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Eclectronics

Mini-Project 1: USB-powered LED Flasher

Purpose:
The goal of this project was to design a USB-powered circuit on a two-layer PCB that could flash an LED. The LED's flashing needed to have a period of 1 second. Through this project, elements of circuit design, worst-case analysis, and PCB layout were learned. Additionally, the use of an op-amp as a hysteretic oscillator was studied and implemented.

Requirements:
- The flashing cycle of the LED needed to be within ±10% of 1 second.
- The power supply had to be a single-ended 3.3V derived from the 5V supply of a typical type-A USB port.
- Certain capacitor and resistor values had been specified from which the circuit had to be designed (10pF - 10μF for capacitors and 10Ω - 10MΩ for resistors)
- A USB connector, linear regulator, and op-amps that were specified had to be used for the design.
- Bypass and bulk capacitors needed to be included as specified.
- Minimum trace width/spacing needed to be 6 mils (15 mils for ground and direct power traces). Minimum via size needed to be 24 mils with a 12 mil drill hole.
- Aim for minimal PCB size

Bill of Materials:
- 1μF Capacitor (C0603C105K3RACTU) x2
- 0.1μF Capacitor (CC0603JRX7R9BB104) x2
- 10 kΩ Resistor (RC0603FR-0710KL) x4
- 3.01MΩ Resistor (RC0603FR-073M01L) x1
- 698kΩ Resistor (RC0603FR-07699KL) x1
- 909kΩ Resistor (RC0603FR-07909KL) x1
- 47.5Ω Resistor (RC0603FR-0747R5L) x1
- Red LED (LTST-C171KRKT) x1
- USB Connector (0480370001) x1
- Linear Regulator (MCP1702T-3302E/CB) x1
- Dual Op-Amp (MCP6022T-I/ST) x1

Theory:
Shown below is a hysteretic oscillator, the base structure for the circuit created for the project. The goal of the oscillator is to create a consistent oscillation of V_{out} between V_{dd} and 0V.

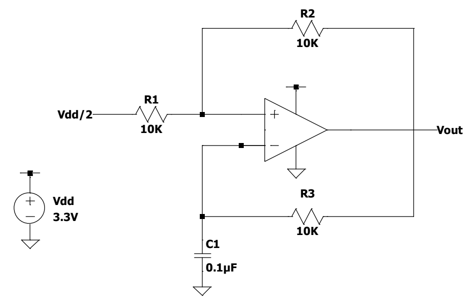


Figure 1: Hysteretic Oscillator circuit schematic (V_{ref} = ½ V_{dd})

To accomplish this, a voltage divider and RC circuit are combined through an op-amp. The op-amp will output V_{dd} if the positive input is larger than the negative input, and the opposite if the negative is larger than the positive.

Assuming that V_{out} starts at V_{dd} (Capacitor C_1 uncharged), as time goes on, current will be provided to the RC circuit, increasing the negative input of the op-amp. When this negative input voltage crosses the positive input voltage, V_{out} from the op-amp will suddenly switch from V_{dd} to 0V. Now, the positive input to the op-amp will drop lower than V_{ref}, and the negative input will also exponentially decrease. When the negative input crosses the positive input, V_{out} will jump up to V_{dd} again. This cycle will continue.

The time period for this oscillation of V_{out} between V_{dd} and 0V is determined by both the voltage divider ratio and RC circuit values. This understanding was used to design the circuit to match the 1 second flash requirement.

