PHYS 3330: Sun Tracking Solar Panel

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1 Motivation

For our project we created sun tracking system for a solar panel. Our interest in this project stems from a desire to investigate applications of electronic circuits used in industry, and in particular in Aerospace. This project will allow us to apply the circuits and methods developed earlier in the class to a real world problem. By developing this product, we will be, at a high level, developing the same circuit and logic needed for solar tracking used on satellites. We chose to develop this project with analog circuitry rather than a microcontroller, due to the greater reliability, to mimic the circuitry needed on orbit. Furthermore, this product could also be used for power generation on Earth, particularly in the context of an increasing prevalence of clean energy sources.

2 Initial Design

Our initial circuit design consisted of a LDR (light dependent resistor) voltage divider, the output of which lead to dual comparators. The output of these comparators then lead to a H-bridge motor driver.

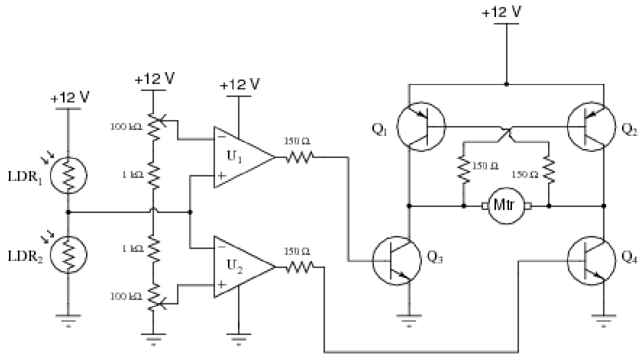

Figure 1: Initial circuit schematic.

2.1 Light Detection

The light detection circuit contains three sections: a LDR voltage divider, a tunable voltage divider, and two comparators.

2.1.1 Light Detecting Resistor Voltage Divider

This the light detection portion of the circuit. With more light, the resistance of the LDRs goes down.

Lighting	LDR1	LDR2
Dark	~2 Mohms	>1Mohms
Room	5.5 kohms	5.5 kohms
Phone	0.6 kohms	2 kohms

Figure 2: Initial LDR voltage divider output

This means that the output of the LDR voltage divider is as follows.

$$V_{out} = V_{in} * \frac{LDR2}{LDR1 + LDR2} \tag{1}$$

With a input voltage of 10V, this gave the following results as expected.

LDR 1	LDR 2	V_{out}
Light	Dark	~10V
Dark	Light	~0V

Figure 3: LDR voltage divider truth table

2.1.2 Comparators

The goal of this portion of the circuit is produce two voltages that depend directly on the amount of light on their corresponding LDR. Each comparator will compare its + and − inputs. If the − input is higher than the + input, the comparator will output a high value. Comparators operate on a range so that the output will range from zero to V_{power}.

The first comparator, U_1, compares V_{out} from the LDR voltage divider and V_1 from the second voltage divider. This will go to "high", closer to V_{power} when V_1 from the resistor voltage divider is higher than V_{out} from the LDRs. The second comparator, U_2, compares V_{out} and V_2. This output will go "high" when V_{out} is higher than V_2. This means that when LDR1 is dark, V_{out} will be close to zero and U_1 will output a higher value while U_2 will output a lower value. When both lights receive equal light, the outputs should be equal.

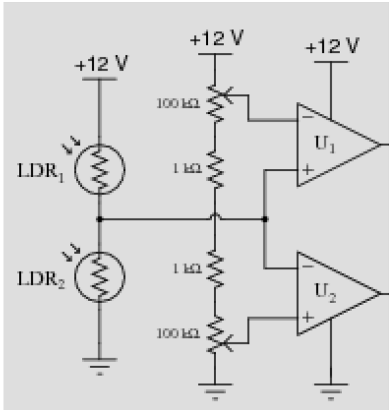

Figure 4: Comparator Circuit

Unfortunately, these did not work as desired. We could "tune" the potentiometer voltage divider to allow U_1's output to be correct, 9.38V, when LDR1 was dark. With this setting and LDR2 dark, U_2's output was only a max of 5V. For the H-bridge motor to properly work, the two outputs need to be equal with equal light. We were finding this very difficult to do with the great precision of the LDRs. This was the first reason that we decided to use a servo motor instead of the normal DC dependant motor.

