Project Manual: Solar Powered Weather Station

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Description

This project implements a solar panel, 3 sensors (photoresistors, temperature sensor, and humidity sensor), wheatstone bridge, and LEDs. The solar panel will act as an energy source that powered each sensor, as well as providing information (whether it's either light energy, the temperature or humidity) into one of these specific sensors as their input. The wheatstone bridge is used to determine the unknown resistances and turn it into DC voltages. The voltage acts as a signal that will connect an op amp as well as an oscillator circuit to convert to sine wave. Buzzers are used to determine whether frequency/voltage meets a certain threshold which will be indicated as high or low “signal” being measured. The signals will then be combined into one sinusoidal wave and filters (using both 1st and 2nd order filters) are used to decode the sine waves to give us the magnitude of the sine wave to give us a conclusive number of the humidity, temperature, and lights which will be output via buzzer.

Flowchart

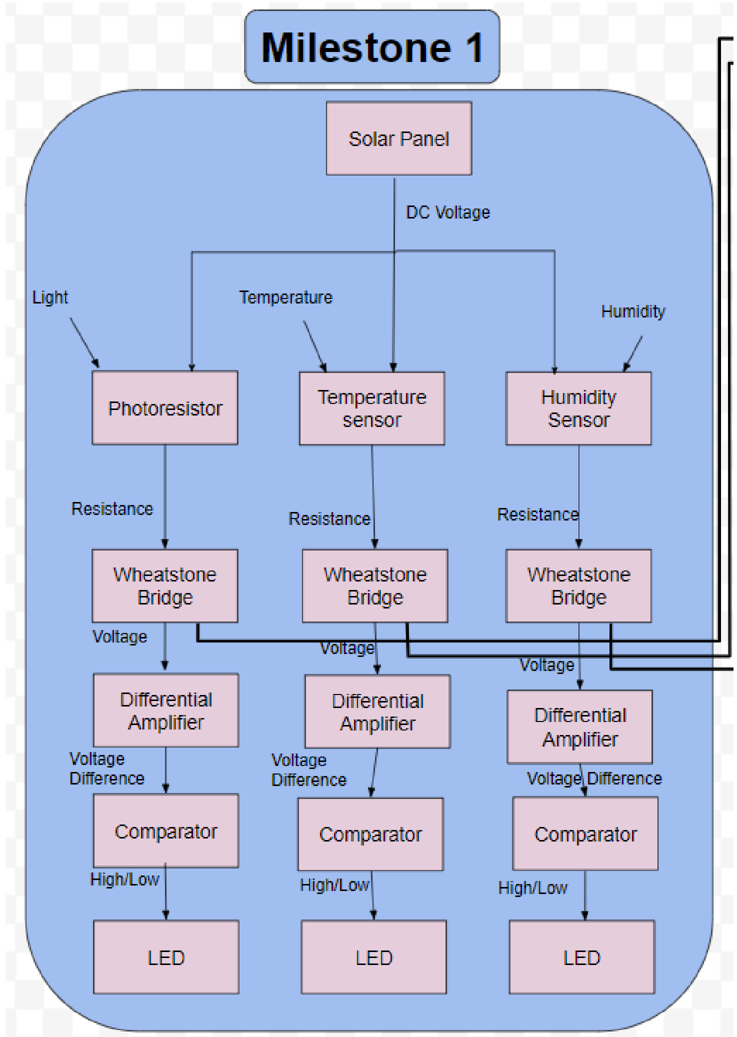


Figure 1: Block Diagram for MS1. Note, the flowchart above is modified and different from the one in the project

The full block diagram for the whole project of the omega lab MS1 is shown in the figure above. There are 3 sensors that have similar circuits that are being builded into the circuits, as they all contained a wheatstone bridge, differential amplifier, and comparator, and a LED. The sensor receives information from the solar panel and its environment and uses a compactor to activate the LEDs criteria. In this milestone, only the wheatstone bridge, compactor, and the LED are being implemented.

LTspice Schematic For MS1

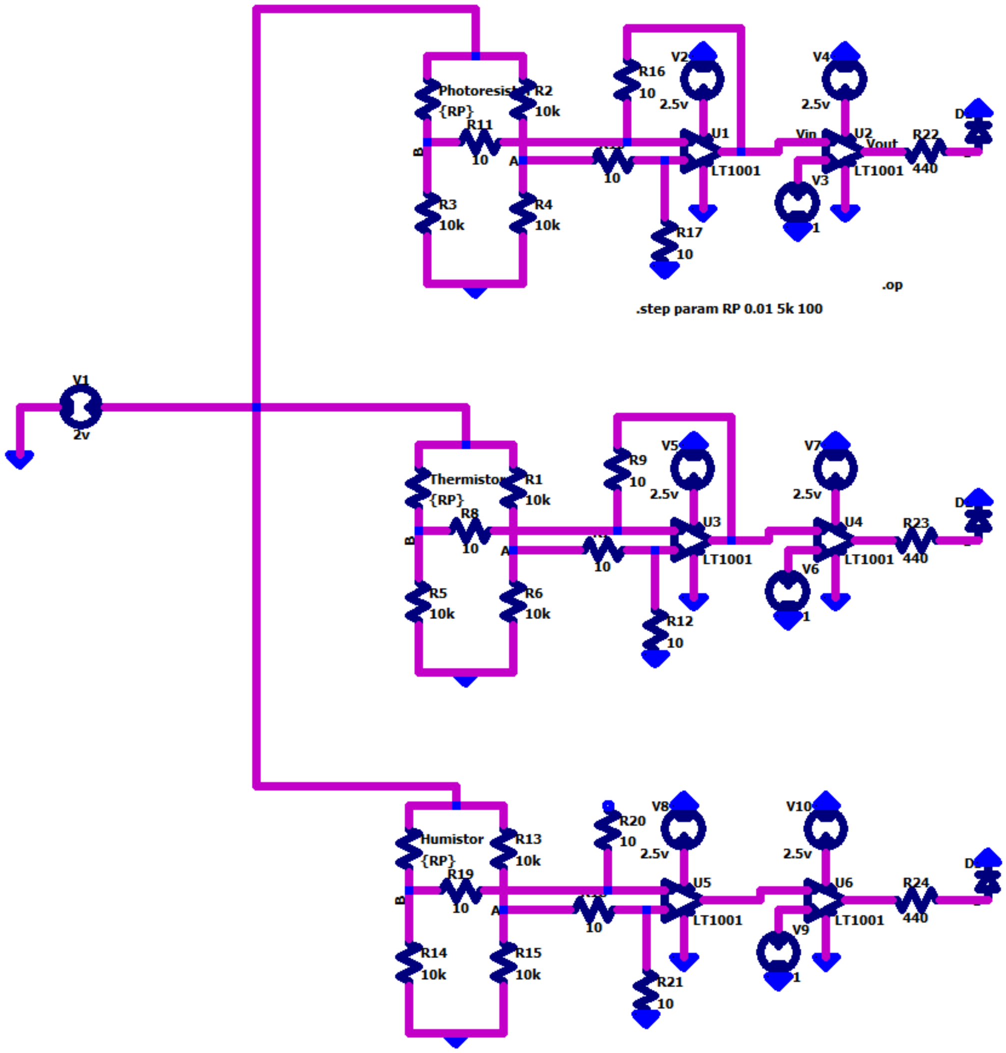


Figure 2: LTspice schematic of the entire circuit

The schematic above is what milestone 1 would look like as all of the wheatstone bridge is connected to the voltage source. For these demonstrations, what would be our solar panel will be replaced as a voltage source of 2V as a replacement. Each wheatstone bridge has 3 known resistors and an unknown resistor which acts as a sensor, since sensors vary on their resistance due to their environment. Thus the voltage output of the wheatstone bridge will be connected to a compactor.

Flowchart for MS3 combining with MS1

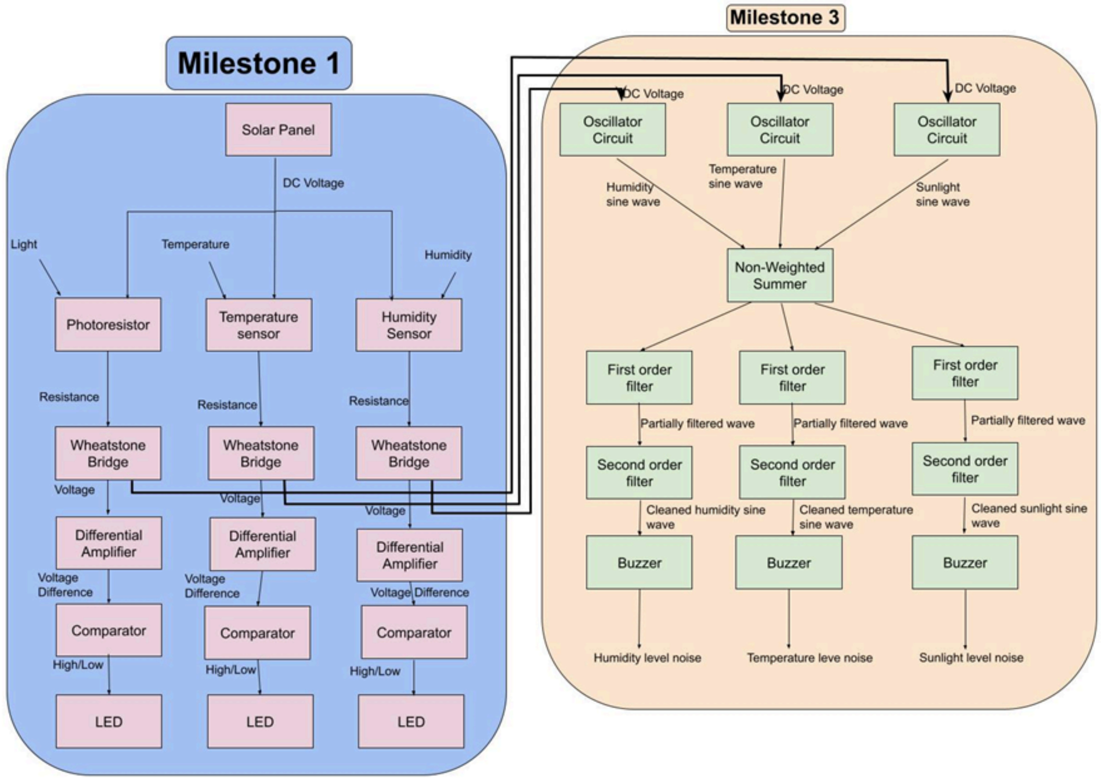


Figure 3: Block Diagram for MS3. In addition, parts of the building block from MS1 is part of the block diagram for MS3

The full block diagram for the whole project of the omega lab MS1 and MS3 is shown in the figure 3. To explain how parts of MS1 are being part of the design choice of MS3, this is how it works. There are 3 sensors that have similar circuits that are being builded into the circuits, as they all contain a wheatstone bridge and maybe the differential amplifier will be part of the design in case there is a problem with the voltage difference. After getting the output from the wheatstone bridge, the voltage would be an DC voltage which serves as an input for the Oscillator circuit. The Oscillator circuit serves the purpose of converting DC voltage and output as AC voltage. Afterwards, all 3's AC voltage will be summed by a non-weighted summer and then each signal will be filtered by a first order filter followed by a 2nd second order filter. Lastly, the buzzer is the output stage to let us know of the filter being filtered by using phasors.