<u>Circuit Design (Op-Amp 1):</u>

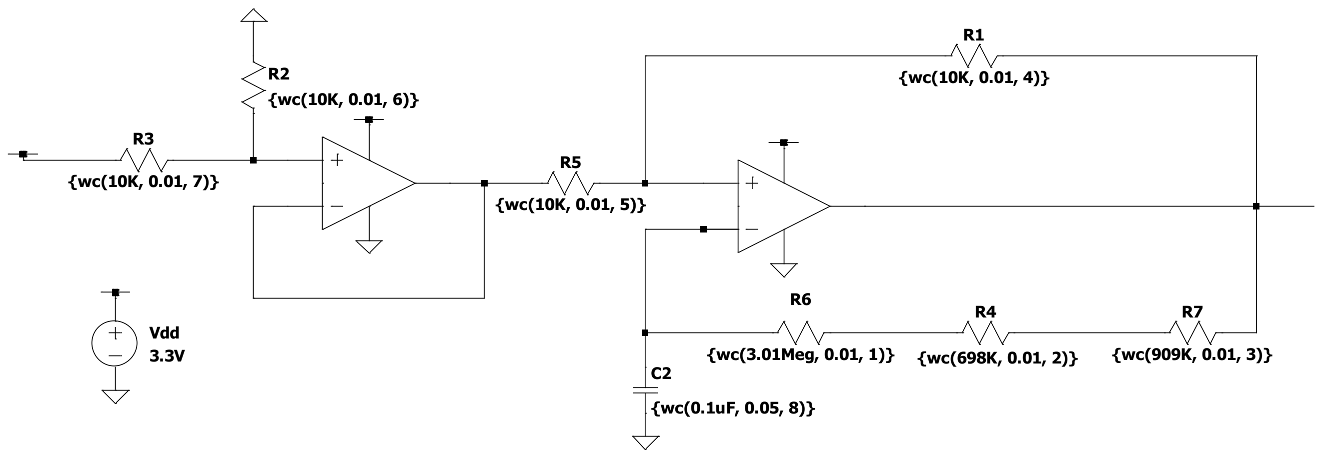


Figure 2: Dual Op-Amp Circuit Design (w/out LED or regulator)

To design the circuit to flash the LED at a period of 1 second, first, the V_{ref} for the second op-amp had to be reduced from 3.3V to half the value (1.65V). By setting V_{ref} to be half of V_{dd} for the second op-amp, the Duty Cycle is set to 50%. This means that half of the oscillation period is spent at V_{dd} and half is spent at 0V. This was a personal design choice for the LED's period.

In order to reduce the input voltage of 3.3V by half, a voltage divider was added to op-amp 1. The usage of an op-amp to step down the voltage was an intentional design decision in order to separate the two sections of the circuit. This would ensure that the voltage inputted into the hysteretic oscillator was exactly 1.65V. The voltage divider of 10K Ohms (R3 and R2) brought the voltage down to 1.65V, which op-amp 1 maintained and brought through to the second op-amp. Without the op-amp present, R2 would have been in parallel to the entire hysteretic oscillator. Therefore, the voltage drop ratio would not be exactly ½ of V_{dd}.

Circuit Design (Op-Amp 2)

For the hysteretic oscillator, the first choice made was to set both R5 and R1 to 10kΩ. This set the hysteresis window to ½ V_{dd}, which allowed the down-going threshold to be ¾ V_{dd} and the up-going threshold to be ¼ V_{dd}. These values were chosen because they are standard for the hysteretic oscillator circuit and because they simplified calculations. Setting R1 and R5 in stone reduced the values that needed to be solved for.

$$V_{up} = 0.25 * V_{dd}$$
$$V_{dn} = 0.75 * V_{dd}$$

Since the RC circuit was what was being altered to change the period of the oscillations, a mathematical approach was taken for this portion of the circuit design:

$$\tau = RC$$

Therefore, the period of the oscillator is given by:

$$T = T_1 + T_h$$

where

$$T_1 = \tau \ln\left(\frac{V_{dn}}{V_{up}}\right)$$
$$T_h = \tau \ln\left(\frac{V_{dd} - V_{up}}{V_{dd} - V_{dn}}\right)$$

Based on the equations provided above for the period of oscillation, the values for V_{dd}, V_{up} and V_{dn} were substituted in, leaving only RC unknown.

$$T = RC \ln\left(\frac{2.4750}{0.8250}\right) + RC \ln \left(\frac{2.4750}{0.8250}\right)$$

To solve for RC in this equation, the approach chosen was setting a capacitor value and solving for the resistance needed. This is because there were less options for capacitors, and thus finding a resistor or series of resistors that matched the value needed would be easier.