V-	V+	Vout
1	0	1
0	1	0
1	1	1
0	0	NA

Figure 5: Comparator truth table

2.2 Motor Driver

Initially we decided to use a simple BJT H-bridge to drive a DC motor that would then be attached to our solar panel. The output from each comparator would allow current to flow through select transistors, causing the motor to move in a given direction (see Figure 6).

To have a successful sun tracking circuit, however, we need the motor to at most rotate 180° but with this motor driver the solar panel would continue to rotate in the direction that was receiving the most light instead of fixing at the position of highest intensity. To overcome this problem, the LDRs would have to be mounted on the solar panel so that they could constantly supply feed back to control the position of the panel. Due too the speed at which the motor would rotate, however, the circuit would not be able to respond fast enough to the changes in angular position and was determined that this was not a feasible solution. As such we looked for solutions to having motion that was more finely controlled for both position and speed, and that could function with static LDRs. From

Q1	Q2	Q3	Q4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor coasts
0	0	1	1	Motor breaks
1	1	0	0	Motor breaks
1	0	1	0	Short circuit
0	1	0	1	Short circuit
1	1	1	1	Short circuit

Figure 6: Truth table for H-bridge motor rotation.

this, we decided to switch from a DC motor to a servo motor, to meet these requirements.

3 Final Design

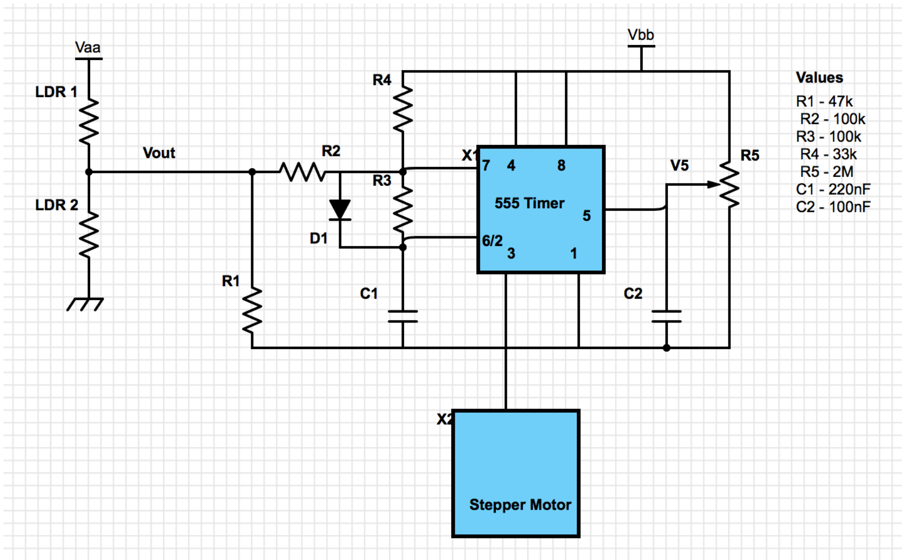

Figure 7: Final Circuit Schematic

3.1 Light Detection

In our final design, we just used the LDR voltage divider without the comparators. When we first switched to using the servo, we researched a motor control circuit that took two inputs (Figure 8). This would have allowed for inputting the two signals from the comparator. This did not work for two reasons. As already mentioned the two output voltages from the comparator circuit could not be tuned to be balanced. Secondly, the voltage divider in the motor control would have been broken. This circuit would not have operated with our two inputs.

We then realized that we could simply use just the LDR voltage divider to control the servo. This would provide only one input voltage into the servo control circuit, which is what we needed.

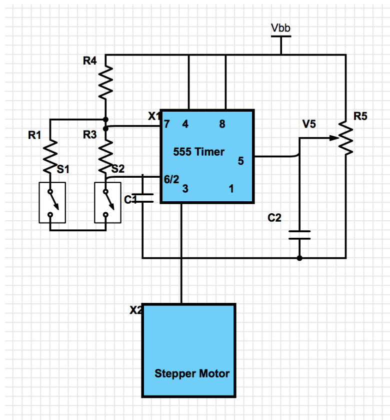

Figure 8: Initial Servo Motor Control

3.2 Motor Driver

As discussed in 2.2 there were inherent flaws in using a DC motor. As such, for our final design, we opted to use a servo motor. This would allow us to have precise position control of the solar panel. In addition, our LDR voltage divider could remain static as the input only depends on the weighted voltage from the direction that has the highest light intensity. The operation of servo motors, however, is significantly different than that of a DC motor. As such, altering our circuit to incorporate this change took quite a bit of research and modification to our original schematic.

