foam board used as a solar panel.
- Solderless Breadboard.

The PNP and NPN transistors, along with 4 resistors of value equal to 1 kΩ, the 4 diodes and the capacitor in parallel with the DC motor make up the first stage of the circuit: The H-bridge as we can see in the following figure.

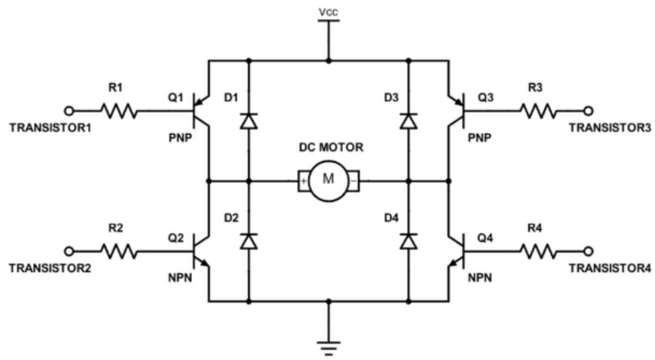

Figure 14: H-bridge Configuration.

The solar tracker as its name states should follow the sun. In this project, the sum is simulated by the flashlight of a phone. Since we needed the motor to turn in two different ways (east and west) the use of the H-bridge was a great choice.

The transistors (datasheets in appendix A and B) were used as switches since two of them will always be off in one mode of operation of the H-bridge (Dahl, 2018).

The diodes (datasheet can be found in appendix C) were mounted in reverse and in parallel with the transistors (between the emitter and the collector) so there's a way for the current to take to disperse the motor's energy and avoid damaging the transistors. The four 1k resistors were connected to the base in order to lower the input current going into the transistor.

The capacitor was connected in parallel with the motor to avoid any fluctuations that could damage the motor.

Going back to the H-bridge, the simpler circuit using switches is as follows:

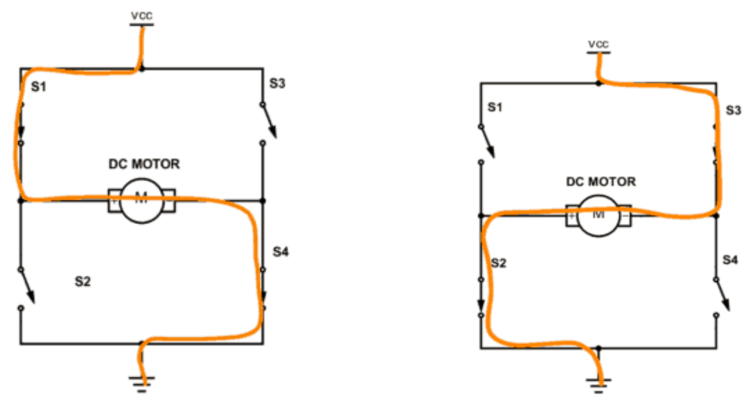

Figure 15: Two Ways of Steering a Motor (using switches)

Using BJTs, the circuit still follows the same modes of operation, based on the following table:

Command	R1	R2	R3	R4
Coast/Roll/Off:	GND or disconnected	+VDC or disconnected	GND or disconnected	+VDC or disconnected
Forward:	GND or disconnected	GND	+VDC	+VDC or disconnected
Reverse:	+VDC	+VDC or disconnected	GND or disconnected	GND
Brake/Slow Down:	+VDC	+VDC or disconnected	+VDC	+VDC or disconnected

Table 1: How to Achieve Different Steering Commands.

The second stage was the configuration needed to output two values (both low and high voltages) to input into the resistors connected to the transistors.

In fact, the goal was to make the H-bridge go into forward and reverse mode.

The idea of the second stage was inspired by a previous experiment using LDRs. It required an input voltage of 6V DC, a 10k resistor, an LDR and an op-amp used as a voltage follower. After calculations (in part V), we decided to use two non-inverting amplifiers and input them into R_1 R_2 and R_3 R_4.