Picking a capacitance of 0.1µF and setting the period (T) to 1 second, the R was calculated to be about 4,617,000 Ω. Given that there were no resistors of this value in the requirements provided, 3 resistors were selected to be placed in series with one another to sum up to a total resistance of 4617 kΩ. These were 3.01 MΩ, 698 kΩ, and 909 kΩ.

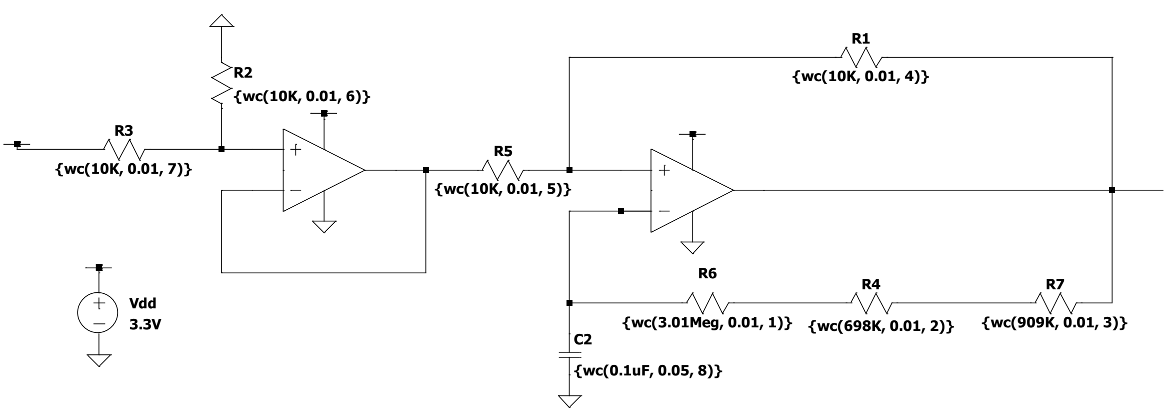
Solving for T with these values placed in:

$$T = 0.4617 * 1.0986 * 2$$
$$T = 1.014\ s$$

In this way, the circuit design for the portions related to the two op-amps was completed, providing a final oscillation period of **1.014 s**.

<u>Worst Case Analysis</u>

After the main circuit was designed, a worst case analysis was completed to ensure that the period of the LED flashing did not vary from 1 second by more than 10%.




```
.func binary(run, index) floor(run/(2**index))-2*floor(run/(2**(index+1)))
.param numruns=256
.step param run 0 256 1
.include engr2420.sub
.tran 0 20 5
.func wc(nom, tol, index) if (run==numruns, nom, if(binary(run, index), nom*(1+tol), nom*(1-tol)))
```

Figure 3: Main Circuit with Worst Case Analysis

Ltspice was used to write the worst-case scenario functions and run a parameter sweep including the error percentages of each of the components in the circuit. Since there were 8 total resistors and capacitors to be included in the analysis, a total of 2^8, or 256 scenarios were run and outputted to a text file, ‘Project1WC.txt’, which was then further analyzed through Matlab.