3.2.1 Servo Theory

Unlike DC motors, servo motors hold a fixed position rather than constantly spinning. The orientation they hold, is dependent on the signal that is supplied to them. This signal is a pulse width modulation (PWM). For the servo we used (Futaba S3003), the required PWM is a 20ms signal that has a high duty cycle of 1-2ms. This duty cycle then changes the position of the servo between one extreme or the other.

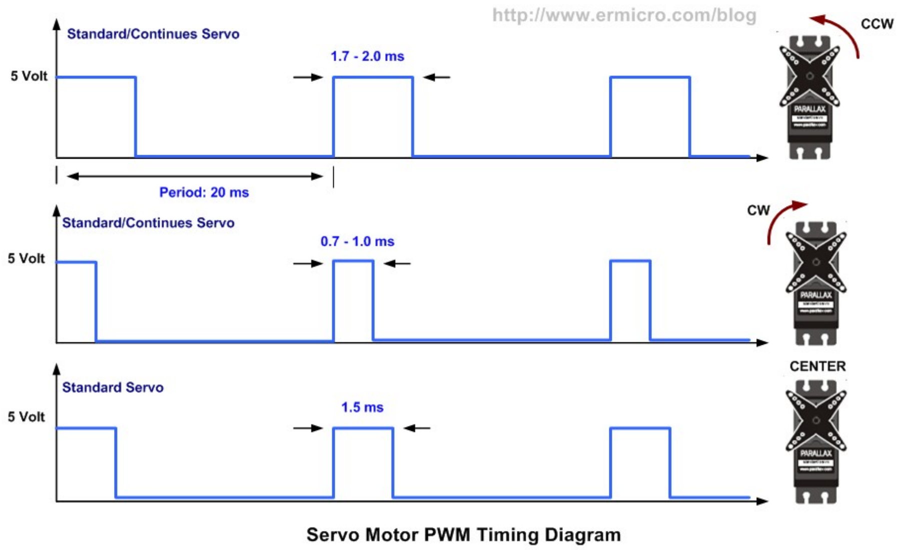

Figure 9: PWM servo control.

For the servo we used, in particular, the angle could be driven from -60° to 60° from center depending on the PWM. So, while this method of control gave us the positioning we needed for the solar panel, we had to develop a system to convert the output of our light detecting portion of the circuit, into a PWM.

3.2.2 555 Timer Component

We concluded with using an astable 555 timer to be our PWM. This is the same state discussed during the earlier experiment in this class. The astable timer produces a square wave with two time periods, T for low voltages and t for high voltages. The main difference in our circuit was the addition of a potentiometer connection to pin 5. This allows for the time constant to be adjusted without changing the actual components. Changing the pot affects two things: range of angle and centered position.

