FINAL ASSIGNMENT

EEE1006F

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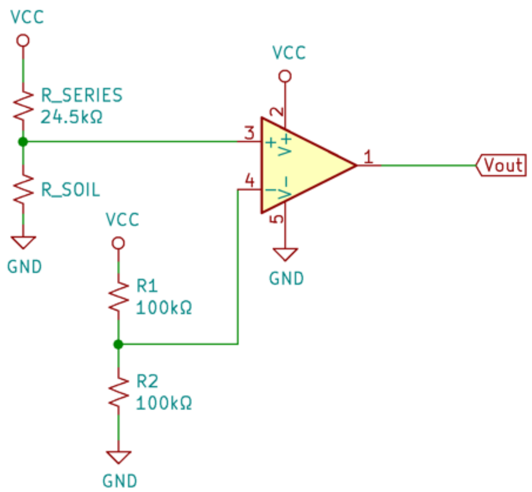
Automatic Watering System:

Parts Required:

- 2 x 100kΩ Resistors
- 1 x 24.5kΩ Resistor
- 1 x Operational Amplifier
- 1 x 3V Battery
- 1 x Pump
- 1 x Motor
- 1 x NPN transistor
- 1 x 12V Battery

Sensor Circuit:

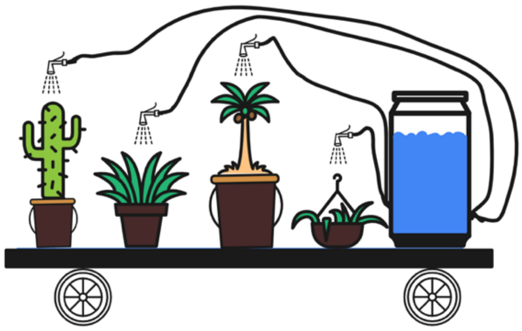
In order to water the plant, we would ideally want to know when the plant needs to be watered as to avoid over watering and use our water conservatively. We therefore need to detect when the plant needs to be watered and this can be done using a circuit with a resistor in the soil and having one outside the soil. We know from research that when the soil is dry, the resistance of the soil is 30kΩ and when wet, the resistance is 19kΩ.



When soil is dry, R_{soil}= 30kΩ. When soil is wet, R_{soil}= 19kΩ. The voltage divider produces a constant voltage of 1.5V for V_{in}^-, this was calculated using the voltage divider equation and knowing that V_{cc} = 3V, V_{in}^- = 3V(100kΩ/100kΩ + 100kΩ). We can calculate V_{in}^+ using V_{in}^+ =3 x (R_{soil}/R_{soil} + 24.5kΩ). When soil is dry we know that V_{in}^+ =3 x (30kΩ /30kΩ + 24.5kΩ) =1.65V, this need to pass through an op-amp as the voltage difference between V_{in}^+ and V_{in}^- is not great enough to interface with digital circuits. The op-amp then amplifies the difference in voltage from the inputs, using the following equation we can calculate V_{out}. V_{out} = A(V_{in}^+ – V_{in}^-), where A is the gain. In this case we are limited by the voltage supplied to the op-amp at V+ on the diagram, which is 3V, so when the soil is dry V_{out}= 3V. When soil is wet, R_{soil}= 19kΩ and V_{in}^+= 3 x (19kΩ /19kΩ + 24.5kΩ)=1.31V, this would mean that V_{in}^+– V_{in}^-<0, which means the output of the op-amp (V_{out}) would tend towards ground which means V_{out}= 0V. Both these operation modes are ideal as when the soil is dry, we want to water the plant, so we would want V_{out} to be 3V, which it is as seen above and when the soil is wet, we don't want to water the plant, so we would want V_{out} = 0V, which is as it is seen above. This circuit can be used for each of the 4 plants to ensure each plant's watering needs are monitored.

Watering System:

The output of the circuit, which is described above, will be connected to a watering system which has a motor, pump and a communal water source from which all plants will be watered. Out of this container there will be 4 pipes, one pipe for each plant. As each plant has its own detection system, each plant will be watered based on what it senses and will be personalised based on its needs. All the plants will be placed on a wooden platform as seen below.