The total circuit diagram simulated on Proteus 8 is as follows:

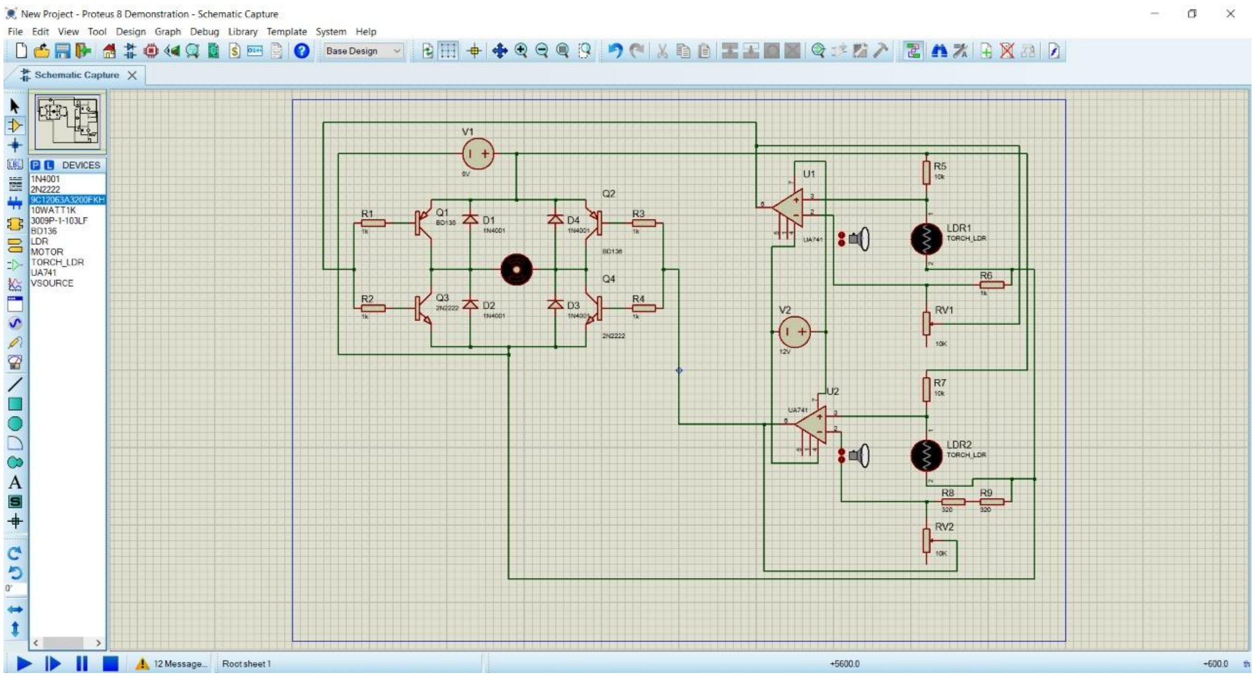

Figure 16: Circuit Diagram.

A DC motor is an electrical component that converts electrical energy into mechanical energy. (Eitel, 2011). The one chosen for this experiment had an internal resistance of 13 Ω.

A torque is a force applied at a distance d from an object's axis of rotation. **When applied to an object, the torque will make it rotate around a certain set point. (Collins, 2017).**

$$\tau = F \cdot d \cdot \sin\theta$$

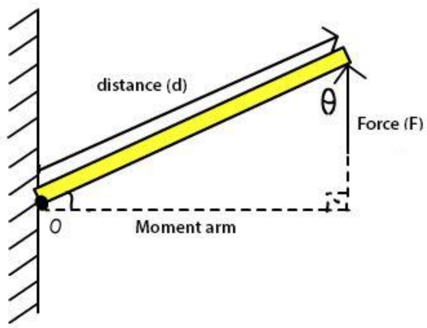

Figure 17: Torque visualized.

As for the motor, its torque is dependent on the original design and the intensity of the input. For the same input voltage, the rotational speed of the motor is inversely proportional to its torque. In fact, the torque is one of the main criteria to consider when choosing a motor along with speed and inertia. This experiment required a medium speed so that we can see the movement of the pane, thus, the motor’s torque was also medium.