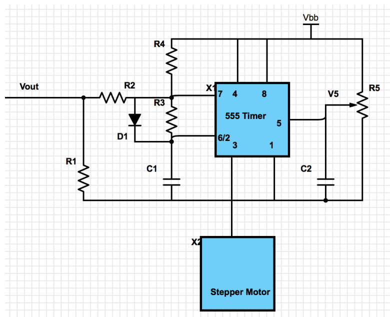

Figure 10: Final Motor Control

3.2.3 Predictions and Data

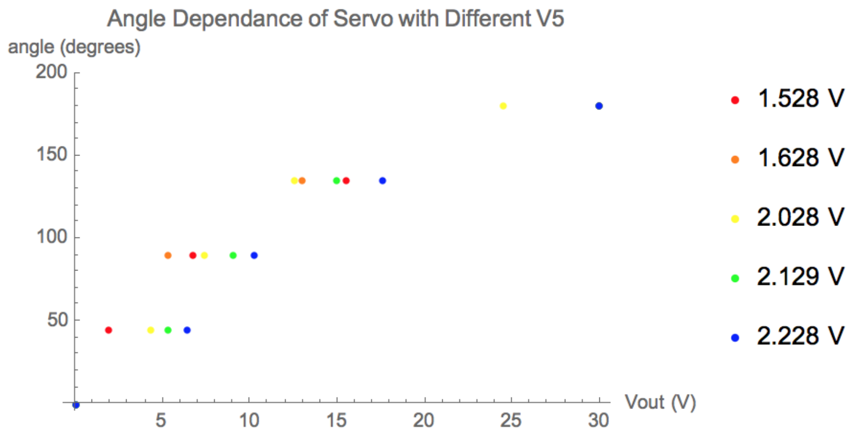

Figure 11: Angle Dependence on Pot

We expected the servo to turn from 0° to 180° with input voltages of 0 to 10V. This was not the case. The servo motor would normally go a range of about 140° with a voltage range of 0 to 15V. While this was different than our predicted voltage, we were able to adjust to it. First, we realized that our servo was not designed to go a full 180°, but 90°. So our slightly increased range of 140° was good. Secondly, we simply adjusted our power voltage into the LRDs to be 15V. This made V_{out} to output a range between 0 and 15V as shown below.

LDR 1	LDR 2	V_{out}
Dark	Dark	0.13
Dark	Room Light	0.037
Room Light	Dark	11.44
Room Light	Room Light	5.8

LDR 1	LDR 2	V_{out}
Dark	Dark	0.13
Dark	Phone Light	0.001
Phone Light	Dark	14.94
Room Light	Room Light	5.8

Figure 12: Output of LDR Voltage Divider with Vpp=15V

As seen in Figure 12, with intense light from a phone, the LDR voltage divider gives the exact desired range.

Even with these adjustments, the pot still could be used for adjusting the motor's angles and center. We took measurements to see how the waveform acted with changes in the poteniometer. These show how much the short period of the wavelength can be affected by the voltage at the pot.