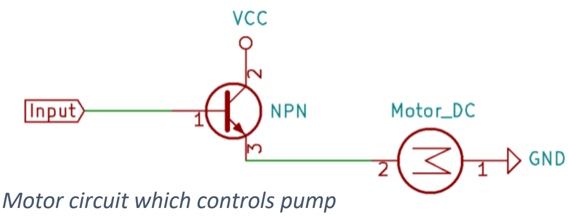


The limitations of this system is that each plant may not receive the same amount of sunlight as one plant could possibly shade another, if the water container is empty and the weight is not evenly distributed, the entire plant and water container system could fall over, this is not ideal. If you can ideally ensure that the size of board and the plants on the board system are placed in a part of the corridor such they all receive enough sunlight and will move to track that sunlight throughout the day and space the plants out nicely so that they do not shade another plant's sensor. This will minimise the limitations faced by this design.

Watering Circuit:

This platform, which the plants are placed on, will provide an easy way for the wires to be constantly attached to the plant such that they have a means of being watered. The water container is also attached to this platform to ensure that the water tubes do not need to be moved and they will be stuck in place acting as a sprinkler system for the plant. A pump is designed below, which uses plastic as piping and sealant, it uses a steel fan which is seen below attached to the yellow triangle, which is connected to a motor. When the motor is switched on, it will rotate the fan, taking water into the output tube, using the pressure of the container as well as the motor to push the water through the piping to the plants where it is needed.

Pump design



Motor circuit which controls pump

The motor circuit will use a V_{CC} of 12V and an NPN transistor, the NPN transistor will allow for current to flow if and only if, the base is at a higher voltage than the emitter – this operation is described in more detail on the next page. This will ensure that the plant will not be watered when the sensor output is low. The base voltage will be higher than the emitter when the soil is dry and will be equal to when the soil is wet. This means the motor will be turned on, watering the plant when the soil is dry. Inversely, it will not be powered when the soil is wet and thus not water the plant as the soil is already wet and does not need watering. This means that the automatic watering system works optimally and as desired.

Water Monitoring System:

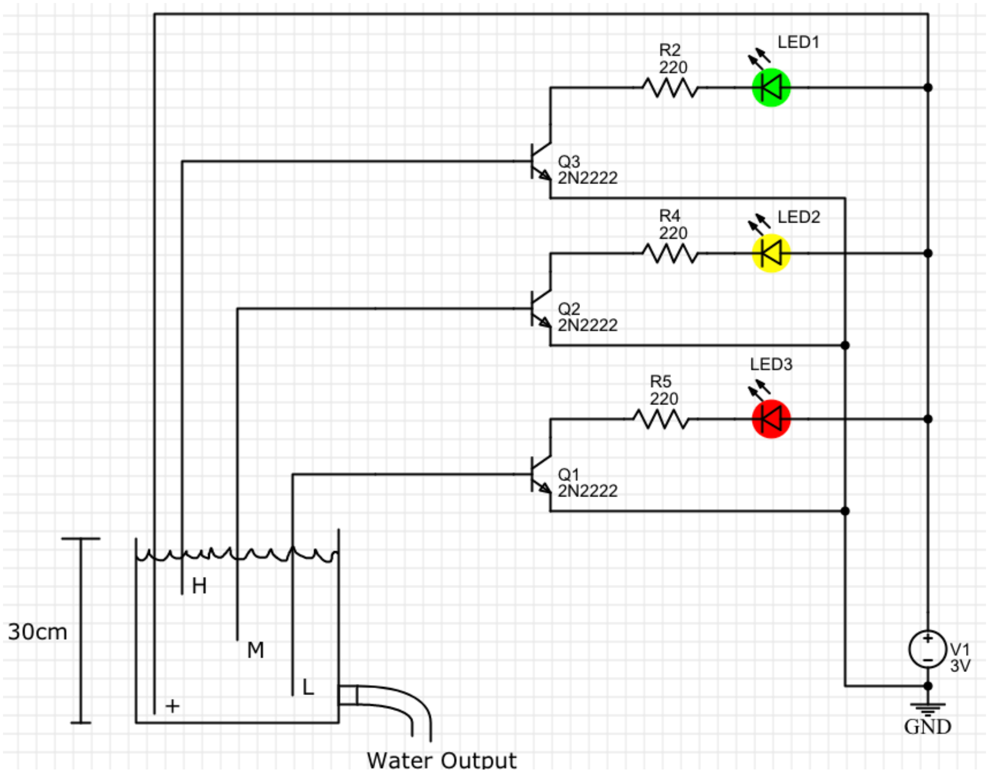
Parts Required:

- 3 x 220Ω Resistors
- 3 x NPN Transistors
- 1 x Green LED
- 1 x Red LED
- 1 x Yellow LED
- 1 x 3V Battery
- Wiring
- Container
- Plastic pipe

Monitoring Circuit:

The wiring of the circuit will be done with insulated wires with exposed ends to ensure that it is not only safe but will operate optimally. Resistors will be used to ensure that the LEDs will not fail or explode due to overloading. This configuration is safe to use inside the complex as it uses a low voltage source, which means even if a person comes into contact with the water, they will not be electrocuted or hurt severely.

The client has specified that the monitoring system is required and that it is desirable that the monitoring system alerts the owner/client how full the water container is – whether the water level is high, medium or low. A circuit is therefore designed using the parts mentioned above and constructed in such a way as to alert the client with the use of LEDs. The following LED configuration will represent the different levels with a green LED representing the water level being high (satisfactory/full), a yellow LED will indicate that the water level is medium and a red LED will indicate that the water is finished or low, if all LEDs are switched off then there is no water left in the container and the container needs to be refilled. This is done using the following circuit configuration:



Wires are connected into the container at different heights – these are used to light up their respective LEDs to represent different height levels of the water, while a wire from the positive terminal of the battery is connected to the lowest point in the container, at the bottom. As the container is filled with water, the connection between the positive battery wire and the other wire connection, labelled L, M and H in the diagram respectively, will be connected as water is conductive and will allow current to flow from wire connected to the battery's positive terminal, labelled + in the diagram, to the respective wire, either L, M or H through to the base of the transistor. This will cause the base to have a voltage of 0.7V and greater, due to base being at a higher potential difference by 0.7V and greater when compared to the emitter, the transistor is switched on as the emitter is connected to ground meaning its voltage/potential is 0V. This will allow current to flow from the positive terminal of the battery to the LED and through the resistor, the collector, emitter and back to the negative terminal of the battery, completing the circuit. In this case the transistor is acting as a switch and the water level will control whether or not it is switched on, this will control whether or not the corresponding LEDs will light up. As the water will act as a conductive medium in which the electrons will flow through and thus allowing current to flow, it will allow the LEDs to switch on when the wires are submerged in water. Subsequently when the water is lowered, due to the plants being watered, the LEDs will switch off as the wires are not submerged in water thus the water will not provide a connection between the positive terminal of the battery and the base of the respective transistor. This will allow for an indication of the water level of the 30cm container.

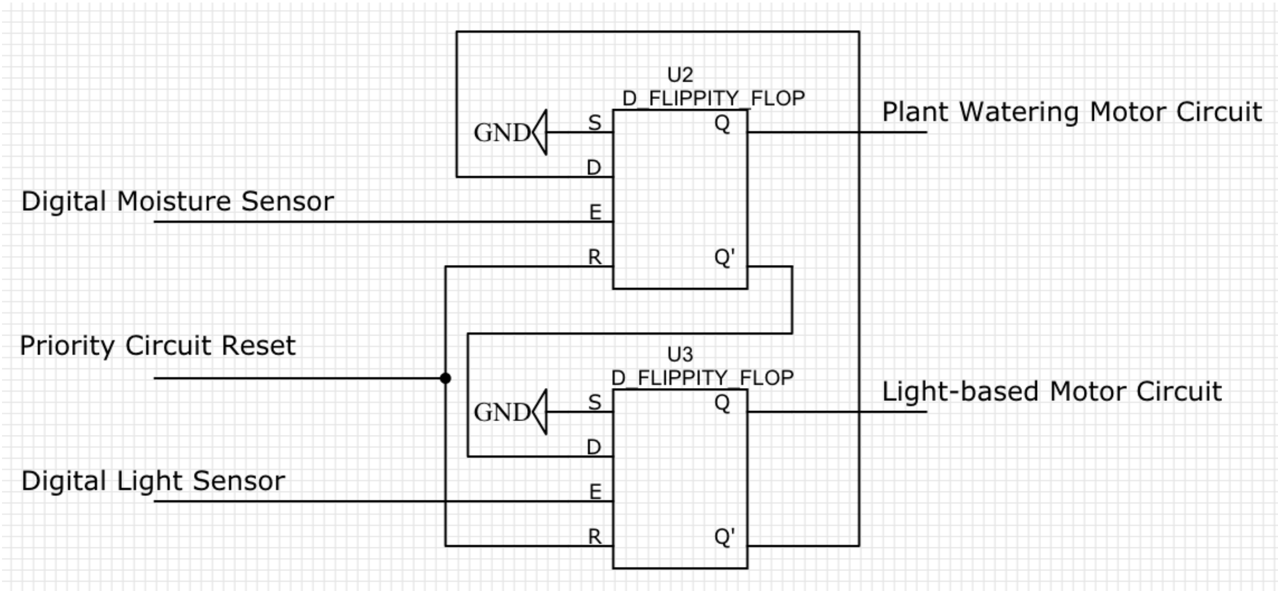
Safety Precaution:
This is optional but highly recommended for safety if a larger container is used with a higher voltage is used to determine fullness of the tank.

