Project Manual

Group Members Names:

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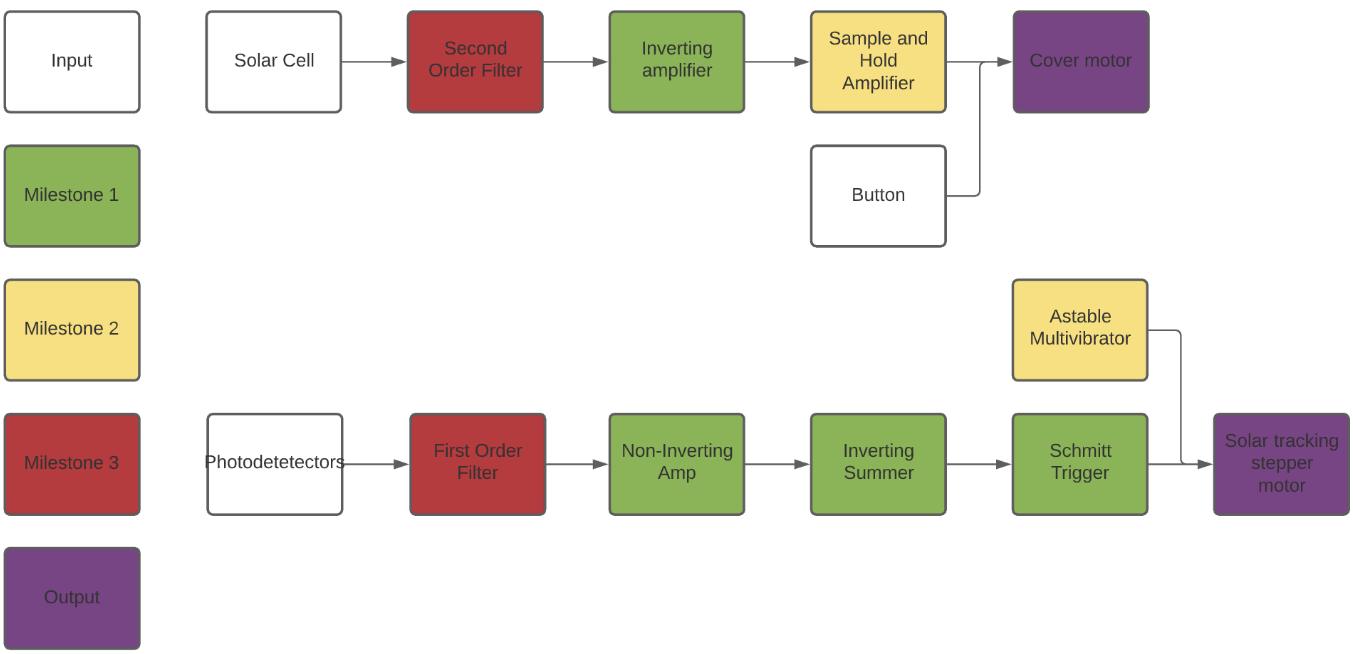
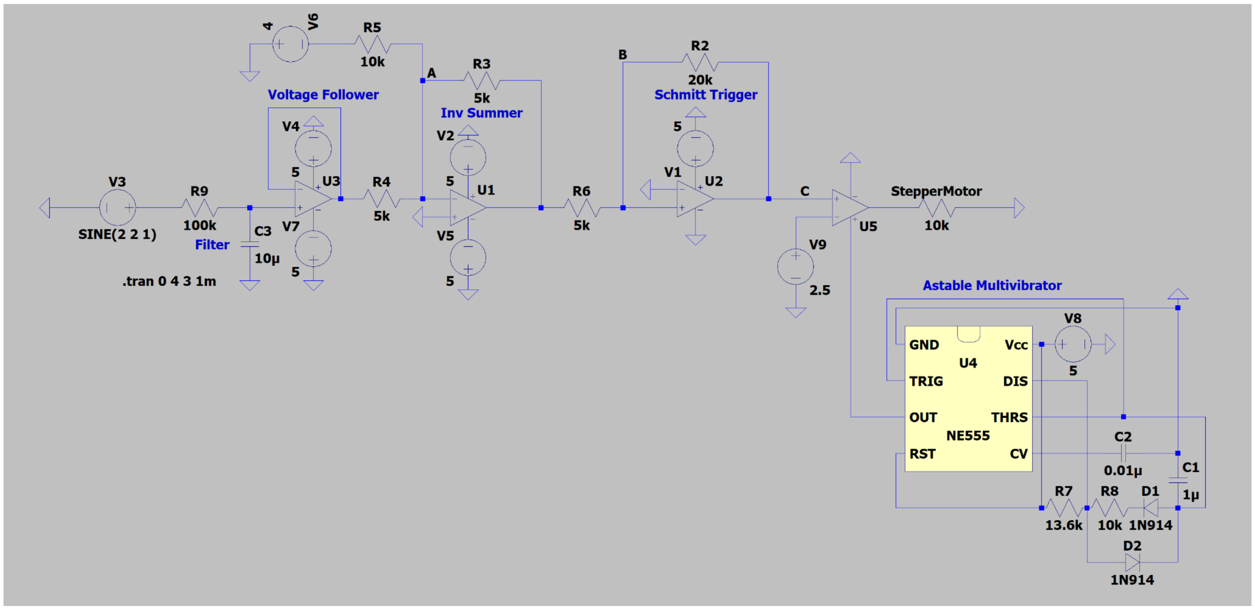
Description

