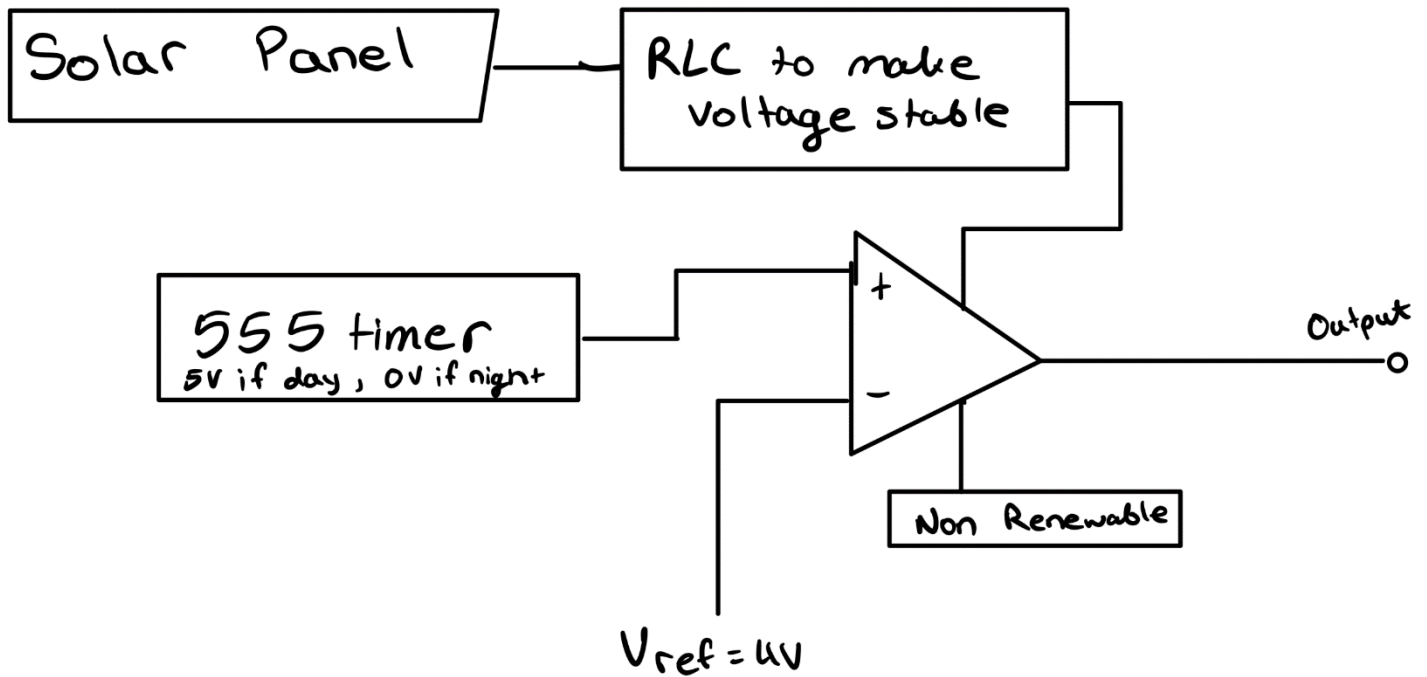


Proof of Concepts Milestone 2

Ethan Wong, Josh Suber, and Kevin Raj

High Level Diagram

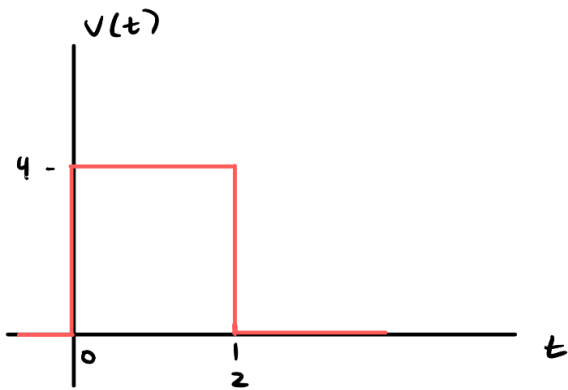


This is the high-level design of our project. We use an RLC to make a stable voltage and current from the solar panel, a 555 timer to mimic the timing of day and night, and an op amp that would switch the voltage sources based on the time of day.

If it is Day time, the 555 timer, based on out time constant, would be 5V, which would be greater than V_{ref} , and the op amp would route the stable solar panel output to the output of the circuit. If it is night, the 555 timer outputs 0V which is less than V_{ref} which would route the Non-Renewable power source (5V constant DC supply) to the output of the circuit.

Concept 1: Continuity Conditions

Description



To model the varying nature of a solar panel, we used a step function that changes voltages at different t values much like a solar panel would change its output voltage based on the amount of light hitting it. The continuity conditions are what make out circuits in this lab do what we want them to do. Knowing that a capacitor cannot change voltage across it immediately, we leveraged this to smooth out the voltage jumps coming from the Solar panel.

Analysis

For our analysis we take a close look at the step function. Our initial conditions for analyzing the circuits would be at $t=0^-$, $t=0^+$, $t=2^-$, $t=2^+$, and $t=\text{infinity}$

Experimental Data

From Experimental data later shown in this report, especially in the RC circuit Experimental Data, we can see that the capacitor works as a smoothing component to smooth out any large voltage jumps that are caused by fluctuating light sources. Furthermore, we can also see the continuity condition for current through an inductor. Unfortunately, we were unable to get out hands on the Experimental data for this since the solar panels we got provided very little current on the order of microamperes. So, when graphing the result for current it is not as apparent to see the continuity conditions at work like they are for voltage.

Concept 2: Time Constant

Step by step:

1. **Press switch:** Initially the 555 timer is in a stable state, not outputting a high signal. When you press the switch connecting the trigger (pin 2) you momentarily connect it to ground. This causes the voltage at pin 2 to drop below $1/3$ of the supply voltage, triggering the 555 timer.
2. **Output goes high:** Once triggered pin 3 goes high. This allows current through the $1k\ \Omega$ resistor and turns the green LED on. The output remains for the duration determined by the timing components to pins 6 and 7. In our case R_1 ($47k\ \Omega$) and C_1 ($220\ \mu F$).
3. **Timing Interval:** During this time the $220\ \mu F$ capacitor being charging through the $47k\ \Omega$ resistor. The voltage across the capacitor increases linearly with time. The output remains high as the capacitor charges.
4. **End of timing cycle:** The timing cycle ends once the voltage across the capacitor reaches $2/3$ of V_s . At this point, the internal threshold circuit inside the 555 timer senses this voltage level at pin 6 causing the output to go low again turning the green LED off.
5. **Discharge:** The discharge pin 7 is connected internally to an open-collector transistor that gets activated when the output goes low. This transistor now connects to ground, allowing the $220\ \mu F$ capacitor to discharge through the $47k\ \Omega$ resistor to pin 7. The circuit is now ready for another trigger.
6. **Stabilization:** Throughout this process, the $10\ \mu F$ capacitor is connected to the control voltage pin (pin 5) helps stabilize the internal threshold voltage against noise, ensuring the timing interval is consistent and reliable.

Mathematical Analysis

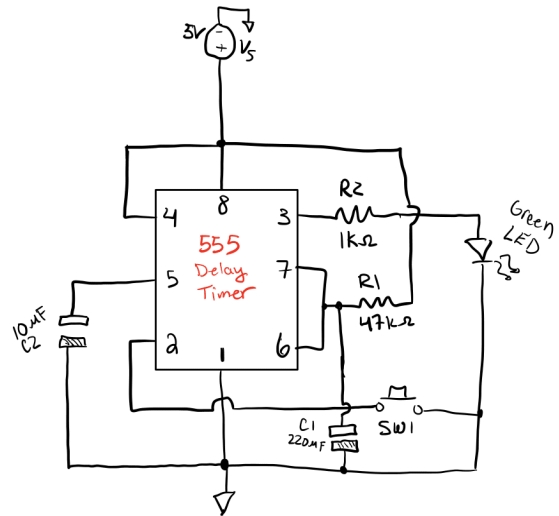
For a 555 timer: $= 1.1 \cdot R \cdot C$, where C in this case would be C_1 which has a capacitance of $220 \cdot 10^{-6}\ F$, and R would be R_1 which has a resistance of $47 \cdot 10^3\ \Omega$. We are using C_1 and R_1 instead of C_2 and R_2 because R_2 is just to limit the voltage going through the LED and C_2 is stabilize the 555 timer.