A switch could be added to the circuit to turn off all voltage supply to the water, so that before filling the container all electricity provided to the water is switched off and no electrocution could take place.

Priority and Timing Functionality:

Priority Circuit:

In order for one operation mode to have a higher priority over the other (to ensure that only one circuit/motor is operational at a given time and not both), a circuit needs to be created in order to decide which gets precedence. The order of precedence will be based on which circuit's input is received first. The circuit which will take in the inputs and will not allow the second input, which is the slowest to allow its respective output to be followed, is shown below:

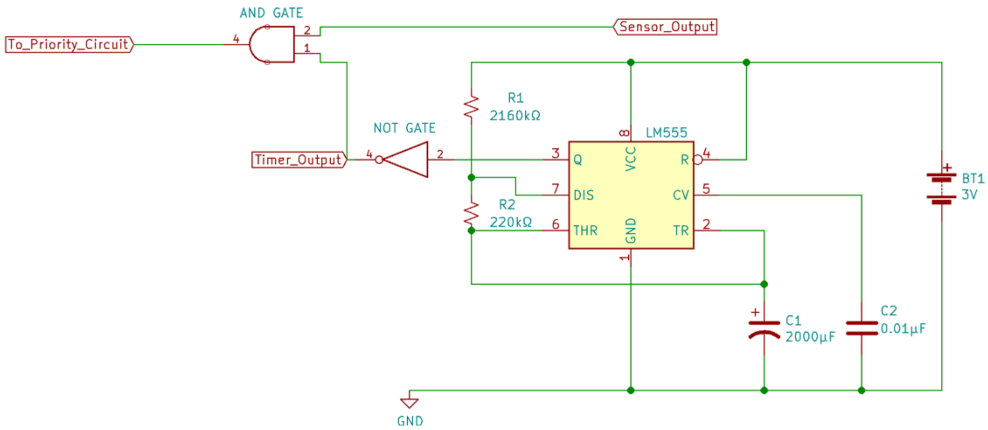


When one of the inputs is set high, either the digital light sensor or the digital moisture sensor, the enable pin, labelled E in the diagram, will be set high, this is referred to as the winner flip-flop and the other is the loser flip-flop. This in turn switches the output pin, labelled Q in the diagram, to be set high. This will send the output from Q to the respective motor circuit and power the motor. The inverses of the output pins, labelled Q' in the diagram, will be the opposite of the output, if Q is high, Q' is low and vice versa, this inverse is connected to the data pin of the opposite flip-flop to which the signal received first, in other words the loser flip-flop. This change thus makes sure that the other sensor circuit's output will not be allowed to flow to its motor as it was the slowest input, as its data pin is set to low, this is because it is the inverse of the faster circuits output. This will continue to be the state of the circuit until it is reset by setting the reset pin to low and then high again, this is done using a timer circuit. If only one input is received, setting one enable pin to high, then its output will be set high and its motor will be powered and the other circuit will not be affected.