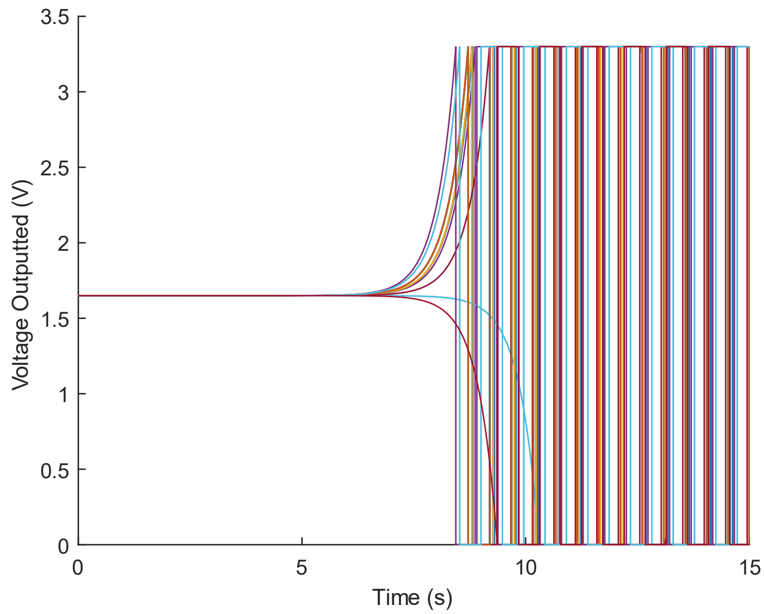


Figure 4: Voltage Outputted vs. Time for each Worst Case Scenario

In ‘projwc.mlx’, the data from the text file was loaded. Each of the 21 scenarios was visualized onto a graph, which is shown above.

From this data, the period for each scenario was calculated. To do this, an algorithm was written to find the times when voltage either dropped from high to low or low to high.

> First, all voltage values were parsed for a ‘low’ value, the threshold for which was specified as a voltage of less than 0.001V. This was recorded as the time for the beginning of the period.
>
> Next, all voltage values after that point in time were parsed for a ‘high’ value, the threshold for which was specified as a voltage of more than 3.2V. This point in time was recorded as the midpoint of the period.
>
> Finally, all voltage values after that point were once again searched for a ‘low’ value, which was recorded as the end of the period. These times were subtracted to find the overall oscillation period.

periods = [0.95355977486672, 0.953559774866728, 0.965939132052426, 0.965939132052426, 0.956470983489730, 0.956470983489730, 0.968999593171828, 0.968999593171828, 0.957237599873018, 0.957237599873018, 0.969770824889661, 0.969770824889661, 0.960181204764712, 0.960181204764712, 0.972795859937474, 0.972795859937474, 0.941965676521622, 0.941965676521622, 0.954399586015439, 0.954399586015439, 0.944927811041096]
minimum = 0.9420
maximum = 0.9728

The code specifying this process resulted in the periods listed above being calculated. As seen here, none of these values were less than 0.9s or above 1.1s, which were the worst-case thresholds for the circuit outlined in the guidelines. Based on this, it could be stated that the LED always blinks with a period between 10% of 1 second.

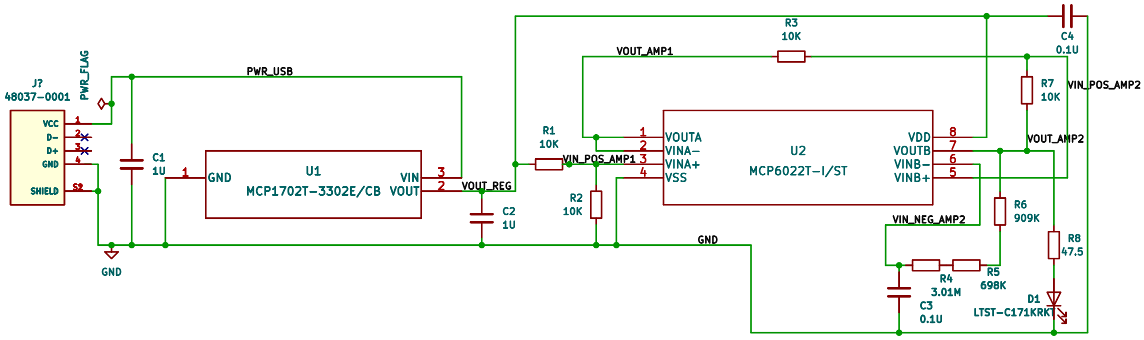


Figure 5: Complete Circuit Schematic

Circuit Design (Bulk/Bypass Capacitors):

As specified in the datasheet, the linear regulator required a 1µF bulk capacitor in parallel with V_{in} from the USB connector and 1µF bulk capacitor in parallel with V_{out} from the linear regulator. Additionally, the op-amp required a 0.1µF capacitor in parallel with V_{dd}, which needed to be within 2 mm of distance. It also required a 1 µF capacitor in parallel with V_{dd}, which could be shared by other parts and needed to be within 100 mm of distance.

