Project Manual

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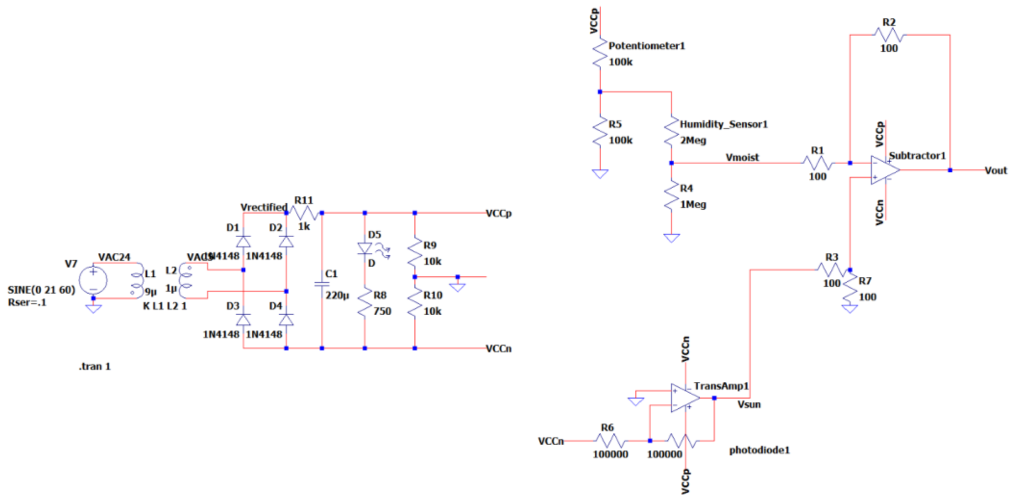
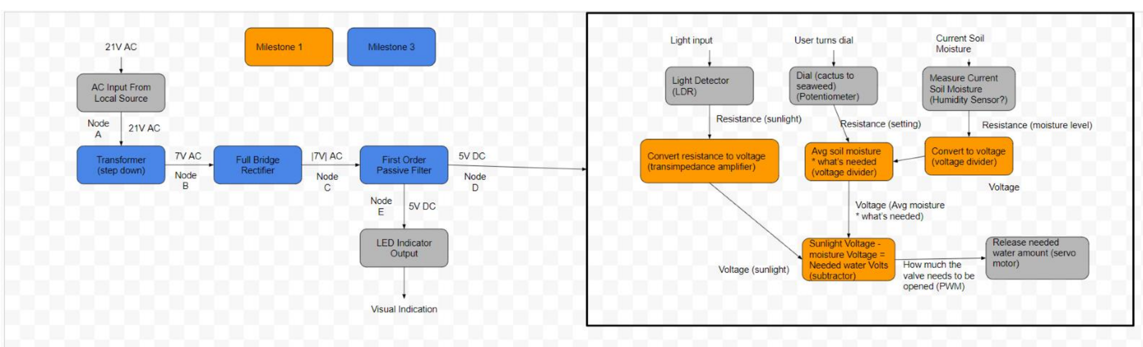
https://github.com/Zombieattackr/HF_DV_CircuitsS23