R_1 has a 5% tolerance so the resistance can vary from **44,650 Ohms to 49,350 Ohms**. This means for the low end $= 1.1(44650\ \Omega)(220 \cdot 10^{-6}\ F) = 10.81s$ and on the high end $= 1.1(49350\ \Omega)(220 \cdot 10^{-6}\ F) = 11.94s$.

This means that our timer will produce an output voltage for **~ 10.81 - 11.94 seconds**.

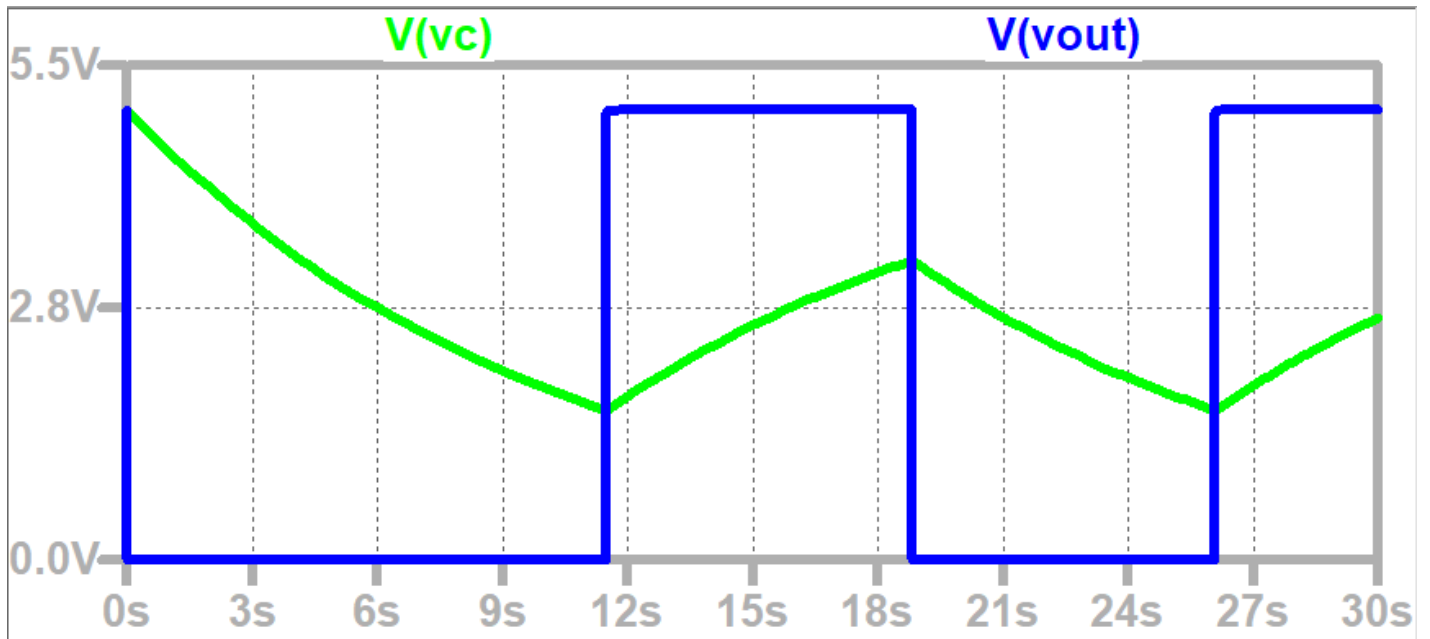
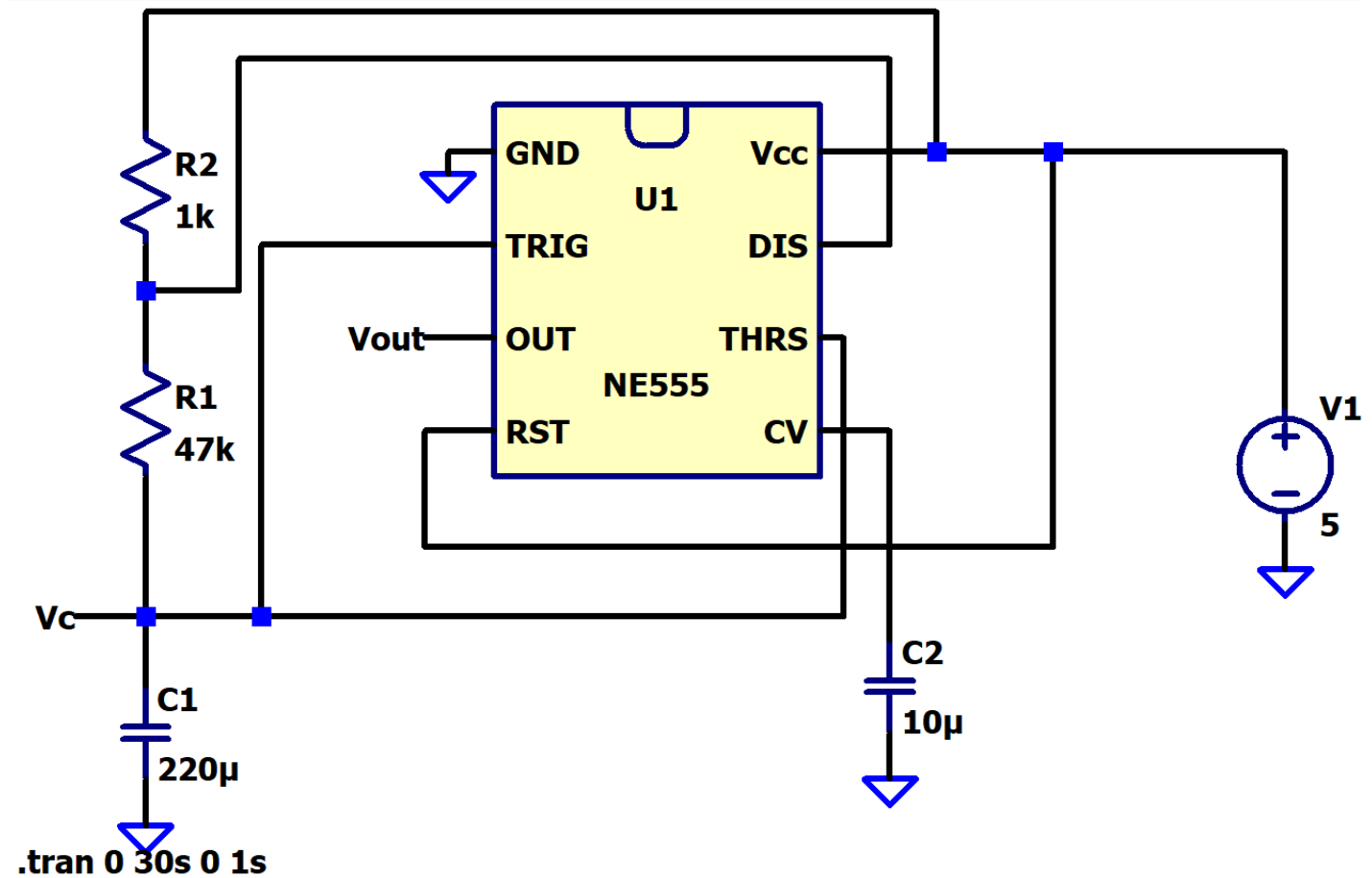
Analysis