LTspice schematic for MS3

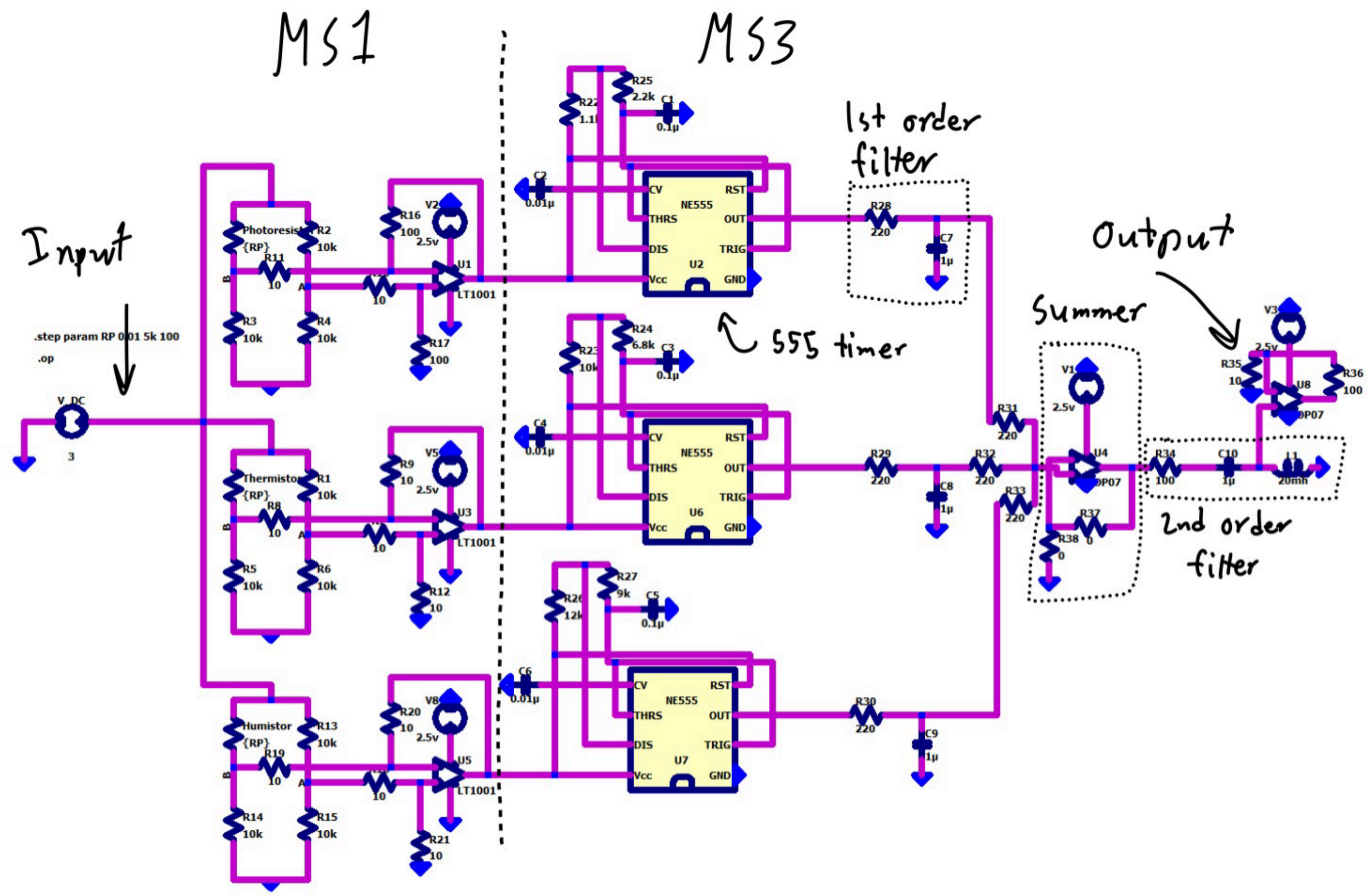


Figure 4: Full schematic with MS1 and MS3 circuit put together

The left side of the schematic is almost the same as the MS1 circuit, where we removed the comparator to LED output, and instead wired the voltage output to the 555 timer. The input of the entire circuit is still the voltage source, but now the output is the non inverting amplifier at the right.

The voltage output from MS1 is wired into each 555 timer, which runs in astable mode. This outputs a square wave with a fixed period, which is then filtered (1st order) to be converted into a sine wave. All three sine waves are combined with a non weighted summer, and then run through a 2nd order filter to isolate one of the the three signals. Which signal we are trying to isolate determines whether it will be a band pass, high pass, or low pass filter.

Photoresistors

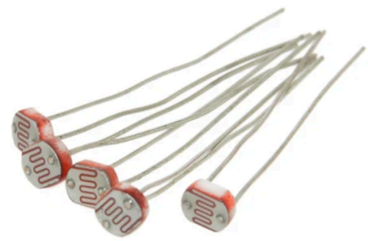


Figure 5: Photoresistors

This is the GL55 series photoresistor that we have used for this project. The datasheet for this photoresistor is included in the references, where it states that the resistance when bright (10 lux) is 5-10 Kilohm, and 0.2 milliohm when dark. It is due to this design that our comparator will only supply the positive voltage when Vin drops below a specified threshold. We want the LED to light when the environment is bright, which has more resistance, and therefore less input voltage.

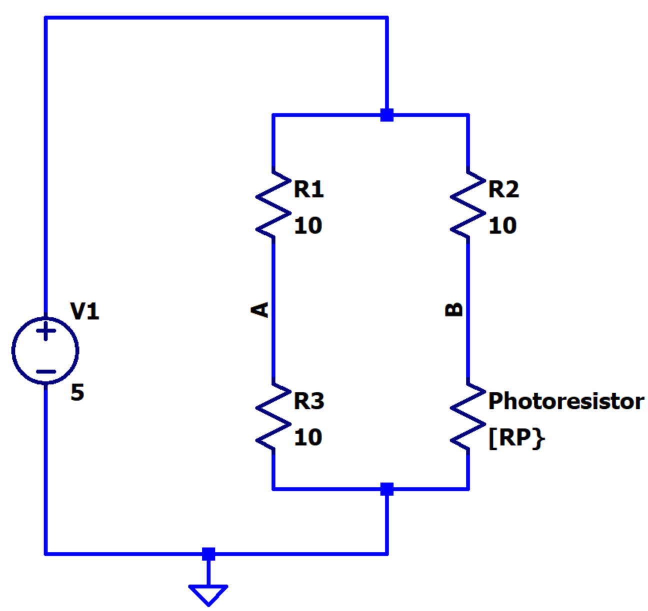


Figure 6: Wheatstone Bridge with sensor

Above is the schematic used to measure the change in voltage due to the photoresistor. The input stage of the photoresistor is part of a wheatstone bridge, which we took from our main schematic. To find Vout for this specific circuit, we need the voltage difference between node A and node B.

The Vout of this circuit would be:

$$V_{out} = V_{in}\left(V_B - V_A\right) \text{ (\#1)}$$

This yield the design equation using the Voltage Divider rule to find V_B and V_A:

$$V_{out} = V_{in}\left(\frac{R_{PR}}{R_2+R_{PR}} - \frac{R_3}{R_1+R_3}\right) \text{ (\#2)}$$

Humistors

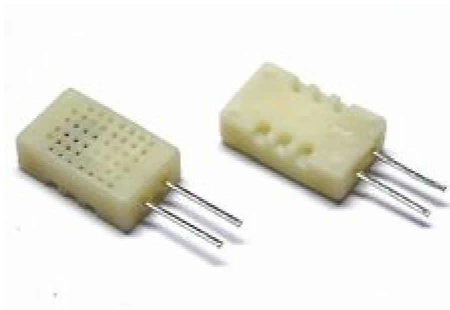


Figure 7: Resistive Humidity Sensor

	0℃	5℃	10℃	15℃	20℃	25℃	30℃	35℃	40℃	45℃	50℃	55℃	60℃
20%RH				10M	6.7M	5.0M	3.9M	3.0M	2.4M	1.75M	1.45M	1.15M	970K
25%RH		10M	7.0M	5.0M	3.4M	2.6M	1.9M	1.5M	1.1M	880K	700K	560K	450K
30%RH	6.4M	4.6M	3.2M	2.3M	1.75M	1.3M	970K	740K	570K	420K	340K	270K	215K
35%RH	2.9M	2.1M	1.5M	1.1M	850K	630K	460K	380K	280K	210K	170K	130K	150K
40%RH	1.4M	1.0M	750K	540K	420K	310K	235K	190K	140K	110K	88K	70K	57K
45%RH	700K	500K	380K	280K	210K	160K	125K	100K	78K	64K	50K	41K	34K
50%RH	370K	26K	200K	150K	115K	87K	69K	56K	45K	38K	31K	25K	21K
55%RH	190K	140K	110K	84K	64K	49K	39K	33K	27K	24K	19.5K	17K	14K
60%RH	105K	80K	62K	50K	39K	31K	25K	20K	17.5K	15K	13K	11K	9.4K
65%RH	62K	48K	37K	30K	24K	19.5K	16K	13K	11.5K	10K	8.6K	7.6K	6.8K
70%RH	38K	30K	24K	19K	15.5K	13K	10.5K	9.0K	8.0K	7.0K	6.0K	5.4K	4.8K
75%RH	23K	18K	15K	12K	10K	8.4K	7.2K	6.2K	5.6K	4.9K	4.2K	3.8K	3.4K
80%RH	15.5K	12.0K	10.0K	8.0K	7.0K	5.7K	5.0K	4.3K	3.9K	3.4K	3.0K	2.7K	2.5K
85%RH	10.5K	8.2K	6.8K	5.5K	4.8K	4.0K	3.5K	3.1K	2.8K	2.4K	2.1K	1.9K	1.8K
90%RH	7.1K	5.3K	4.7K	4.0K	3.3K	2.8K	2.5K	2.2K	2.0K	1.8K	1.55K	1.4K	1.3K

Figure 8: Resistance and Humidity Table

Above is the HR202 resistive humidity sensor. The datasheet for this device is included in the references, and below is a table measuring the resistance of the sensor at different relative humidity and temperature.

Relative humidity is measured based on how much water vapor is in the air, relative to the temperature of the air. Essentially, it is a measure of the actual amount of water vapor in the air compared to the total amount of vapor that can exist in the air at its current temperature. As indicated in the table, less humidity will lead to a greater resistance, and less will have a lesser resistance. For human comfort, any

RH percentage under 30 is too dry, and over 50% is too high. Since we want to measure when the humidity is high, we will wire the comparator to be the opposite of the photoresistor. When the input voltage is greater than a set threshold, the LED will turn on. Other than that, the schematic should match figure 6, and the mathematical equations are exactly the same as the photoresistor.

Thermistor

Figure 9: Thermistor

Above is the B57164K103J thermistor, which will decrease its resistance when temperature increases, and vice versa. As we want to measure when the temperature is generally high, this sensor's comparator will have the same design as the humidity sensor. The schematic and mathematical equations will also be the same as the photoresistor and humidity sensor.

555 Timer

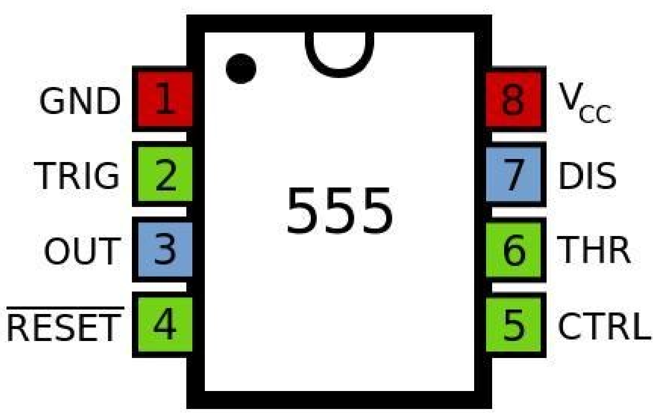


Figure 10: 555 Timer Schematic

Figure 10 is an op-amp 555 timer, which serves in this lab as our oscillating circuit. The way of how we structure the use of the 555 timer is that we make an input of a DC voltage and then output a AC voltage that is a square wave. Note, because this is a square wave and we wanted a sine wave, we have to use an RC circuit to convert it to solve the issue. More about this will be explained later in the section for how we solve a problem.

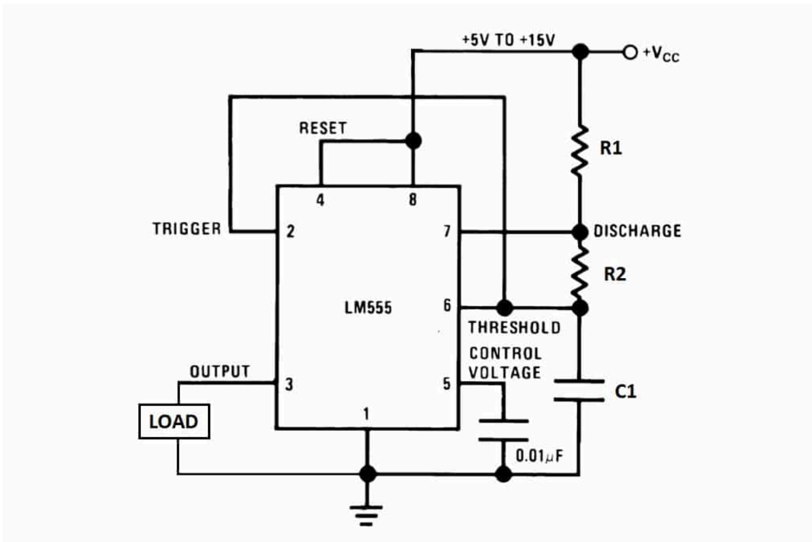


Figure 11: Astable mode configuration

To find the frequency of the 555 timer astable mode is given:

$$f = \frac{1.44}{(R_1 + 2R_2)} \quad (\#3)$$

Thus, having the frequency would have to be used for the filter application in the math in the future section.

Operation and Design

Solar Panel:
Our input stage would be the solar panel overall as it's going to provide the V_{DC} towards all 3 sensors and varies depending on the amount of sunlight it receives. As of right now, the solar panel wasn't available when we first started this project as it was in the shipping.

Photoresistors:

For now, we will explain our other input sensor which is the photoresistor. Please see Figure 5 of what we are talking about for the description about it. In addition, please see Figure 6 for schematic of the input block as the photoresistor was part of the wheatstone building, so the wheatstone is part of the input. The design equation are shown in the equation #1 and #2 from above, so you can make a reference of the math from there.