Timer for Watering System:

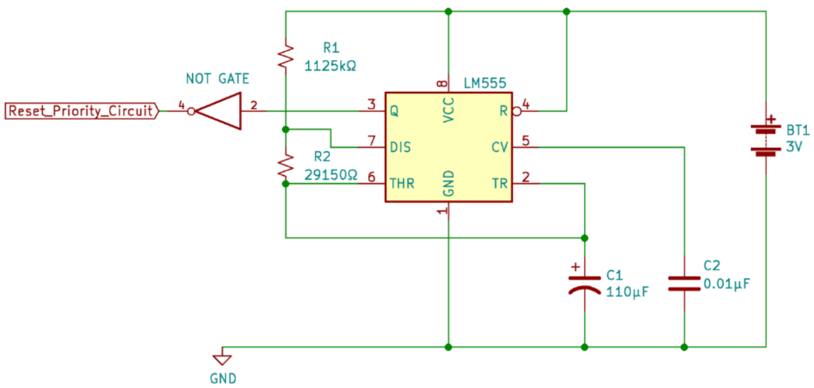
It was stated in the brief that the client desires that the plants will be watered for 5 minutes every hour, we therefore need to create a timer circuit which will ensure that this desired characteristic is fulfilled (Circuit Digest, 2020)

The design is as follows:



To calculate the time high, we use the following equation, knowing that the capacitor needs to be 2mF, that R2 is 220kΩ, that time high needs to be close to 3300 seconds, we can calculate R1, using the following equation (Circuit Digest, 2020): Time High=$\ln(2)x(R_1 + R_2)xC_1$ $\ln(2)x(R_2+220x10^3)x(2x10^{-3})$= 3300, as this is 5 minutes, we can now solve for R2, which is close to $2160x10^3$. However because of the NOT gate placed in the circuit, time high will be the opposite of what it is calculated to be, which is time low, which is calculated using the following equation: time low = $\ln(2)$ x R_2 x C_1 = $\ln(2)$ x $220x10^3$ x $2x10^{-3}$ = 304.99seconds, which is close to 300 seconds, which is 5 minutes. As stated earlier, the NOT gate ensures that the time high will actually be time low and time low will be time high. This means time high will be 5 minutes and time low will be 55 minutes. This output combined with the moisture sensor will ensure that for 5 minutes every hour, if the plant needs to be watered water, it will be watered in the 5 minute slot of the hour. This is done using an AND gate, as seen in the diagram, the AND gate will ensure that when both outputs of the sensor and the timer are high, the plant will be able to be watered, otherwise it would not be watered. This ensures that only when the plant needs to be watered and the timer allows it to be watered, will the plant physically be watered.

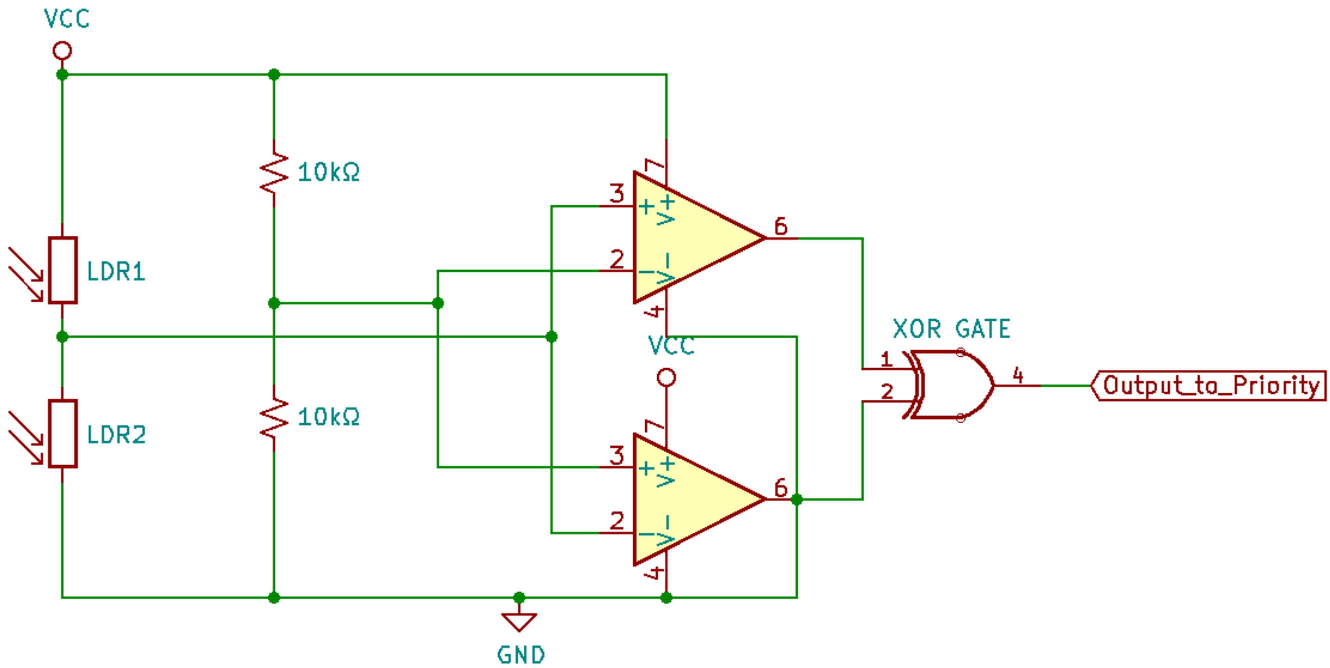
Reset Timer:



This timer ensures that every 1 minute and 30 seconds, the priority circuit is reset. The reason the timer is reset every 1 minute and 30 seconds is that the moving of the plants and watering of these plants should not take longer than 1 minute and 30 seconds, therefore we need the reset pin to be high for a brief period of time (e.g. 2 seconds) and then return to low, for this we use a 555-duty timer, like the one above and using the method done above we can calculate the resistor values and the capacitor value to be what they are in the diagram above with the period of 90 seconds, time high to be 2 seconds and time low to be 88 seconds.

Sunlight Tracking and Motor Circuit:

LDR detection to Priority circuit:



When both LDRs are occluded or exposed:

When both LDRs are occluded, half the input is sent to the op-amp, which is the same as the input from the voltage dividers being the same all the time. This means that the output from the both op-amp will be the same. Therefore, the XOR gate will receive the same inputs. The XOR gate will only have an output of high if the two inputs are different. In this scenario the output will be low and sent to the priority circuit.

When one LDR is occluded and the other is not:

If one LDR's resistance is greater than the others then the opamp's output will be less than 1.5V, which is the input to one of the op-amps and therefore the outputs of the respective op-amps will be different which is then fed to the XOR gate. The inputs to the XOR gate are different which will then feed an output of high to the priority circuit.

This combination of work is ideal as it'll allow the sensor circuit to interface with the priority circuit as well as let the priority circuit control the motor circuit below which is ideal.

Motor Circuit after priority received:

Using the following equation, $V_{in-} = V+ - ((V+ - V-)/(R_1+R_2)) \times R_1$, where V+ is the positive voltage(V_{ss}=1.5V) supply and V- is the negative voltage supply($-V_{ss}$=1.5V), R_1 is LDR_1 and R_2 is

LDR_2, we can calculate Vin– for when either of the LDRs are occluded and the other is not or when both are occluded or exposed. As seen below:

When LDR_1 is occluded:

LDR_1 = 1kΩ, LDR2=500Ω. Using the following equation, V_{in}–= 1.5- ((1.5 – (-1.5))/(1000+500))x 1000, ∴ V_{in}= - 0.5V.

When LDR_2 is occluded:

LDR_1=500Ω, LDR2=1kΩ. Using the following equation, V_{in}–= 1.5- ((1.5 – (-1.5))/(1000+500))x 500, V_{in}–= 0.5V.

When both LDRs are occluded or exposed:

LDR_1 = LDR_2, we can rewrite the following equation, V_{in}–= V+ - ((V+ - V-)/(2R_1)) x R_1 => V_{in}–= V+ - (V+ - V-)/2, using this equation we can determine that when both LDRs are exposed or occluded, the voltage is equal to 0V. V_{in}–= 1.5 - (1.5 – (-1.5))/2 => V_{in}–= 1.5 – 3/2 = 1.5 - 1.5 =0V.