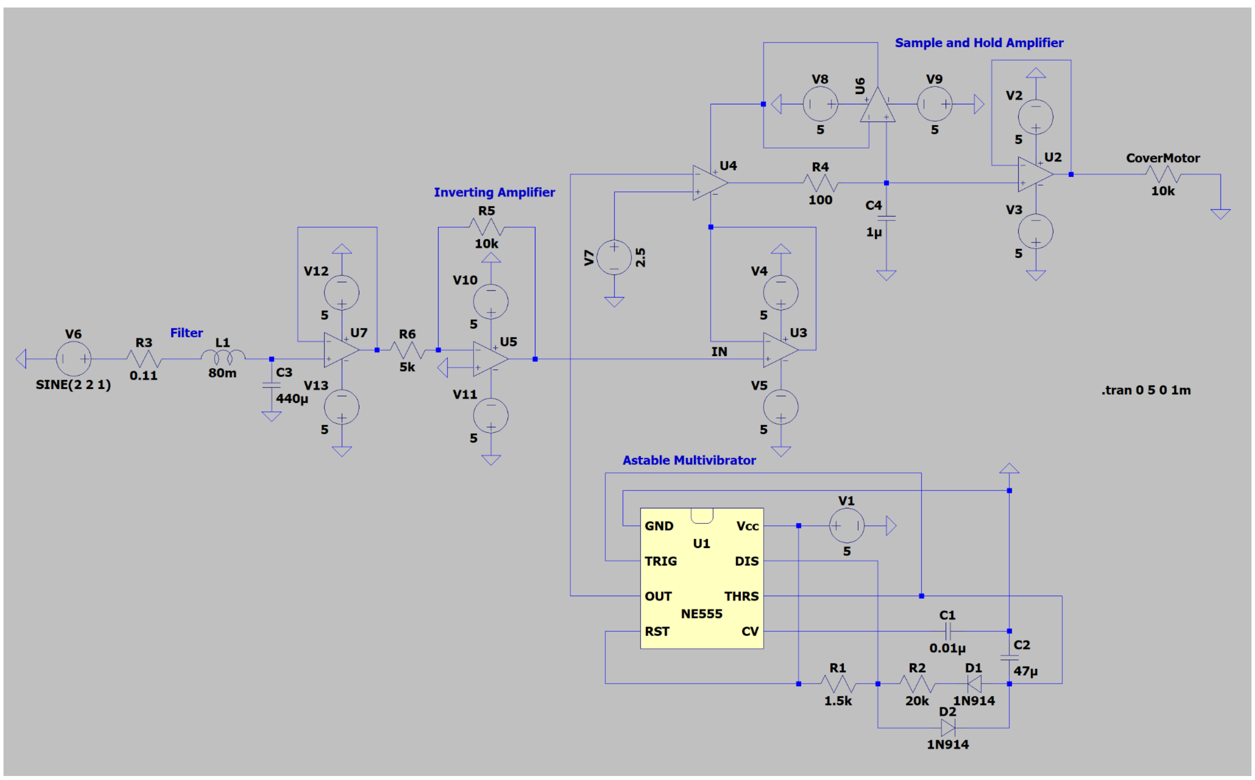
Block Diagram



Schematic for Stepper Motor Circuit



Schematic for Cover Circuit



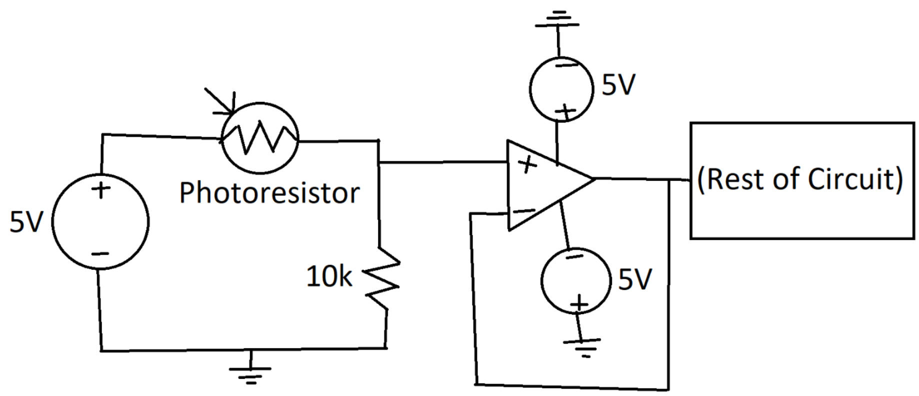
Description

The circuit will allow for a solar panel to track the sun using photodetectors to sense light and motors to adjust the angle of the panel. It will also allow the panel to cover itself to prevent dust build-up for uses in environments like the surface of Mars. Solar tracking will be achieved by placing photoresistors behind the panel in a configuration that leaves them in the shade when the panel is correctly aligned. When the sun moves, it will expose a photoresistor to sunlight, which in turn activates a motor and realigns the panel until the photoresistor is once again in the shade. Cover motor activation is achieved by measuring the voltage provided by the panel, and when it drops low enough (as a result of less sunlight hitting it from dust), the cover will be deployed to protect the solar panel from further buildup.

The sun-tracking system allows for the solar panel to maximize its energy output because it ensures that the maximum amount of sunlight is always hitting the surface. Systems like this already exist in the real world due to the amount of energy they save. Some studies have shown that without consistent rain, solar panel efficiency can be reduced by around 10% due to dust buildup. (Source) On a planet like mars with frequent dust storms and no rainfall, this would be an even bigger problem. The most resource efficient system would be to not let the dust build up in the first place, which is the purpose for the addition of the cover.

Operation and Design

Input Block

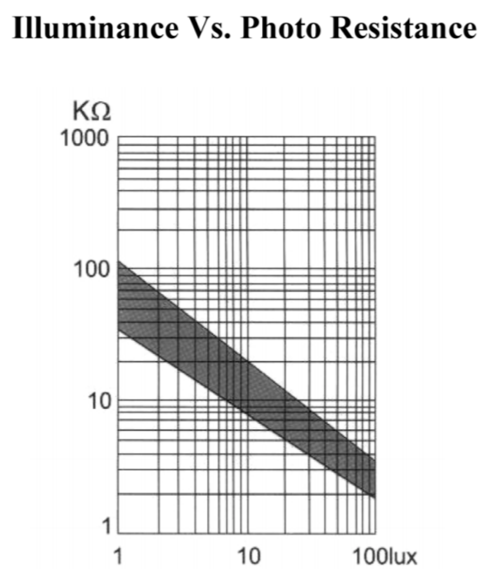


Design Equation

Our first input is the photoresistor setup shown above. Since there is no well known equation between input light intensity and resistance, this cannot be written as an explicit equation, however we know that as light intensity increases, photodetector resistance decreases, thus increasing the voltage across the 10K resistor and the value of V_{IN}, the voltage output by the isolating amplifier.

Our second input will simply be the voltage output of the solar cell.

Approximate Input/Output Plot:

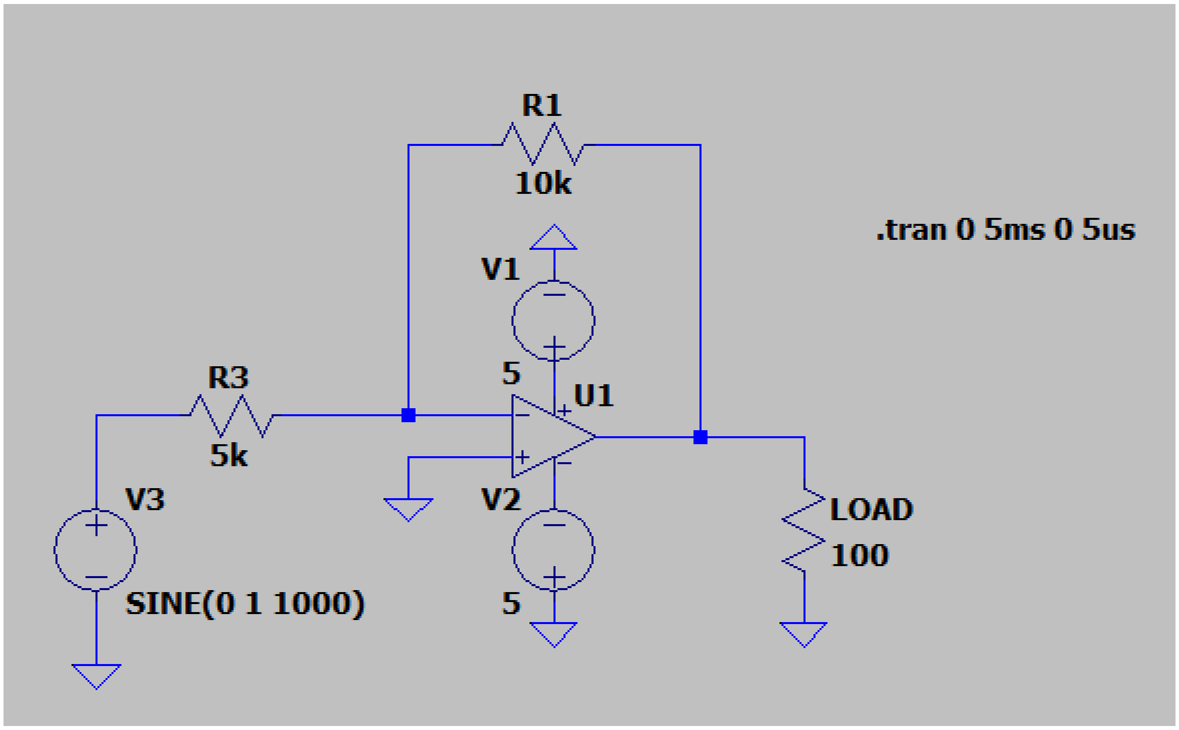


(Source: https://cdn.sparkfun.com/datasheets/Sensors/LightImaging/SEN-09088.pdf)

(Note: for ease of simulation, the input circuit was replaced by a sinusoid with a similar range of voltages. This allows us to see the circuit's behavior for the full range of inputs with one simulation)