The Voltage difference is found at the A-B V reading:

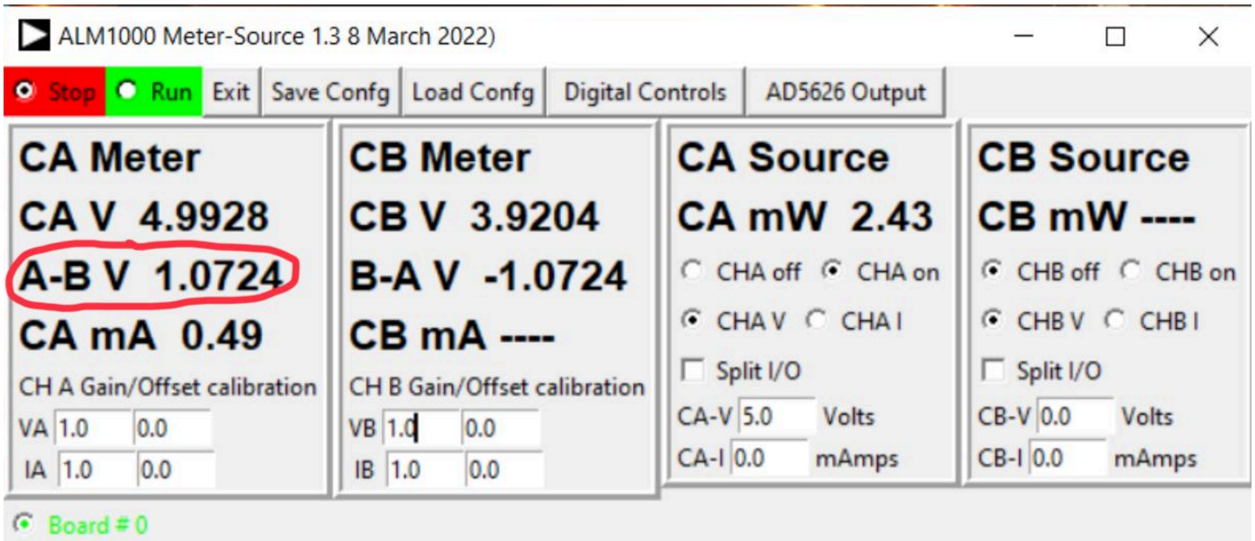


Figure 12: Photoresistor In a dark environment

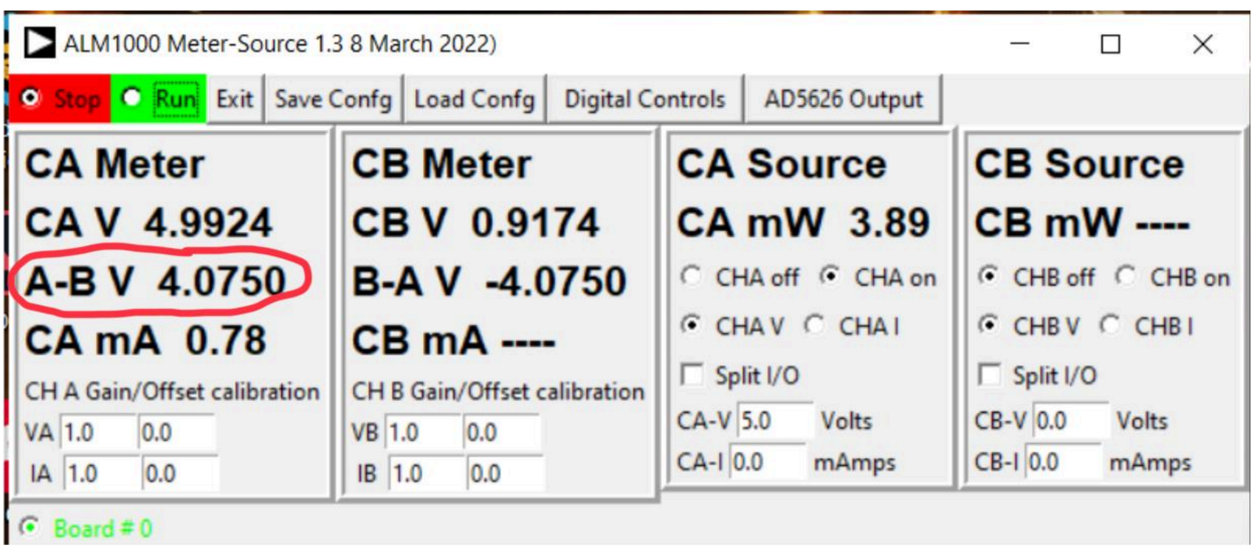
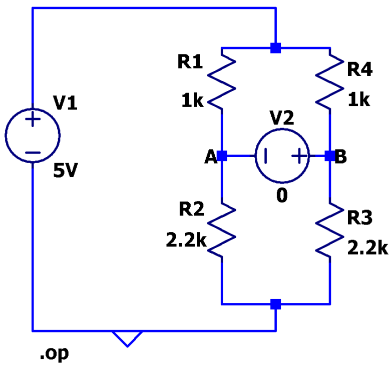
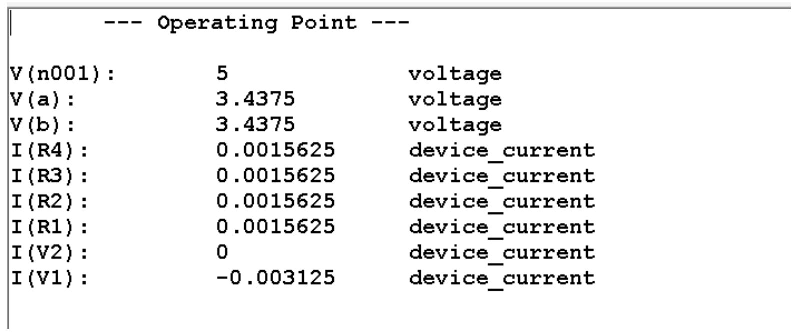


Figure 13: Photoresistor in a well lit environment

Figure 12 shows the voltage output from the photoresistor within the wheatstone bridge in a dark environment as well as Figure 13 is the opposite environment conditions.

MS1 Building Block 1: Wheatstone Bridge





```
--- Operating Point ---

V(n001):      5            voltage
V(a):         3.4375       voltage
V(b):         3.4375       voltage
I(R4):        0.0015625    device_current
I(R3):        0.0015625    device_current
I(R2):        0.0015625    device_current
I(R1):        0.0015625    device_current
I(V2):        0            device_current
I(V1):        -0.003125    device_current
```

Figure 14: Wheatstone Bridge example

$V\ = v_s \frac{R_b}{R_a+R_b}$ -> This equation use v_s which is the voltage source and R_b is the resistor at the bottom of the bridge while R_a is the top resistor. We do this twice and subtract the difference to get the voltage in between.

$$V_A = v_s \frac{R_2}{R_1+R_2} = 5v\frac{2.2k}{2.2k+1K} = 3.33V$$

$$V_B = v_s \frac{R_3}{R_3+R_4} = 5v\frac{2.2k}{2.2k+1K} = 3.33V$$

$$V_B - V_A = 3.33 - 3.33 = 0V \ (\#4)$$

The resistors were chosen in this way to make the wheatstone bridge balanced but one of the resistors will be the sensor. There is a voltage source in the middle that is needed for the wheatstone bridge to work and we used 0 voltage so it doesn't interfere with the circuit's output. For an unbalanced wheatstone bridge we can use a 0 current source. An easier way would be to just leave that as a short circuit.

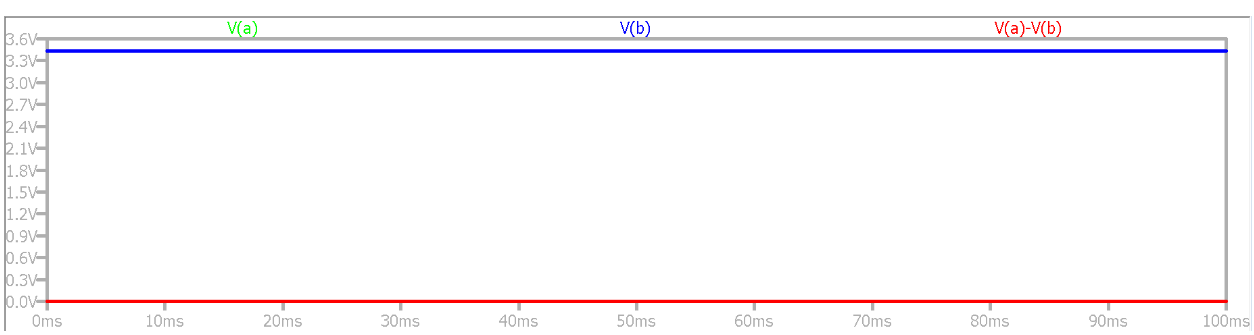


Figure 15: Wheatstone voltage difference

Figure 15, we see from the graph that when the wheatstone bridge is balanced the voltage between node A and B is 0. When we replace one of the resistors with a sensor it will change the voltage causing the bridge to be unbalanced and producing a voltage.

MS1 Building Block 2: OP-amp as a comparator

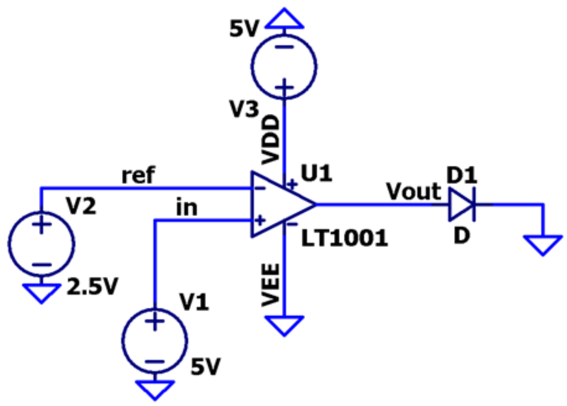


Figure 16: Op-amp with Vin = 5V

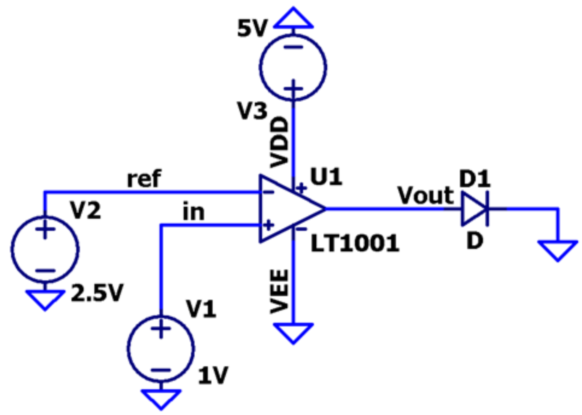


Figure 17: Op-amp with Vin = 1V

If $V_{in} > V_{ref}, V_{Out} = V_{DD}$ (#5)
If $V_{in} < V_{ref}, V_{out} = V_{EE}$
If $V_{LED} > 1.8V,\ LED\ will\ shine$
-> Here we compare the input voltage with the reference voltage. If the input voltage is higher than we output VDD else we output VEE. The voltage needed for an LED is around 1.8V to shine.

$V_{in} = 5V,\ V_{ref} = 2.5V$ (#6)
$5V > 2.5V,\ V_{out} = 5V$

$V_{in} = 1V,\ V_{ref} = 2.5V$
$2.5V > 1V,\ V_{out} = 0V$

We chose to use an op-amp as a comparator for Milestone 1 because it would help us show the reading that we get. Based on the voltage output by the wheatstone bridge with the sensors, we use the op-amp to output voltage to turn on a LED or don't output any voltage.

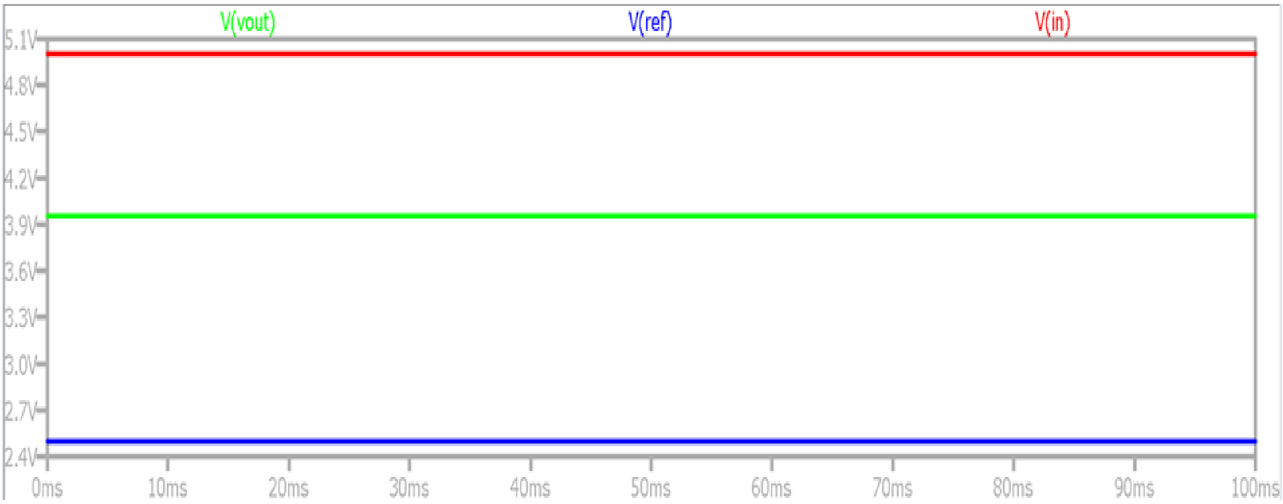


Figure 18: Output for Figure 16

When Vin is greater than Vref it outputs a high voltage. It is close to 5V but not exactly due to the op-amp we used in LTSpice. With a voltage output of 4.1 V, the LED in the schematic should shine.