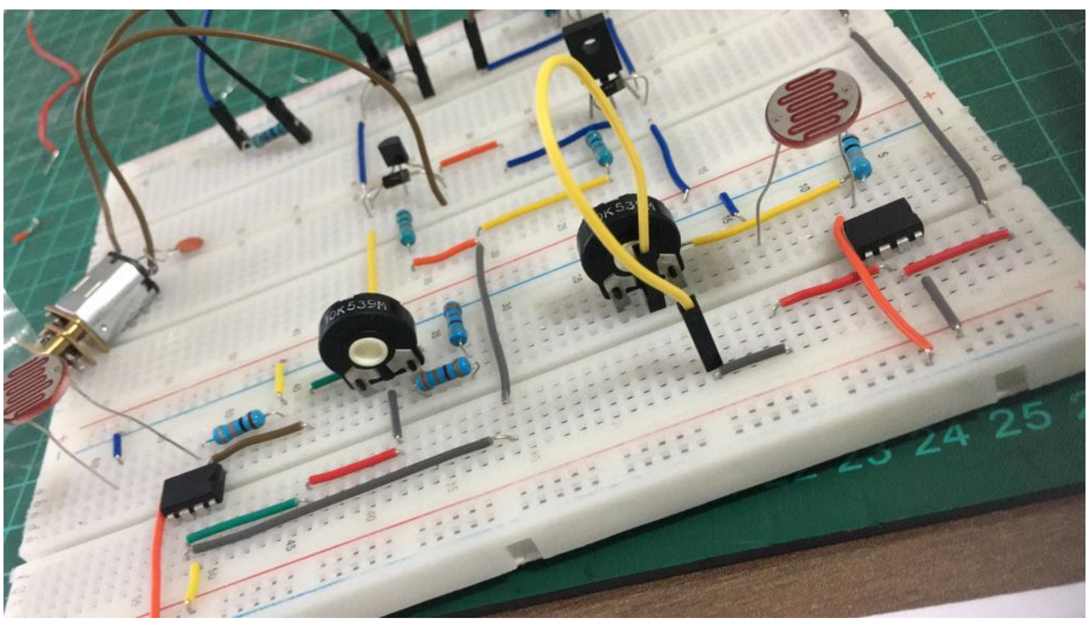

Figure 18: Solderless Breadboard Implementation.

Video Demo

IV. Implementation on a perforated breadboard (Soldering phase):

The first step was to choose the most adequate tin to lead ratio to use. In fact, this ratio affects the melting temperature of the solder and differentiates between applications of soldering. For this project, a ratio of 63/37 (tin to lead ratio) was selected. In fact, after some research, it was clear that this ratio fits our electronics project perfectly since it transitions fast between in its liquid and solid forms. On another note, we found the most appropriate size of perforated breadboard to be 12 x 18 cm since our circuit was relatively small. (Burris, 2019).

