Blinking LED PCB Design
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Introduction

The goal of this project was to design a PCB that makes an LED blink at 1Hz given a list of available components. The tolerance for the period of the blinking must be below 10%. One end of the PCB is attached to a USB-A connector so the LED can blink when it is plugged into a computer. All relevant files including KiCAD files and the bill of materials are included in this zip file: https://olincollege-my.sharepoint.com/:u:/g/personal/kburpee_olin_edu/EW8MCzyPG49EukYk63YV8gYBgqtWFN6eweybFeGkA_5cAw?e=6YMJT9

Schematic

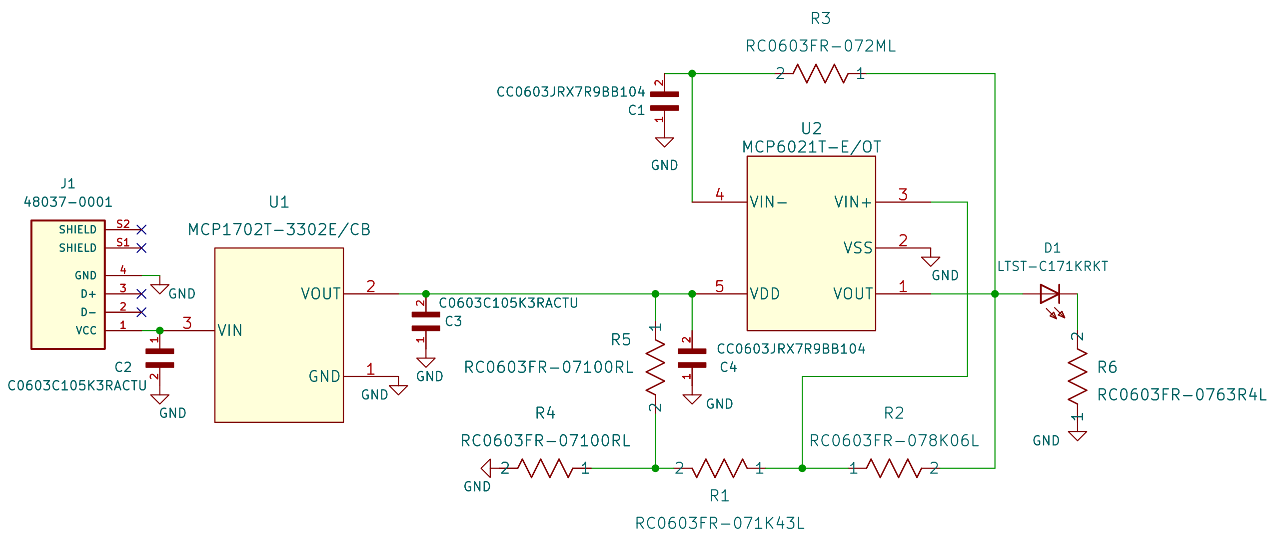

Fig. 1: Circuit schematic for the PCB. The circuit consists of a USB-A connector (J1), 5V to 3.3V voltage regulator (U1), hysteretic oscillator (U2, R1-R3, C1), voltage divider (R4, R5), LED and current-limiting resistor (D1, R6), and bypass and bulk capacitors (C2-C4). Each of the circuit components will be explained in the following sections.

Voltage Divider

I started my circuit design by deciding that I wanted the duty cycle of my LED to be 50%. For a hysteretic oscillator's duty cycle to be 50%, the reference voltage that is the input of the oscillator must be half of the op-amp's Vdd. Therefore, I used R4 and R5 (same resistance) in my circuit to create a voltage divider so that the reference voltage would be half of Vdd. I chose a relatively low resistance of 100Ω for R4 and R5 so it would have minimal interference with the hysteretic oscillator.