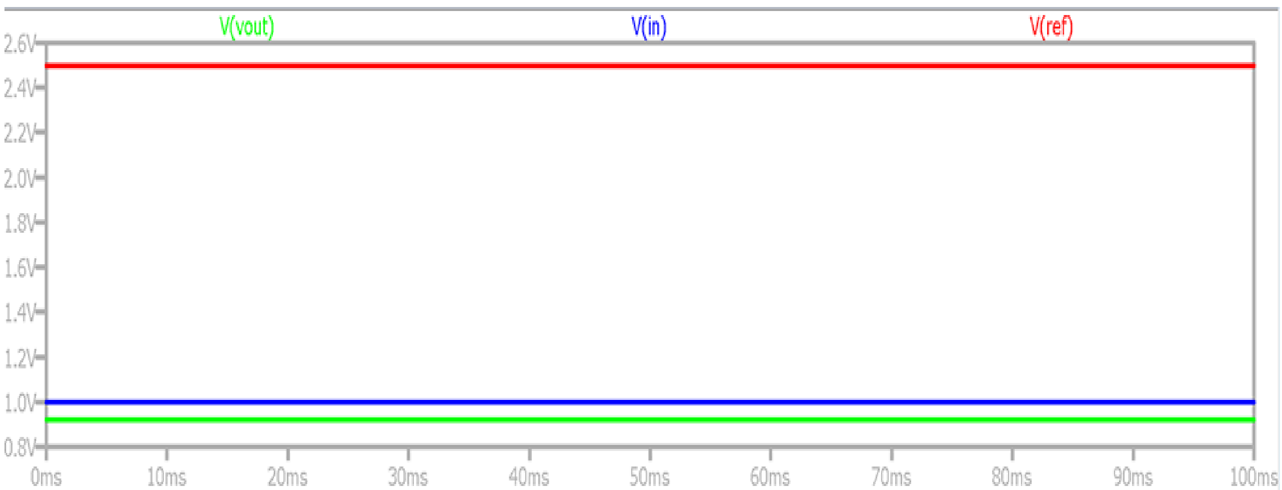


Figure 19: Output for Figure 17

When Vin is lower than that it should output GND but because of the op-amp and it not being ideal there would be a slight difference to it. With a voltage output of only 0.9V, the LED will not shine.

MS3 Building Block 1: Passive First-order Low Pass Filter

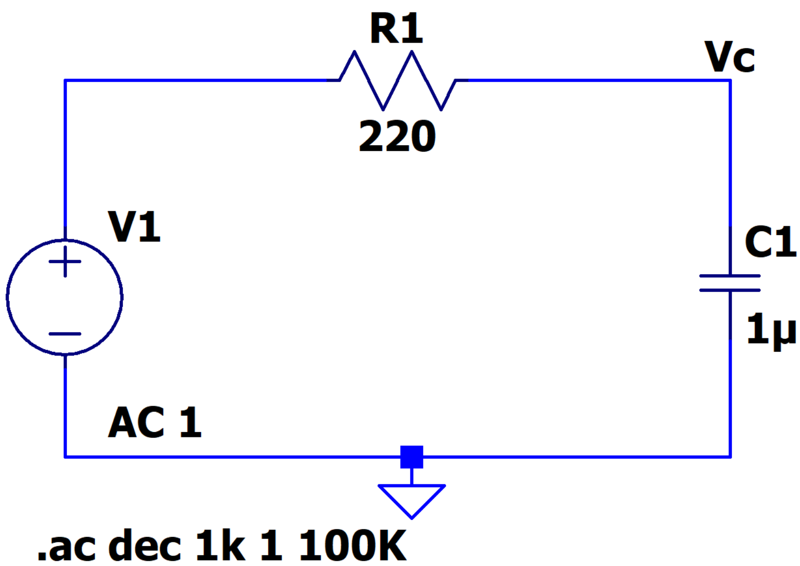


Figure 20: 1st order RC passive filter

The transfer function for 1st order RC filter:

$$H_s = \frac{w_c}{s+w_s} = \frac{4545}{s+4545} \text{ (\#7)}$$

Where the $w_c = \frac{1}{RC} = 4545$, but in terms of radians/sec, the cutoff frequency would be:

$$w_c = \frac{1}{2\pi RC} = 723.43\ Hz \text{ (\#8)}$$

Based on the transfer function, there are N/A zeroes and a single pole of 4545. When checking the frequency region of the bode plot for the rolloff frequency:

When $s << 4545$: $\frac{4545}{0+4545} = 1 \Rightarrow 20log(1) = 0\ dB$

When $s >> 4545$: $\frac{4545}{s}$ is proportional to $\frac{1}{s} \Rightarrow 20log(\frac{1}{s}) = 20log(1) - 20log(s) =- 20\ db$

The resistor and the capacitor were chosen in this way to make the square wave into more of a sine wave during the actual experimental section when measuring as well as try to balance out the voltage output from the sensors. The voltage source is an AC analysis as we can gain the bode plot of the schematic.

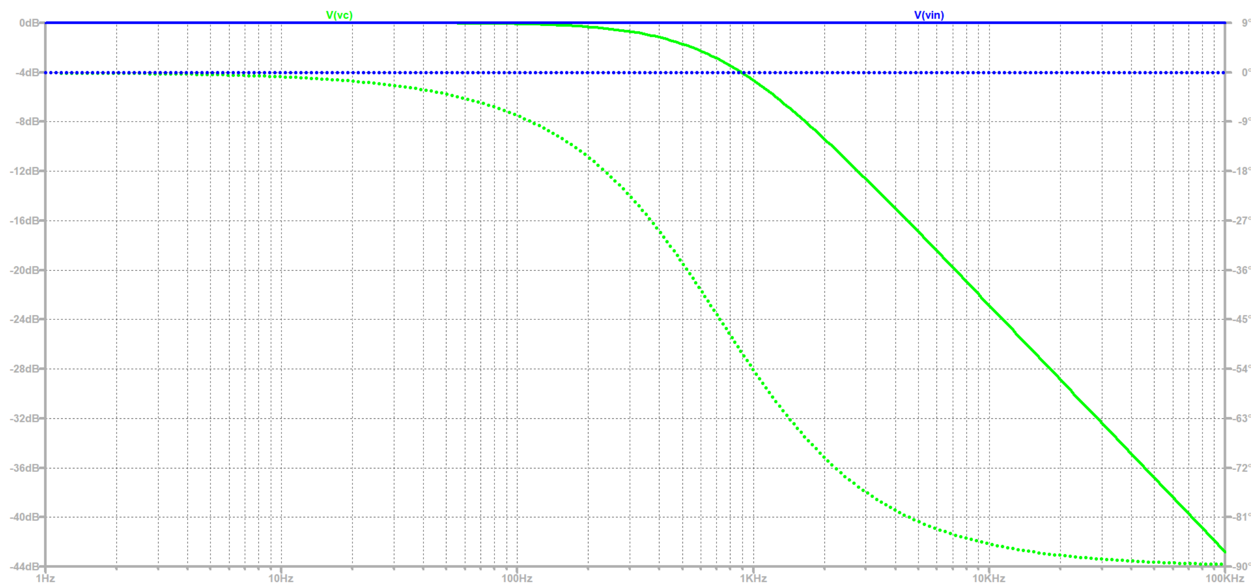


Figure 21: RC filter output

Figure 21 shows the bode plot of the capacitor voltage (represents as V_c as the green line) in which we will mainly focus on that graph. The y-axis measures in dB on the left-hand side while the x-axis is in frequency and the right-hand side is the phases.

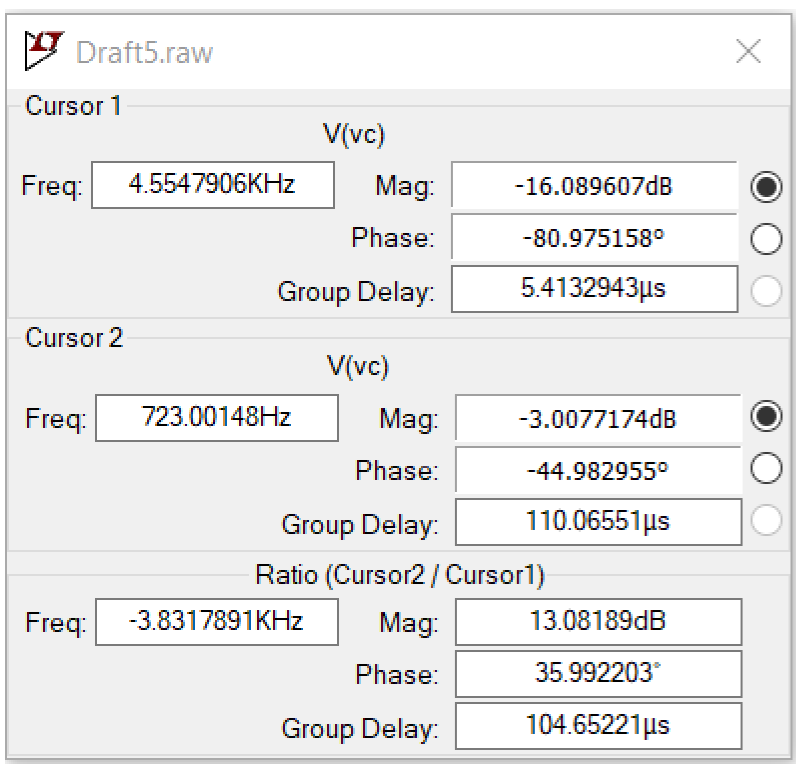


Figure 22: Curver of the 1st order RC filter bode plot

Figure 22 we have examined two cursors on the graph. Cursor 1 measures the frequency without the Hz as this is part of the poles. Meanwhile, cursor 2 measured the cut frequency measured in Hz. As you can see that at -3dB, the cutout frequency is 723 Hz which matches the equation 8 as calculated. In addition, figure 21 shows the runoff frequency region from starting at 0 dB and then dropping at a rate of -20dB once it reaches the pole.

MS3 Building Block 2: Active Second-Order High Pass Filter

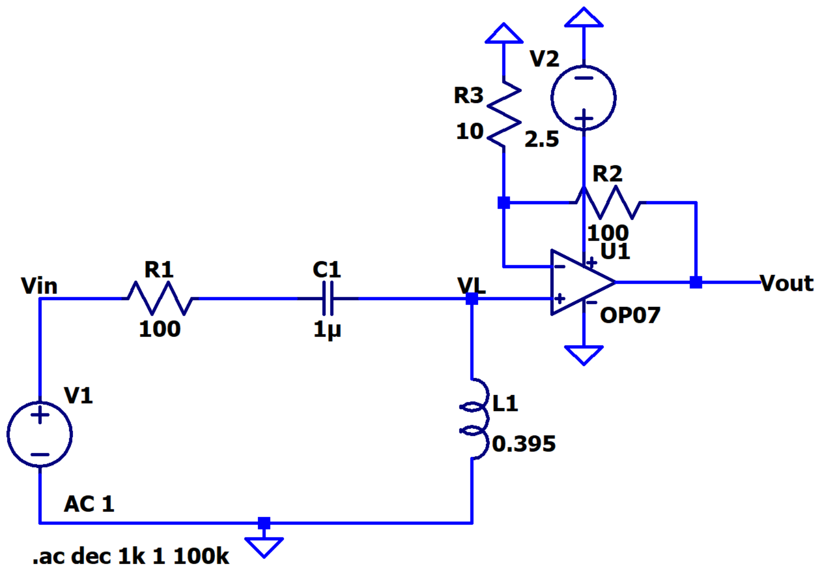


Figure 23: 2nd order Active High pass filter that has an non-inverting amplifier

The transfer function for 2nd order RC filter:

$$H(s) = \frac{V_L(s)}{V_1(s)} = \frac{s^2}{s^2+2\alpha s+w_0^2} = \frac{s^2}{s^2+253s+2.53*10^6} \text{ (\#9)}$$

Where $2\alpha = \frac{R}{L} = 253$ and $w_0^2 = \frac{1}{LC} = 2.53 * 10^6$.

As a result, we can see that the damping ratio ($\frac{\alpha}{w_0}$) is approximately 0.08 which means this system is underdamped. Overall, the cutoff frequency of this transfer function is when:

$$w_0 = \frac{1}{2\pi\sqrt{LC}} = 253.23\ Hz \text{ (\#10)}$$

From the transfer function equation 9, we can see that the zeros are 0 but at n=2 and the poles are complex numbers where if you were to solve for it, it would be: $x = \frac{-253\pm\sqrt{-64009+\frac{253*10^6}{25}i}}{2}$.