For this reason, the final circuit was designed so that one of the 1 µF capacitors could be shared between the op-amp and the linear regulator. When doing PCB layout, the distance requirement for the bypass capacitor was kept in mind.

These additions are shown in Figure 5 above. C1 and C2 are the bulk capacitors, with C2 also acting as a bulk capacitor for the op-amp. C4 is the bypass capacitor.

Circuit Design (LED):

Finally, a red LED in series with a resistor were added to the output of the second op-amp to display the output of the oscillation. To calculate the resistor value here (R8), the datasheet for the LED was referred to. The forward current specified for the LED was about 30mA. Given that the output of the op-amp was a maximum of 3.3V and the typical voltage across the LED was 2V, the difference in voltage across the resistor was found to be 1.3V.

$$V = IR$$

Therefore, by this equation,

$$1.3V = 30mA * R$$

Solving for resistance gave a resistance of 43.3Ω. Since this resistor value was not available, to stay on the safe side and ensure current through the LED did not become excessive, the closest higher resistor, which was at a value of 47.5Ω was used.

In Figure 5, the resistor and LED are depicted by R8 and D1.

<u>PCB Layout:</u>

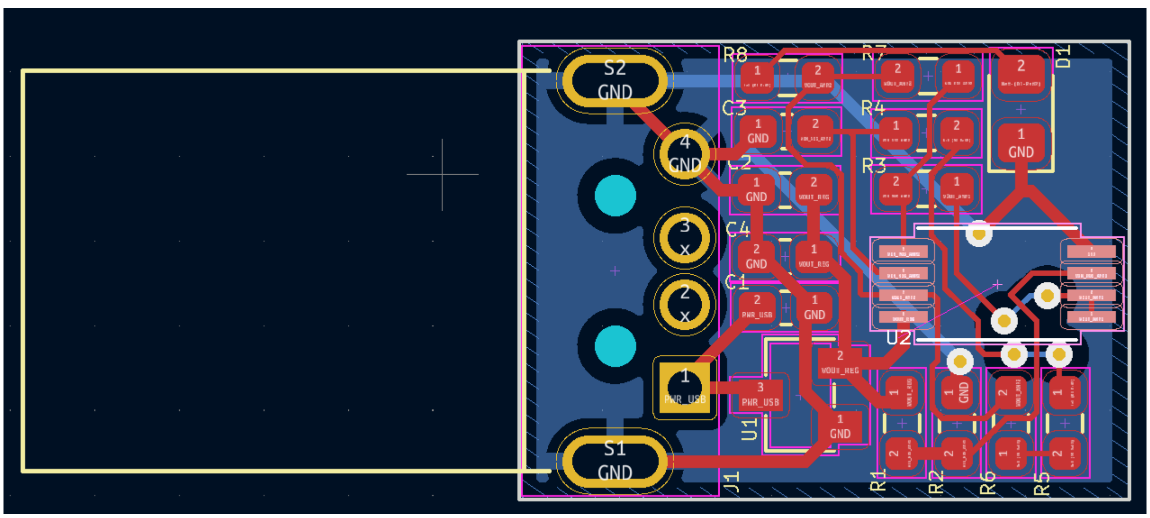


Figure 6: PCB Layout for Circuit in Figure 5

After a few iterations of changes, this layout was chosen for the PCB. The aim of minimizing size was achieved by keeping the length to about 18 mm and the width to about 13.5 mm. The layout was created to be concise and orderly.