Hysteretic Oscillator

The main part of the circuit that makes the LED blink consists of a hysteretic oscillator. In the schematic, this is the op-amp U2, resistors R1 to R3, and capacitor C1. To calculate all the component values, I started by choosing a capacitor. Since the total tolerance of the period must be below 10%, I was limited to using the capacitors with either 5% or 1% tolerance. I was going to use a 1% tolerance capacitor to be safe, but the highest capacitance available at that tolerance was 1nF, which was too small considering the resistors available to get a reasonable RC value for the low-pass filter on the oscillator. Therefore, I chose to use the 0.1µF capacitor with 5% tolerance.

The equation that determines the period P of the oscillator is P=τ*ln((Vdd- α (Vdd-Vref))/(α (Vdd-Vref))*(Vdd- α *Vref)/(α *Vref)) where τ is R3 * C1 and α is R2/(R1+R2). In my circuit, Vdd is 3.3V and Vref is 1.65V. When I plugged these numbers into the equation and solved for α, I found that an RC value lower than 0.1 would make it difficult to find a good resistor ratio for R1 and R2 because α would be too small. Therefore, I used the 2MΩ resistor for R3 to make my RC value 0.2. Using this value to solve the equation for α, I determined that my ideal α was 0.1517.

To avoid solving for the best R1 and R2 values by hand, I used an Excel spreadsheet to find the best combination. I made a multiplication table of the available resistor values for this project, except my output was R2/(R1+R2) instead of the product of the two values. Through this method, I found the combination of resistors that was closest to my ideal α, which were 1.43kΩ (R1) and 8.06kΩ (R2). The α of these resistors is 0.1507, only 0.001 off from the ideal value. Plugging in this value to the period equation, the period of the LED if all the components behave ideally is 1.003 seconds, which is a 0.3% deviation from the ideal period.

	10	11	12.7	14.3	15.8	20	30.1	31.6	40.2
10	0.5	0.52381	0.559471	0.588477	0.612403	0.666667	0.750623	0.759615	0.800797
11	0.47619	0.5	0.535865	0.565217	0.589552	0.645161	0.73236	0.741784	0.785156
12.7	0.440529	0.464135	0.5	0.52963	0.554386	0.611621	0.703271	0.713318	0.759924
14.3	0.411523	0.434783	0.47037	0.5	0.524917	0.58309	0.677928	0.688453	0.737615
15.8	0.387597	0.410448	0.445614	0.475083	0.5	0.558659	0.655773	0.666667	0.717857
20	0.333333	0.354839	0.388379	0.41691	0.441341	0.5	0.600798	0.612403	0.667774
30.1	0.249377	0.26764	0.296729	0.322072	0.344227	0.399202	0.5	0.512156	0.571835
31.6	0.240385	0.258216	0.286682	0.311547	0.333333	0.387597	0.487844	0.5	0.559889
40.2	0.199203	0.214844	0.240076	0.262385	0.282143	0.332226	0.428165	0.440111	0.5
47.5	0.173913	0.188034	0.210963	0.231392	0.249605	0.296296	0.387887	0.399494	0.458381
49.9	0.166945	0.180624	0.202875	0.222741	0.240487	0.286123	0.37625	0.38773	0.446171
60.4	0.142045	0.154062	0.173735	0.191432	0.207349	0.248756	0.332597	0.343478	0.399602
63.4	0.13624	0.147849	0.166886	0.184041	0.199495	0.239808	0.321925	0.332632	0.388031
69.8	0.125313	0.136139	0.153939	0.170036	0.184579	0.222717	0.301301	0.311637	0.365455
80.6	0.110375	0.120087	0.13612	0.150685	0.1639	0.198807	0.271906	0.28164	0.332781
90.9	0.099108	0.107949	0.122587	0.135932	0.148079	0.180343	0.24876	0.257959	0.306636
95.3	0.094967	0.103481	0.117593	0.130474	0.142214	0.173461	0.240032	0.249015	0.296679
100	0.090909	0.099099	0.112689	0.125109	0.136442	0.166667	0.23136	0.240122	0.286733
110	0.083333	0.090909	0.103504	0.115044	0.125596	0.153846	0.214847	0.223164	0.267643
127	0.072993	0.07971	0.090909	0.101203	0.110644	0.136054	0.191598	0.199243	0.240431
143	0.065359	0.071429	0.081567	0.090909	0.099496	0.122699	0.173888	0.180985	0.219432
158	0.059524	0.065089	0.0744	0.082995	0.090909	0.11236	0.160021	0.166667	0.202825
200	0.047619	0.052133	0.059709	0.066729	0.073216	0.090909	0.130813	0.136442	0.167361

Fig. 2: A section of the spreadsheet used to find best combination of resistors to get as close to ideal α as possible. Values close to the ideal are highlighted in yellow. The best value is selected with the green box.