555 Timer Diagram



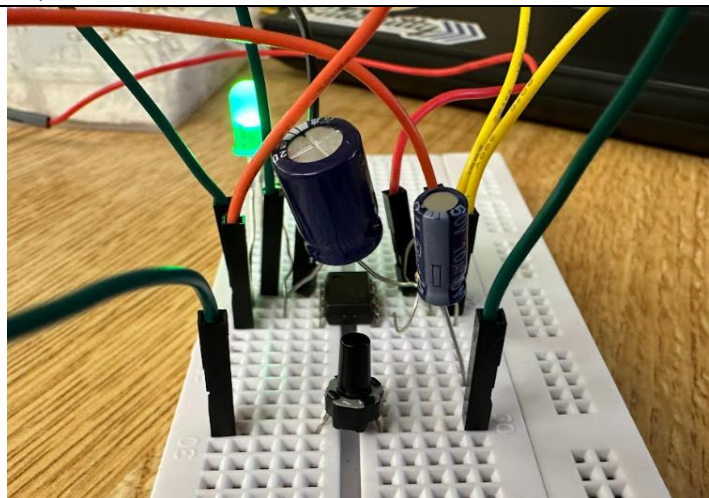
Pins

1. **Ground**
2. **Trigger** – output of the 555 turns high and starts timing when this pin's voltage drops below $1/3$ of V_s
3. **Output** – goes high for the duration of the timing cycle
4. **Reset** – applying a low voltage to this pin resets the timer
5. **Control** – allows to adjust the threshold and trigger level, connecting a capacitor to this pin filters noise; it can also be used to modulate the timing externally
6. **Threshold** – connected to capacitor and resistor for timing; 555 turns low when voltage of the capacitor reaches $2/3$ of V_s
7. **Discharge** – connected internally to a transistor that can discharge the timing capacitor to ground
8. **VCC** – typically ranges from 4.5V to 12V

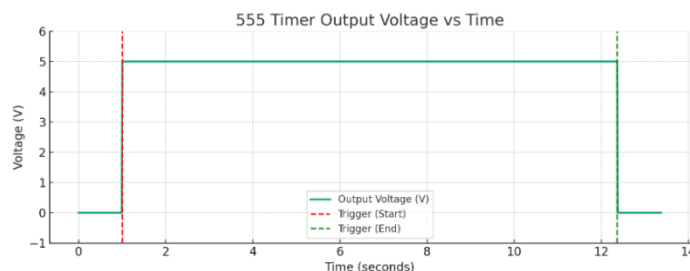


Here you can see that the timer is on/off for ~11.5 seconds which is in line with our mathematical calculations.

Experimental Data



This is the circuit which is drawn up above.



This is from exported data I got from scopy and graphed it in excel so I can show the triggers cleaner. This is with a slightly modified circuit that does not use the LED instead I am just measuring the voltage of the output directly.

Here is a link to a video of the timer running:

https://drive.google.com/file/d/1dvlp-3B2E8qhAseZCAaHSiOTktfk0HI0/view?usp=drive_link
(shows LED turning on for ~11.5s)

Results

Concept and Analysis

- This analysis centers on the 555 timer circuit, aimed at examining the time constant—the period necessary for capacitors to reach 64% charge.
- The process begins by grounding the trigger pin of the 555 timer, leading to the output going high for a duration determined by the timing components connected to pins 6 and 7 (namely, R1 and C1).

Mathematical Analysis

- The duration for which the output remains high is calculated using the formula $T = 1.1 \times R \times C$, where $C = 220 \mu\text{F}$ and $R = 47 \text{k}\Omega$, with a 5% tolerance, yielding a timing range approximately between 10.81 to 11.94 seconds.

LT SPICE Simulation

- The simulation corroborates the theoretical analysis, demonstrating the timer switching on/off for an interval of about 11.5 seconds, closely matching the anticipated timing duration.

Experimental Data

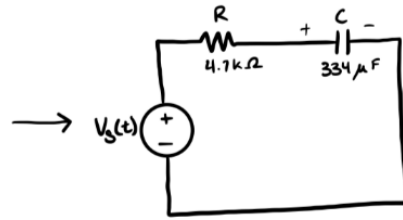
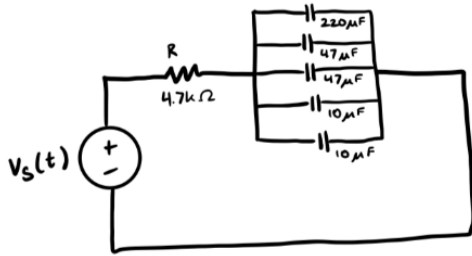
- The circuit was slightly modified by excluding the LED to directly measure the output voltage. This modification did not significantly alter the timer's behavior, which stayed consistent with the theoretical expectations and simulation results.

Results Summary

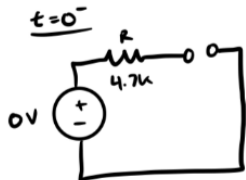
- This analysis successfully demonstrated the 555 timer's functionality in a timing application, with the observed and calculated time constants closely aligning. Considering component tolerances, the expected range of the time constant was accurately predicted and verified through simulation and direct measurements.

Concept 3: First Order Circuit RC (Differential Equations)

Analysis



$$\tau = RC = 4.7E3 (334E-6) = 1.57$$



$$V_C = 0V \\ I_C = 0A$$

$$0 < t < 2 \quad V_S(t) = 4V$$

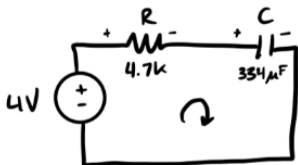
$$V_{C1}(t) = k_1 e^{-t/\tau} + k_2$$

$$t = 0^+ : 0 = k_1 + k_2$$

$$t \rightarrow \infty : 4 = k_2$$

$$V_{C1}(t) = -4e^{-t/1.57} + 4$$

$$t = 0^+$$



$$V_C = 0 \\ I_C = I_R = \frac{V_R}{R} = 0.85mA$$

$$-4 + V_R + V_C = 0 \\ V_R = 4$$

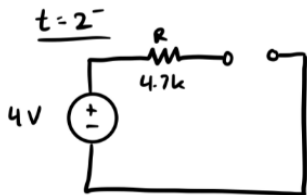
$$t > 2$$

$$V_{C2}(t) = k_1 e^{-t/\tau}$$

$$t = 2^+ : 4V = k_1 e^{-2/1.57}$$

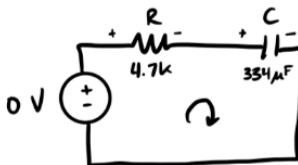
$$k_1 = 14.3$$

$$V_{C2}(t) = 14.3e^{-t/1.57}$$



$$V_C = 4V \\ I_C = 0A$$

$$t = 2^+$$

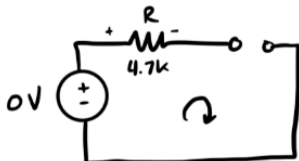


$$V_C = 4V \\ I_C = I_R = \frac{V_R}{R} = -0.85mA$$

$$0V + V_R + V_C = 0 \\ V_R = -4V$$

$$V_C(t) = \begin{cases} -4e^{-t/1.57} + 4 & 0 < t < 2 \\ 14.3e^{-t/1.57} & t > 2 \end{cases}$$

