HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF ELECTRICAL ENGINEERING

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ELECTRONICS DESIGN

PROJECT REPORT

Dual axis solar tracker

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Abbreviation

- PV: Photovoltaics
- LED: Light-Emitting Diode
- DC: Direct Current
- BD: Block Diagram

I. Introduction to the process

1.1 Block Diagram

The overall design project consists of four blocks: power supply, control unit, user interface and mechanical components.

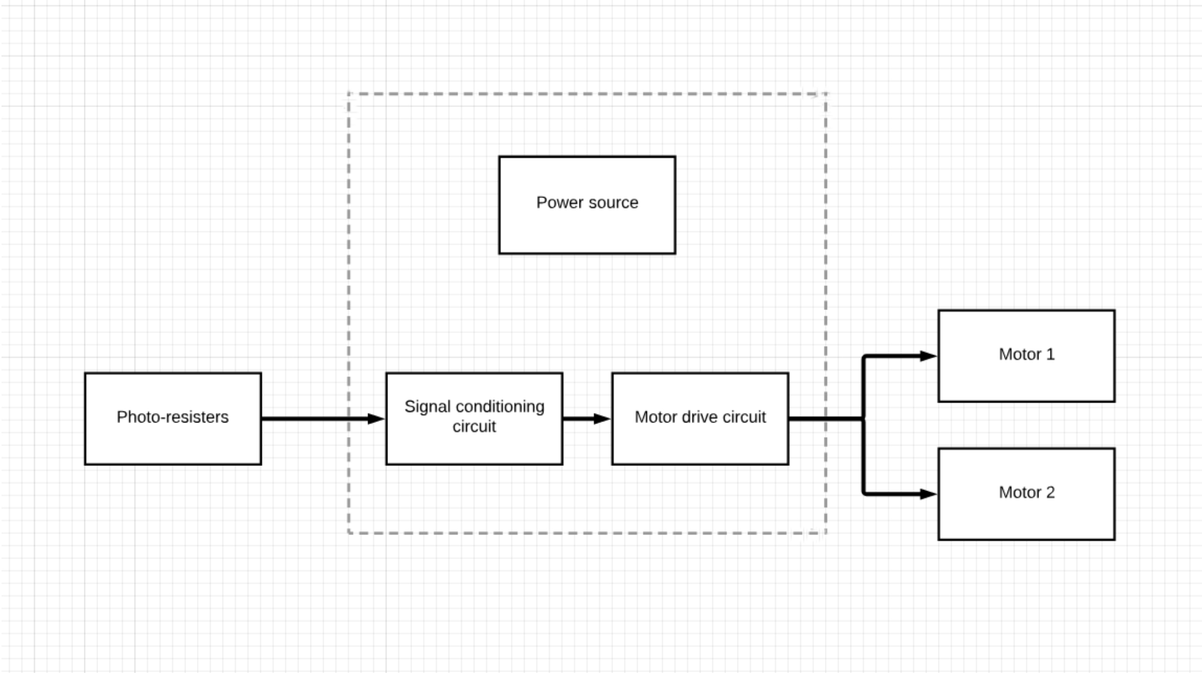


Figure 1: Block diagram

1.2 Power Supply

The power supply block consists of an AC to DC converter. The AC to DC converter from 220VAC to 12VDC is the primary power source to supply for motor driver circuit. Using an DC-DC buck converter (12VDC – 5VDC) to supply for signal conditioning circuit.

1.3 Motors and motor drive

The mechanical unit consists of two DC motors and the tracking platform. DC motors provide sufficient torques to rotate both the platform and the solar panel during the tracking process.

Figure 2: DC motor with gearbox

Specifications:

- Operating voltage: DC 3V~6V
- Maximum torque: 800g.cm with 1:48 (3V)
- No load speed:
  + DC3V: 150mA 90RPM+-10RPM
  + DC6V: 200mA 200RPM+- 10RPM
- No load current: 70mA (250mA maximum)
- Stall current: 1A

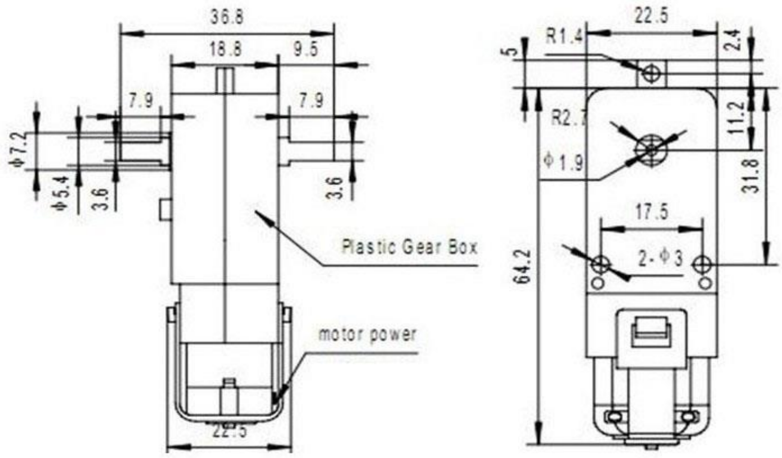


Figure 3: DC motor with gearbox mechanical

The DC motors get control signal from motor drive circuit. The motor drive module controls 2 motors, corresponding to 2 axes by 2 channels, OUT1, OUT2 for the first motor and OUT3, OUT4 for the second motor. It will receive commands from the comparing circuit and will also be powered by the main source.

1.5 Comparison circuit

For comparing signals from 8 photo-resistors, we use IC LM339N quad differential comparator. The LM339N device is a quad general-purpose operational amplifier. The device is short-circuiting protected, and the internal frequency compensation ensures stability without external components.

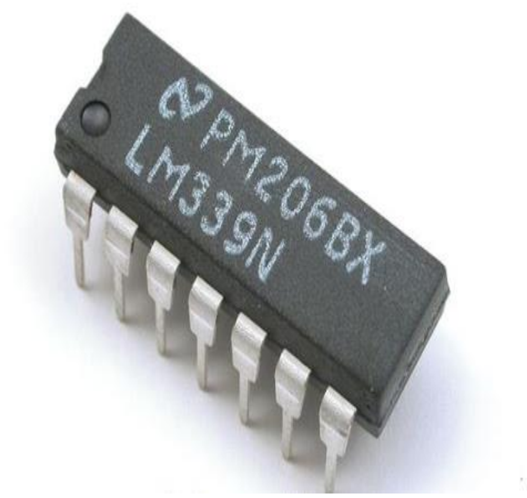


Figure 4: IC LM339N

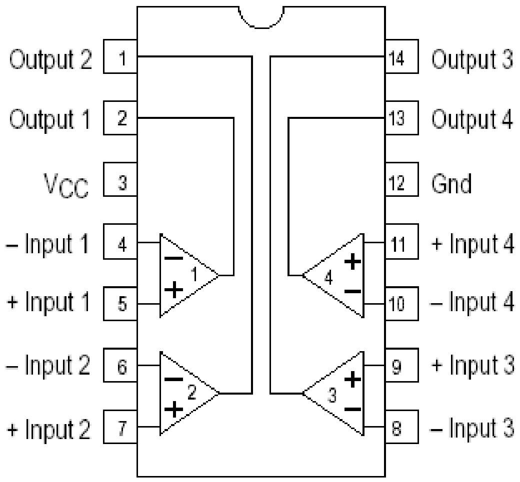


Figure 5: IC LM339N schematic

II. Design of Sun Tracking Solar Panel

2.1. Power Sources

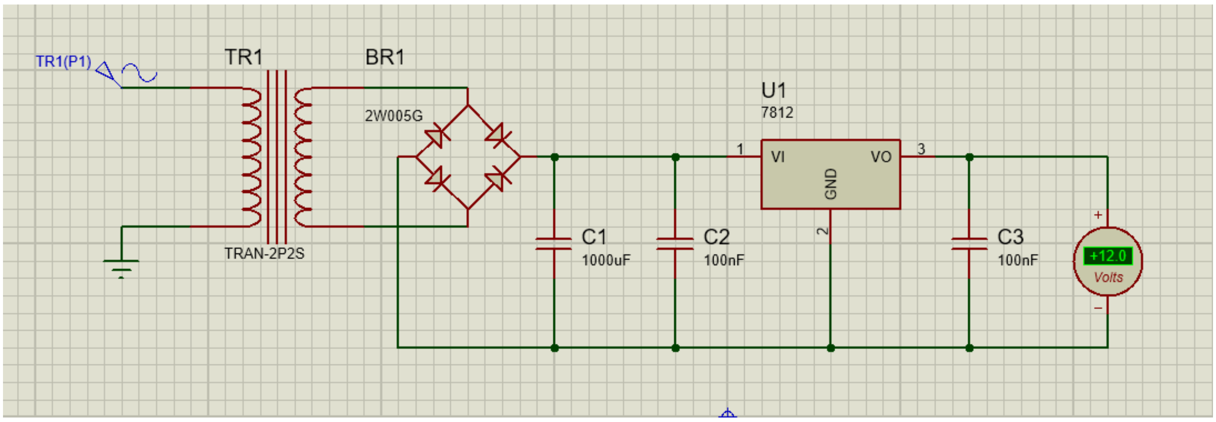


Figure 6: AC-DC converter using linear IC LM7812

To provide energy for the entire platform, we use a transformer to convert 220VAC to 12VAC then using a bridge diode to convert AC to DC voltage. Three capacitors are used as filters and power reservoir. Filter capacitor will be responsible for eliminating high frequency noise, power reservoir capacitors (electrolytic) will compensate power in the case of changing load or changing power source drastically. IC LM7812 is used to stabilize the voltage 12 at the output.