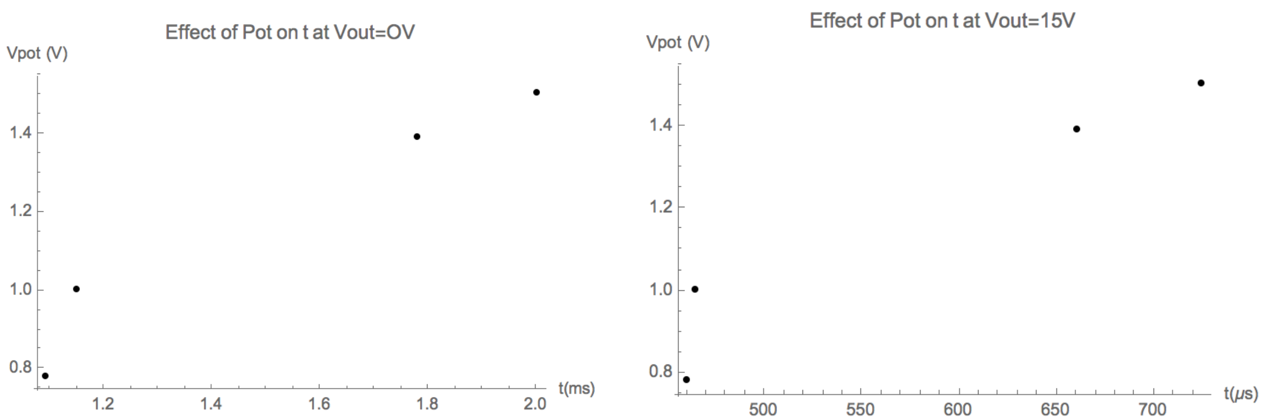

Figure 13: Period Dependance on Voltage at the Potfor Vout=15V

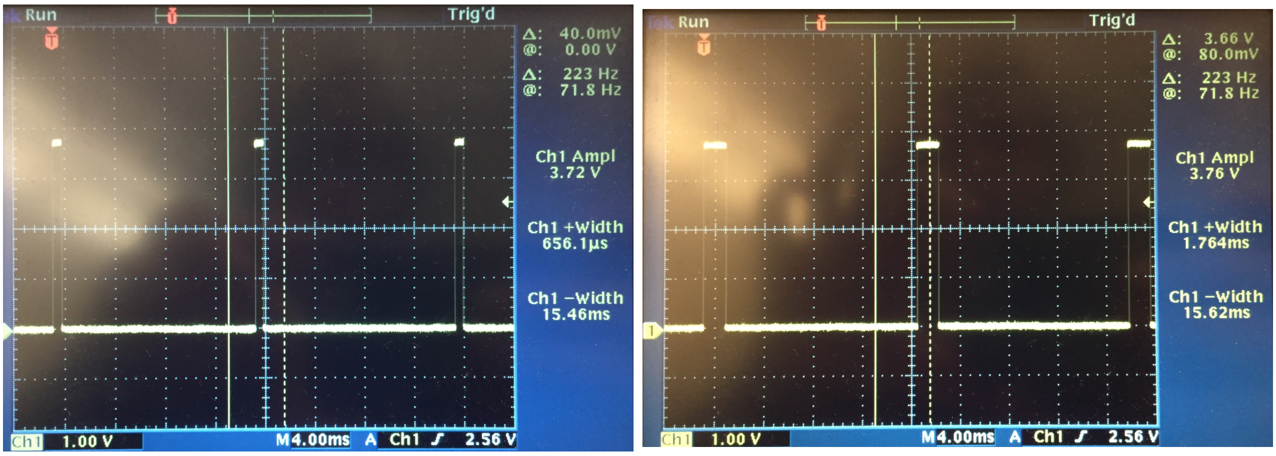

Figure 14: Waveform going into servo at Vout (of LDR) = 0V and 15V

Ideally there would be a linear relationship between the input voltage to the 555 timer and the PWM produced. This would then correlate to a linear relationship between the output from the LDR voltage divider and the angle that the servo took on, which was our end goal.

As seen in Figure 15 the relationships are not quite linear as we idealized, due to the 555 timer circuit weighting lower voltages to have a larger PWM change. This causes our horizontal solar panel angle to occur around a $Vout = 4.5V$ in our range of $0V - 15V$.

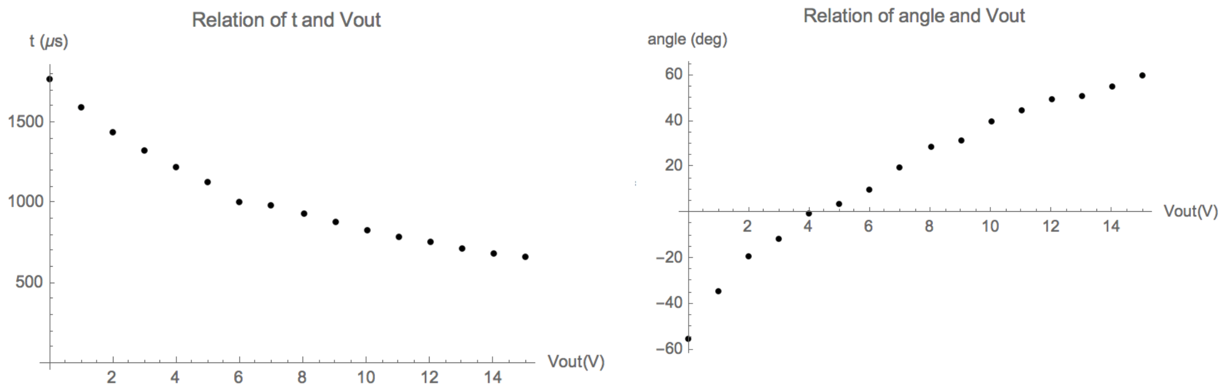

Figure 15: Dependance of PWM (left) and servo angle (right) to output voltage from LDR divider.

4 Final Results

The main goal of this circuit is to produce more voltage by allowing more light to hit the solar panel.