MS1 Building Block 1: Inverting Amplifier

Schematic



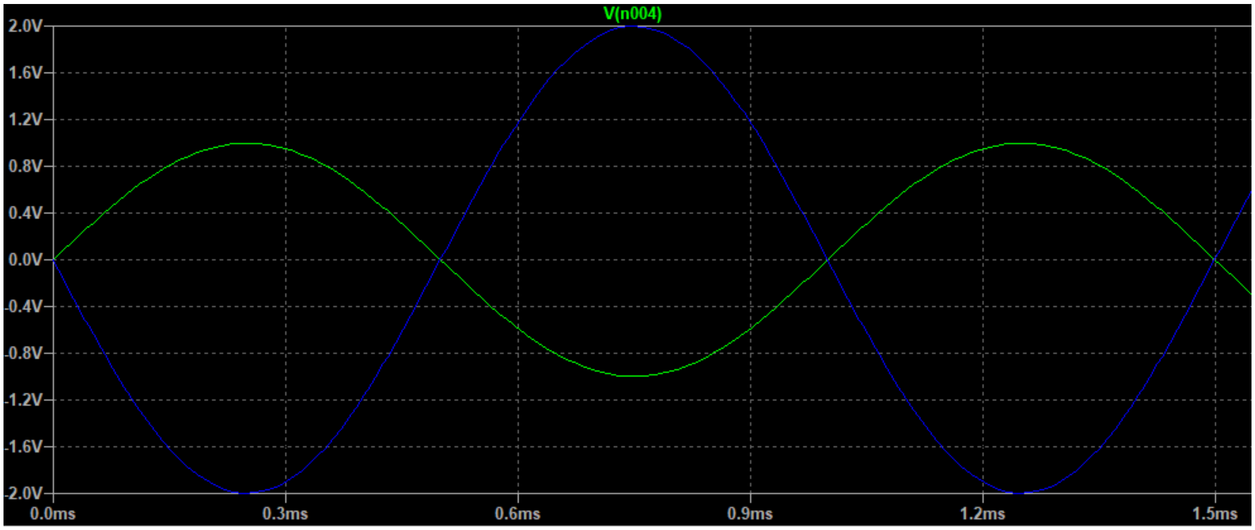
Design Equation

$$V_{out} = \frac{-R_1}{R_3}$$

Discussion of Component Choices

Because we need this amplifier to have a gain of two, we selected our resistances to have a 2:1 ratio between R1 and R3. We chose 10k and 5k so as to reduce current draw and potentially reduce power draw, which may be an issue due to the number of Op-Amps that we are using in the rest of the circuit.

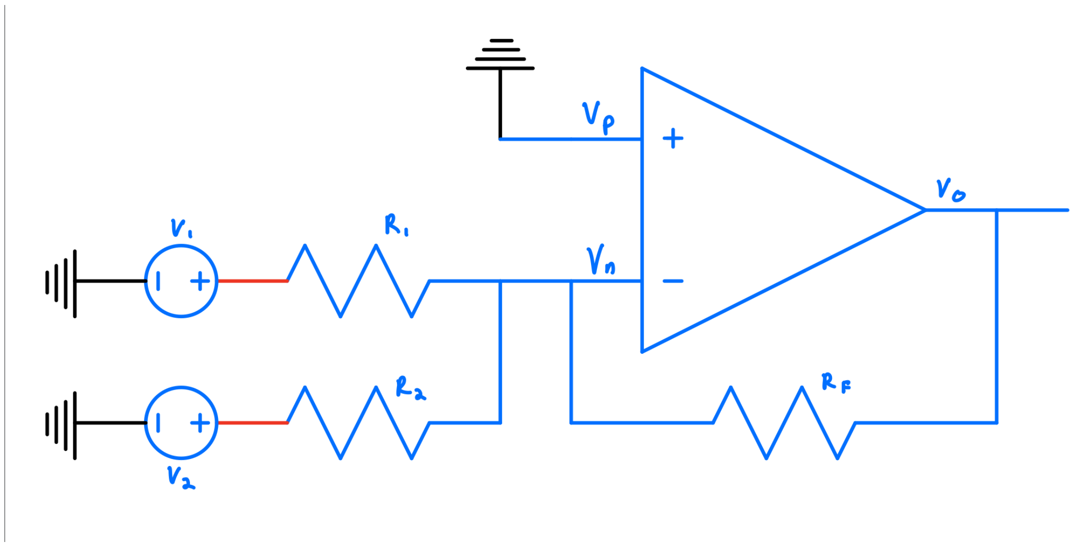
Plot of Simulated Input (Green) against Output (Blue)



The inverting amplifier is working as intended, with the output inverted relative to the input, and with twice the amplitude.

MS1 Building Block 2: Inverting Summer

Schematic



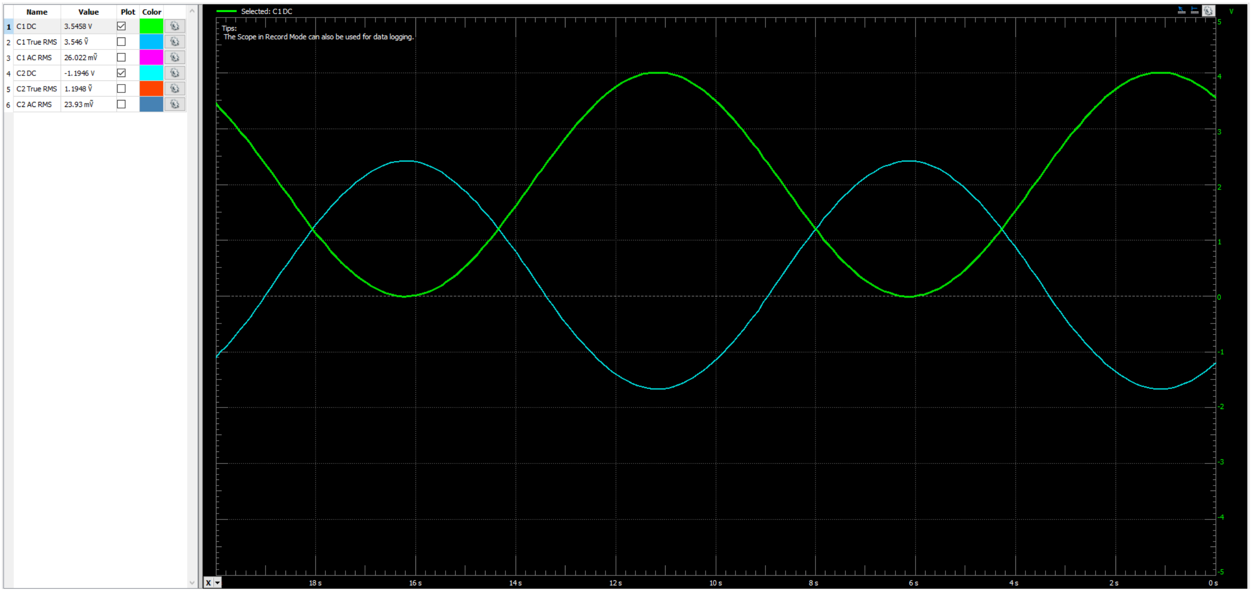
Design Equation

$$V_{out} = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)$$

Discussion of Component Choices

The inverting summer combines the voltage from the input and a negative DC source voltage. The goal of this is to shift the input voltages into a range that will cross the threshold voltages of the Schmitt trigger. As we did not want the range of values from the input to change (i.e. wanted to keep 4V from maximum to minimum), The resistor connecting the isolated input to the negative terminal of the op amp, R_1, needed to have the same value as the feedback resistor, R_F . It was found experimentally that the best DC voltage to sum with the input was an equivalent to -2V. To use a value near our already used source of 5V and not need an external power supply, we opted to use a -4V source with a resistor, R_2, with twice the resistance of the feedback resistor, R_F . Then, a multiplier for these values was chosen somewhat arbitrarily, with its final value of 5000 being chosen due to the ease of working with its multiples, and its availability in the parts kit. This gave final values of 10kΩ, 5kΩ, and 5kΩ for R_1 , R_2 , and R_F , respectively.