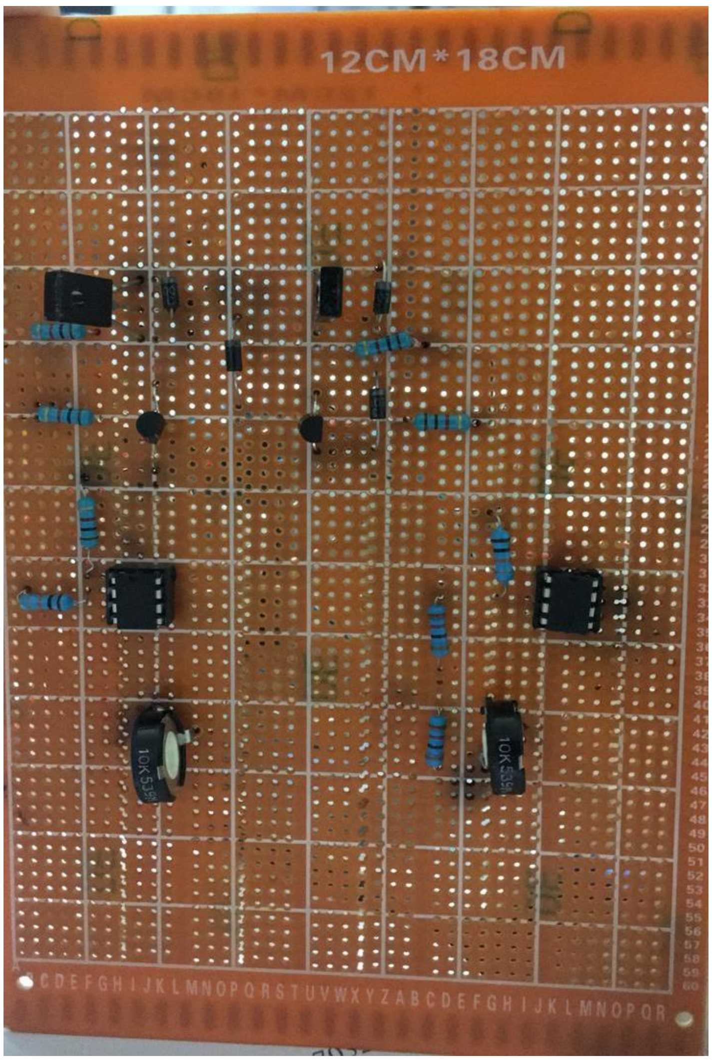

Figure 19: Perforated Breadboard (front).

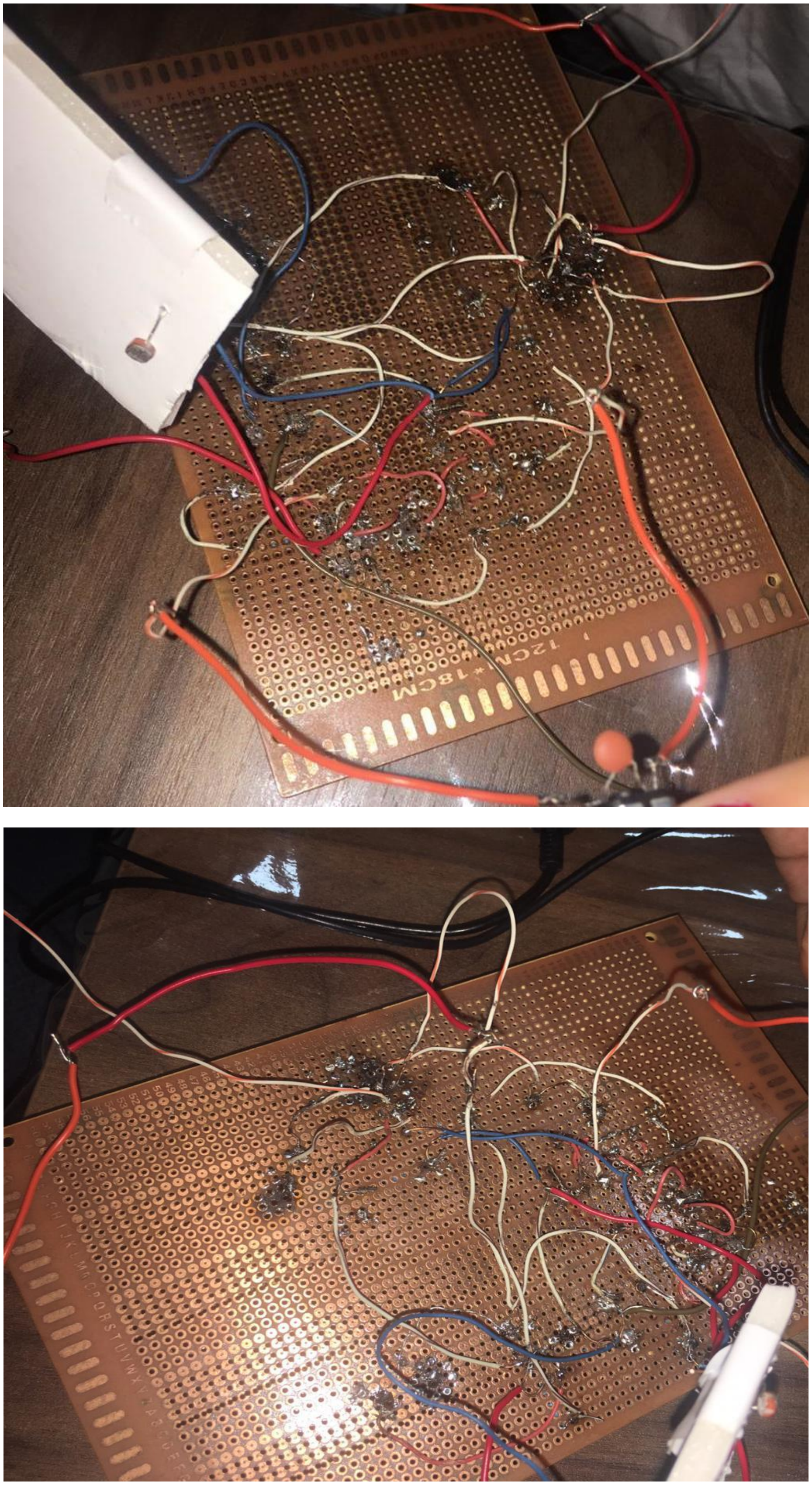

Figure 20: Perforated Breadboard (back).