C_1 is calculated with the formula: $$C = \frac{V_{max}}{\Delta V f_p R_L}$$

With:

- $V_{max} = V_{out}\sqrt{2} = 12\sqrt{2}$ (V)
- $\Delta V = 12\sqrt{2} - 1$ (V)
- $f_p = 2\times50 = 100$ Hz
- $R_L = 8$ Ohm (estimated)

We have $C_1 \approx 1\times10^{-3}$ F

C_1 is a ripple filter capacitor

C_2 is used to cancel any inductance present

C_3 is a high frequency filter ($C_3 < 0.1$ uF), used to improve the transient response

So, choose

$C_1 = 1000$uF.

$C_2 = 100$nF.

$C_3 = 100$nF as suggested by the datasheet.

DC-DC buck converter 12V to 5V circuit to supply for comparison circuit and 2 motors. Because the stall current of 2 motors can reach 2A, linear IC like LM7805 can't respond. LM2576 is a source IC integrated pulse source circuit according to the principle of buck circuit. The output voltage is always adjusted continuously so that the output voltage is always constant.

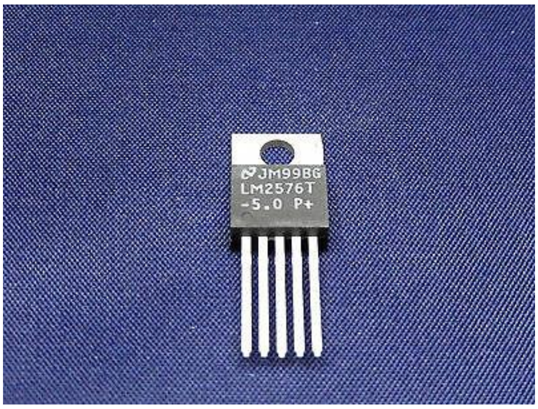


Figure 7: IC LM2576T-5.0

LM2576T-5.0 has:

Input voltage: 8VDC – 40VDC

Current consumption: 0.5A-3A

Switching frequency: 52kHz

Feedback current: 50nA typical at 25°C

On/Off pin input voltage: -0.3 < V< +Vin

Operating temperature range: -40°C to 125°C

Choose inductor L1:

The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of 1.15 x I load by the formular:

$$E * T = (V_{in} - V_{out}) \times \frac{V_{out}}{V_{in}} \times \frac{1000}{F} \quad (V * uS)$$

Then, select the maximum load current in horizontal axis and select E*T in vertical axis in reference figure in the datasheet.

$$E * T = (16 - 5) \times \frac{5}{16} \times \frac{1000}{52} = 66.1 \ \ (V * uS)$$

$$and\ I_{max} = 3A$$

So, choose L100 is L1 = 100uH

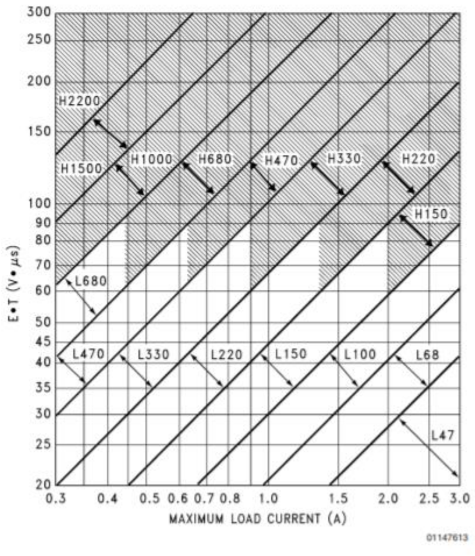


Figure 8: Recommend for inductor in LM2576 datasheet

Output Capacitor Selection (Cout) The value of the output capacitor together with the inductor defined. The dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{out} \geq 13{,}300 \times \frac{V_{in}max}{V_{out} \times L(uH)} \quad (uF)$$

The above formula will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula. The capacitor's voltage rating should be at last 1.5 times greater than the output voltage.

$$C_{out} \geq 13{,}300 \times \frac{16}{5 \times 100(uH)} = 425.6\ (uF)$$

So, choose $C_{out} = 1000uF$

Choose catch diode (D1). The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.

V_R	Schottky		Fast Recovery	
	3A	4A–6A	3A	4A–6A
20V	1N5820 MBR320P SR302	1N5823	The following diodes are all rated to 100V 31DF1 HER302	The following diodes are all rated to 100V 50WF10 MUR410 HER602
30V	1N5821 MBR330 31DQ03 SR303	50WQ03 1N5824		
40V	1N5822 MBR340 31DQ04 SR304	MBR340 50WQ04 1N5825		
50V	MBR350 31DQ05 SR305	50WQ05		
60V	MBR360 DQ06 SR306	50WR06 50SQ060		

Figure 9: Recommend for diode in datasheet of LM2576.

Vr < 20V and maximum load current is 3A. So, choose 1N5820 Schottky diode.

Input Capacitor (CIN) A 100 µF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing. And ignore ripple voltage.

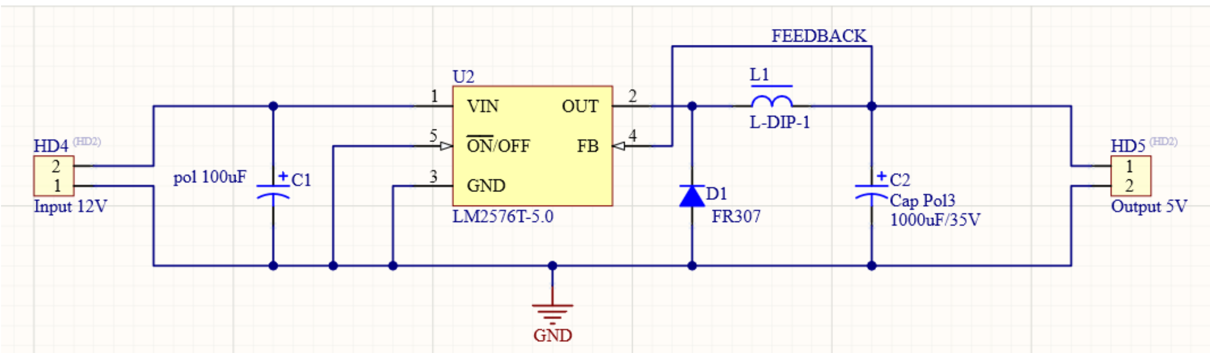


Figure 10: Power supply 5VDC buck converter schematic

2.2. Logic Comparator Circuit Design

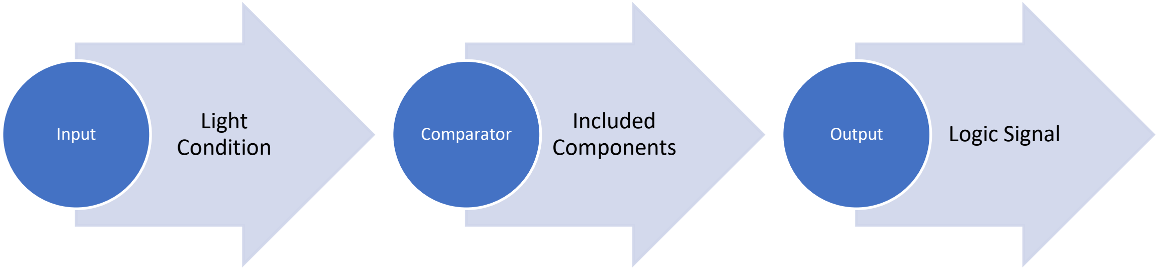


Figure 11 Logic Comparator Design Diagram

From the diagram, firstly, we have to choose the components used for this Circuit. To read the light condition from the environment, the photo-resistor 5537 was selected. The resistance of 5537 photo-resistor can reduced from 2 MΩ to 16 - 50 kΩ when absorbing the light but in fact it reduces from 16k kΩ to 2k7 - 3k2 Ω.

To gain Logic Signal, IC LM339 which can be the main component in comparator was chose.

Comparator IC = Two inputs of the IC are compared to each other as below:

- When "V+" is more positive than "V-" Output Vo will go high to +VCC.
- When "V-" is more positive than "V+" Output Vo will go low to –VCC.