LED

For the LED (D1 in schematic), we had a choice of red, green, or blue. I chose the red one because it was the one that had a maximum forward voltage of 2.4V, well below the 3.3V output of the op-amp in the hysteretic oscillator. I put a current-limiting resistor in series with the LED in the circuit. To choose this resistor value, I first calculated the voltage drop across the resistor. I assumed typical forward voltage (2.0V according to the data sheet) for the LED, so it would be 3.3V - 2.0V = 1.3V. In the LED data sheet, I found that the maximum DC forward current rating was 30mA and the forward voltage was measured at I = 20mA, so I decided that I wanted the current through the LED to be 20mA. I then used Ohm's law to calculate a resistor value and got 1.3V/0.02A = 65Ω. Since I didn't have access to a 65Ω resistor, I chose to use the 63.4Ω one instead.

Bypass Capacitors

C2-C4 in the schematic are bypass capacitors for the integrated circuits. The voltage regulator (U1) requires an input and output capacitor, both 1μF, so I added them (C2 and C3) close to Vin and Vout on U1. The op-amp requires a 0.1μF bypass capacitor as close to the positive input rail as possible, so I added C4. The op-amp also requires a 1μF bulk capacitor, but according to the data sheet, it can be shared with other analog components if it is within 100mm of the op-amp, so I decided that the output capacitor C3 for the voltage regulator was sufficient for this purpose.

Worst Case Circuit Analysis

I performed worst case circuit analysis in LTspice to make sure that the LED would always blink at a period within 10% of one second. In my simulation, I included all parts of the hysteretic oscillator and the voltage divider.

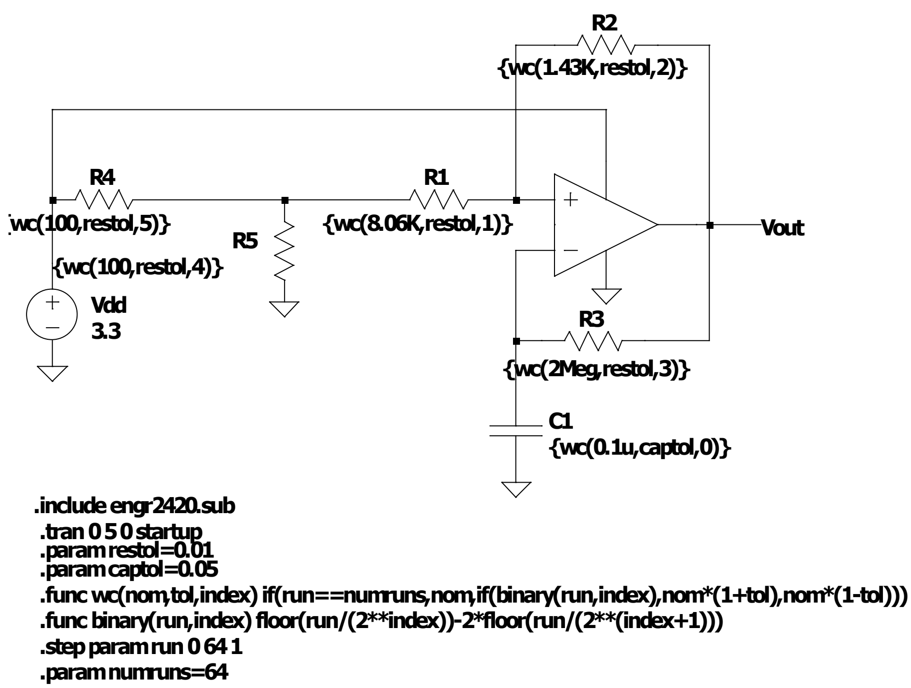

Fig. 3: LTspice schematic for worst case circuit analysis. Includes hysteretic oscillator (op-amp, R1-R3, C1) and voltage divider (R4, R5).