V. Results and Testing:

The first step was going back to the LDR experiment. We started by measuring the resistance of the LDRs in two scenarios: exposed to regular room light and to a phone's flash light. We got a value of 2.3 kΩ in regular light and 0.79 kΩ with the flash light. Since we needed to output two different values (one high one low), we worked with two op-amps. The next step was to choose the configurations needed. We powered these op-amps with a DC power supply delivering 10 V. With a voltage supply of +6 V in series with a 10 kΩ resistor and the LDR connected between the resistor and the ground, the input voltage to the resistor with regular light on one LDR was: (acknowledging the measured value of the 10k resistor to be 9.89 kΩ)

$V_{in} = \frac{2.3k}{12.19k} \times 6 = 1.13$ V.

Repeating the same configuration (power supply, 10 kΩ resistor, LDR, op-amp), the other LDR is exposed to the flash light:

The input voltage at the second amplifier would be:

$V_{in} = \frac{0.79k}{10.68k} \times 6 = 0.444$ V.

We see that we have reached two values of voltages one high and one low. Since the goal of our project is to follow the light, and the DC motor needs a minimum 3 V voltage to turn on and the overall H-bridge needs around 5 V to operate, we decided to use two non-inverting amplifiers. This configuration was needed to amplify our voltage while keeping it positive. Since the needed values for resistors for unknown, we chose to get two 10k potentiometers. The minimum gain needed was 5 for both amplifiers.

We get the following values of voltages on the outputs of the amplifiers:

→For the LDR exposed to flash light: $V_{out} = 5 \times V_{in} = 2.22\ V$ (low voltage that does not let the H-bridge operate).

→For the LDR exposed to regular light: $V_{out} = 5 \times V_{in} = 5.65\ V$ (high voltage that allows the H-bridge to work).

One output of the op-amps was then linked to both R_1 and R_2 while the other was linked to both R_3, R_4. Thus, each pair will receive either a high voltage or a low voltage, which leads the H-bridge to function in both reverse (R_1, R_2 to V_{CC} and R_3, R_4 to ground) and in forward (R_1, R_2 to ground and R_3, R_4 to V_{CC}). Most importantly, it is important to note that the H-bridge and the second stage of the circuit was linked to a common ground.

One of the main limitations was the lack of resistors. In fact, for the non-inverting configurations with a gain of 5 we needed one 1kΩ resistor along with another 4 kΩ resistor. For the feedback resistor, we set the value of the potentiometer to 4 kΩ for one amplifier but since we had only two 330 Ω resistors left (with measured value of 320 Ω) and we wanted to achieve a gain of 5, we mounted them in series. We then solved for the needed value of the feedback resistor:

$$1 + \frac{R_F}{0.64} = 5$$

We get $R_F = 2.56$ kΩ.

Another limitation was our very modest knowledge of soldering which affected the time and quality of the soldering phase very heavily. In fact, each soldering step was slow and the results were very humble. The final outcome was weak since the joints were disconnecting when adding any other joints.

VI. Conclusion:

This project was done as an alternative to replace current ways of electricity generation. Its main advantage is that it's eco-friendly, and uses renewable energy rather than limited and harmful fossil fuels. The project consisted of several stages. The first being implementation on a solderless breadboard, followed by an implementation on a perforated breadboard, and finally results and testing in both stages. Pictures, as well as calculations were added to each of these stages. The problems that we faced and the projects and limitations were also discussed thoroughly. Finally, a research was conducted at this stage discussing PV cells, modules, and arrays; going deeper into their physical properties and work mechanisms, their dependency on sunlight and its path throughout the different times of the day and year, and the present solutions to static PV modules (which included different types of solar trackers). All of this was a means to study and implement the importance of a solar tracker system.