For the non-inverting amplifier, the gain is

$$(1 + \frac{R_f}{R_I}) = 11 \text{ (\#11)}$$

We have chosen the value of the resistor, capacitor, and the inductor because resistance doesn't matter about what frequency we are calculating but only the capacitor and the inductor. So therefore we use the values of the inductor's filtration that will give us a frequency to be used for the buzzer, aka once we configure the whole circuit it will give us a graph that somewhat would look like a sinusoidal wave. The non-inverting op-amp is used to increase gain of the output of the graph by a certain factor so the voltage wouldn't be too low.

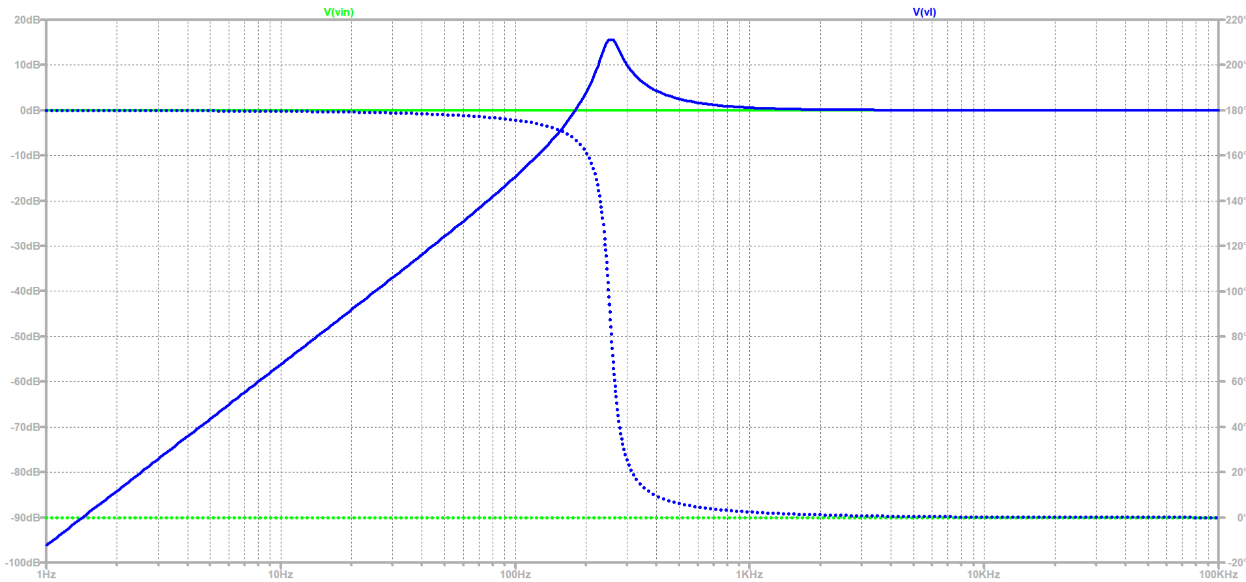


Figure 24: LTSpice Bode plot for the active 2nd order

In figure 24 we have plotted out the bode plot for the 2nd order active filter. The green line represents Vin while the blue line represents VL which is the output of the inductor. Based on the graph, we can see that it shows an underdamped system of the filter which did match our calculations as the damping ratio would be less than 1.

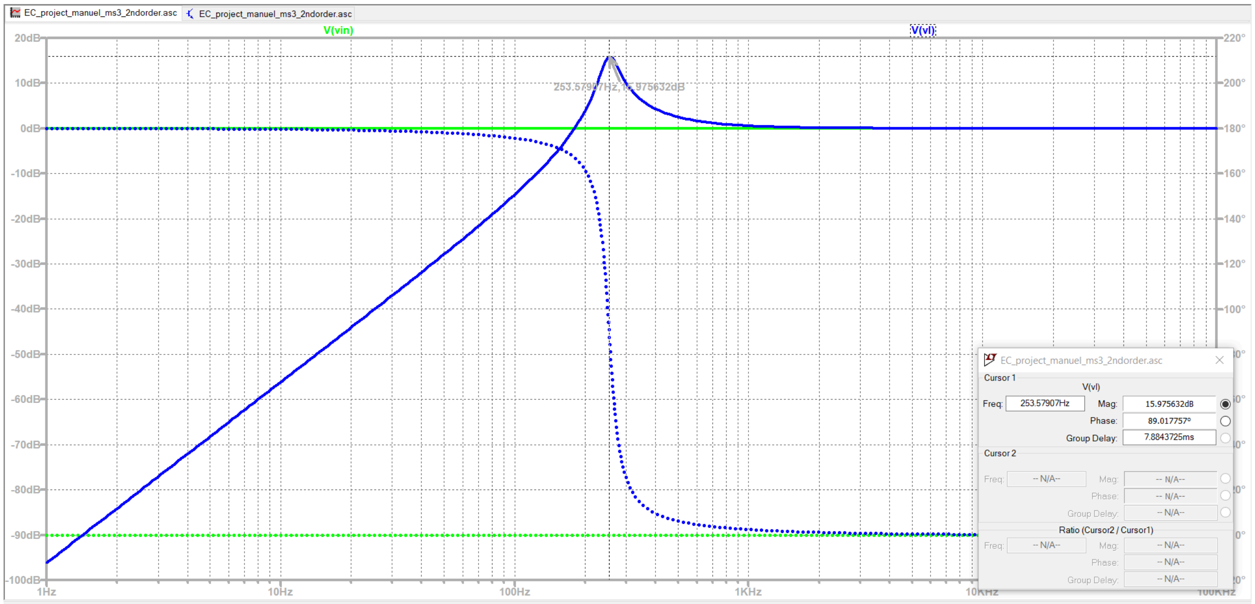


Figure 25: Vin and VL graph with cursor data plot with label

We had added the cursor tool to measure the peak of the VL graph, as the moment before the peak fall represents the cutoff frequency. In addition, we have labeled a plot at the top where it matches the cursor data at the bottom right.

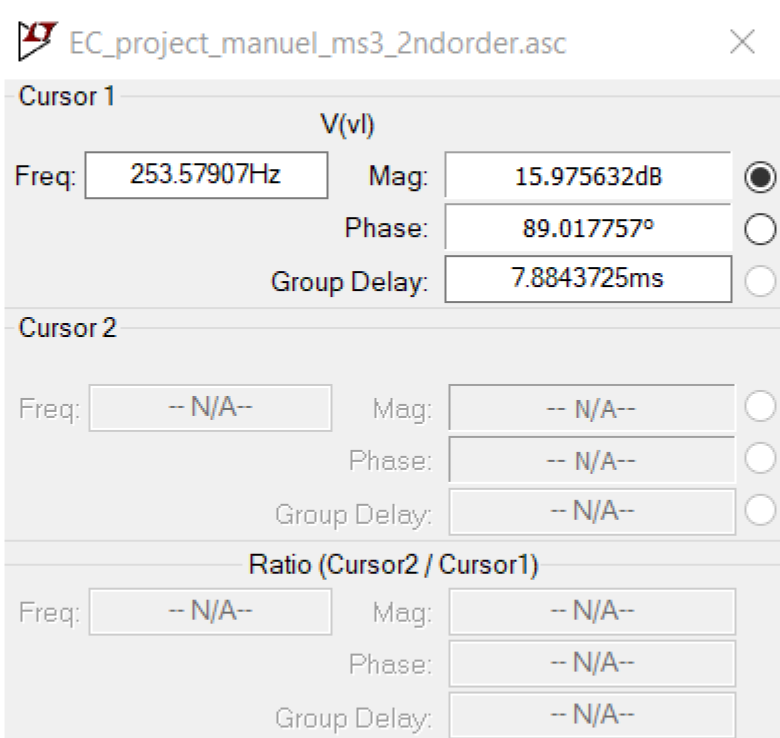


Figure 26: Zoom-in of the cursor data for VL graph

When using the cursor tool to measure the VL graph, we can see that the cutoff frequency of the graph is approximately 253 Hz which is about the same frequency we have calculated. As it would leave the high frequencies untouched while mitigating low frequencies for our entire circuit schematics. And since it's an underdamped circuit, the graph would overshoot its frequencies until it reaches steady state.

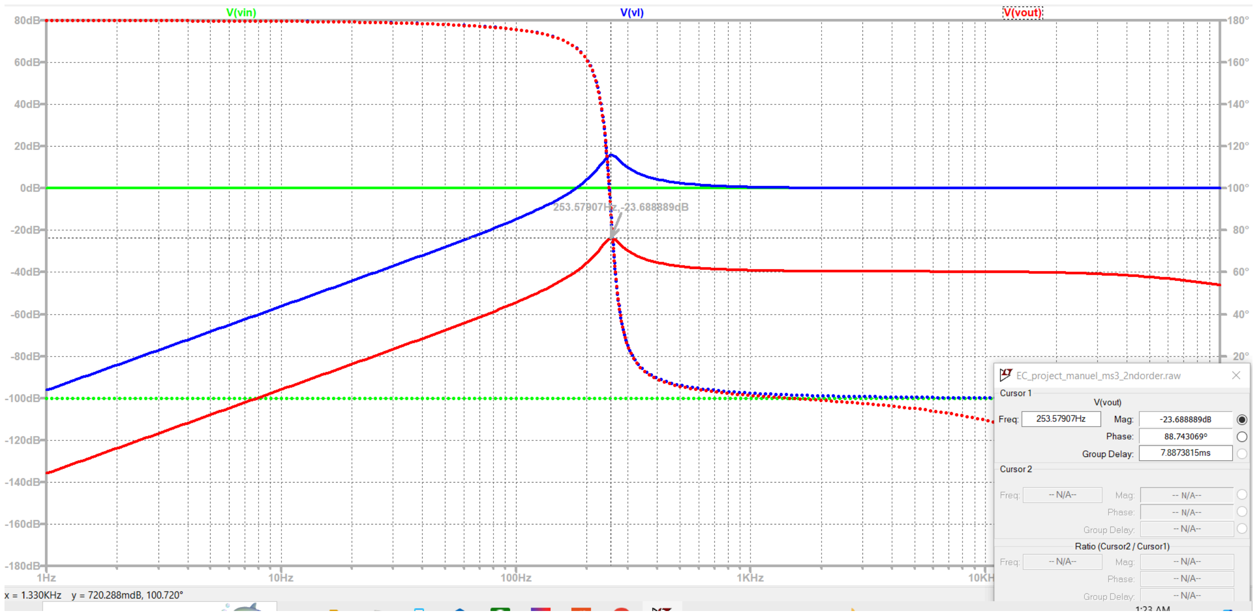


Figure 27: Appended the Vout graph (amplifier) onto the Bode plot with the rest of the reference points

In the figure 27, I have added another reference point into the bode graph, in which the red line represents the Vout (voltage output of the non-inverting amplifier). If you look closely at the peak of the red graph, I've added a data point that summarizes the cursor data that I've added at the bottom right.

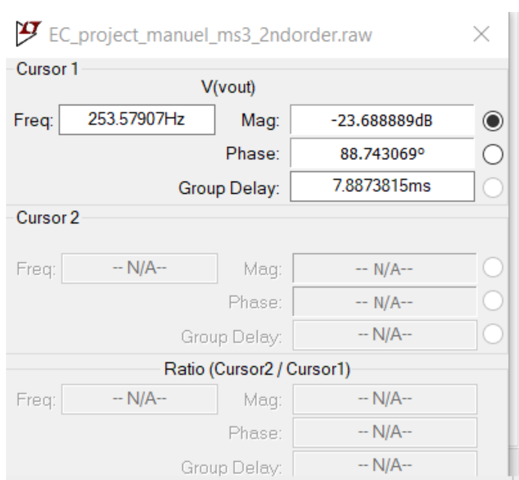


Figure 28: Zoom-in of the cursor data for Vout

On the zoom-in version of the cursor data shown in figure 28, we can see that the frequency of the amplifier has stayed the same of 253Hz, but the mag of it changed to -24dB which is to be expected from the non-amplifier gain shown from equation 11.

Output Block: LED

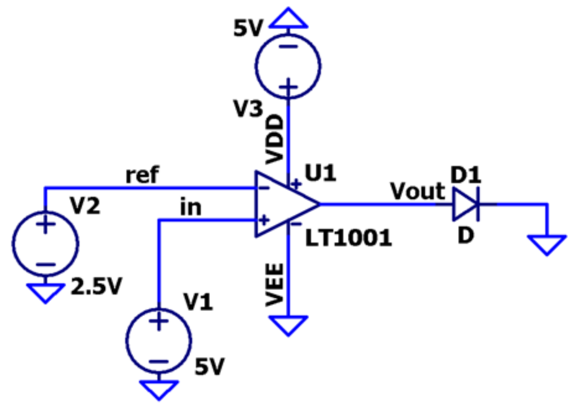


Figure 29: Example of a LED connected from an comparator

Our output is to a LED. The LED is connected to the op-amp as a comparator as shown above. For our math and output of the LED, refer to the Op-amp Figure 16/17 as it was explained there as well as the math designed equation. Based on the output of the op-amp, it would either turn on the LED by supplying it with enough voltage or turn it off by supplying it no voltage. The graph from the Op-amp shows the input of the LED as well as the output of the LED.