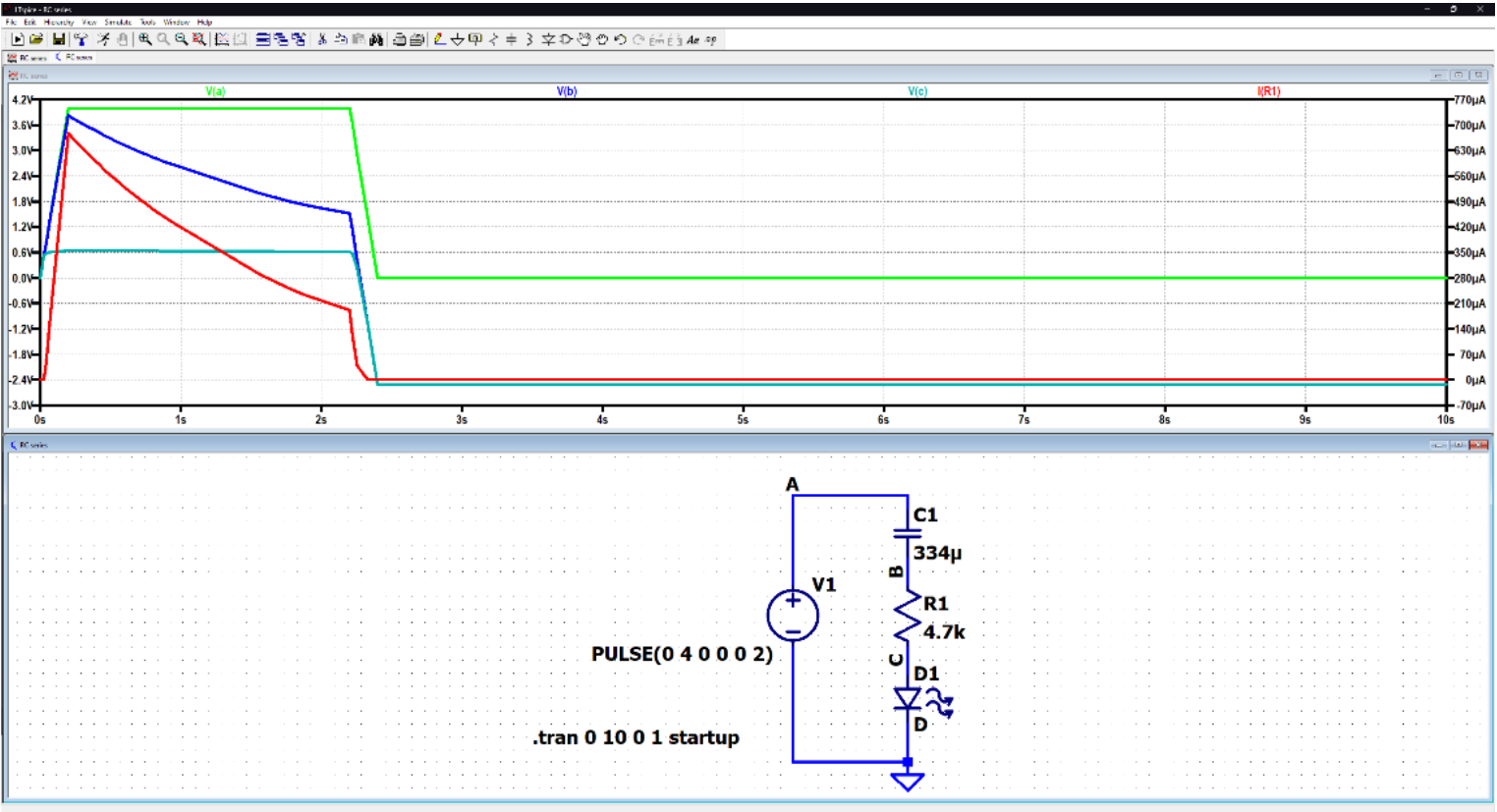
$$t \rightarrow \infty$$



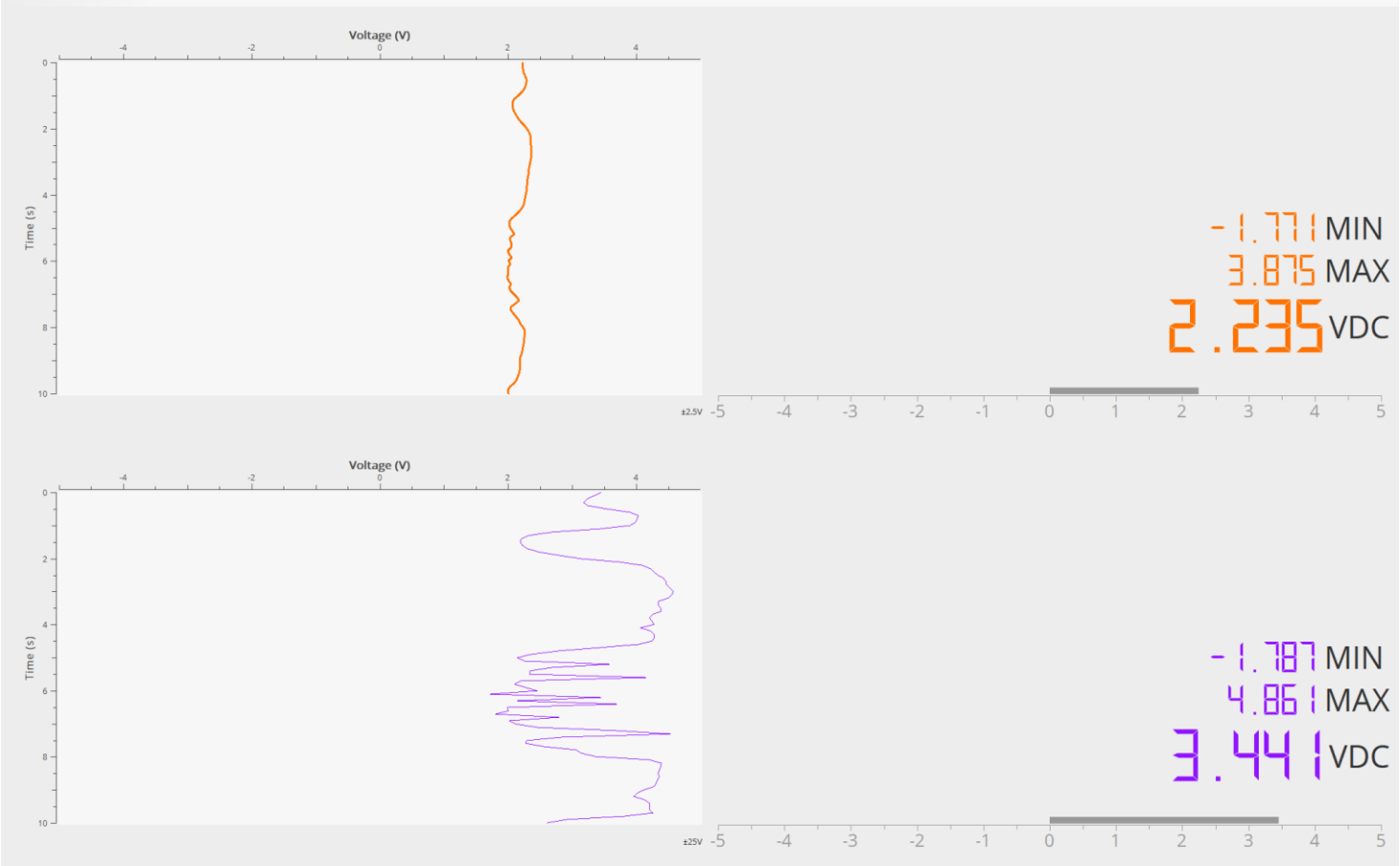
$$V_C = 0V \\ I_C = 0A$$

For the analysis of our RC circuit, we made use of Capacitor continuity conditions, and differential is which in our case is the voltage across the capacitor. The voltage source we used models the voltage from the solar panel by varying the voltage at different times. We then needed to find 2 $V_C(t)$ equations for the 2 ranges $0 < t < 2$ and $t > 2$.