Calculating R_i, R_f, and the gain:

We know that the current flowing into R_i is the same at R_f, as no current will flow into the op-amp, using Ohm's law, we can therefore state that I= V_{in}/-R_i = V_{out}/R_f, we know that V_{out} will be negative as it passes through the inverting input. We also know that Vout= - R_f/R_i x (V_{in}), where -R_f/R_i is the gain. We can now use V_{in}/-R_i = V_{out}/R_f, as we know the values of V_{in}, we know what we want V_{out} to be, we can let R_i= 100kΩ and calculate R_f, which we can therefore use to calculate the gain.

When LDR_1 is occluded:

1.5= - R_f/100kΩ(-0.5) => = R_f= 3 x 100kΩ => R_f= 300000Ω = 300kΩ.

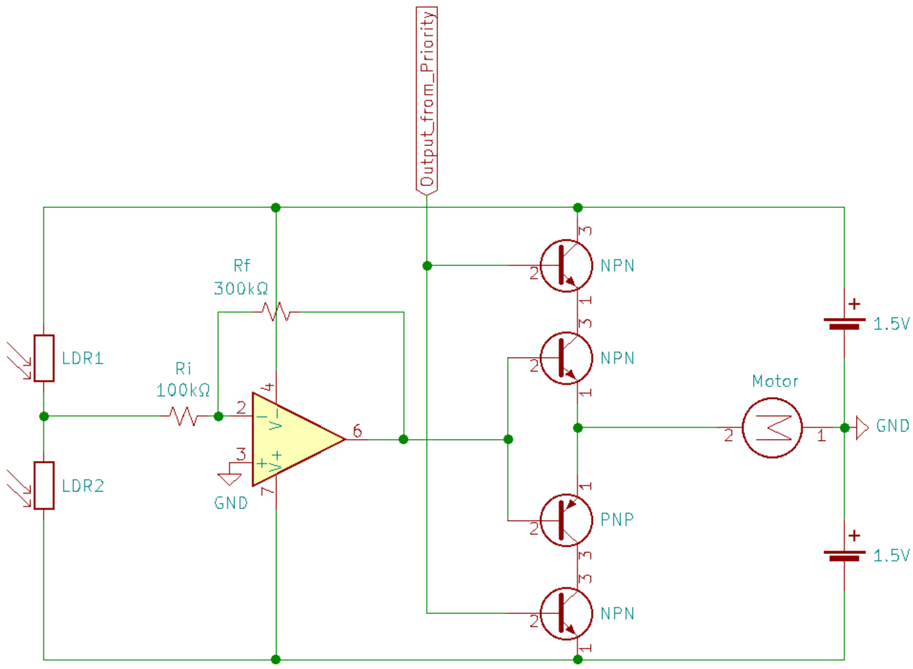
When LDR2 is occluded:

-1.5= - R_f/100kΩ(0.5) => R_f = 3 x 100kΩ => R_f= 300kΩ

We can now safely say that we know Rf is 300kΩ, we can now use -R_f/R_i to calculate the gain of our op-amp.

Gain = -300kΩ/100kΩ => Gain = -3.

If the motor circuit receives priority, the two NPN transistors will be switched on allowing current to flow through them and allowing the following operations to occur:



<u>When LDR_1 is occluded:</u>

LDR_2= 500Ω and LDR_1= 1kΩ, we now know that when V_{in-}= -0.5V, the op-amp's output will be equal to 1.5V, as V_{out}= - R_f/R_i x (V_{in}) which can be rewritten as V_{out}= -3 x V_{in} , which is the base of the transistors. This will now turn on the NPN transistor as the base is at a higher potential than the emitter by 0.7V and greater, as the emitter voltage is equal to zero as it is connected to ground, thus allowing current to flow from the collector through the transistor, out the emitter, through the motor and back to the battery. Note the motor will be powered in one direction.