Description



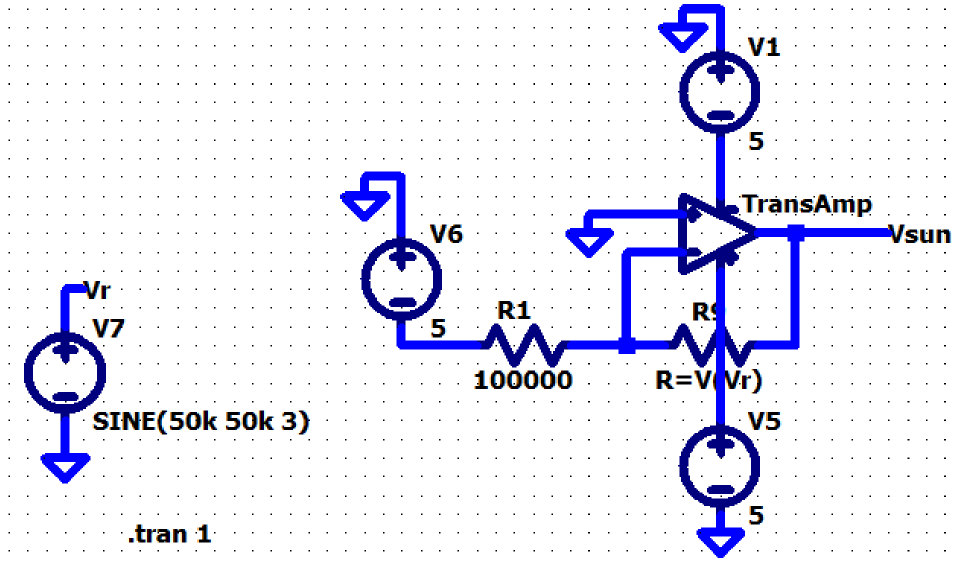


This project implements several circuits with the intention to automatically water a plant. Our circuit from milestone 3 essentially acts as a power adapter for electronic devices, in that it is meant to take a high ac voltage supply from a given source and convert it to a low dc voltage supply for a given machine. This circuit works by taking high ac voltage as input, here we are using 21V however any high voltage supply can work. This ac voltage is sent to an ideal transformer, which steps down the voltage to a safer, lower voltage (here that voltage is 7V). The transformer then feeds into a full bridge rectifier which takes the absolute value of the ac voltage, and then feeds into a first order passive filter which converts the voltage from ac to dc, and a voltage divider to give us +5V, GND, and –5V. Finally, this voltage is supplied to a separate device, as well as an indicator LED.

Our circuit in MS3 works in conjunction with our circuit from MS1 since MS1 is an automatic plant-water supplier and takes DC voltage input. The inputs for the circuit created in milestone 1, are a light sensor, a moisture sensor, and a dial for user input settings, and the output is a servo motor. Signals are processed in the form of analog voltages. The sunlight gives us an output voltage and the combined moisture and manual setting gives us a 'reduction' voltage. These are then subtracted to give us how much water the plant needs.

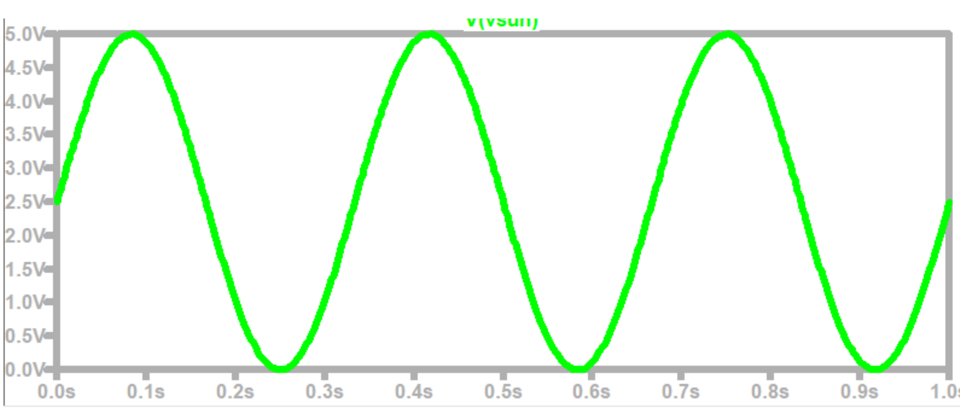
Current watering systems don't account for changes in sunlight conditions and don't measure the moisture in the soil, they just water at a set rate. If this system was to be calibrated by someone who actually knew how to take care of plants properly, it could be much better than a simple system that waters at a set rate.