Simulation



Experimental Data

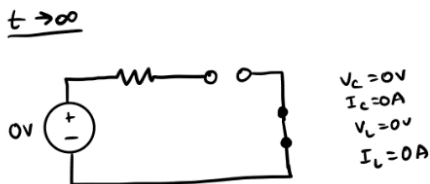
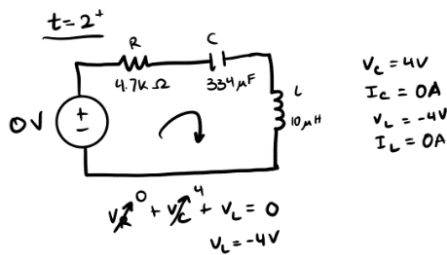
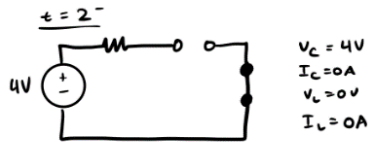
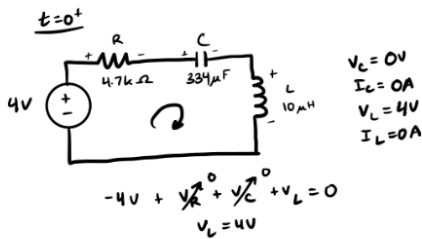
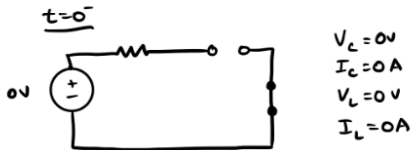
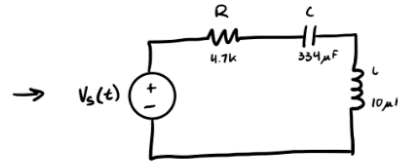
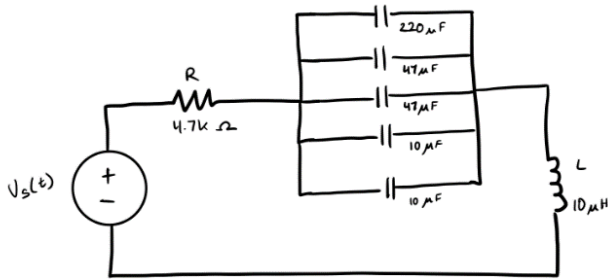


Results

We first built an RC circuit to mitigate the jumpy voltage characteristics that our solar panels exhibited. We used a light source that fluctuated rapidly, like moving a flashlight moderately fast in and out of the solar panels scope, we saw that the voltage jumps from around 2V (which is caused by general room light) to around 4.3V (at the specific time where the flashlight is directly above the solar panel). This caused voltage spikes that could potentially damage components and have unwanted effects. By using an RC circuit, we were able to control the voltage spikes and create a smoother voltage output from our solar panel. In the above experimental data, channel one graph (Orange) is the voltage across the capacitor which is our Vout. Channel 2 graph (purple) is the voltage given by the solar panel. The screenshot above shows the jumpy behavior of the solar panel, and channel one's graph shows the smoothed-out voltage. We can see a lot of the peaks get smoothed out and we create a more stable Vout from our solar panel. In our simulation we observed properties that matched with an RC circuits when stepping voltages. Obviously we cannot simulate the properties of a solar panel in LT spice.

Concept 4: Second Order Circuit RLC (Differential Equations)

Analysis



$\alpha = \frac{R}{2L} = 2.35E8$ since $\alpha > \omega_0$, system is critically damped
 $\omega_0 = \frac{1}{\sqrt{LC}} = 17303.2$

$V_C(t) = V_{CN}(t) + V_{CF}(t)$
 $= A_1 e^{-\alpha_1 t} + A_2 e^{-\alpha_2 t} + A_3$

$-\alpha_1, -\alpha_2 = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$
 $= 4.7E8, 0.63702$

$0 < t < 2$
 $t = 0^+$: $0 = A_1 + A_2 + A_3 \Rightarrow A_1 = -4 - A_2 \Rightarrow A_1 = 0$

$t \rightarrow \infty$: $4 = A_1 e^{-\alpha_1(2)} + A_2 e^{-\alpha_2(2)} + A_3$

$\frac{dV_C(t=0^+)}{dt} = 0$

$0 = -\alpha_1 A_1 + -\alpha_2 A_2 + A_3$

$\begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix} = \begin{bmatrix} 0 \\ -11.0199 \\ 11.0199 \end{bmatrix}$

$V_{C1}(t) = -11.0199 e^{0.63702t} + 11.0199$

$t > 2$

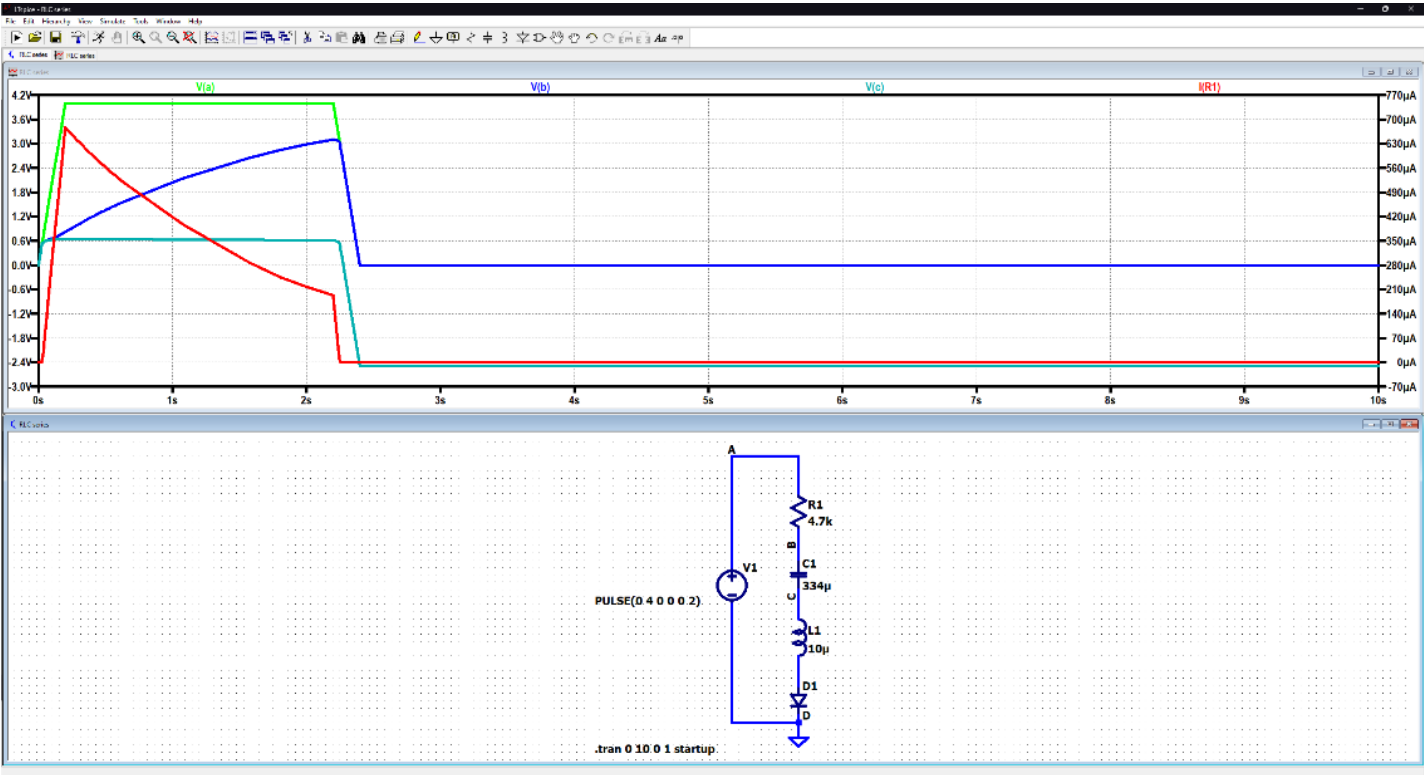
$t = 2^+$: $4V = A_1 e^{-\alpha_1(2)} + A_2 e^{-\alpha_2(2)}$