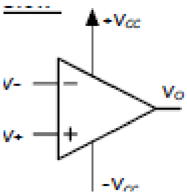


Figure 12 Comparator IC

Base on above characteristics of IC, we have light sensing circuit given below:

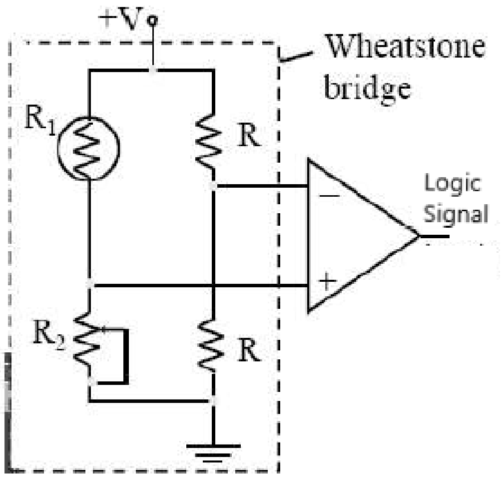


Figure 13: Light Sensing Circuit

Where:

- R1 and R2 are resistance of photo-resistors;
- If PR1 is lighter than PR2, R1 < R2, op-amp output is -Vsat;
- If PR2 is lighter than PR1, R1 > R2, op-amp output is +Vsat;
- If PR1 and PR2 are dark or PR1 and PR2 are light, R1 = R2, op-amp output is zero.

$V_{in} = \pm 5V, V_{HI} = +5V, V_{LO} = -5V, V_{REF} = 0V$

Apply for the Light Sensing Circuit, we calculated that:

Resistance R = 60k Ω

LTL = 0V

HTL = 5V

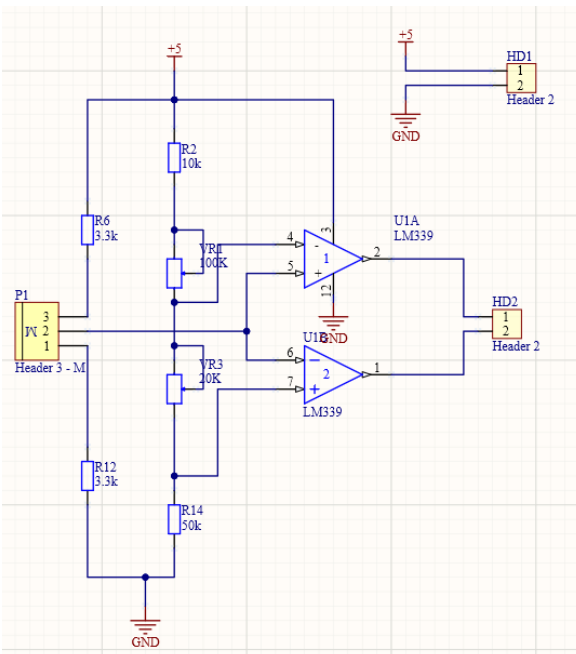


Figure 14: Logic comparator circuit schematic

Two resistors 3k3 are used for reducing the noise of Circuit which will be explained in Chapter III.

2.3. Motor Drive Module Design

After designing logic comparator circuit, the signal will transfer to Motor Drive Module. The Motor Drive Module makes DC Motor with GRU rotating to the sunshine direction. The Motor Drive Module is a combination of two H-bridge circuits.

2.3.1. H-Bridge Introduction

The motor controller follows the H-bridge configuration, which is handy when controlling the direction of rotation of a DC motor. A simplified H-bridge is shown below:

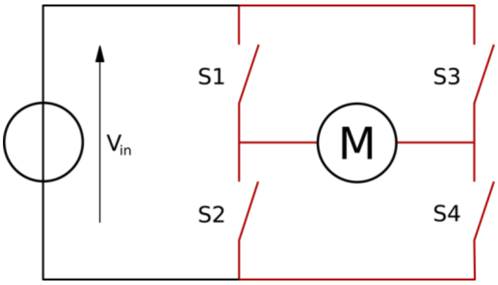


Figure 15 Simple Model of H-bridge Circuit

Here, the motor rotates in the direction dictated by the switches. When S1 and S4 are on, the left motor terminal is more positive than the right terminal, and the motor rotates in a certain direction. On the other hand, when S2 and S3 are on, the right motor terminal is more positive than the left motor terminal, making the motor rotate in the other direction.

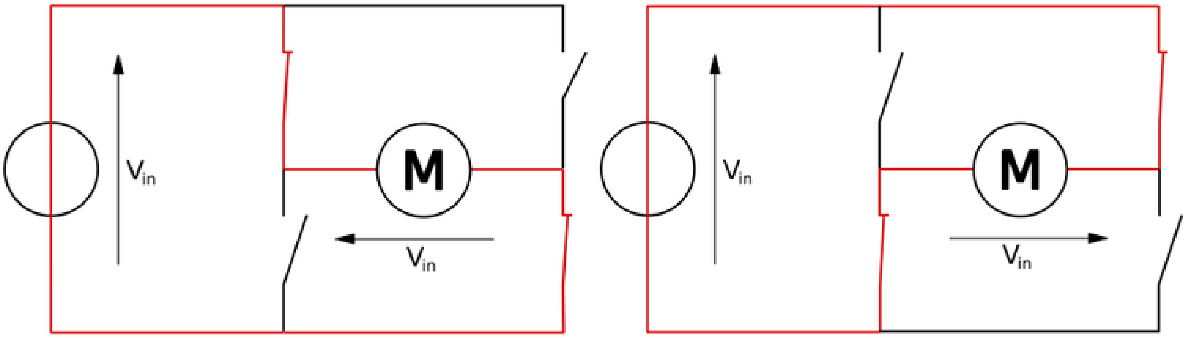


Figure 16: H-Bridge Operation

The other benefit of using an H-bridge is that you can provide a separate power supply to the motors. This is very significant especially that the 5V power source is simply not enough for two DC motors.

2.3.2. H-Bridge design

We use 2 P-channel enhancement MOSFETs for High-side and 2 N-channel enhancement MOSFETs for Low-side Bridge. 2 MOSFETs on the same side are Gate-common . This arrangement ensure that they never conduct at the same time (which can damage the circuit).

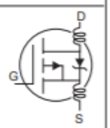
The resistor R4 and R5 are pull-up resistor. The MOSFET gates are normally pulled high by these resistor. This results in both the N- channel MOSFETs turning on, but this is not a problem since no current can flow. When the PWM signal is applied to the gates of one port A or B, the N and P-channel MOSFETs are turned on and off alternately, controlling the power.

- Q3,Q4: IRF9540N P-channel enhancement MOSFETs

  Key specs :

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ -10V	-23	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ -10V	-16	
I_{DM}	Pulsed Drain Current ①	-76	
P_D @T_C = 25°C	Power Dissipation	140	W
	Linear Derating Factor	0.91	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	430	mJ
I_{AR}	Avalanche Current①	-11	A
E_{AR}	Repetitive Avalanche Energy①	14	mJ
dv/dt	Peak Diode Recovery dv/dt ③	-5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Tab 2. Maximum ratings of IRF9540N

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	-100	——	——	V	V_{GS} = 0V, I_D = -250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	——	-0.11	——	V/°C	Reference to 25°C, I_D = -1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	——	——	0.117	Ω	V_{GS} = -10V, I_D = -11A ④
$V_{GS(th)}$	Gate Threshold Voltage	-2.0	——	-4.0	V	V_{DS} = V_{GS}, I_D = -250μA
g_{fs}	Forward Transconductance	5.3	——	——	S	V_{DS} = -50V, I_D = -11A
I_{DSS}	Drain-to-Source Leakage Current	——	——	-25	μA	V_{DS} = -100V, V_{GS} = 0V
		——	——	-250		V_{DS} = -80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	——	——	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	——	——	-100		V_{GS} = -20V
Q_g	Total Gate Charge	——	——	97	nC	I_D = -11A
Q_{gs}	Gate-to-Source Charge	——	——	15		V_{DS} = -80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	——	——	51		V_{GS} = -10V, See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	——	15	——	ns	V_{DD} = -50V
t_r	Rise Time	——	67	——		I_D = -11A
$t_{d(off)}$	Turn-Off Delay Time	——	51	——		R_G = 5.1Ω
t_f	Fall Time	——	51	——		R_D = 4.2Ω, See Fig. 10 ④
L_D	Internal Drain Inductance	——	4.5	——	nH	Between lead, 6mm (0.25in.)
L_S	Internal Source Inductance	——	7.5	——		from package and center of die contact 
C_{iss}	Input Capacitance	——	1300	——	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	——	400	——		V_{DS} = -25V
C_{rss}	Reverse Transfer Capacitance	——	240	——		f = 1.0MHz, See Fig. 5