To perform the analysis, I created a function to run the simulation, assuming each of the components was at the high or low end of its tolerance during any given simulation. The combination of highs and lows would change each simulation, and since there were six components, I ran $2^6 = 64$ simulations. The resistors had a 1% tolerance each, and the capacitor had a 5% tolerance.

Once I got my data, I put it into MATLAB to perform my analysis. I first visualized the parameter sweep with all the outputs plotted on top of each other.

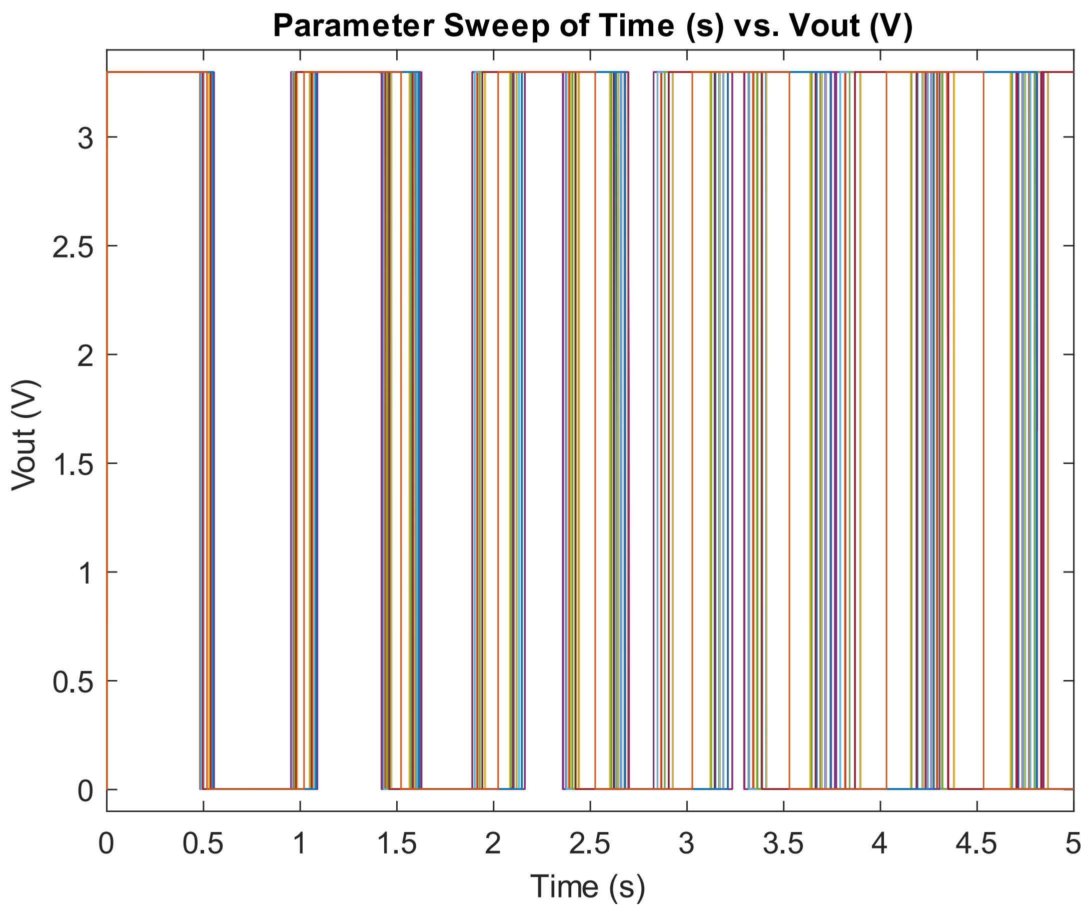

Fig. 4: MATLAB plot of the worst case parameter sweep. All 64 outputs are plotted on top of each other. The figure shows that the period for all the sweeps is around one second, and this initial difference causes more spread in the graph as time goes on.