$t \rightarrow \infty$: $0 = A_3$

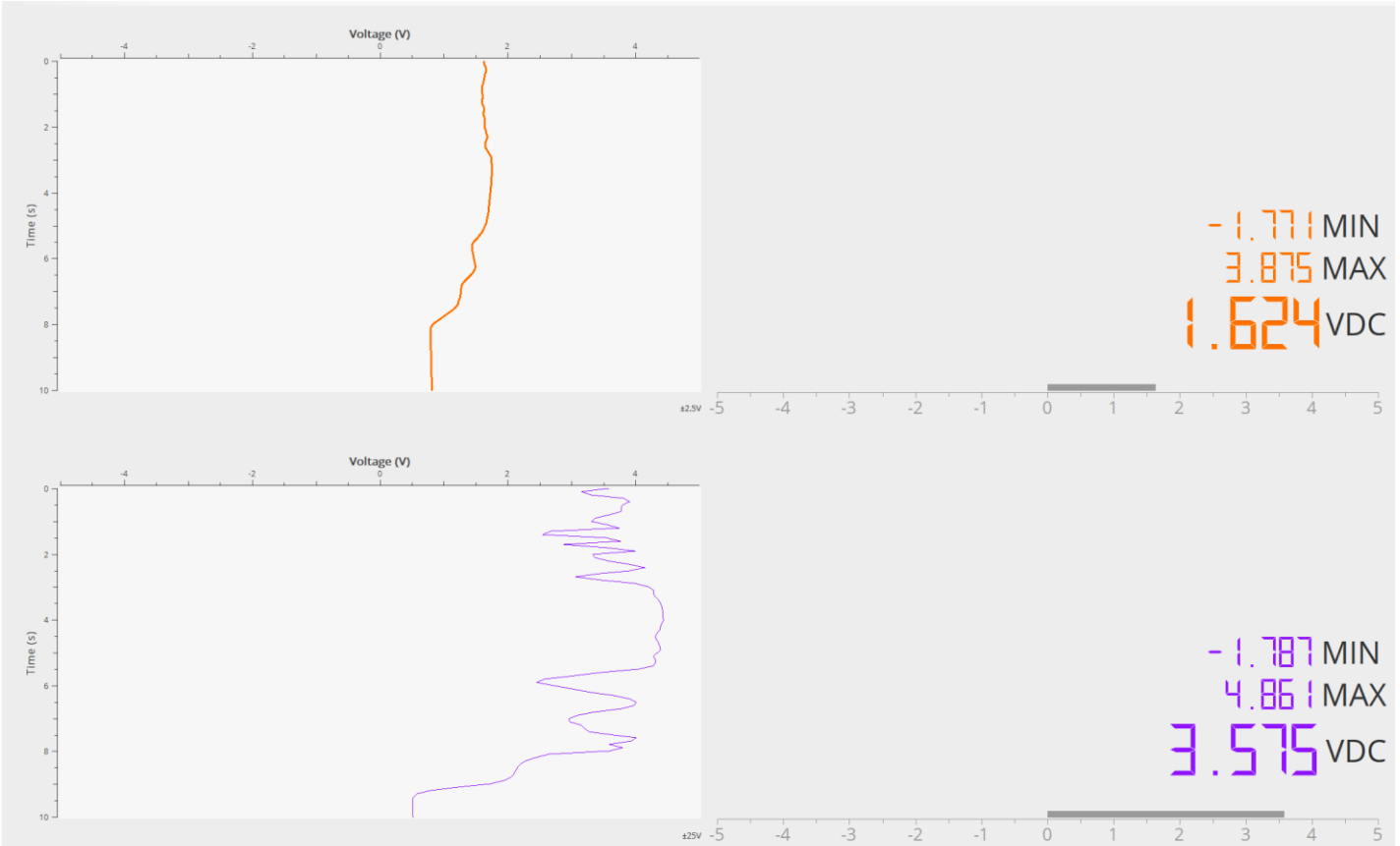
$\frac{dV_C(t=2^+)}{dt} = 0$: $0 = -A_1 \alpha_1 e^{-\alpha_1(2)} - A_2 \alpha_2 e^{-\alpha_2(2)}$

$V_C(t) = \begin{cases} -11.0199 e^{0.63702t} + 11.0199 & 0 < t < 2 \\ 0 & t > 2 \end{cases}$

Simulation



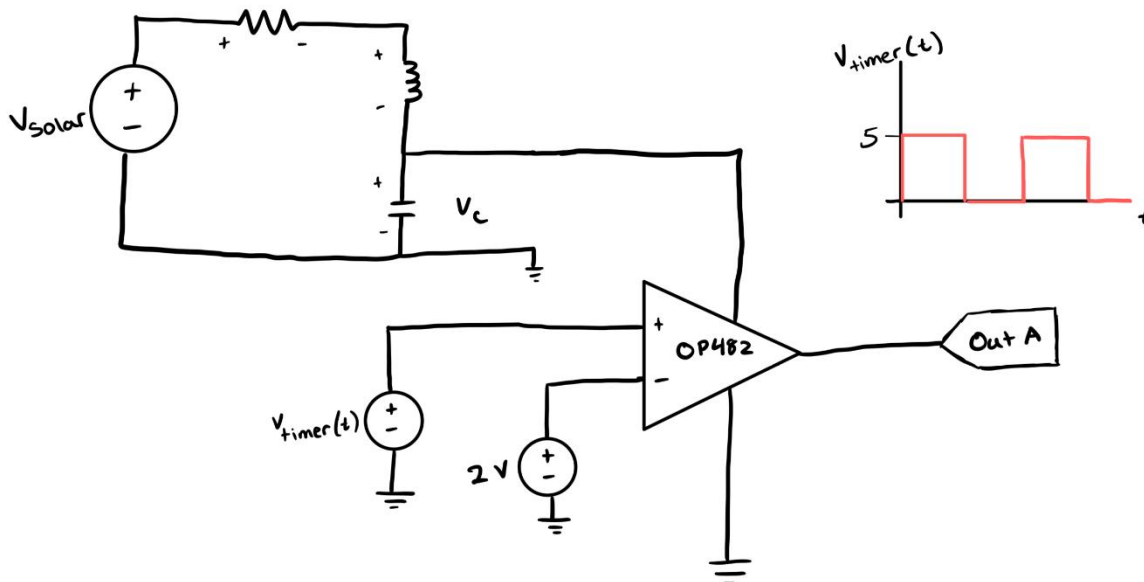
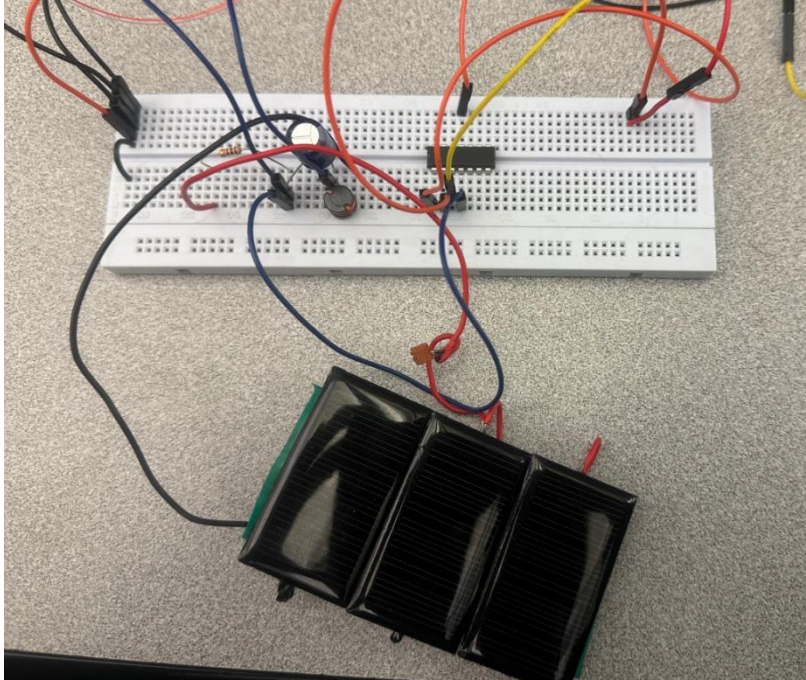
Experimental Data



Results

To make our voltage from the solar panel more stable, we also added an inductor to resist changes / spikes in current. This makes our RC circuit into an RLC circuit. Unfortunately, this is the point in our lab where we hit a major roadblock. Our circuit is heavily current limited. The current we get from the solar panel is on the order of microamps and it made out measurements of current inaccurate and unusable. Theoretically what the inductor would do for us is limit current spikes while the capacitor limits voltage spikes. This would give a V_{out} (Voltage across the capacitor) a stable output in both voltage and current sense. In our simulation we observed properties that matched with an RLC circuits when stepping voltages. Obviously we cannot simulate the properties of a solar panel in LT spice.