Output Block for MS3: Buzzer

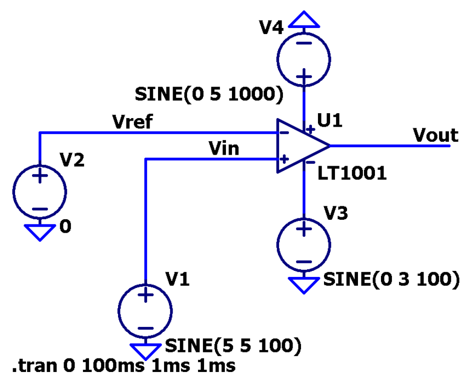


Figure 30: Example of a buzzer output based on input

Our output for MS3 is a buzzer, however in LTSpice there is no component that is a buzzer. However, we can use op-amps and sinusoidal voltage sources to simulate what is happening with the buzzer. In the circuit, we have a sinusoidal voltage source. We use an op-amp as a comparator with two sinusoidal outputs. Here, if we shine the light on a sensor then the output would be a wave with higher frequency and higher amplitude which is similar to what the buzzer does as the buzzer becomes slightly more high pitch and louder. When the sensor does not have any changes, the buzzer has a lower frequency and at a lower volume. This is exactly what happens to our buzzer based on what we do to the sensors. Look at figure 39 to see a potential output of the graph where the active 2nd order filter would enter the buzzer and output.

Integration and Optimization for MS1

The usual first stage of our circuit is the Solar panel to the 3 individual sensors which produces a DC voltage, V_{DC}. Our speculations would have connected the solar panel where one of the wires is connected to ground, and the other wire would be supplied towards the photoresistor, temperature sensor, and the humidity sensor to allow incoming V_{DC} to pass through and as a result, an output of those senor would be an resistance for the next stage.

However, an issue that had come up during this project was that the solar panel that we had ordered didn't come at the time during the circuit building and the presentation. In addition, what we have heard from Professor Patterson is that other groups have a small problem where the solar panel that they have brought doesn't supply enough voltages. Therefore, a way that we get around this is for now, to have a set voltage supplying to the sensors for the time being.

The second stage of our circuit is the photoresistor to the wheatstone bridge to produce voltage (Vout). As V_{DC} enters the photoresistor and outputs an resistance R_{pr} which would then be used as an input for the wheatstone bridge. To connect these two components together, we must use a Differential amplifier to receive Vout, while the actual connection between the photoresistor and the wheatstone is just basically a wheatstone configuration with one of its resistors as a photoresistor.

I like to point out the reason why we have to use a differential amplifier op-amp in order to gain our Vout when building the circuit. The original design involves using a voltage divider to find the difference in voltage (Vout) in the wheatstone bridge. However, the Vout values we received didn't match our values we have tested. Therefore, the solution that we have proposed to get our building block working together is to use the differential amplifier as Vout would just be the difference between V_A and V_B. Please reference Figure 31 for the math behind.

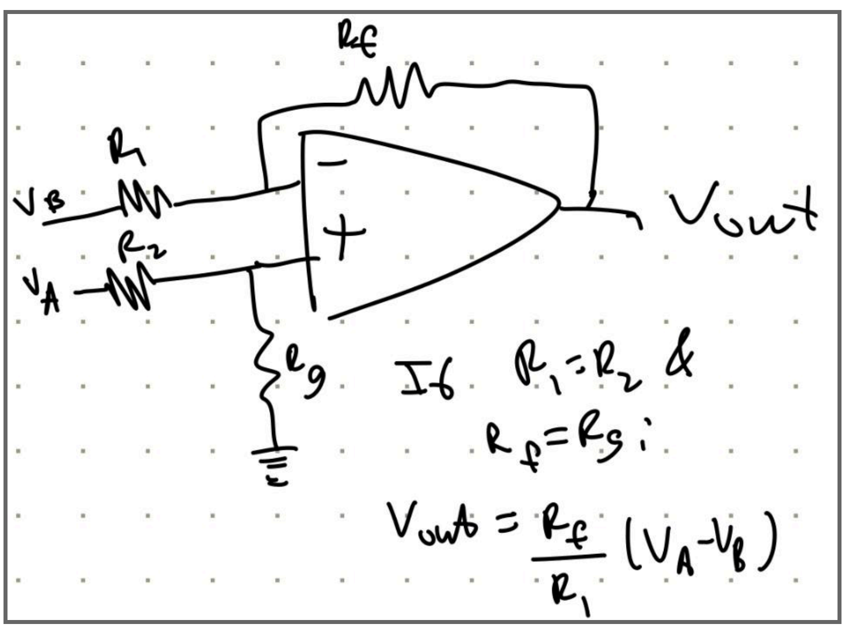


Figure 31: Differential Amplifier math for solving Vout.

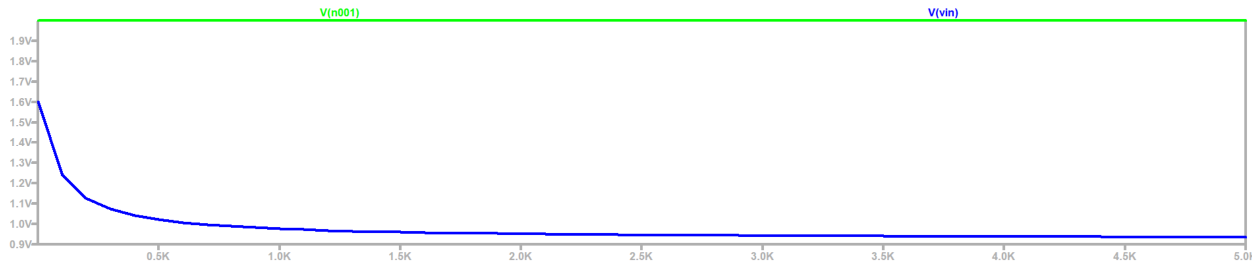


Figure 32: Output of Photoresistor within the Wheatstone Bridge after the Differential Amplifier

Figure 32 shows the input and the output of the whole photoresistor operations as V_{DC} is our input while Vout is the output from the differential amplifier. As V_{DC} (shown from this simulation as V(n001)) is being measured as 2V which is the representative of the solar panel DC voltage. The Vout shows a decaying exponential line as a range from 1.6V-1.0V. The reason why we are using a step parameter function is because in the environment, the photoresistor is always changing the amount of light it senses so we have no defined exact value for it.

For Stage 3 and 4, which the temperature and the humidity sensor, are configured and explained in the exact same way as the photoresistor description. As both sensors use V_{DC} as their input to power its resistor and output an resistance value inside the wheatstone bridge to produce a voltage output (Vout). The plot of those sensors would be the same as shown in Figure 32. The way of how these building blocks are connected together is that they all share the same shared voltage source V_{DC}, but they are constructed separately due to what our plans for milestone 3.

The final stage of our circuit is the comparator to the LED configuration. Each wheatstone's Vout is used as the input for the comparator and used to compare against a different value that we have personally set to as what we define as "room value". We use a comparator only to make a decision on whether or not to turn on the LED light.

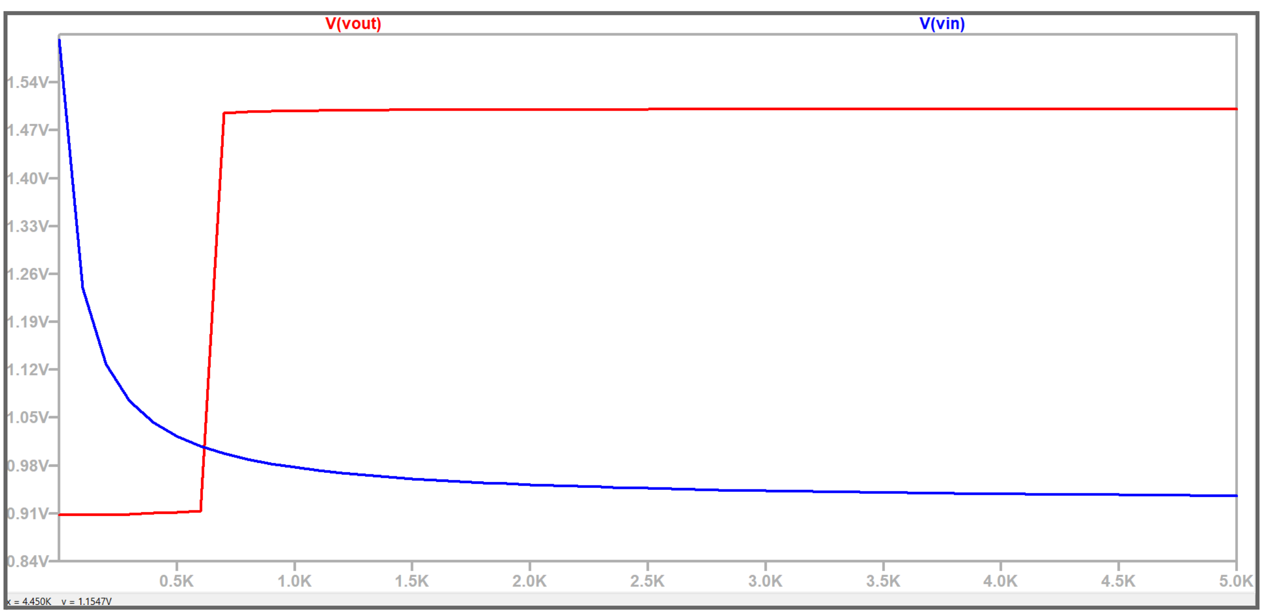


Figure 33: Input (Vin) and Output (Vout) of the Comparator

Figure 33 shows the input of the comparator and the resulting output from the photoresistor building block side.

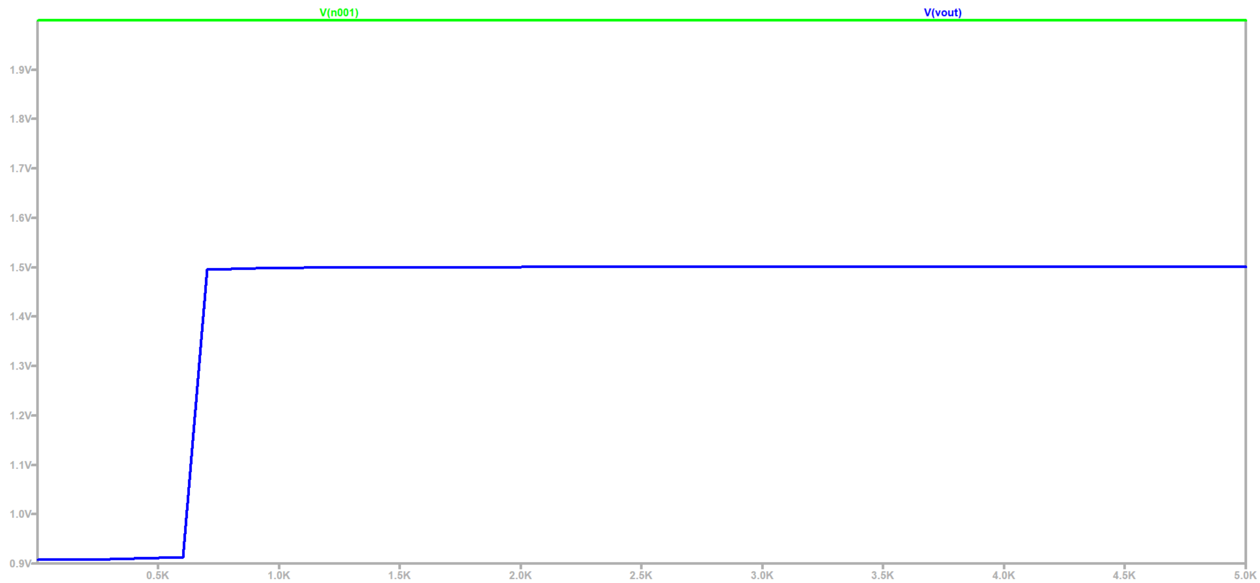


Figure 34: Example input and output

Figure 34 shows an example input and output of the overall circuit. The input noted here V(n001) represents as our V_{DC} is measured as our “pretend” solar panel. While the output (Vout) is measured at the output of the comparator before the LED. The input for this demonstration as we don’t have the actual solar panel during the time is set at 2V which is being represented as an DC voltage signal of a straight line. The output shows the Vout as 1.5V being applied to the LED.

Integration and Optimization for MS3

The first stage of Milestone 3 is the oscillator circuit, which was built using the 555 timer. This component was used because it could easily take a DC voltage, and convert it into a waveform. In essence, it was converting DC to AC, which is what we needed to perform signal analysis. The 555 timer was set up in astable mode, which allowed you to set the frequency of the output wave using resistors and capacitors. The formula for this can be referenced back at equation 3.