Tab 3. Electrical characteristics of

- Q1,Q2 : IRF530N N-channel enhancement MOSFETs

  Key specs :

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	17	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	12	
I_{DM}	Pulsed Drain Current ①	60	
P_D @T_C = 25°C	Power Dissipation	79	W
	Linear Derating Factor	0.53	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②	150	mJ
I_{AR}	Avalanche Current①	9.0	A
E_{AR}	Repetitive Avalanche Energy①	7.9	mJ
dv/dt	Peak Diode Recovery dv/dt ③	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Tab 4. Maximum ratings of IRF530N

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	—	—	V	V_{GS} = 0V, I_D = 250µA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.12	—	V/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.11	Ω	V_{GS} = 10V, I_D = 9.0A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250µA
g_{fs}	Forward Transconductance	6.4	—	—	S	V_{DS} = 50V, I_D = 9.0A
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	µA	V_{DS} = 100V, V_{GS} = 0V
		—	—	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	44	nC	I_D = 9.0A
Q_{gs}	Gate-to-Source Charge	—	—	6.2		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	21		V_{GS} = 10V, See Fig. 6 and 13 ④
$t_{d(on)}$	Turn-On Delay Time	—	6.4	—	ns	V_{DD} = 50V
t_r	Rise Time	—	27	—		I_D = 9.0A
$t_{d(off)}$	Turn-Off Delay Time	—	37	—		R_G = 12Ω
t_f	Fall Time	—	25	—		R_D = 5.5Ω, See Fig. 10 ④
L_D	Internal Drain Inductance	—	4.5	—	nH	Between lead, 6mm (0.25in.) from package and center of die contact 
L_S	Internal Source Inductance	—	7.5	—		
C_{iss}	Input Capacitance	—	640	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	160	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	88	—		f = 1.0MHz, See Fig. 5

Tab 5. Electrical characteristics of IRF530N

- R4, R1 : 10k Ohm, 1/4W resistor
- DI01, DI02, DI05, DI06 are reverse current protection diode

Connecting diodes to the circuit is to overcome the reverse current generated from the motor (because the motor has an inductor), when the bridge circuit is operating and the motor has DC current flowing through, the power supply is suddenly cut off, the transistor stops working, because the motor has an inductor, so the motor will generate quite a lot of electrical energy (electromagnetic induction phenomenon), because the current generated by the motor is quite large and there is a danger of being greater than the withstand current. of transistors. At that time, the transistor will be broken by the current generated by the motor, if the protection diode system is added, the current generated by the motor will discharge through the diode to the source, protecting the circuit.

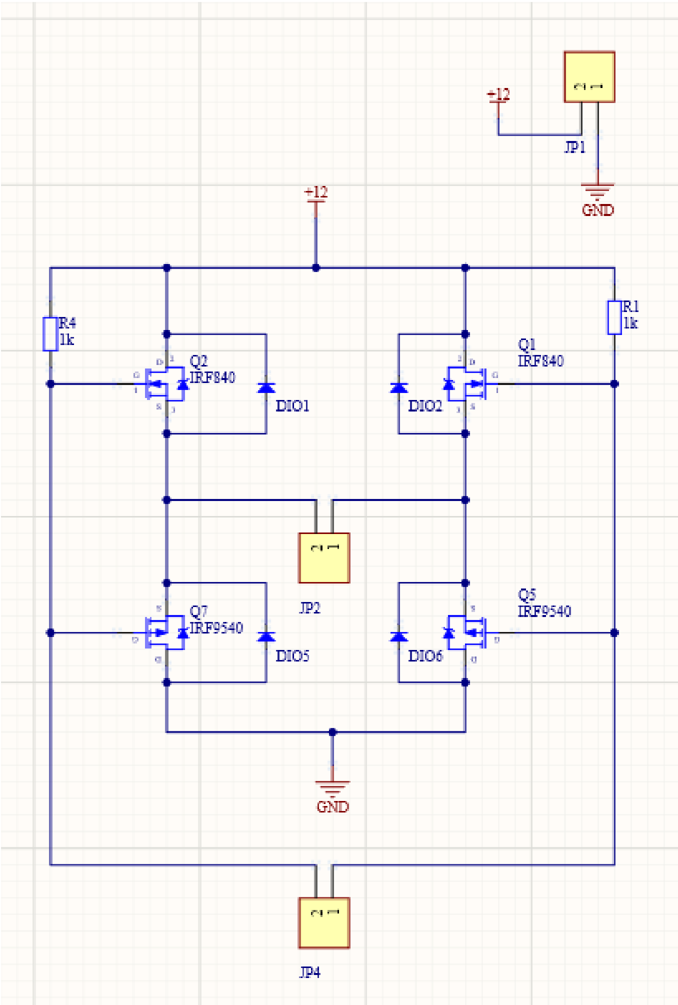


Figure 17: H-Bridge motor drive circuit

2.3.3. Connecting a DC Motor to the H-bridge

Here is a wiring diagram for connecting two DC motors to the L298N driver board.

Figure 18: Block Diagram for controlling DC MOTOR 1

Figure 19: Block Diagram for controlling DC MOTOR 2

2.3.4. Controlling directions of DC Motors

We have two truth tables to control the directions of DC Motors:

Table 1 Motor 1 Truth Table

ENA	IN1	IN2	Description
0	X	X	Motor 1 is off
1	0	0	Motor 1 is stopped (brakes)
1	0	1	Motor 1 is on and turning backwards
1	1	0	Motor 1 is on and turning forwards
1	1	1	Motor 1 is stopped (brakes)

Table 2 Motor 2 Truth Table

ENB	IN3	IN4	Description
0	X	X	Motor 2 is off
1	0	0	Motor 2 is stopped (brakes)
1	0	1	Motor 2 is on and turning backwards
1	1	0	Motor 2 is on and turning forwards
1	1	1	Motor 2 is stopped (brakes)

2.3.5. Finishing Designing

To make sure two motors do not rotate over their limitation, switches SS1 to SS4 are added. **Hence, the Motor Drive Module circuit is below:**