I then precisely calculated the period of each trial. To do so, I used an algorithm that found the first point in the data where the voltage drops below 3V. I then found the second point in the data where the voltage drops below 3V and found the time between the two points. I aggregated this data and created a new plot, which showed that my circuit design was within the 10% tolerance range for the period. All the periods were between 0.9 seconds and 1.1 seconds.

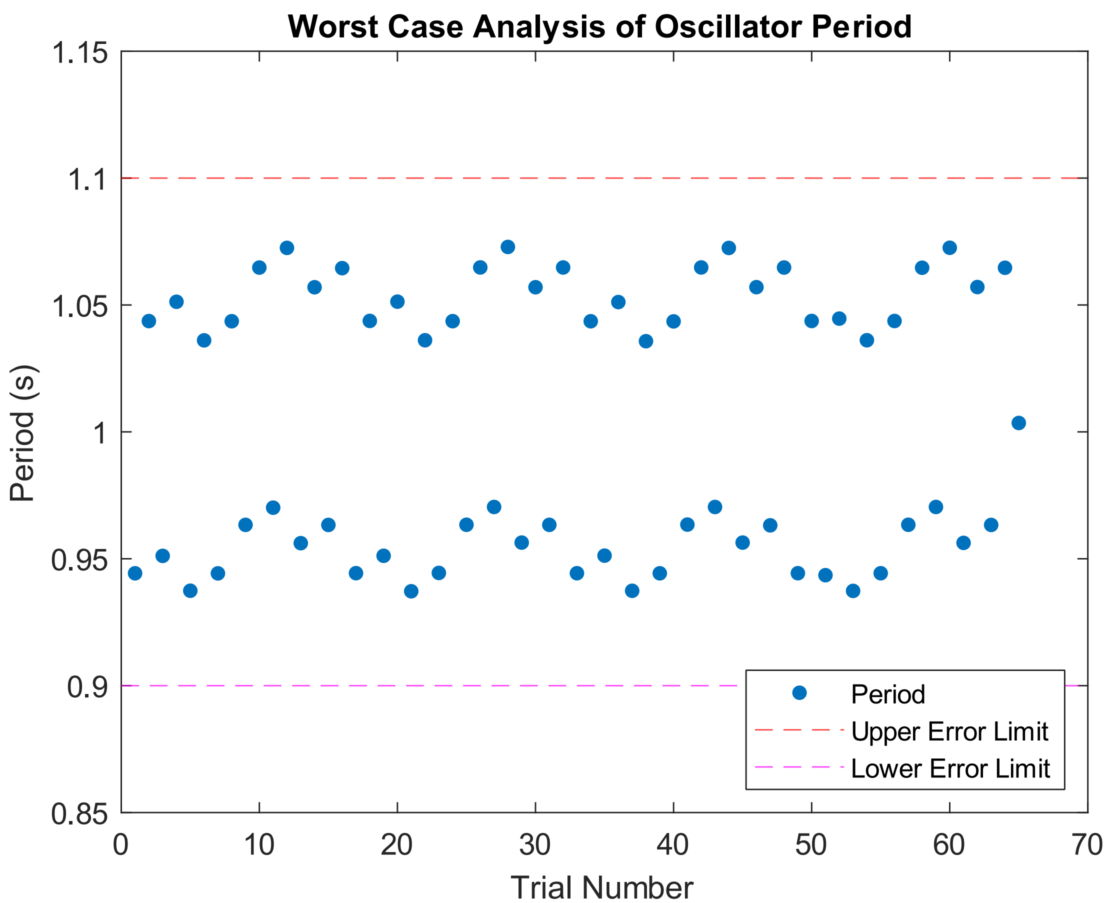

Fig. 5: MATLAB plot of the period of each trial in LTspice. All the periods are within the 10% tolerance range.