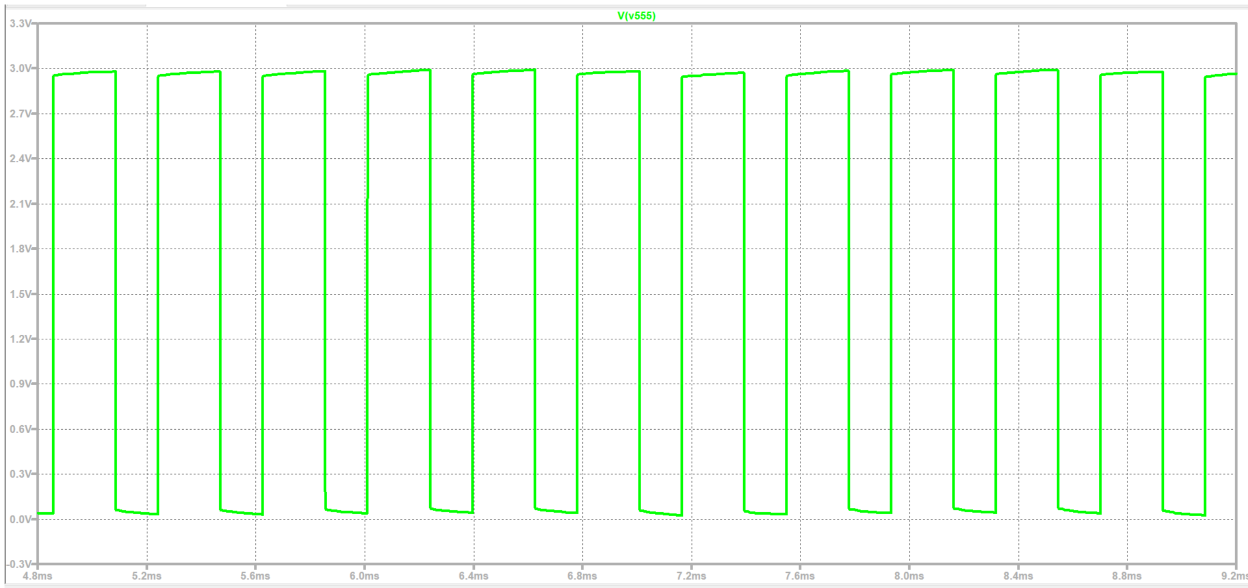


Figure 35: 555 timer astable mode LTspice output of an Photoresistor sensor

As Figure 35 represents one of the 555 timer outputs represented in green graph. As shown, the graph is a square wave which serves as the purpose of an oscillating circuit as we have previously mentioned that it will convert a DC to AC in square wave. From the figure above, we can see that the square wave oscillates from 0V-3.0V which for MS3 simulation, its input is a 3V source. You may be asking yourself why we used a 3V voltage source as our input when the input is supposed to be the output of the differential amplifier. Well the answer is that we ran into the problem on LTSpice where because of how our circuit (from figure 4) has too many components and its complexity, the simulation either crashed up or was constantly loading. So a way to fix that is to just break up the connection for now and run the simulation for the 555 timer with the input source of 3V. The frequency of this square wave can be calculated as f=1/T, where T is the time period. Since the time period of the wave is 0.4ms, then the frequency is 2500 Hz.

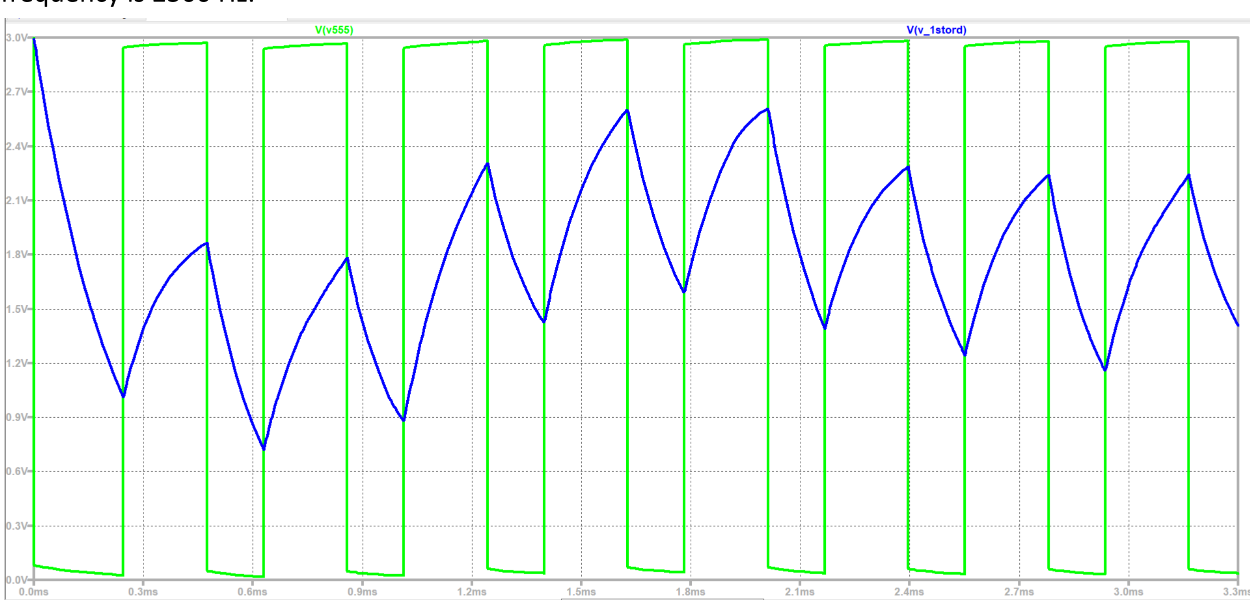


Figure 36: Output of the 1st order RC filter from the 555 timer

It was important to set a very different frequency for each signal, as it made filtering them out later on much easier. The output wave however, was a square wave. This meant that we needed to somehow convert it into a sine wave in order for it to be easier to filter, and for the math side of the calculations. To accomplish this, a RC passive first order circuit was used. It was important to choose very specific values for the resistor and capacitor, as the wave would either remain a square wave, or be close to a flat DC voltage if the cutoff frequency wasn't correct as shown from figure 36. This concludes the oscillator circuit block. Like to point out that the output of the 1st order RC filter mainly looks like a sawtooth wave because one of the problems is to get the output of the 555 timer input the RC circuits to be looking like a sinusoidal wave. One of the problems is that we potentially tested out values that would work best but the more absurd values we have inputted for either the resistance and capacitor wave would not be possible to make for the real circuits as we won't have the exact capacitor values needed. Later on in the section, we might have found a possible solution for this problem is to configure the RC circuit into an LC circuit as it will convert it into sinusoidal wave based on our research (more will explain in the Operating conditions).

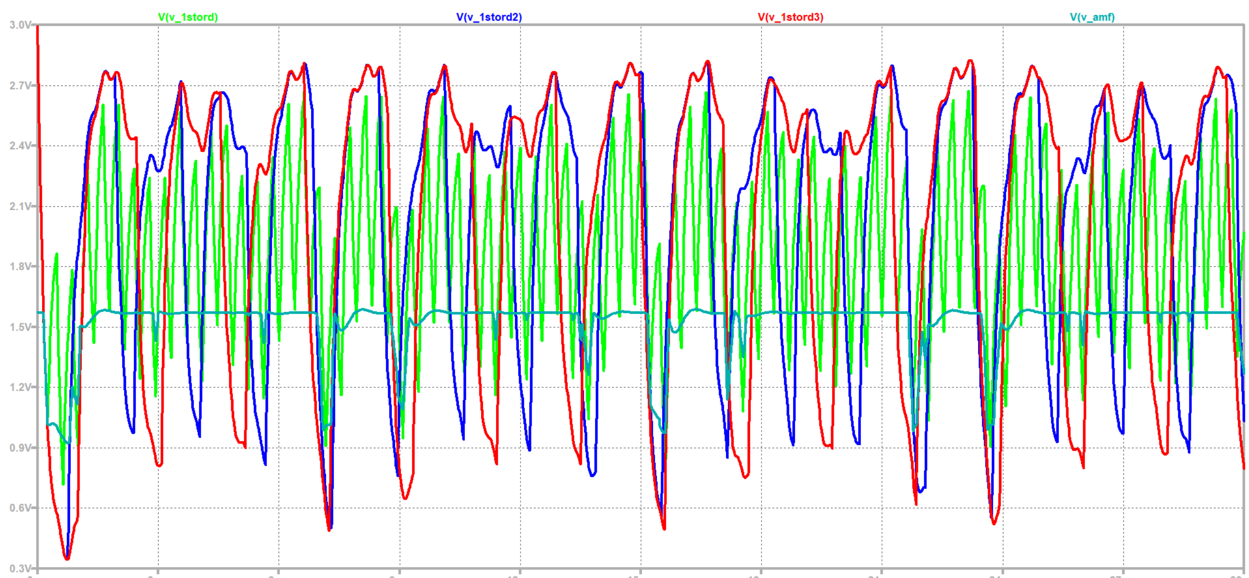


Figure 37: 3 inputs from each 555 timers and an output of the non-inverting summer amplifier

Eqn for an non-inverting summer: $V_{amf} = V_{in}(1 + \frac{R_f}{R_i})$, where $V_{in} = V_1 + V_2 + V_3$ (#12)

After this step, the waves were simply wired into a non weighted summer. This was a very simple step, as the op amp set up for this step was the same as if the three signals were simply DC voltages. Simply connect all three signals to the positive terminal of the op amp, and connect the negative terminal to the output. As shown from figure 37, the green line represents photoresistor signal, blue line represents thermistor signal, red line represents the humidity signal, and lastly the aqua (greenish-blue) line represents the voltage output of the non-inverting summer amplifier. Since this was simply the summer, additional gain from the op amp was not necessary, therefore $\frac{R_f}{R_i} = 0$ which means that $V_{amf} = V_{in}$.

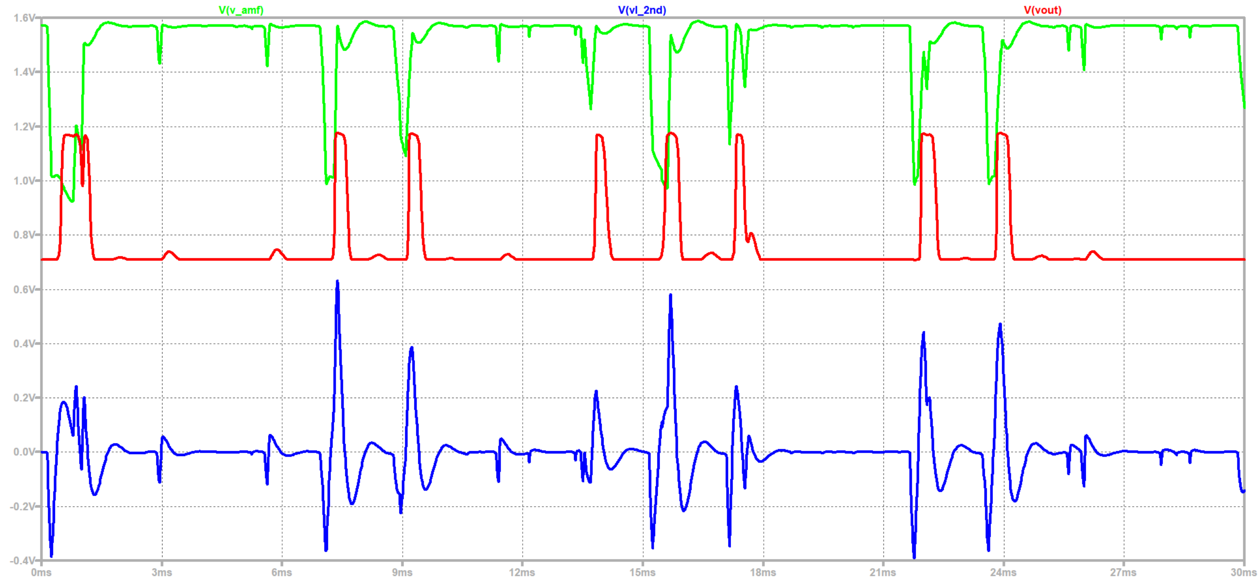


Figure 38: Vamp (input) vs VL_2nd (2nd order filter of VL) vs Vout (output of the system of the non-inverting amp)

Then, the entire summed wave was going to be put through a 2nd order filter in order to isolate one of the three filters. In our physical circuit, we simplified the build to only two signals being summed, which would make it much easier to filter out one of the two signals. The circuit was already very complex, and adding a third sensor would not only make the wiring more difficult, but lead to more overall errors. Regardless, the 2nd order high pass filter consisted of two RC 1st order high pass filters cascaded together. While this design did effectively filter the signal, the output was very confusing to look at. We ended up altering out LTspice schematic to instead use a RCL circuit, where the resistor, capacitor, and inductor was wired in series. This ended up producing an output that was more similar in shape to the experimental measurement than using the old 2nd high pass filter design, and gave us a clearer signal to read as shown from the figure 38 for the blue line (VL).

To explain the graph from figure 38, the input is the voltage from the non-inverting summer going through an active 2nd order high pass filter that has a non-inverting op-amp as its output. The green line represents the input which is the summer, the blue line represents the VL of the 2nd order filter and lastly the Vout of the system is represented as the red line. As a result, you can see that the 2nd order high pass filter is filtering out the lower frequency hence you can see on the blue graph, as the math explained can be viewed from the MS3 building block 2 of equation 9. Afterwards, the circuit is entering to an non-inverting amplifier which its calculation is viewed as the gain of $V_{out} = (1 + \frac{R_f}{R_i})V_{in}$ where the ratio to R_f and R_i is 10 (because 100/10 is 10) which means that the gain increased by a factor of 11 (view from figure 4 to see the resistors value).