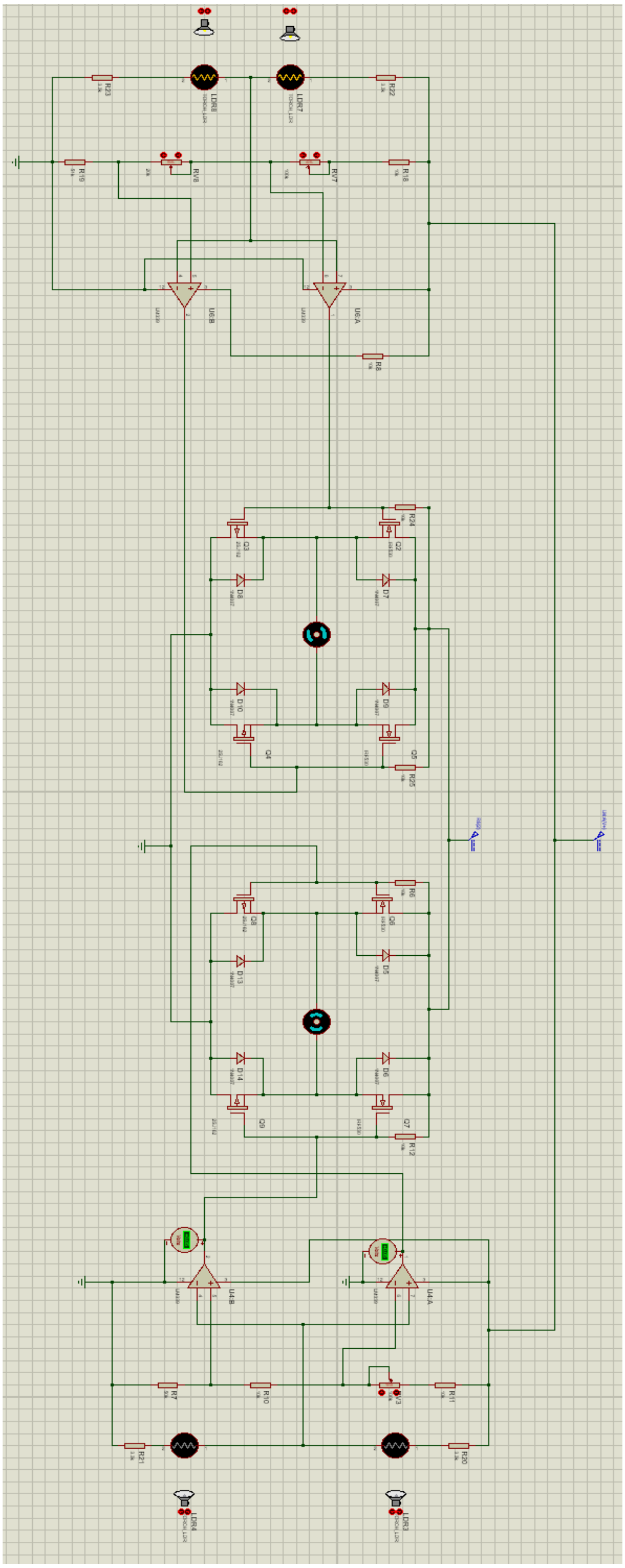


Figure 20: Motor Drive Module Circuit

2.4. Altium PCB design

2.4.1. Power supply circuit

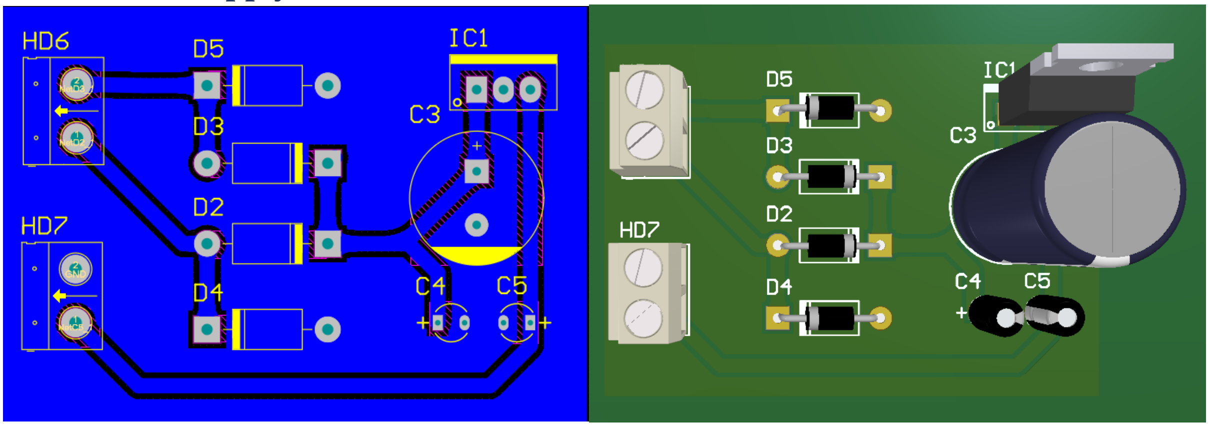


Figure 21: PCB power supply 12VAC to 12VDC circuit

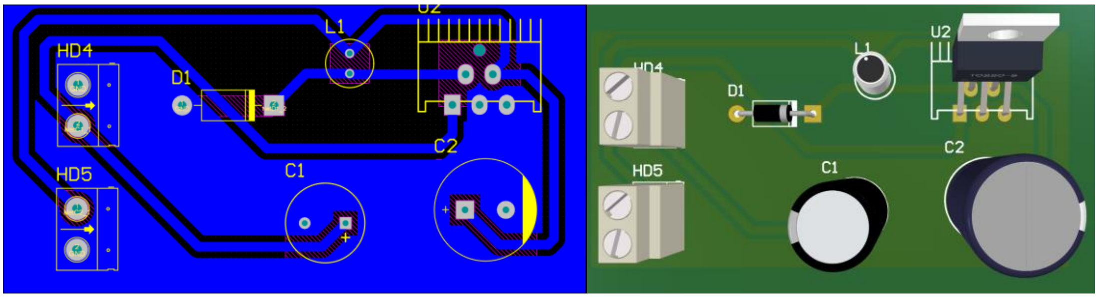


Figure 22: PCB DC-DC buck converter 12VDC to 5VDC circuit

2.4.2. Comparison circuit

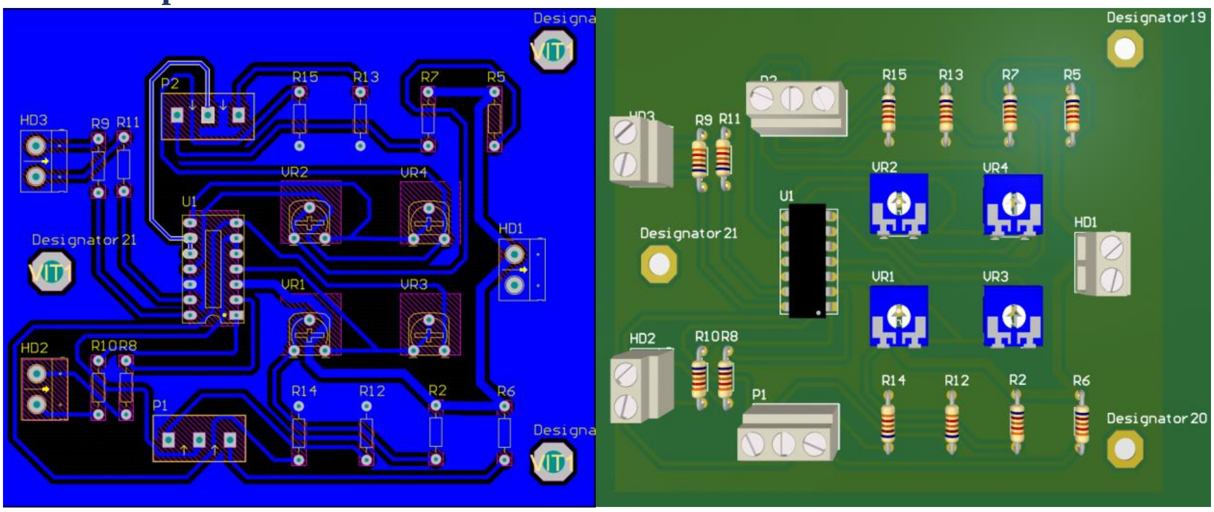


Figure 23: PCB Logic comparator circuit

2.4.3. H-bridge circuit

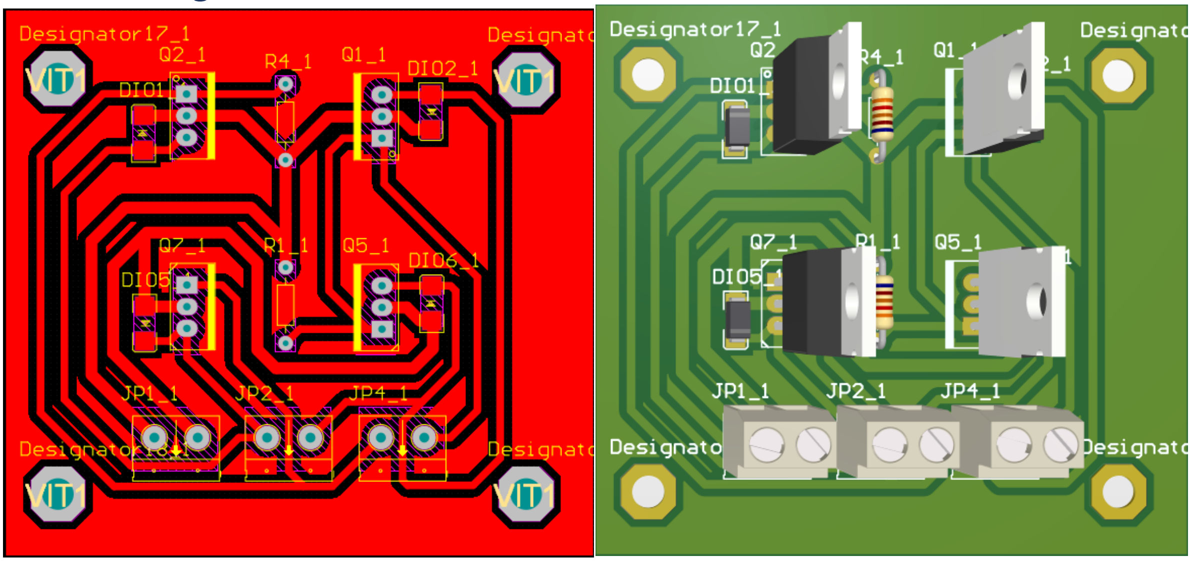


Figure 24: PCB H-Bridge motor driver circuit

III. Result and implementation

3.1. Power Source Implementation

Simulate on PSIM to check the filter.