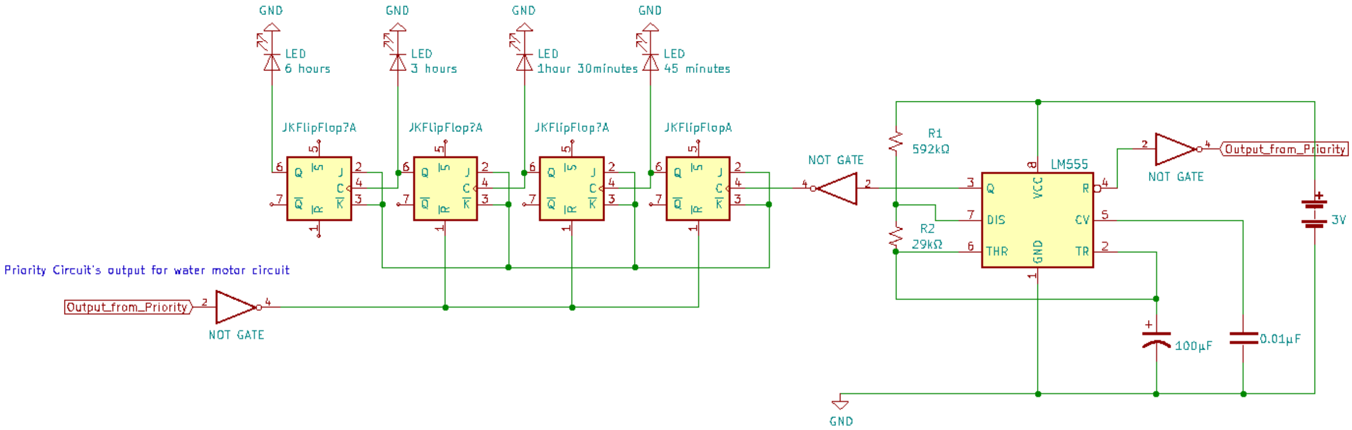
<u>When LDR_2 is occluded:</u>

When LDR_2= 1kΩ and LDR_1= 500Ω , we know that V_{in-}= 0.5V, the op-amp's output will be equal to -1.5V, as V_{out}= - R_f/R_i x (V_{in}) which can be rewritten as V_{out}= -3 x V_{in}, which is the base of the transistors. This will now turn on the PNP transistor as the emitter is at a higher potential than the base, as the emitter voltage is equal to zero which is greater than the base voltage by 0.7V and greater. This will allow current to flow from the battery through to the motor into the PNP transistor's emitter through to the collector and back to the battery, thus completing the circuit. This will power the motor in the opposite direction to the one stated above.

<u>When both LDRs are occluded or exposed:</u>

When LDR_1= LDR_2, we know when that V_{in-}= 0V, the op-amp's output will be 0V as well, as V_{out}= - R_f/R_i x (V_{in}) which can be rewritten as V_{out}= -3 x V_{in}, which is the base of the transistors. This means that neither of the transistors is on because the potential difference between the base and emitter or vice versa is not greater than 0.7V and greater, which would turn on the transistors, this means that the motor would not be switched on or powered. This is different to the state described in question 1, as the voltage will not oscillate between the positive supplied rail of the op-amp and the negative supplied rail of the op-amp, jumping between 1.5V and -1.5V, this new modification will allow the voltage received to be stable and constant at 0V, meaning the plant will retain its position.

Plant Health Monitor:



It is stated that the client would like to know for how long the plant has not been watered for. A simple JK flip-flop counter can be used to count in binary how long it has been in terms of time since it has been watered. For the timer we again use a 555 duty cycle timer to tell how long it has been. We let the time be 45 minutes and want the output to be high for 2 seconds, we let the capacitor be 100µF, R2 to be 29kΩ and calculate R1 to be 592kΩ. This timer circuit is connected to our counter which will add binary together and visually represent how long it has been with a visual representation via LED's, each LED will have a corresponding time associated with it as seen below. The client can then colour each LED to which time and through frequent use will be able to identify how long it has been without having to reference the manual.
This circuit will count up to 11 hours and 15 minutes. Hopefully the plant does not go that long without water. The counter system is reset when the motor circuit for the watering of the plant is activated, as this means the plant is receiving water. Once this occurs, the timer will start again.

Using the same circuit, the reset pin can also be connected to the output of the priority circuit for the motor which controls the sunlight detection's motors. This will give an indication of how long it has been since the plant has wanted to move but couldn't because of an obstruction. You could also adjust the timer by changing the capacitor value and respective resistances.

Using the same method described above it could also be used for telling you how long it has been since the water container has been filled, connecting the reset pin to top LED which indicates that the container is filled.

Bibliography

Circuit Digest, 2020. *Circuit Digest.* [Online]
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[Accessed 6 July 2020].