MS1 Building Block 1, input block, transimpedance amplifier, sunlight input

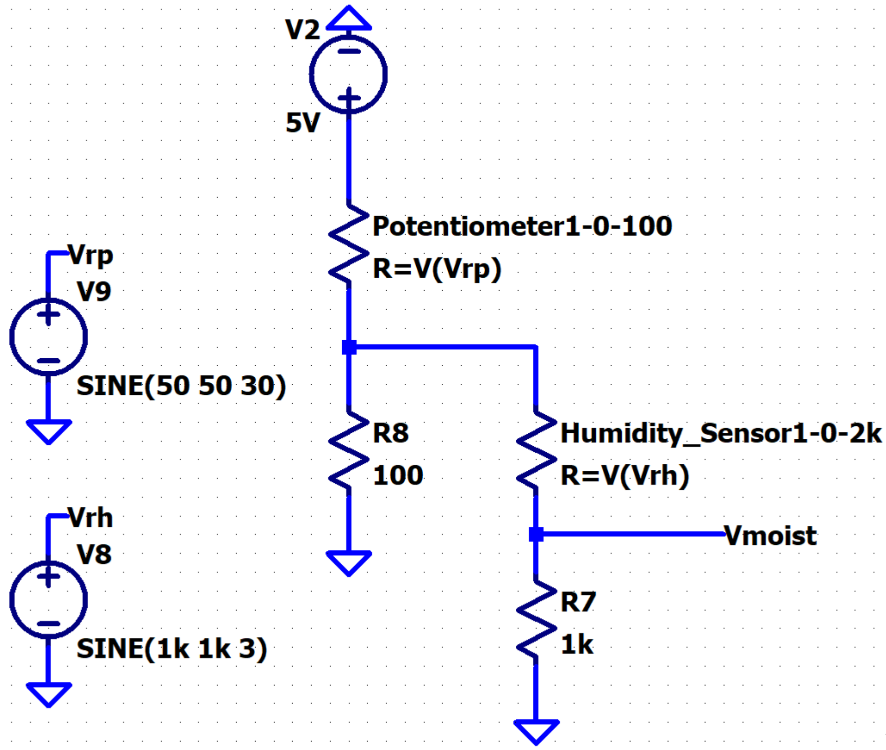


We chose the value for R1 here because it matches the highest possible resistive value of the LDR we are using. The equation above shows that if the LDR reaches its highest possible value, meaning there is high light intensity, the circuit's output voltage would be 5V, which causes more water to be supplied later on. Conversely, if the LDR reaches its lowest possible value, virtually no voltage will be output.

$$-5 < V_{out} \;=\; -(-5)\cdot\frac{Rf}{100000} < 5$$



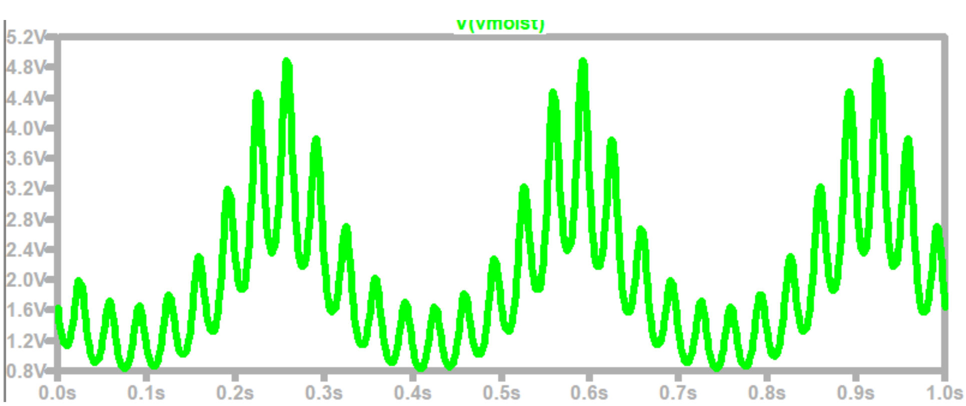
MS1 Building Block 2, input block, voltage divider, setting and moisture



$$V_{out} = V_{in} \cdot \frac{1000}{1000+R_{Hum.}} \cdot \frac{\left((1000+R_{Hum.})^{-1}+100^{-1}\right)^{-1}}{R_{Pot.}+\left((1000+R_{Hum.})^{-1}+100^{-1}\right)^{-1}}$$