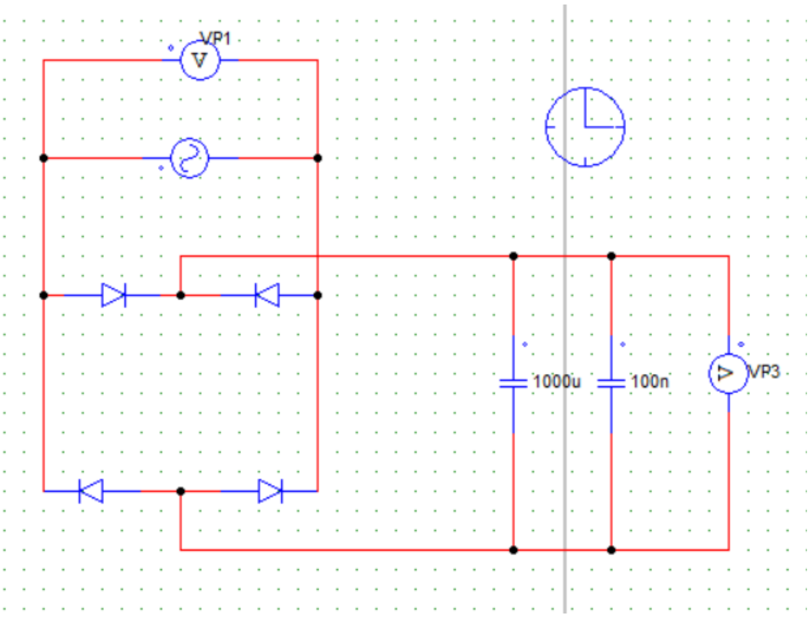


Figure 25: PSIM simulation circuit

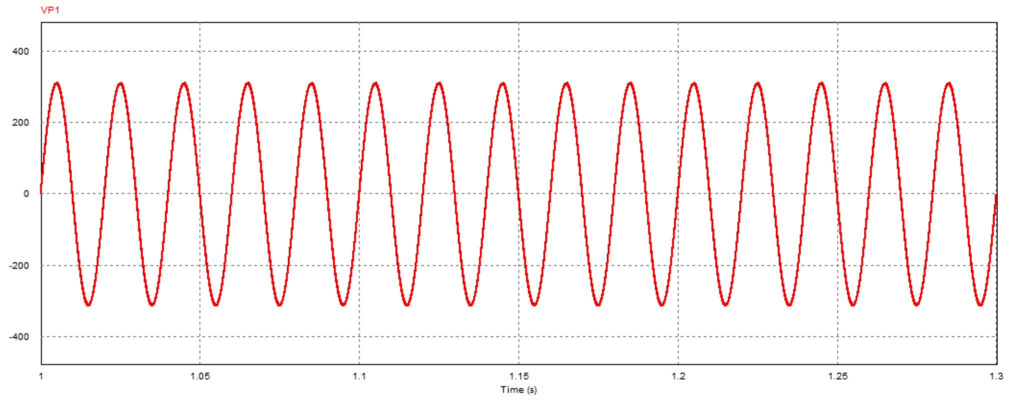


Figure 26: Voltage graph without using rectifier

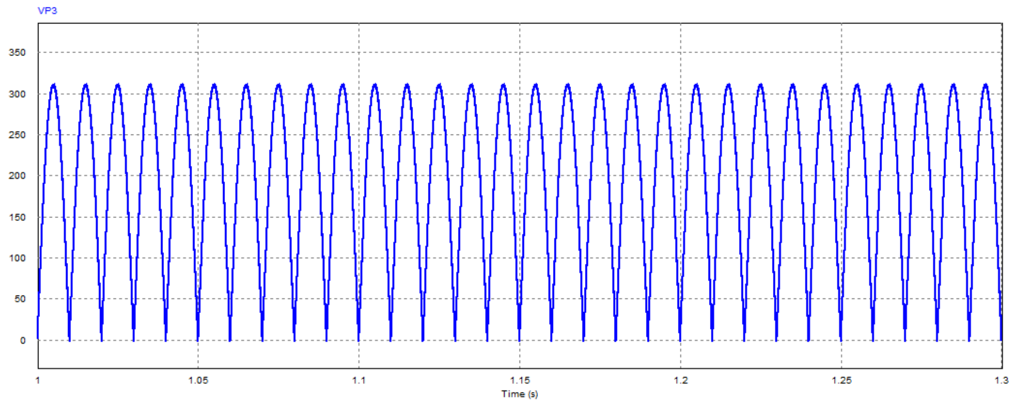


Figure 27: Voltage graph after passing through bridge diode

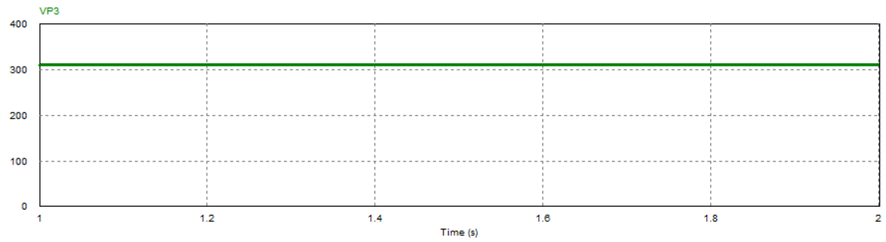


Figure 28 Output Voltage Graph after passing through filter capacitors

3.2. Logic Comparator Implementation

In theory, the ideal photo-transistor has resistance at dark state 2 MΩ and reduces to 16 - 50 kΩ when absorbing the light.

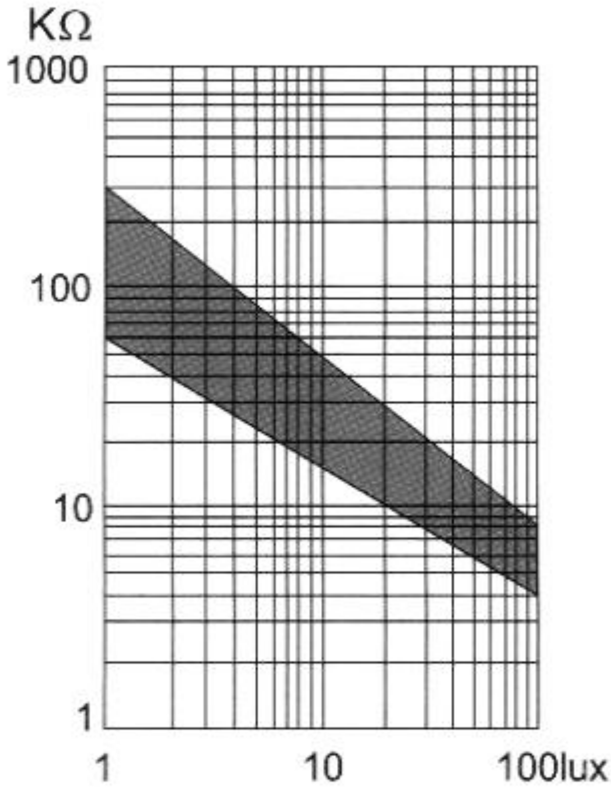


Figure 29: Illuminance vs Photo Resistance of CDS 5537

However, in fact, after testing in 16 photo-resistors CDS 5537, we received the result below:

Table 3 Table of photo-resistance CDS5537

Sample	Dark resistance (Ω)	Light resistance (Ω)
1.	16002	2705
2.	15792	3203
3.	15880	2805
4.	16010	2703
5.	15900	2902
6.	15954	3201
7.	16100	3203
8.	15820	2704
9.	32004	5192
10.	30102	6123
11.	31200	7133
12.	32220	5182
13.	33220	5234
14.	33100	5300
15.	32130	5100
16.	33410	6000

If we use first comparator design **(Figure 13 - Chapter II)**, the result received is not exact. The motor drive module keeps two motors rotating despite of the same light conditions. To resolve this problem, we continue using Photo-resistors CDS 5537 with light resistance about 2k7 to 3k2 Ω and dark resistance about 15k to 16k Ω, but we add two more resistors 3k3 Ω to the circuit, the noise reduces, and the circuit works more effectively.

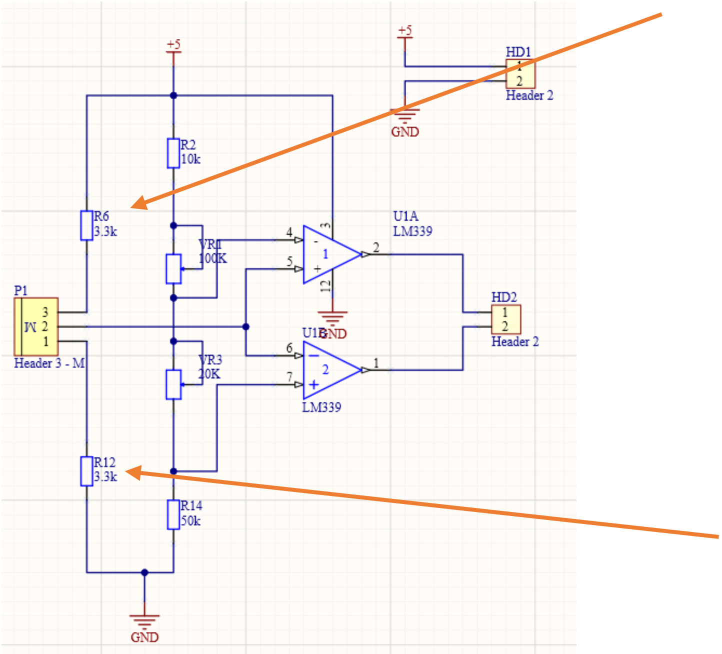


Figure 30: 2 filter resistors be added in logic circuit

3.3. Result and real circuit

After testing Power Source Circuit and Logic Comparator Circuit and fixing some bugs, the final result of System is received (below):