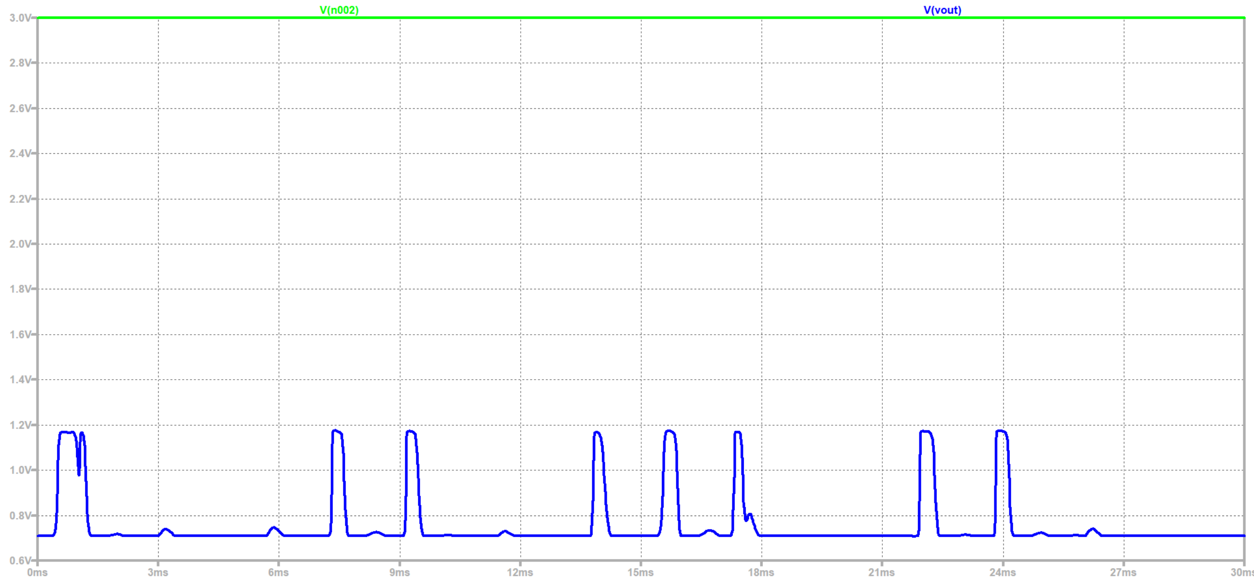


Figure 39: Example input and Output of the circuit

Figure 39 shows an example input and output of the overall circuit between MS1 and MS3. The input here is noted as V(n002) which is the green line as this represents our V_{DC} as our "pretend" solar panel. While the output (Vout) is measured at the output of the non-inverting amplifier as its part of the 2nd order active High pass filter right before the buzzer. Based on the building block for 2nd order active high pass filter in MS3, the op-amp has amplified the gain of the output of the 2nd order high pass filter which will have the same frequency but increased voltage due to the gain increased. The output shows that a sinusoid-like wave is being output as 0.7V-1.2V being applied to the buzzer with a frequency of 253 Hz from equation 10.

Operating Conditions MS1

One major limitation to our circuit is related to our power source. The original idea was to use a solar panel to power the entire circuit, making it fully sustainable and able to be placed off the grid. However, not only did the solar panel not arrive in time for the milestone, but it is supposedly not fully functional for our circuit. While it does provide adequate current, it does supply enough voltage for our OP484 op amp. This component is crucial to our design, and so not being able to power it would make the entire design fail. Another aspect of this limitation is the fact that the design does not function without sunlight. At night, the solar panel would not supply any voltage, and none of the sensors would therefore work during that time. Being able to sense the changes in the weather during the night is just as important as during the day, so this would be a major flaw.

Another limitation to our circuit is the amount of circuit components and wires being used. Some resistance changes are very small, and which leads to very small changes in the voltages. This was evident when testing the photoresistor, where pointing a flashlight at the sensor created changes of 0.001 volts. This was due to the lighting of the room itself. Changes in the voltage was only easily detected after I completely obstructed the photoresistor from light, and then instantly removed that covering. Additionally, the voltage difference from the wheatstone bridge has to pass through a differential amplifier, and multiple wires before reaching the comparator. While these wires have miniscule resistance, it is enough to affect the already small voltage changes. This leads to even more difficulty in measuring the changes in voltage.

One tradeoff in the current circuit was the decision to replace the BiLED at the output stage to a regular LED. The original plan was for the BiLED to be constantly one color, and then shift to another when the appropriate voltage was supplied to the comparator. However, this was very difficult to pull off as a BiLED changes colors when the current flows in a different direction. One possible solution would've been to create an H-bridge circuit, but that would've added unnecessary complexity to a circuit that should have a simple output stage. Using a regular LED is much simpler, as we are only looking for when the component lights up or not. The problem with this design is that there is simply less information being outputted. For example, there may be a problem with the circuit, causing the LED to never light up. However, due to the nature of the comparator, we may blame this on the resistance of the sensor not changing, increasing overall debugging time. We ultimately made the tradeoff to simplify the design in exchange for less information being displayed.

The circuit could be improved by implementing multiple sensors for each type of information. Using only a single sensor can be unreliable, as the resistance can change through a number of factors. For example, in testing the change in temperature of the thermistor, we would often rub it with our fingers to create friction. This was done in an attempt to create some heat. However, this could easily have changed the conductivity of the resistor, as the human body does produce its own electrical signals. Other electrical disturbances that result from heat could also occur, so adding additional sensors would mitigate this problem. The average voltage difference could be taken from each sensor, creating a more reliable data point. However we would likely not go down this route, as it is simply overcomplicating the circuit, as well as requiring more parts to be obtained.

Operating Conditions MS3

Before starting to talk about the limitations of MS3, we would like to mention a similar limitation that occurs from MS1 that still applies here, which is the issue of the power source. To reiterate the limitation of the power source (the solar panel), the solar panel doesn't power enough voltage to our circuit in the sun. So a problem that would solve this is to get a better solar panel but we figure the shipping would not be enough time for the project, hence to solve this issue for our project, we just power it thru the m1k. This component is crucial to our design, and so not being able to power it would make the entire design fail. In addition, the limitations of the whole project would be obvious: the solar power weather station would only work during the daytime and not at nighttime, so the information collected is only usable for half of the day, which is when the sun is out.

One major limitation of the circuit was the fact that the 555 timer for the temperature sensor did not fully function. When everything was originally wired together, the 555 timer for the temperature and light sensors functioned as intended. It generated a square wave with a fixed frequency, which did require a large time div value in ALICE to be seen. However, I could always stop the program, and reduce it so that the graph doesn't have an excessive number of periods. But after moving onto the later blocks, and going back to test the 555 timer of the temperature sensor, the 555 timer would only produce a DC voltage. When the sensor itself was replaced with the photoresistor (light sensor), the 555 timer output was perfectly normal. This meant that this wasn't a wiring issue, or an issue with any of the other components in the circuit. And the thermistor (temperature sensor) itself was swapped for a new one multiple times, and the output remained the same. The only likely conclusion is that the thermistor is simply not responsive enough compared to the photoresistor. Our best method of increasing its temperature was aiming a hair dryer at it. While this method did work, it can be destructive to the other components on the breadboard. Additionally, the thermistor is made to detect very high temperatures, reading hundreds of degrees. This is not easily achievable, compared to the photoresistor's requirement of simply a bright flashlight. To fix this, next time we would purchase a more sensitive thermistor, and attach it away from the main breadboard to prevent damage from heat. Adding on another limitation of the 555 timer before we learn that u can convert the square wave to sine wave with a simple 1st order filter, we were given an output of a square wave. During the moment, a way how we were able to solve the issue of having the sine wave is to use an RC first order filter. So for this project we used an RC filter, but note upon further inspection if we want to improve the project in the future, then the best solution would be to use an LC circuit in values. This would result in having more visual representation of a sine wave if we choose the right values of the inductor and capacitor.

Another limitation of the circuit was related to the OP484 chip that was used throughout the entire circuit. This component has four independent op amps in the package, which means that it should be possible to wire multiple amplifiers into the same chip. This was attempted with the first milestone, where a differential amplifier was used for each wheatstone bridge. However, this did not work, as the second output pin would only provide the positive supply voltage no matter what the setup was. This OP484 was swapped out multiple times, and this did not fix it. Additionally, the summer and active filter were also connected to a single OP484, and it functioned as intended. There were a few likely reasons for this, one being the fact that each differential amplifier set up had two input voltages. This could have oversaturated the output pin, leading to the positive supply being outputted instead. It could also be due to interference from this many signals coming into one component, or simply general limitations of the OP484. In the end, this was solved by simply acquiring more OP484 chips and using those instead.

One tradeoff in this overall circuit was its complexity. We wanted to utilize three sensors in order to get a more accurate reading of what weather would be, since it is such a complex concept to predict. That is where the temperature, humidity, and light sensors came in. However, it leads to a lot of room for error when building the circuit. In our physical design, we only made two wheatstone bridges, two oscillator circuits, and so on. This was because adding another sensor would require more bread boards, more op amps, and a greater likelihood of wiring errors. Not only is this a resource sink, but would introduce more troubleshooting time in this design. There was already a large amount of time dedicated to troubleshooting with two sensors, and the thermistor already failed to work as intended. A greater amount of complexity would be great to make this project more successful and useful, but unfortunately leads to less efficiency and design compactness as well.

This circuit could definitely be improved with more high quality sensors, as well as the addition of all the sensors that were originally planned. With more quality sensors, they would be more sensitive, and help with the response of the signal, as shown with the thermistor. They would also be easier to test, as the humidity sensor was nearly impossible to test without damaging the rest of the circuit. And if we were to include the humidity sensor in the design, it would help with the goal of the project, even if it wasn't achievable in the time provided. And lastly, the circuit could be improved with the inclusion of more 2nd order filters. The current design only filters out one of the three signals, when the goal is to separate each signal from the summed one, and measure them all at the same time. This is a clear time and cost constraint, as the M1k can only measure two signals at a time, and would require more op amps and breadboards to be done. Furthermore, for filters in general , a method to make the filtering more accurate to output the type of graph we wanted is to test out more values for the capacitors/inductors using more math as getting the right value would make the graph more sinusoidal wave.

References

[1] W. Storr, "Wheatstone bridge circuit and theory of Operation," Basic Electronics Tutorials, [Online]. Available: https://www.electronics-tutorials.ws/blog/wheatstone-bridge.html#:~:text=The%20Wheatstone%20Bridge%20circuit%20is,two%20parallel%20branches%20when%20balanced (accessed Feb. 27, 2024).

[2] "NTC thermistors - temperature measurement with a Wheatstone Bridge," Ametherm, [Online]. Available: https://www.ametherm.com/thermistor/ntc-thermistors-temperature-measurement-with-wheatstone-bridge#:~:text=For%20measuring%20temperature%2C%20a%20Wheatstone,precision%20measurement%20using%20the%20thermistor (accessed Feb. 27, 2024).

[3] W. Storr, "Wheatstone bridge circuit and theory of Operation," Basic Electronics Tutorials, [Online]. Available: https://www.electronics-tutorials.ws/blog/wheatstone-bridge.html#:~:text=The%20Wheatstone%20Bridge%20circuit%20is,two%20parallel%20branches%20when%20balanced (accessed Feb. 27, 2024).

[4] “GL55 series photoresistor,” CdS Photoresistor Manual , [Online]. Available: https://www.kth.se/social/files/54ef17dbf27654753f437c56/GL5537.pdf (accessed Feb. 27, 2024).

[5] N. US Department of Commerce, “Discussion on humidity,” National Weather Service, [Online]. Available: https://www.weather.gov/lmk/humidity (accessed Feb. 27, 2024).

[6] “Resistive humidity sensor, model: HR202,” Elecrow, [Online]. Available: https://www.elecrow.com/download/HR202%20Humidity%20Sensor.pdf (accessed Feb. 28, 2024).

[7] E. Technology, “Types of passive high pass filters - 1st Order & 2nd order passive filters,” ELECTRICAL TECHNOLOGY, https://www.electricaltechnology.org/2019/07/types-of-passive-high-pass-filters.html (accessed Apr. 27, 2024).

[8] W. Storr, “Low pass filter - passive RC filter tutorial,” Basic Electronics Tutorials, https://www.electronics-tutorials.ws/filter/filter_2.html (accessed Apr. 27, 2024).

[9] R. Teja, “Summing amplifier,” ElectronicsHub USA, https://www.electronicshub.org/summing-amplifier/ (accessed Apr. 27, 2024).

[10] W. Storr, “Summing amplifier is an op-amp voltage adder,” Basic Electronics Tutorials, https://www.electronics-tutorials.ws/opamp/opamp_4.html (accessed Apr. 27, 2024).

[11] W. Storr, “555 oscillator tutorial - the astable multivibrator,” Basic Electronics Tutorials, https://www.electronics-tutorials.ws/waveforms/555_oscillator.html (accessed Apr. 27, 2024).