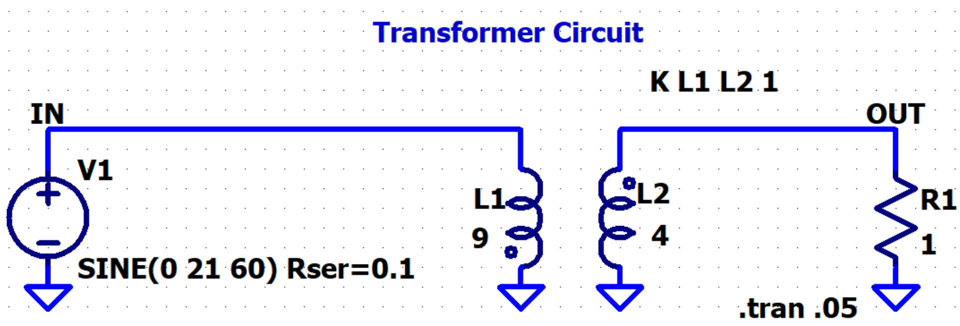
We chose the values in the humidity sensor/ voltage divider based on research of soil moisture sensors. We chose the values for potentiometer/voltage divider to be much smaller than the humidity voltage divider, so that the humidity divider doesn’t interfere with the potentiometer divider to a significant degree. The values for the resistors in either voltage divider could easily be changed if someone that actually knows how to take care of plants had any suggestions. These suggestions would be helpful, since the resistors determine the importance of soil moisture and user settings.

V_moist output vs time. Humidity resistance changed as a sin wave at 3hz, potentiometer resistance changed as a sin wave at 30hz.



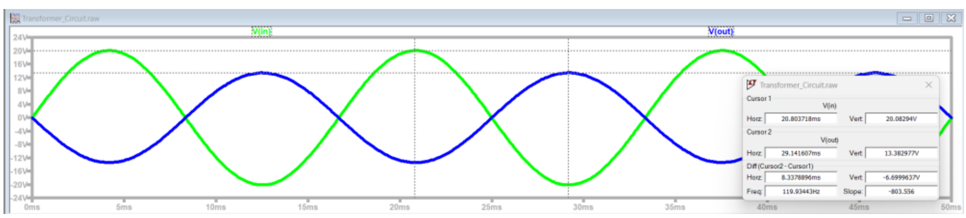
Since this includes two inputs, the low frequency is the humidity sensor and the high frequency is the potentiometer. If the potentiometer is set to max water, the plot will follow the bottom of this as humidity changes. If the potentiometer is set to min water, the plot will follow the top of this as humidity changes.

MS3 Building Block 1, input block, transformer, stepping down the supplied voltage

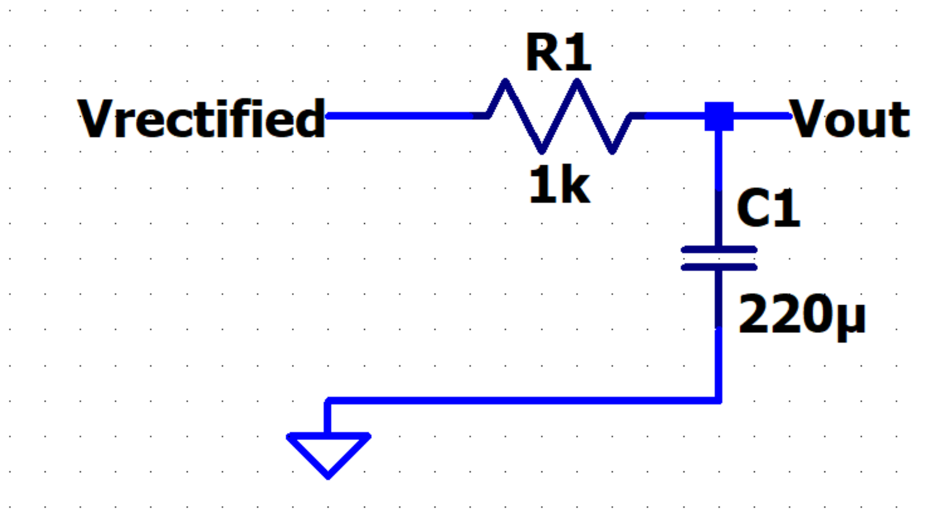


$$V_{out} = N_{turns} \cdot V_{in}$$

We chose a 3:2 turns ratio because we chose an input voltage of 21V and need an output of 14V, for larger voltages this ratio would need to be increased. We chose 21V because safety regulations restricted us to voltages <24V, but is still larger than the 14V output we need by a simple turn ratio. We need that 14V output because once you take the RMS of it, we get 10V, which can be split into the +-5V we need for our plant watering system. Notably, LT Spice does not have a turns feature for inductors so in order to make a transformer, we squared the ratio.