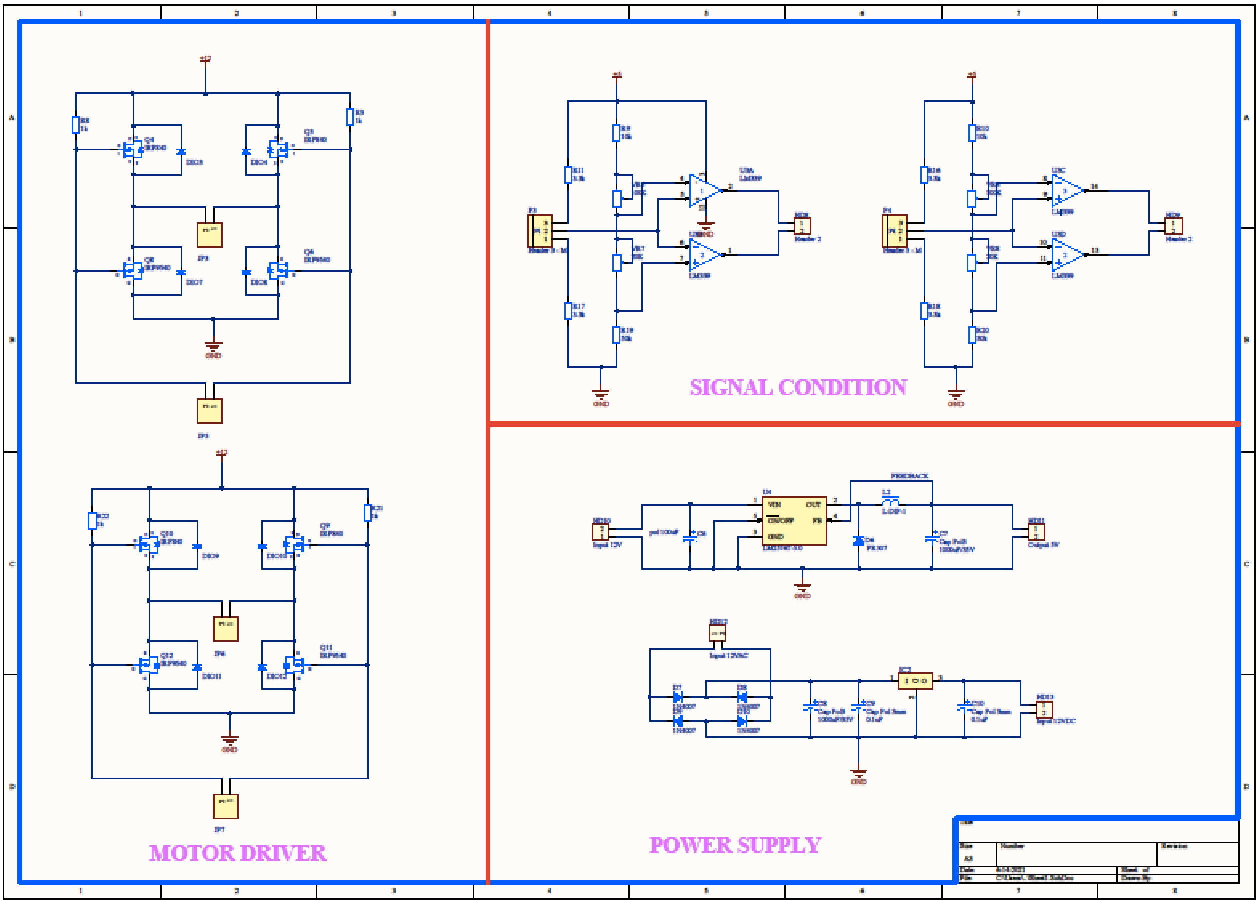


Figure 31: System of Solar Tracker

- **Power supply**

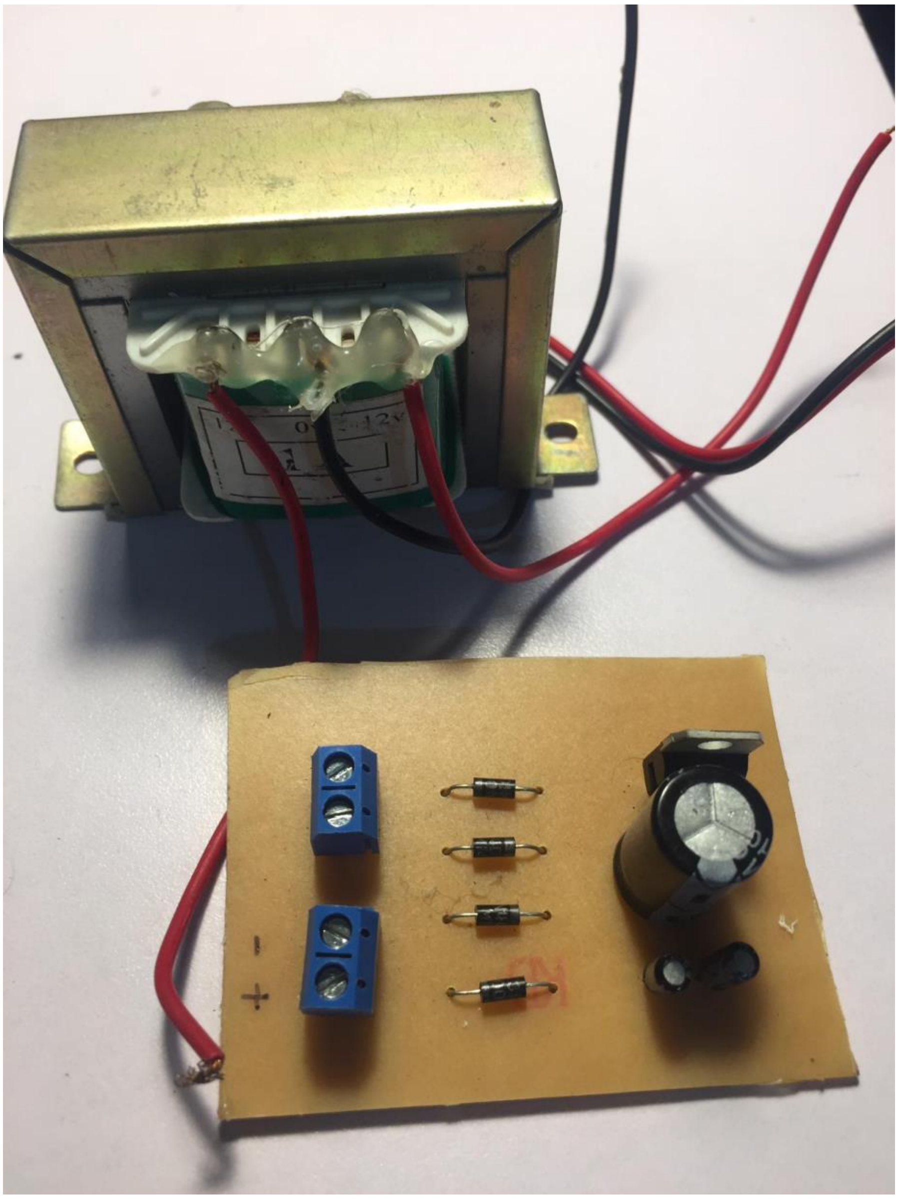


Figure 32: AC-DC converter (220VAC – 12VDC) circuit

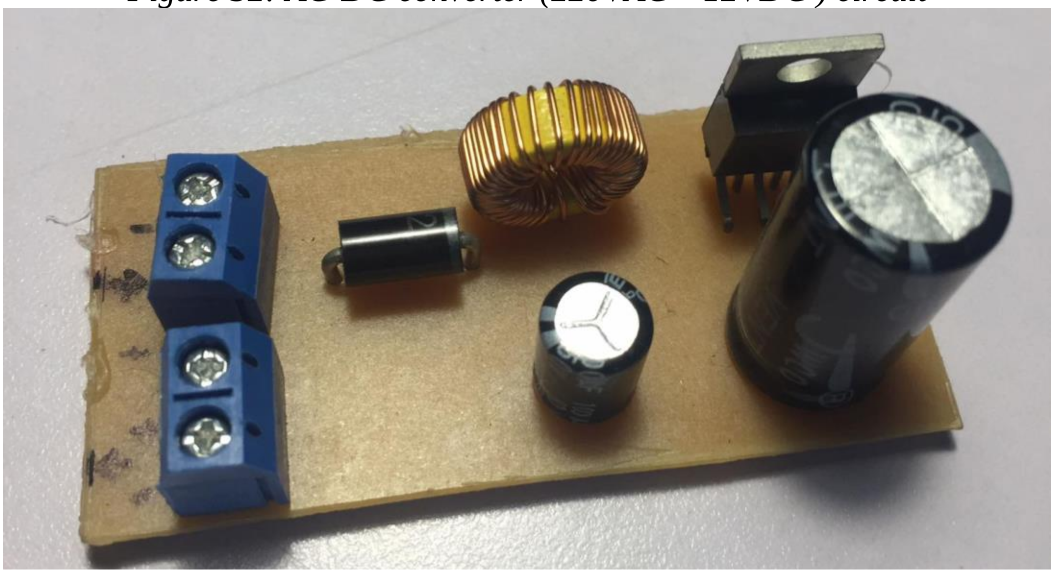


Figure 33: DC-DC buck converter 12VDC to 5VDC circuit.