Plot of Simulated Input (Green) against Output (Blue)



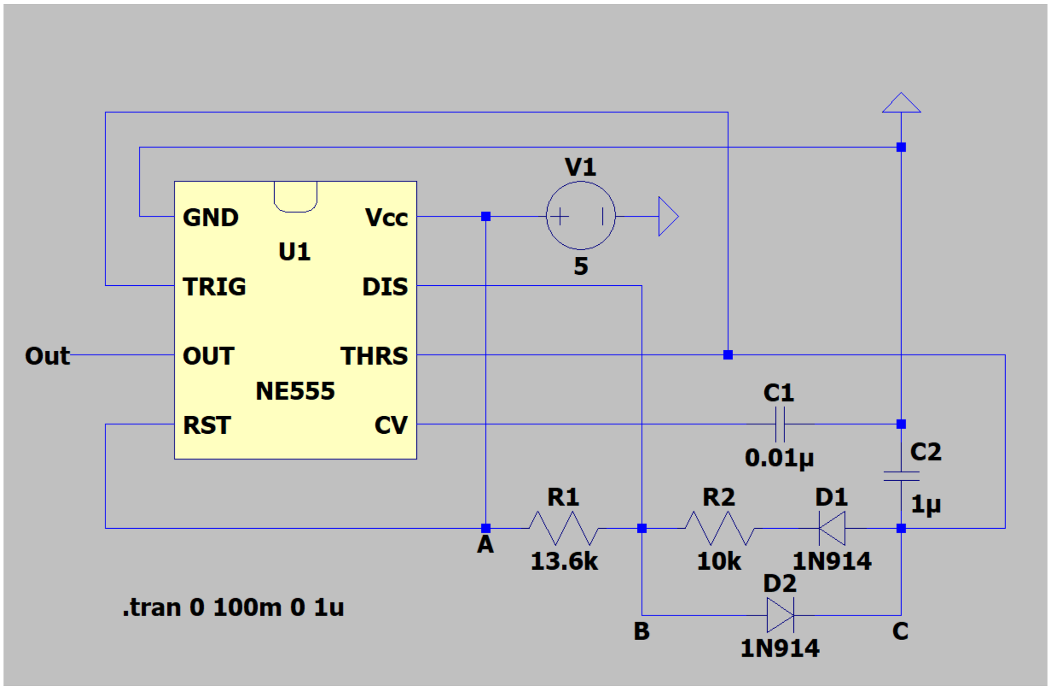
Substituting the component values into the equation: $V_{out} = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)$

Yields: $V_{out} = \ -V_1 + 2$

This allows us to convert our current expected input range from 0 - 4V to -2 - 2V which crosses both thresholds for the Schmitt trigger that will power our motors.

MS2 Building Block 1: Astable Multivibrator

Schematic



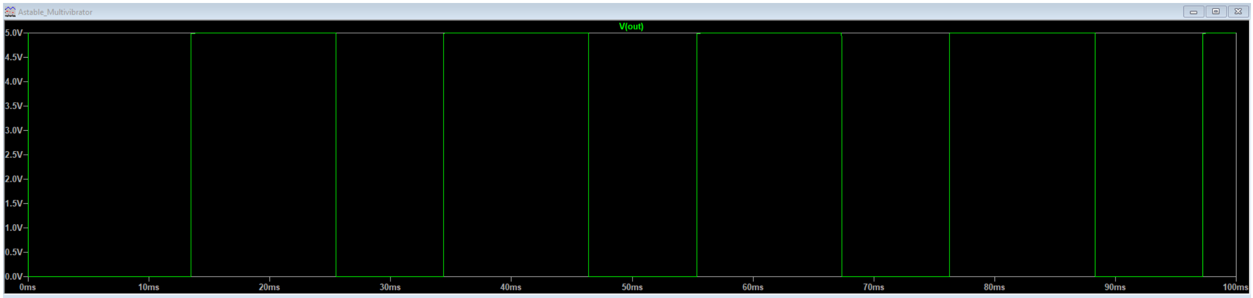
Design Equations

$$\tau_c = R_1 C_2, \ \tau_d = R_2 C_2$$

Discussion of Component Choices

For this Astable Multivibrator, we utilize diodes to control current flow to allow for different resistance through which we charge and discharge the capacitor. This gave us the uneven duty cycle we were looking for and allowed us to control each time constant independently. The resistances of R_1 and R_2 and the capacitance of C_2 were chosen to yield a time constant around 20 ms, while using components that were available in the parts kit or could easily be created (e.g. a 13.6 kΩ resistor can be replaced by 2 6.8 kΩ resistors in series).

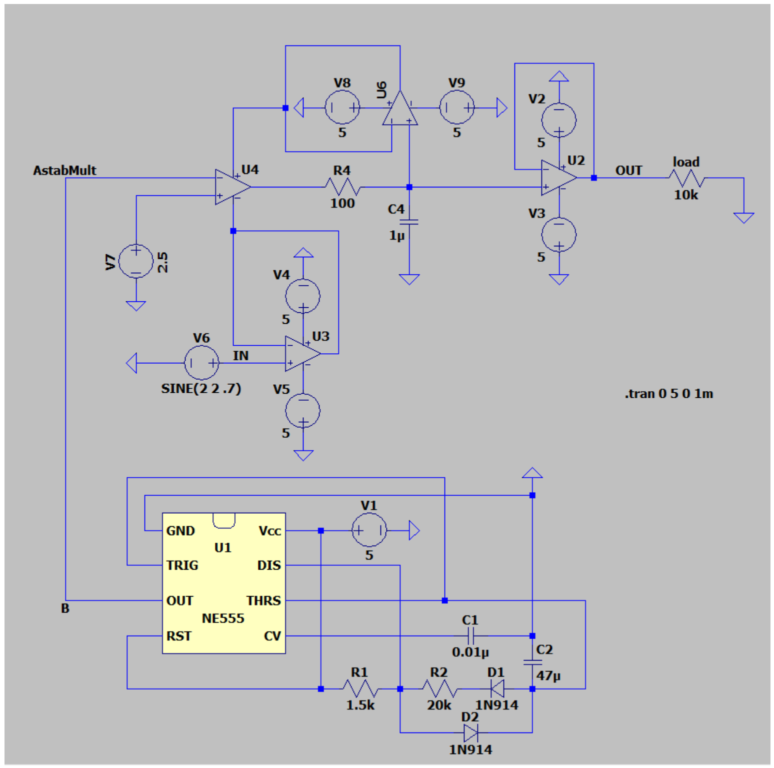
Plot of Simulated Output (Green)



As a result of the varied resistance between nodes A and C depending on the direction of current flow, we see that the signal does not spend exactly half its time high and half low, but is high a bit more than half of the time. This is expected due to the discharge resistance being higher than the charging resistance.

MS2 Building Block 2: Sample and Hold Amplifier

Schematic



Design Equation

While multivibrator output is high:

$$V_{SHOUT} = V_{IN} = 2 + 2sin(1.4\pi t)$$

While multivibrator output is low:

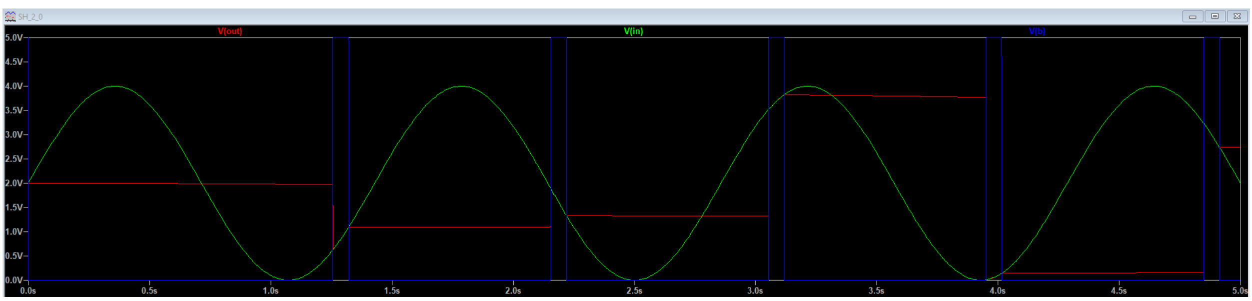
$$V_{SHOUT} = V_{SHOUT}(t_{switch}),$$

where t_{switch} is the time at which the multivibrator output became low.