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VIII. Appendices:

A. BD136-16 PNP transistors: (Electronics Components Datasheets Search, n.d)

25C D ■ 8235605 0004338 5 ■SIEG D T-33-17

SIEMENS AKTIENGESELLSCHAF

BD 136
BD 138
BD 140

Static characteristics (T_{amb} = 25°C)

The transistors BD 136, BD 138, and BD 140 are grouped according to the DC current gain h_{FE} and marked by numerals of the German DIN standard.

h_{FE} group	6	10	16	
Type	BD 136 BD 138 BD 140	BD 136 BD 138 BD 140	BD 136 – –	BD 136 BD 138 BD 140
$-I_C$ (mA)	h_{FE} I_C/I_B	h_{FE} I_C/I_B	h_{FE} I_C/I_B	$-V_{BE}$ (V)
5	>25	>25	>25	–
150	63 (40 to 100)	100 (63 to 160)	160 (100 to 250)	–
500	>25	>25	>25	1,2

Static characteristics (T_{amb} = 25°C)		BD 136	BD 138	BD 140	
Collector-emitter-saturation voltage ($-I_C$ = 500 mA; $-I_B$ = 500 mA)	$-V_{CEsat}$	<0.5	>0.5	<0.5	V
Collector cutoff current ($-V_{CB}$ = 30 V)	$-I_{CBO}$	<100	<100	<100	nA
Collector cutoff current ($-V_{CB}$ = 30 V; T_{amb} = 125°C)	$-I_{CBO}$	≤10	≤10	≤10	µA
Emitter cutoff current ($-V_{EB}$ = 5 V)	$-I_{EBO}$	≤10	≤10	≤10	µA
Collector-emitter breakdown voltage ($-I_{CEO}$ = 50 mA)	$-V_{(BR)CEO}$	>45	>60	>80	V
Condition for matching pairs ($-I_C$ = 150 mA; $-V_{CE}$ = 2 V)	$\frac{h_{FE1}}{h_{FE2}}$	≤1.41	≤1.41	≤1.41	–
Dynamic characteristics (T_{amb} = 25°C)					
Transition frequency ($-I_C$ = 50 mA; $-V_{CE}$ = 10 V; f = 100 MHz)	f_T	>75	>75	>75	MHz

B. KN2222 NPN transistors: (Futurlec, n.d)

Philips Semiconductors | Product specification

NPN switching transistors | 2N2222; 2N2222A

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

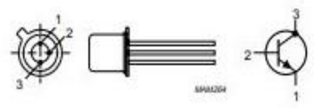

Fig.1 Simplified outline (TO-18) and symbol.

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

C. 1N4007 Diode : (Futurlec, n.d)

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Order this document
by 1N4001/D

Axial Lead Standard Recovery Rectifiers

This data sheet provides information on subminiature size, axial lead mounted rectifiers for general–purpose low–power applications.

Mechanical Characteristics

- Case: Epoxy, Molded
- Weight: 0.4 gram (approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
- Lead and Mounting Surface Temperature for Soldering Purposes: 220°C Max. for 10 Seconds, 1/16" from case
- Shipped in plastic bags, 1000 per bag.
- Available Tape and Reeled, 5000 per reel, by adding a "RL" suffix to the part number
- Polarity: Cathode indicated by Polarity Band
- Marking: 1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

1N4001 thru 1N4007

1N4004 and 1N4007 are Motorola Preferred Devices

LEAD MOUNTED RECTIFIERS
50–1000 VOLTS
DIFFUSED JUNCTION

CASE 59–03
DO–41

MAXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
*Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
*Non–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
*RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
*Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, $T_A = 75°C$)	I_O	1.0							Amp
*Non–Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	30 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +175							°C

ELECTRICAL CHARACTERISTICS*

Rating	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop ($i_F = 1.0$ Amp, $T_J = 25°C$) Figure 1	v_F	0.93	1.1	Volts
Maximum Full–Cycle Average Forward Voltage Drop ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$V_{F(AV)}$	—	0.8	Volts
Maximum Reverse Current (rated dc voltage) ($T_J = 25°C$) ($T_J = 100°C$)	I_R	 0.05 1.0	 10 50	μA
Maximum Full–Cycle Average Reverse Current ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$I_{R(AV)}$	—	30	μA

*Indicates JEDEC Registered Data

Preferred devices are Motorola recommended choices for future use and best overall value.

Rev 5

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