- **Signal conditioning circuit**

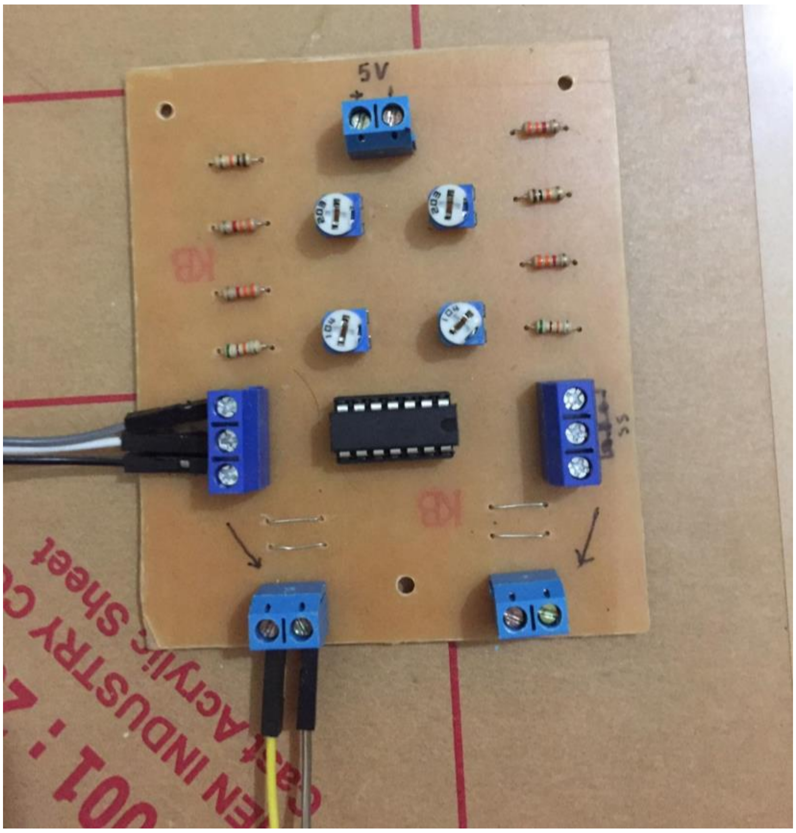


Figure 34: signal condition circuit

- **Motor drive circuit**

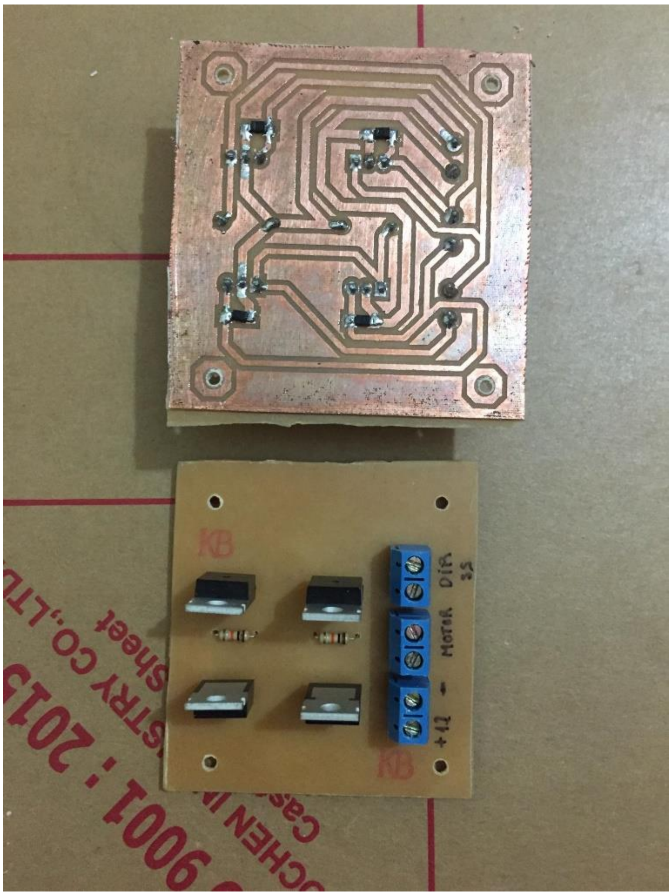


Figure 35: Motor driver circuit.

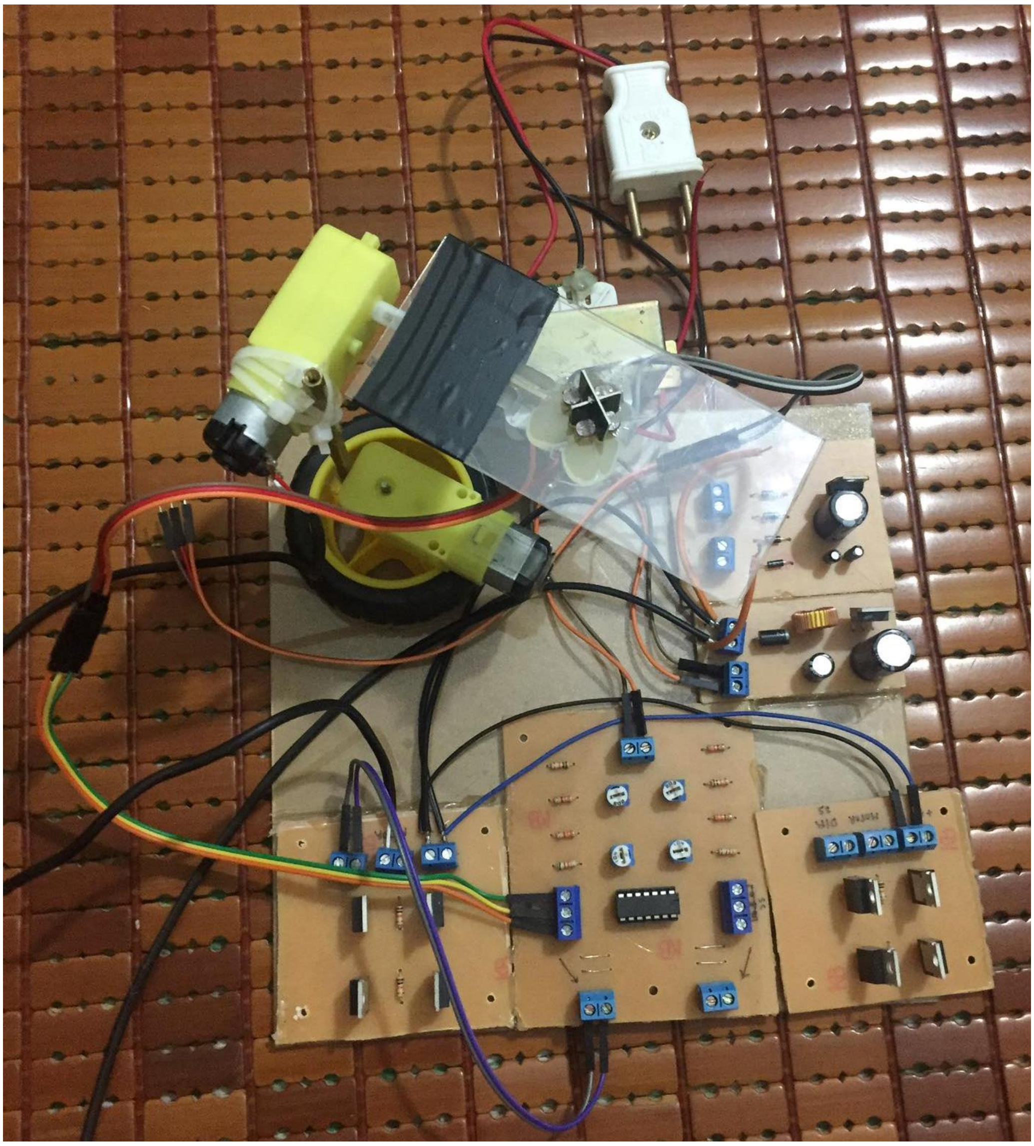


Figure 36: Dual axis solar tracker system

- **Video (youtube Nguyễn Tuấn Hùng)**
  https://youtu.be/6mvmfFFhz8w

REFERENCE

[1] Dual Axis Solar Tracker Explained In youtube
https://www.youtube.com/watch?v=Q7smbj3Yt3M