Discussion of Component Choices

We used three isolating amplifiers to ensure that the system was not being affected by leaks or feedback from any other parts of the circuit. Despite these precautions, there is a significant amount of feedback that we are still attempting to overcome. The primary function of this building block is accomplished by the comparator (U4 in the above schematic), which compares the signal from the multivibrator to a 2.5V control. While the multivibrator's output is higher than 2.5V, the comparator outputs the input voltage, V_{IN}. While the multivibrator's output is lower than 2.5V, the voltage is held constant. This allows the building block as a whole to "sample" the input and then "hold" that value until the next time the multivibrator's output is high. The timing of the sampling was determined in the same manner as the timing for the astable multivabrator used in the sun tracking circuit. For this circuit we wanted a much smaller duty cycle which was reflected in the choice of a much smaller resistor for charging the circuit than discharging it. Then, the total period was decided upon and possible values were then chosen based on availability in the parts kit and their adherence to these design parameters.

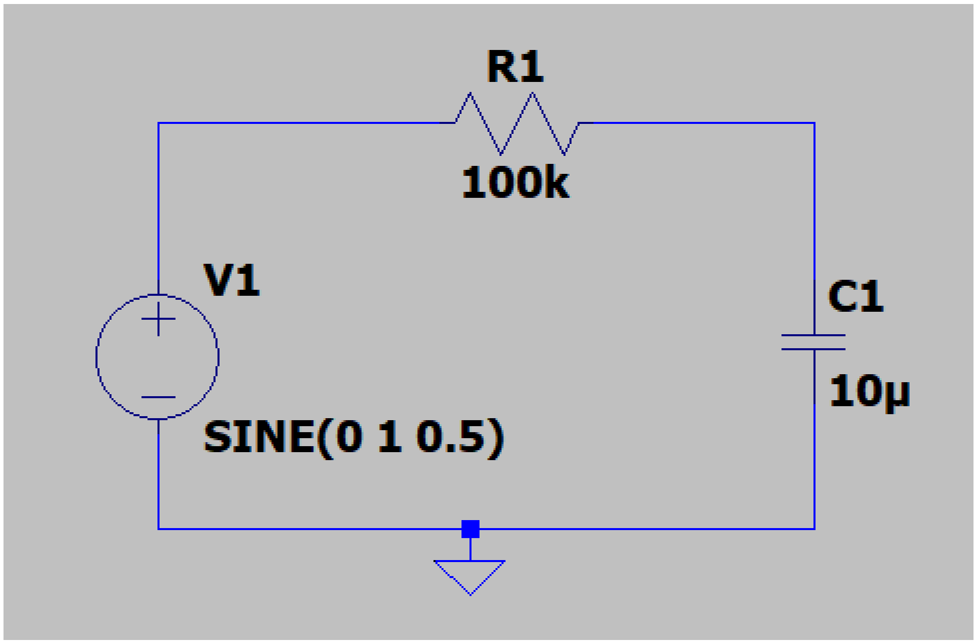
Plot of Simulated Inputs (Green and Blue) vs Simulated Output (Red)



This shows our Sample and Hold Amplifier working as intended, where when the Astable Multivibrator output (blue) is high, the output is equal to the sinusoidal input (green). All other times, the output is equal to the value of the sinusoid at the last time where the Astable Multivibrator was high.

MS3 Building Block 1: First Order Filter

Schematic



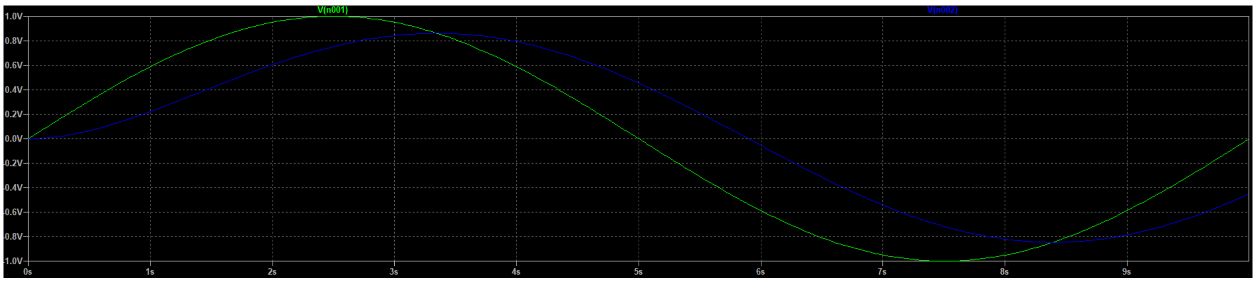
Design Equations

$$\tau = RC$$

Discussion of Component Choices

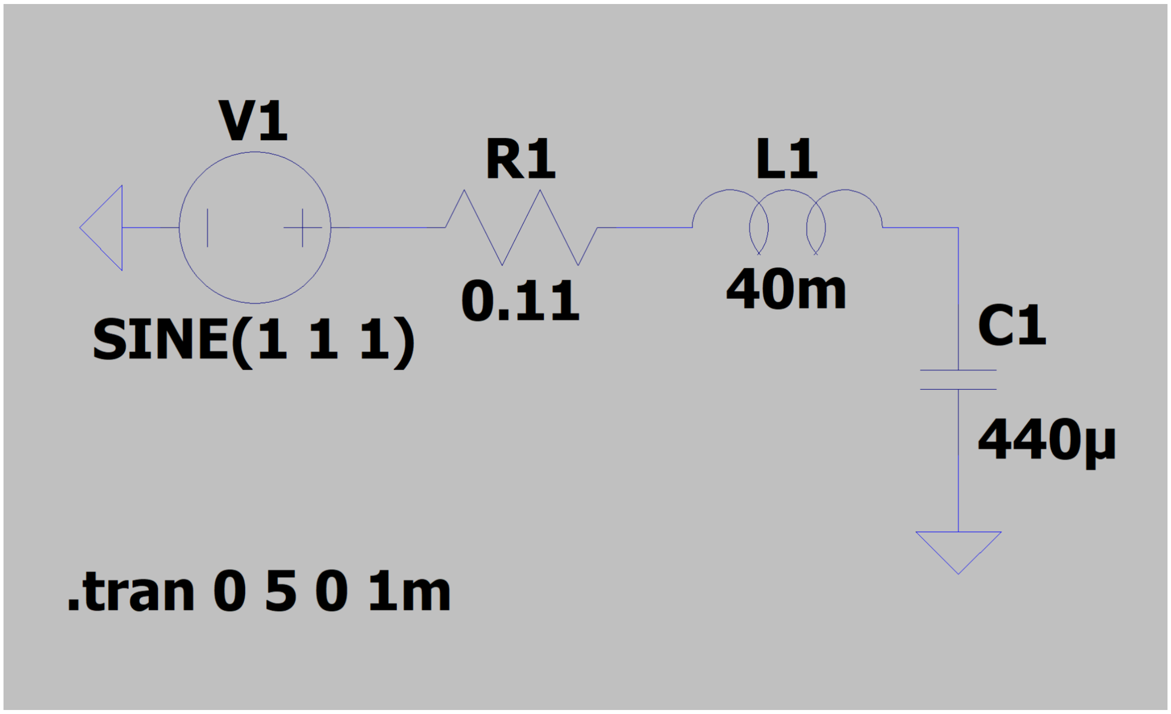
We wanted a filter with a time constant with a time constant approximately equal to 1. This required having the resistance and capacitance values that we used be multiplicative inverses of each other. We simply used one easy pairing from the parts kit with a resistance of 100 kΩ and a capacitance of 10 µF.