MS3 Building Block 2, intermediate block, first order passive filter, filter rectified AC to DC

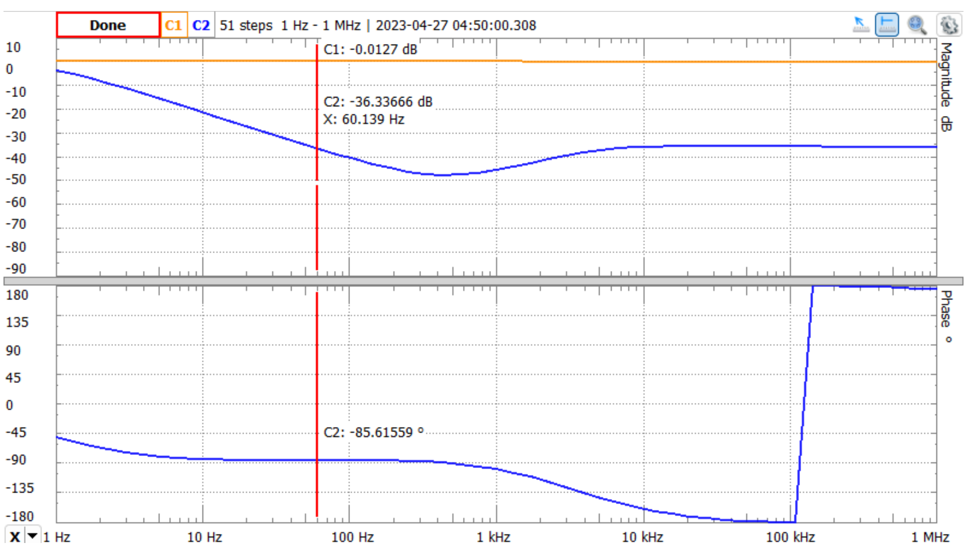


$$\omega_c = \frac{1}{RC} = \frac{1}{1k \cdot 220\mu} = 4.545$$

$$H(s) = \frac{\omega_c}{s + \omega_c} = \frac{4.545}{s + 4.545}$$

We chose these values to filter out the 120Hz signal. We use a low pass filter since we're filtering to DC, and we found the values by using a desmos tool I created to give the bode plots and response curve, and found realistic part values that have a large enough reduction at the frequency we're working with.

Experimental Bode plot



Integration and Optimization

Describe the overall integration of the building blocks into one circuit:

AC voltage input is supplied by the user (realistically, via wall outlet) which is fed into the transformer to step it down. This voltage goes through a full bridge rectifier and a passive first order filter to convert the AC to DC. This voltage powers an indicator LED and is split into +-5V to supply the watering circuit.

The watering circuit takes three resistive inputs. The sunlight input comes from a light dependent resistor which is part of a transimpedance amplifier, which is essentially an inverting amplifier but with variable resistance and set voltage. The moisture and settings dial come in as resistances as well, with a moisture sensor (basically measuring the resistance of the soil) and a potentiometer. These are parts of two separate voltage dividers, which are connected in series. The outputs of the transimpedance amplifier and the voltage dividers are then fed into a simple subtractor to give us our final output.

Explain how you designed each building block so they could be connected together (support design choices):

We made sure the resistances of voltage dividers increased as we moved along to make sure one voltage divider is basically unaffected by those past it. This takes place when we split our 10V into + -5V with 10k resistors, then divide that with the "settings" voltage divider with 100k resistors, and then divide that with the moisture sensor with around 1M resistance.

We designed a power supply that supplies +-5V because that's what the rest of our watering circuit required.

Reference the building block design equations to explain how each building block was designed and how they work together:

The voltage dividers and transimpedance amplifiers were designed to output voltages in a range so that the subtractor will output 0-5V.

The power supply components all fit together in a fairly standard manner, the only thing that's "unconventional" here is not using the transformer itself as our voltage divider, which we chose

Discuss any issues you had in getting building blocks to work together:

While designing this circuit we experienced several issues. One of which being the lack of an AC power supply. The largest function generator we have supplies a max of 10V 20mA, which isn't the 21V we need and is likely far less current than needed. We took a small attempt at boosting this with a larger DC power supply, but didn't have the time to investigate this as much as I'd have liked to.