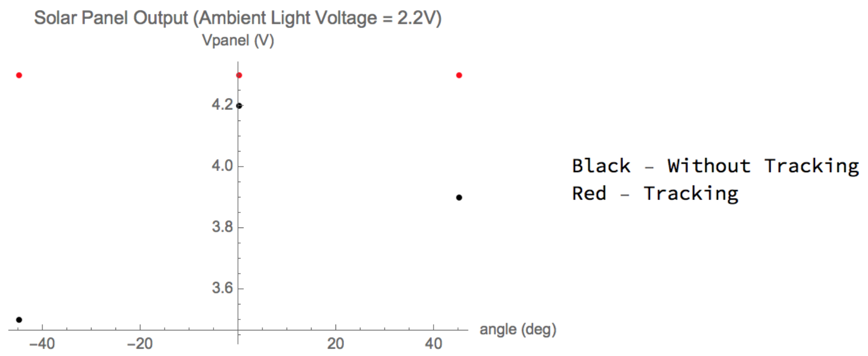

Figure 16: Solar panel output with and without tracking

As seen in Figure 16, there was a improvement in the solar panel's output with our tracking circuit. We had taken this same measurement with a much higher ambient light, and the data showed less of a difference as seen in Figure 17.

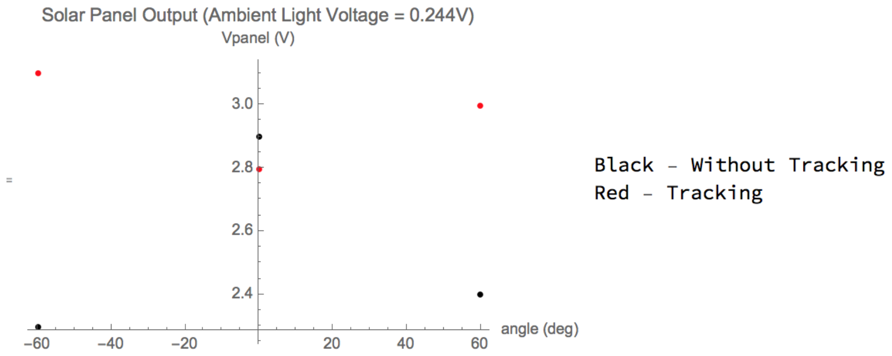

Figure 17: Solar panel output with and without tracking with increased ambient light.

We took this measurement by putting a phone's light on the solar panel from the angles at equal distances. For the tracking measurement, we put the panel to the furthest angle by lighting only one detector. A different method of measurement could have decreased error to give a better result. It would have been better to be able to better replicate the motion of the sun. Overall, our results did show an improvement in output voltage by using our circuit.

5 Extensions

Given more time and resources, there are some improvements and modifications for the future direction of this project.

The first improvement, would be to correct for the non-linear relationship between the input voltage to the 555 timer circuit and the generated PWM. To do this, we would likely add a log amp in between the output of our LDR voltage divider and the input to the 555 timer circuitry. By doing this, the relationship between the divider output and the PWM will be linear, ultimately making the relationship between the divider output and the solar panel angle linear. The only other change associated with this, would be to then adjust the 555 timer potentiometer to once again have sensitivity to around thee right voltages.

In addition, an extension to this project would be to create a duplicate circuit to give the solar panel the ability to move along two axes. The only change, however, is that the servo that controls the orientation (rather than the angular control that we built in this project) would have to have 180° rotation to be able to track the entire sky.

Lastly, with aforementioned improvements, it would be the ultimate goal to modify our circuit to have the sensitivity to track light from the sun (rather than our test light source) in ambient daylight to test the feasibility of creating our circuit on a industrial scale for use in solar plants. Along these lines, it would by interesting to test our circuit in solar conditions as those experienced in different geocentric orbits in order to tests the circuits practicality for use on satellites.

6 Conclusions

As shown in this report, we were able to develop a functioning light tracking circuit, that met our initial design goal. In this project we incorporated several concepts that taught throughout PHYS3330. Furthermore, we expanded on these fundamental concepts to to meet our needs and to integrate them into a fully operational circuit. Throughout the many phases of this project, we used our knowledge from the class to realize the steps needed to go from an initial design goal to a final product, while overcoming the many design challenges in between.

7 Project Division

During the building of this project, we worked together. There were about two occasions that we collected data individually, but building was always done together.

For the report, we split the sections between us. Those sections were as follows:
Shayla Cogan - Both sections on light detection, section on the 555 timer, and solar panel data.
Robert Sewell - both motor sections, section on the servo, extensions, and conclusion