Plot of Simulated Input (Green) and Output (Blue)



MS3 Building Block 2: Second Order Filter

Schematic

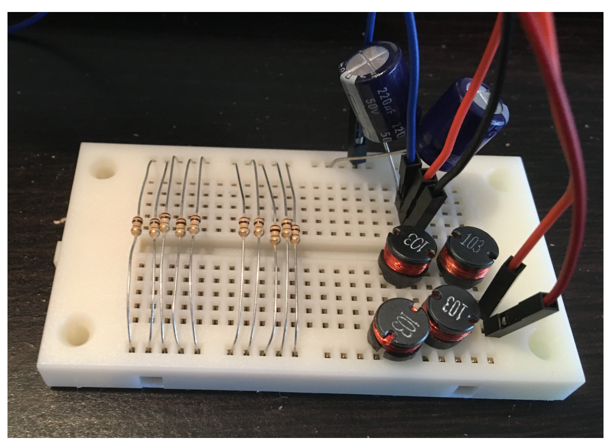


Design Equations

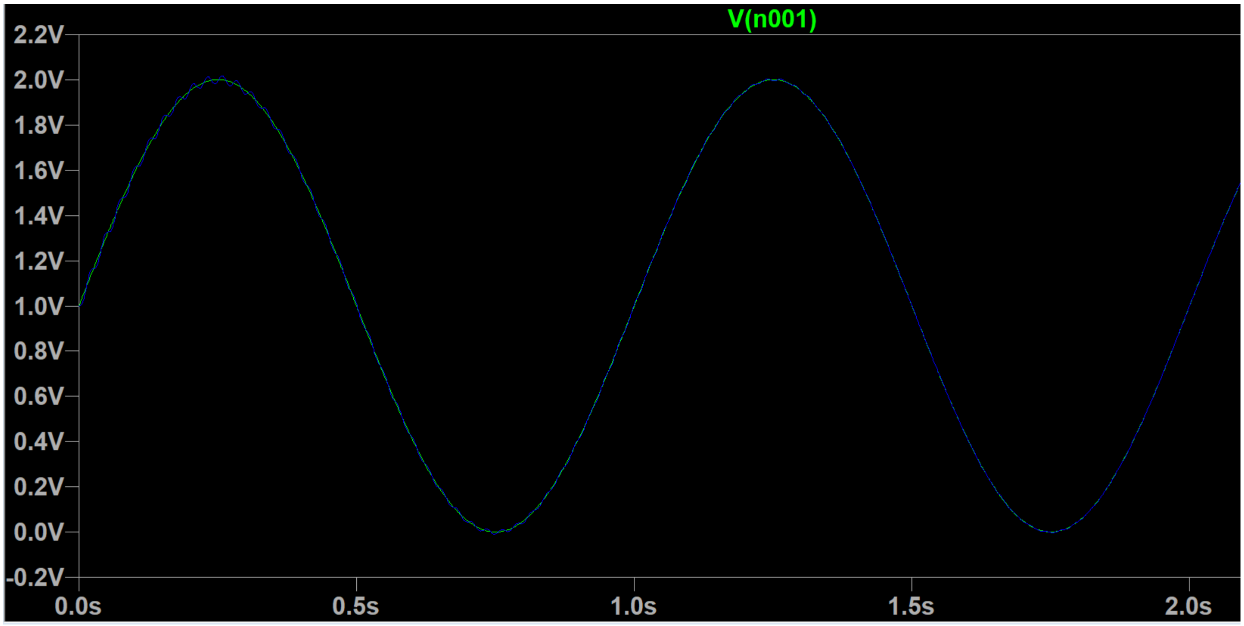
$$\alpha = \frac{R}{2L} \qquad \omega_0 = \frac{1}{\sqrt{LC}} \qquad \zeta = \frac{\alpha}{\omega_0}$$

Discussion of Component Choices

For this circuit our goal was to filter out all frequencies above 1Hz. This was not easily doable with the components available in the parts kit. Because of this, we simply attempted to make a filter with the lowest cutoff frequency that we could. We therefore wanted the lowest resistance, highest inductance, and highest capacitance we could reasonably create. This required combining ten 1.1 Ω resistors in parallel, four 10 mH inductors in series, and two 220 µF capacitors in parallel before placing each of these in series with each other.



Plot of Simulated Input (Green) vs Output (Blue)



Output Block

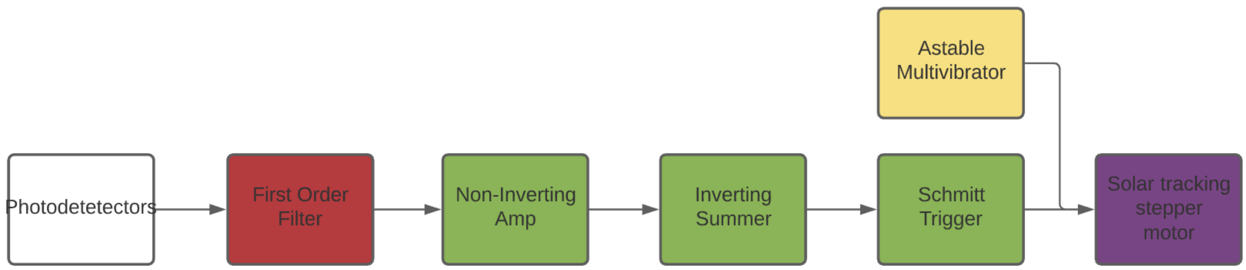
Our outputs are two motors. The stepper motor uses the input from the first subcircuit to control the angle of the solar panel. The DC motor is used to move the cover with the output of the second subcircuit. These each are directly powered and controlled by the subcircuits with no additional circuitry as this was the purpose of the subcircuits.

Integration and Optimization

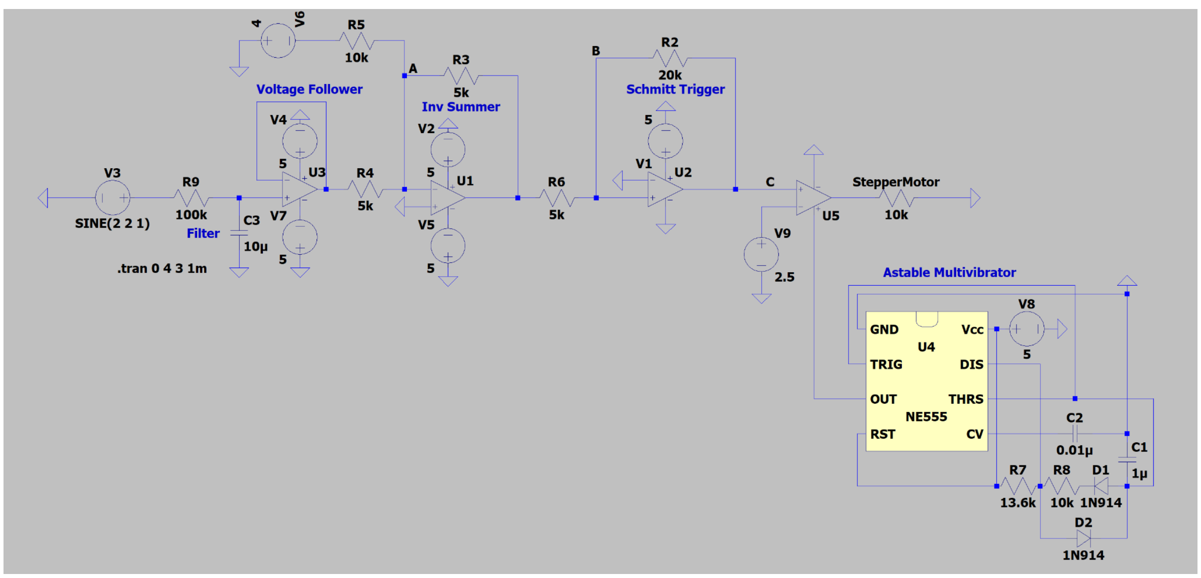
Our project consists of two independent sub circuits: one controlling a stepper motor to allow the solar panel to be moved to follow the sun, and one to control a dc motor that moves a cover over the solar panel.