Another issue we experienced was that the full bridge rectifier was not working as intended. This was due to our measurement probes being grounded, which we found two possible solutions for. We could use something totally disconnected from ground like an Analog Discovery 2 with the laptop unplugged, or use differential pairs via the math function on our benchtop oscilloscope.

We had issues with the transimpedance amplifier, as the conventional circuit replaced R_in with the variable resistor, but this gives a 1/x relationship, resulting in a very narrow range between 5 and effectively 0. This was fixed by swapping the LDR from the R_in position to the R_f position, resulting in a simple x relationship.

We initially had an issue with the two voltage dividers. In the initial design the moisture sensor in the kΩ range fed into the potentiometer divider, which is in the 100Ω range. This led to the second 1k resistor in the first divider being negligible compared to the second divider that was in parallel with it. We simply swapped the two divers, so now the moisture sensor has a very small impact on the 100Ω resistor from the first divider.

We're currently having issues with the subtractor as well, which is giving outputs of ~2.3V when we would expect 4V, where the positive input is 5 and the negative is 1, giving us 5-1=4V.

Plot the overall input and output of the integrated circuit and any other measurements that would be helpful in explaining operation:

Given three inputs, it's hard to plot, but we have increased "setting" or sunlight increase water out, and increase moisture decreases water out. The AC power input is a given that shouldn't change.

Operating Conditions

A limiting factor present in our MS3 circuit, the power adapter, is that increasing the input voltage would also require the winding ratio in the transformer to be altered. If the input voltage is raised beyond 21V, the winding ratio in the transformer would need to increase as well. This process would be confusing and dangerous for non-electrical engineers as they could be handling components that are being subjected to high voltages, but could be solved for with a simple 120/240 switch. Small differences between say 115 and 125 would have a negligible change in output voltage that our MS1 op amps would still be perfectly happy with.

A trade-off in MS3 involves the fact that we are expecting the adapter to be powered by an outlet. This is a trade-off since it is restricting the possible locations this device can be used, which is unfortunate for a plant waterer since the plant already restricts the device to locations with sunlight. By using plug-in power instead of batteries, we are relying on the fact that users have outlets near their windows or outside their house.

This circuit can be improved by attempting to solve this trade-off. Some ideas that could solve this problem include: relying purely on disposable batteries for power, an internal battery for the device that could be plugged in at the end of the day, or the inclusion of a UV lighting system in the device to eliminate the need for sunlight.

(I misread this and added two per block, sorry...)
One major limiting factor is that, as mentioned, this will not be calibrated to actually take very good care of a plant, as we don't have the time or plant knowledge to calibrate it accurately.

Our circuit is currently limited by the settings, as you can only really scale the total water up or down and can't change the range that it operates in due to the simple voltage divider setup. This could be improved by creating an adder with variable power inputs to create upper and lower bounds and a variable offset to add to the measured voltage. The small resistance may be problematic as these resistors can dissipate around a 16th of a watt of heat, which is within the rating, but it's not fun to touch, and it doesn't exactly make it power efficient, so battery power is currently out of the question.

Our circuit currently has negative outputs from the subtractor that will likely end up being truncated. This can possibly be solved by altering the resistor values to give us a 0-5V output. The subtractor also doesn't work or simulate as our equations expect when we have larger V_moist and smaller V_sun. Firstly, we don't reach the negative values we would expect, such as 0-5=2.5, while we still have the correct 0-0=0, 5-5=0, and 5-0=5 elsewhere. Secondly, 100Ω is likely far too small, as these resistors can again get quite hot sitting idle, but thankfully this is a much easier fix as it's not constrained by existing sensors, specifically the moisture sensor.

The transimpedance amplifier works as expected but is limited by how well it can measure due to the LDR and is limited in what it can do with that since it simply multiplies the signal by a constant, so you can't have any more advanced functions with the current design.

One tradeoff is caused by our three different input sources, these many input sources could cause confusion for theoretical users and could allow for more components to fail or otherwise negatively affect each other. Increase the resistor values and finding a better implementation for the voltage dividers, as those values can’t simply be increased., decreasing power draw and heat.

References

Datasheet

[1] Texas Instruments, “OPA602: High-Speed Precision Difet? Operational Amplifier datasheet (Rev. A)”, OPA602 datasheet, Aug. 1987 [Revised Oct. 2022]

https://www.ti.com/lit/ds/symlink/opa602.pdf