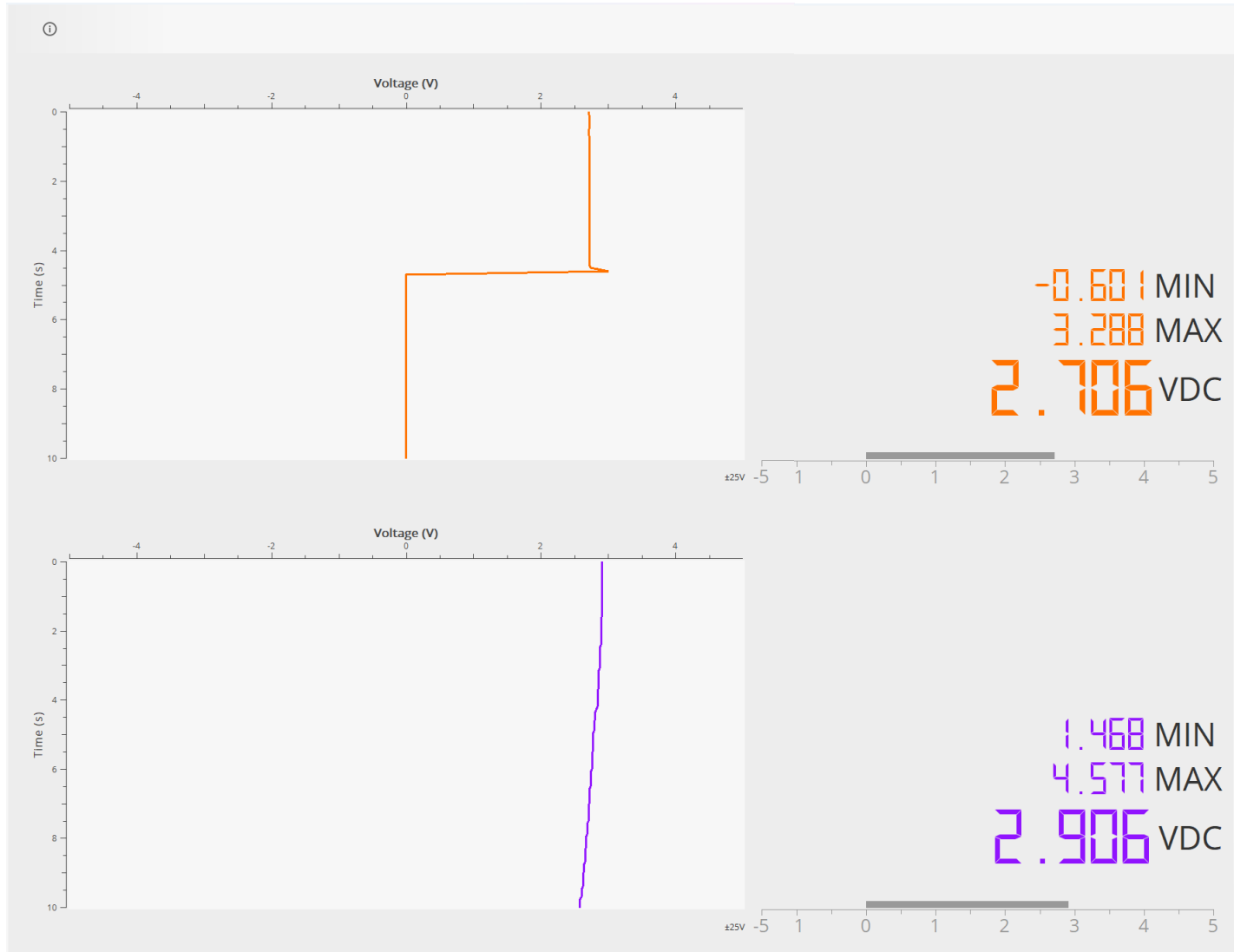
Putting it All together



For Simplification purposes, $V_{timer}(t)$ is simulated to act just like the 555 Timer circuit shown previously in this report. We used the Waveform generator on the m2k to generate this timer like signal.

https://www.analog.com/media/en/technical-documentation/data-sheets/op282_482.pdf [Datasheet for OpAmp used]