Sub-Circuit 1: Sun-Tracking

Block Diagram:



Schematic:

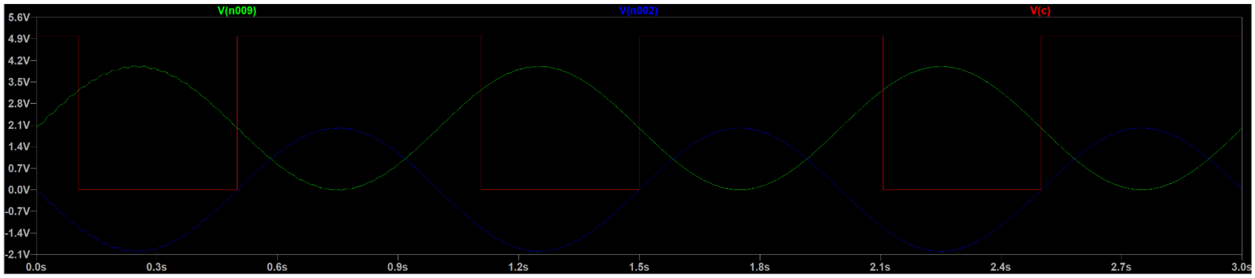


This circuit uses the majority of the Milestone 1 circuitry as well as the astable multivibrator from Milestone 2. This subcircuit converts the signal created due to the light on the photoresistors into a usable form for the stepper motor, allowing the solar panel to track the sun.

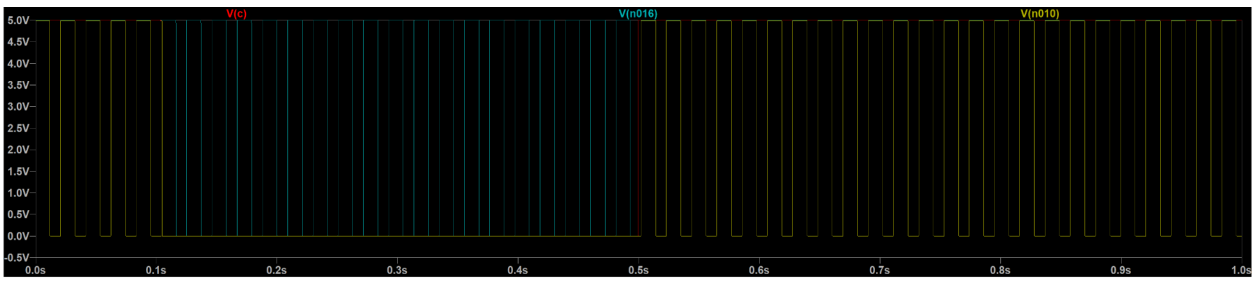
This subcircuit's input stage begins with the sun. As sunlight falls on the circuit it will affect the resistance of our photoresistor in our input block, thereby changing the voltage across the photoresistor and the resistor that it is in series with. The voltage across this regular resistor will be isolated then used as the input for the Summer-Schmitt-trigger circuit from Milestone 1.

The output voltage of the Schmitt trigger is then combined with the output of the astable multivibrator using a comparator to output the voltage waveform needed for the stepper motor that will be used for sun tracking. This can be seen in the plot on the next page.

Plot of Input (Green), Output of Filter (Blue), and Output of Schmitt Trigger (Red)



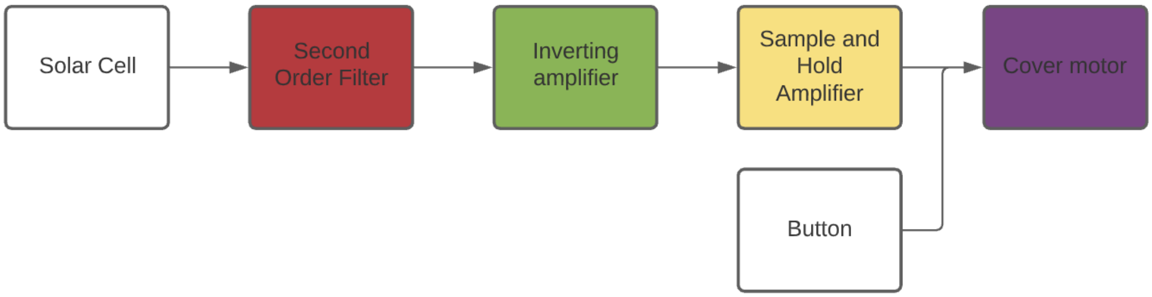
Plot of Output of Schmitt Trigger (Red), Output of Astable Multivibrator (Light Blue), and Output to Stepper Motor (Gold)



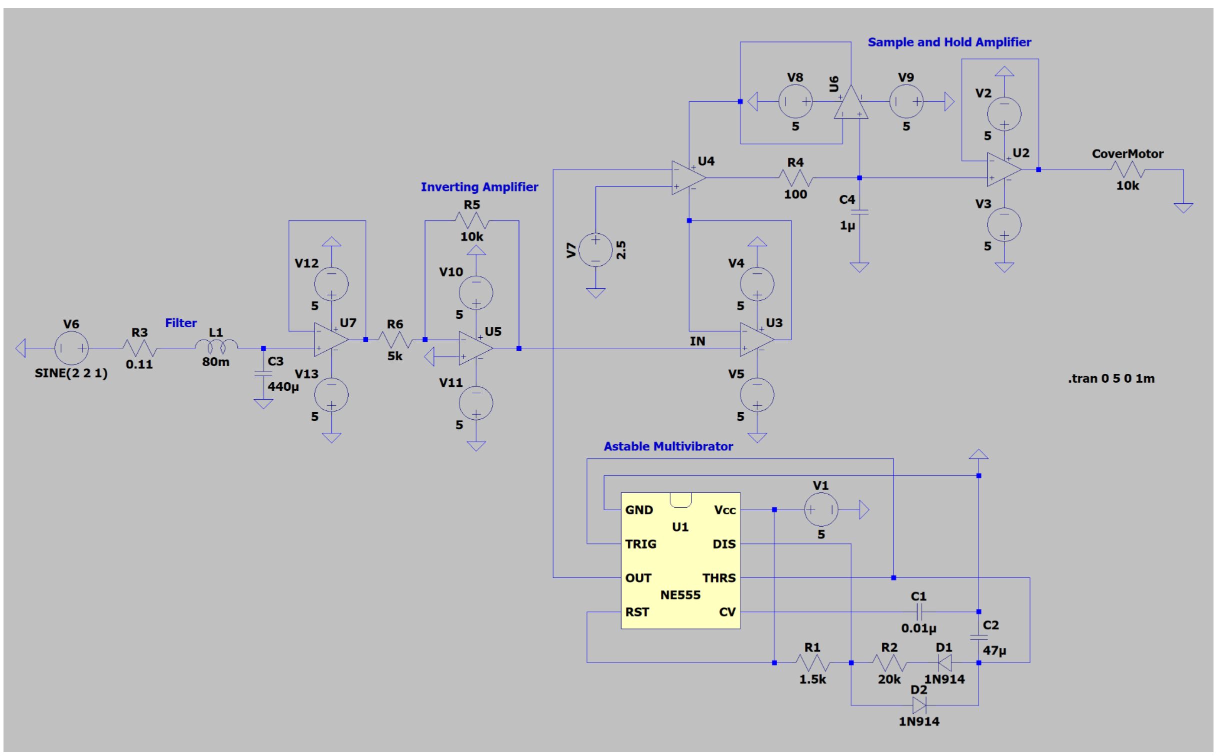
(Note: The output to the stepper motor matches that from the multivibrator when the output of the schmitt trigger is high, and the multivibrator output is therefore difficult to see during those periods.)