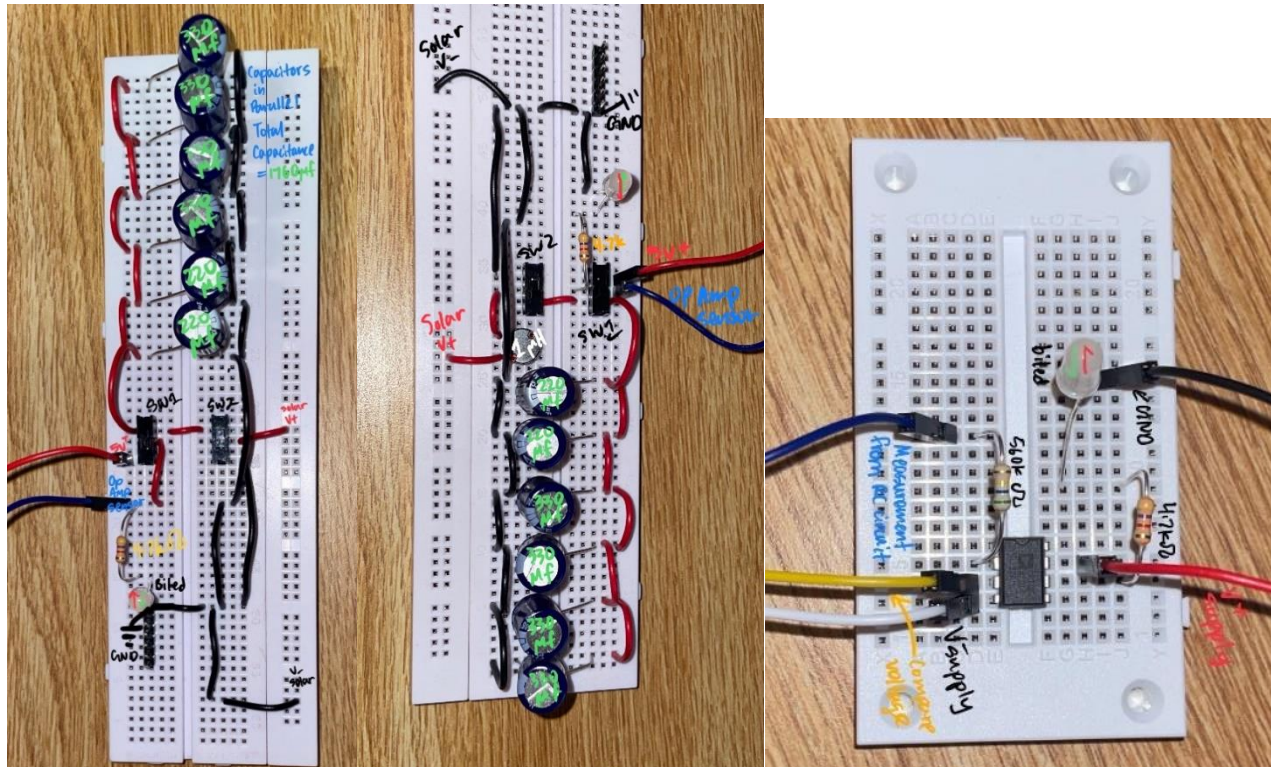
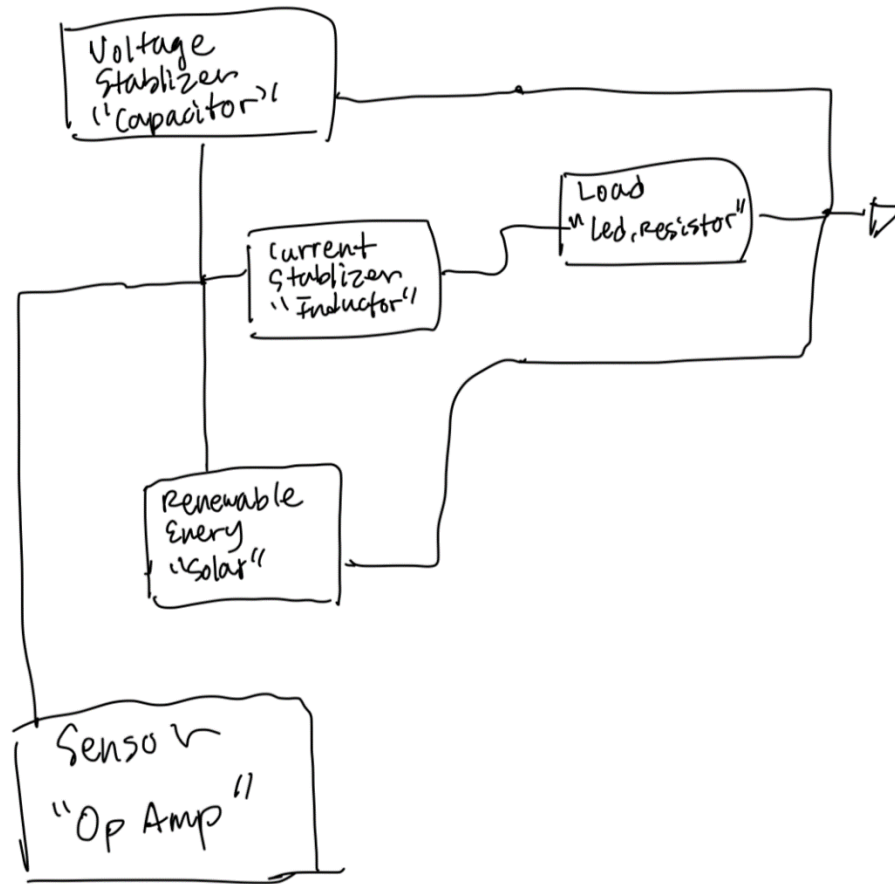
Experimental Measurements



In this measurement, Channel 2 (Purple) is measuring V_c , the voltage across the capacitor, which for our purposes is the smoothed-out voltage from the solar panel. Channel 1 (orange) is the voltage across V_{a_out} , the output of the opamp, and ground. Unfortunately, we could not directly show the pulsed voltage, but we used a multimeter to make sure the circuit was behaving the way it should. When the $V_{timer}(t)$ is 0V, V_{a_out} would go to its negative saturation which is ground (0V). When the $V_{time}(t)$ is 5V, the opamp would switch to the positive supply saturation which in our circuit was V_c . And this is shown in the measurements as well. Although we lost some of the voltage along the way, we say around .2-.4 voltage loss, this proves that our circuit works as intended. Every time the pulsed signal is 5, signifying day time, the circuit switches to a Renewable energy source, solar panel, and when the pulsed signal is 0, signifying nighttime, the circuit switches to a Non-renewable energy source, in this case ground.

Conclusions and Results:

Original Idea:



State 0:

- The op-amp sensor indicates steady output. It is daytime and good weather. The solar output is high. The capacitor smooths out any voltage drop from clouds or temporary blockages. Solar is currently the main source of power.

State 1:

- Our op-amp sensor indicates that we have weak voltage, and we switch over to on grid power. Solar output is weak and variable due to bad weather. The capacitor has limitations to how much power it can store based on such a weak solar output. Switching to the grid gives us a constant DC voltage.

State 2:

- It is nighttime, our timer (555) indicates that we should turn on our on-grid power, so we do not lose power before nightfall.

Solar Panel Specification:

- **Output From Single Panel:**
 - 5 volts
 - 3 milliamps
- **Output From array:**
 - 5 volts
 - 9 milliamps

Capacitor Array:

- Total capacitance is 1760 micro farads.

****Slide Switches are for testing purposes has no real functionality**

SW1 disconnects the solar panel and connects it to a constant dc source

SW2 disconnects the solar panel to allow the capacitors to deplete

Working Prototype However circumstances did not allow for proper mathematical analysis and simulation**

Difficulties with original concept

Originally our attempt was to have a parallel RC circuit. With difficulty mathematically analyzing this parallel rc and series/parallel RLC circuit we decided to default to and RC and RLC circuit.

However, while attempting to use a parallel RC and parallel/series RLC circuit we observed properties that would be ideal for our project. Not only were we able to stabilize the power output of the solar panels by charging up the capacitors, but we were able to divert current when steady state was reached for both the parallel rc and parallel/series RLC circuit.

RC Parallel vs RC Series

Fully Charging with Solar:

While discussing with Professor Patterson, we determined that our parallel rc circuit works because when the capacitor reaches steady state it becomes an open circuit. This forces all the voltage and current from the solar panels through the resistor and led. This allows our led to stay lit while connected to the solar panel.

On the other hand, using a series RC circuit would create an open circuit between the capacitors effectively stopping any current flow to the led and resulting in failing to light the led.

Depletion:

When disconnected the solar source from the circuit, our RC parallel is no longer an open circuit and deplete whatever stored charge into the resistor and led. This allow for the stored charge from the capacitor to create a voltage and a current that continues to power our led.

On the other hand, with a regular RC circuit this depletion process happens as well, but as it reaches steady state of 0 the current end up drops as well. This also causes our led to stop lighting.

RLC Series/parallel vs RLC Series

Fully Charing with Solar and Depletion:

In the case of the RLC series/parallel it exhibits the same properties as the RC parallel, but with the addition of the inductor we are able to limit large current spikes. This is the same for the RLC series circuit. We see that that the inductor limits current spikes. We were unable to measure the current since our m2k couldn't measure current lower than 1mA. Our solar panels measured from last omega lab only output a max of 3 amps without a resistor.

Future improvements:

Realizing that current is a pretty important aspect of measurement when building 2nd order circuits with inductors, I would have definitely opted for a higher output solar panel array. Additionally, if given more time we could research more on the mathematical analysis of RC and RLC circuits that are neither in parallel or in series. Furthermore, more research could be done on the properties of a LED as the iv curve can affect current and voltage in the circuit. This can be due to the turn on voltage and the current draw of the LED.

What we learned:

Modeling a power grid is much more complex than we expected. We realized that certain properties of capacitors and inductors can cause issues such creating an open circuit or a short. This can cause us to lose all our current. Without both current and voltage we realize that we cannot transmit power.

However, we decided to re-design the circuit to focus on 2 things, limit voltage spikes and use a 555 timer to simulate day and night. We used an opamp from our MS1 to act as a switch which would switch to a Renewable energy source when it was day and NonRenewable energy when it was night. We saw that redesigning help us get a usable informative output from the circuit but we are still curious about the workings of the original plan. We hope to do more research and either correct or come up with better ways to implement our plan in MS3.