Sub-Circuit 2: Dust Cover

Block Diagram:



Schematic:



This subcircuit uses a single building block from each milestone to process the incident light on the solar panel and send a signal to close the cover of the solar panel when necessary.

The input is taken from a solar cell, which measures the amount of sunlight incident upon it and outputs a corresponding voltage. This will be passed through a second order low pass filter to prevent any sudden changes in lighting conditions from affecting the circuit's operation (e.g. we do not want someone walking in front of the circuit to have a noticeable effect).

This filtered voltage is then used as the negative input of the inverting amplifier from Milestone 1. This will shift the voltage into a usable range for the remainder of the circuit. We opted to use an inverting amplifier instead of a noninverting amplifier as it allows for a greater range of gains and gives our circuit greater flexibility.

The next building block in this circuit is the sample and hold amplifier from Milestone 2, which takes the inverting amplifier's voltage output as its main input. This voltage signal will then be used to power the output motor to close the cover if the amount of sunlight is low enough for long enough to pass through the filter.

Operating Conditions

Limitations

One limitation of our circuit is that it uses the same power source for a lot of components, and at a certain point, the discovery board may not supply enough power to support it alone. It already does not seem to function at 100% when used on testing in addition to the main circuit. We should be able to add external power supplies if needed but at the moment the circuit is able to function properly with just one and that helps to simplify the wiring.

Another limitation is that the circuit will not handle inputs outside of the expected range very well. It is possible that it could not trigger when it is supposed to if there was a non-sun light source nearby, and even in testing this will need to be controlled. The photoresistor gave varying results even in preliminary testing. It would be possible to adjust the thresholds at which the circuit acts for a certain set, but then we would shift even further from the desired result for other conditions. By the end of the project, we will have fine tuned the thresholds better and/or changed the resistor in the input circuit to allow the circuit as a whole to better execute its function, but they are currently to what we believe to be appropriate.

The biggest limitation of our design is seeming to be the sheer number of op amps required to implement it. This is becoming a problem for two reasons. The first is that it is making our circuit very hard to interpret visually which makes troubleshooting more difficult than it already is. The other is that we are beginning to have problems with nonidealities. A small example of this is the discharge of the capacitor in the sample and hold amplifier. This has no connection to ground other through the op amps, and therefore should maintain its charge, though in reality it loses charge over time. There are also problems with feedback through op amps that we still do not fully understand.

Another limitation is the size of the circuit. With the number of op amp and 555 timer chips required to implement our design, it is easily taking up the majority of the bread board space available. This has become a problem even when only implementing one subcircuit and will most likely only get worse as we attempt to implement both at the same time. This space constraint also leads to components and wires needing to be very close together which can lead to shorts or extra feedback if we are not careful.

The biggest limitation for Milestone 3 was attempting to implement a second order filter that would be both helpful and usable. The initial designs required components that were unobtainable. Other designs required a large number of components that meant we lost those as options for other parts of the circuit. This large number of components also required a large amount of space. This took valuable space from the other building blocks in our circuit. It is good that this was one of the last things to implement because we would most likely have had to relocate it later on as it needed to be quite compact.

Another limitation with our circuit's functionality is that it can't filter noise out on the scale that would be necessary for a real solar panel system. Even with our best possible second order filter, we simply could not get lower cutoff frequencies than about one second. This would mean a small cloud could completely shut down the system if it were implemented in real life with no alterations. Although filtering out noise with magnitudes in single seconds is enough for testing the concept and design, it would not work for our real intended application which is disappointing.

Trade-offs

The biggest tradeoff of Milestone 1 is the choice of threshold voltages for the Schmitt trigger. If they are further apart, the circuit will run the (currently unimplemented) motors less frequently which will save energy. On the other hand, having the two thresholds closer together would allow for the solar panels to make small adjustments that would allow it to perfectly match the angle of maximum sunlight, and therefore produce the most energy. We have currently opted for a value that is roughly in the middle of these two, and we are attempting to refine the thresholds further for even better efficiency.

There are a number of tradeoffs in the sample and hold amplifier implemented in Milestone 2. The biggest of these involves the capacitance of the capacitor used to hold the voltage from the input. A low capacitance will give the circuit a low time constant and allow the amplifier to quickly adjust at the beginning of each sampling period and follow the input voltage more closely during this time. This allows for a more accurate value to be output and lessens the time needed to be confident in a sample's accuracy. This low time constant, however, also leads to a faster divergence from the held value during the holding period. This is due to the nonidealities of the op amps in the circuit which cause a small amount of charge to leak from the capacitor. This causes the voltage output to become less accurate over time and requires sampling more often which would eventually negate the benefits of the sample and hold amplifier if taken to an extreme. We have opted for a relatively small capacitance in our sample and hold amplifier, as its frequency of sampling is high enough that the loss of charge over time does not significantly affect the stored voltage value.

For Milestone 3, a tradeoff we had to deal with was the added control and steeper drop off of second order filter compared with the simplicity and broader range of corner frequencies of a first order filter. For example, to build a Low Pass Filter with a corner frequency of 1, we had a broad assortment of options available for a first order filter, but only one possible configuration with a cutoff frequency that low with a second order filter, and it required 10 resistors in parallel, two large capacitors in parallel, and four inductors in series to work as intended. We ended up using one of each of these and ran into significantly more problems with the second order filter, though it did have a much sharper cutoff (after overcoming the 40 dB resonance).

Constraints

It would be helpful to have a greater variety of resistors within a certain range. We have a lot of resistors from 1Ω to 5MΩ but only 6 different values from 1kΩ to 10kΩ which is the range that most of the used resistors fall into. It's also not very reasonable to try to combine resistors to make other values as that can create long chains very quickly. Having a greater variety of ~kΩ resistors would allow for the circuit to stay more compact and make it easier to see connections between components.

While it would be incredibly inefficient, it would be nice to only use each op amp chip once as it would make the circuit easier to understand and troubleshoot. Since some outputs from op amps run directly into the inputs of others, there are some resistors that run directly over the top of the op amps, and there is a lot of crossing of wires that makes it difficult to tell which components are connected to each other. This could be 'fixed' by having more op amp chips, each with only one side being used. This however, feels like a waste of resources, including money, and will therefore not be implemented.

One limitation of our Milestone 2 circuitry is the large amount of feedback created by our astable multivibrators. They are integral to our design as the creation of square waves with modifiable periods and duty cycles allows us to use similar designs for circuits as different as a sample and hold amplifier and a stepper motor. On the other hand, they have sharp jumps in voltage/current that interfere with the rest of the circuit, sometimes in debilitating ways. This causes them to nearly offset their usefulness with extra work required to safe-guard the circuit and forces us to not use them however we want to.

One of our biggest constraints is the power output of the Analog Discovery 2 board. It simply cannot put out enough power to run larger circuits, as we suspect was becoming an issue with our sample and hold amplifier. External power sources are an option, and will most likely be the solution we employ, but with everyone remote, it's harder to manage and implement these in a COVID safe way, and using multiple power sources can cause its own issues.

One constraint for our filter design specifically was that we were not able to get the components that we wanted. We wanted a very low cutoff frequency and the only way we could do that while maintaining precise control over the other parameters of the filter required the use of kF capacitors or kH inductors which are either non existent, very expensive, far too large to effectively use, or a combination of these reasons. This forced us to get a little creative and make do with what we had. All in all I believe this helped with our circuit design skills as it forced us to approach the problem in a way that we wouldn't have had to in something like a homework or exam where theory is more important.

Another constraint we encountered was the size/functionality of our breadboards. Our power rails in particular were troublesome, and may be defective, but even as our circuits started combining and getting larger, we began to run out of space for having two circuits on our breadboards. This was addressed by using smaller, 5-pin rails as additional power rails, and using one full sized breadboard for each of our circuits, with isolation testing and filters being implemented on smaller boards kept nearby and connected with jumpers. This forced us to be more careful and considerate when planning where to construct each building block.