Sound Activated Switch Report

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Contents

1 Abstract

In this project, the aim was to create a device in which an LED illuminates when a clap is performed. This device has requirements to be met such as stability with temperature, power consumption, adjustable LED on-time from 1-10 seconds, and meeting a certain sound threshold for a clap. The end of the production period brought a device that satisfies almost all of the requirements with only one exception. Additionally, the sensitivity of the clap can be adjusted, the LED on-time is adjustable from 1 to over 10 seconds, and power dissipated while the LED is on is limited to 150mW. A small bug exists with this device in which when powered on, the LED illuminates regardless of noise in the room. There are plans in place to fix this bug in future iterations.

2 Introduction

This project brought about the task of creating a device with the following specifications to deliver to a client.

1. The circuit must be designed using components from the Votey 334 lab.
2. The circuit shall include an LED that is illuminated when the output is activated and remains on until the output is deactivated.
3. The circuit output shall have an adjustable on-time of between 1 and 10 seconds. This time can either be adjusted by a potentiometer or by switching out fixed resistors if a potentiometer is not available.
4. The circuit shall operate from a single 9 Volt battery.

From these specifications, requirements and a test plan were created, and a device was built to satisfy each requirement. The design process was extensive and required analysis, datasheet interpretation, hands on circuit building, and trial and error. The design was constructed over a a 5-week period in tandem with other coursework. The final design came with many figures of merit, but also some limitations. Future work is planned to further improve this device.

3 Requirements

The important of requirements is to communicate clearly to the client what can be expected of the final product. The requirements may be adjusted as necessary during the process as needed as long as communicated with the client. These requirements were communicated and approved by the client.

3.1 Definitions

- A ”clap” shall be defined as a sound at or above 100dB measured by the DecibelX app on an iPhone 12 Pro.
- A ”non-clap” shall be a sound at or below 80dB as measured by the DecibelX app on an iPhone 12 Pro.
- The LED ”active” state shall be defined as 1mA of current traveling through the LED.
- The LED ”inactive” state shall be defined as a current less than 10μA

3.2 Requirements

1010. The device shall run on a 9V battery.

1020. The device shall not exceed a volume of 216 in^3.

1030. The device shall not exceed a weight of 2 lbs.

1040. The device shall last at least 24 hrs.

1050. The LED shall transition to the active state when a clap is detected.

1060. All requirements shall be met over a temperature range of 10-40°C.

1070. The LED timer shall not reset with another clap registered while the LED is illuminated.

1080. The device shall cost less than $20 to manufacture.

1090. The time the LED is active shall be adjustable from at least 1-10 seconds.

1100. The power consumed by the device shall not exceed 9W.

1110. The LED shall illuminate with at least 1mA of current.

1120. The device shall be manufactured within 4 weeks.

1130. The LED shall transition to active within 500ms of detecting a valid clap.

1140. The pulse width shall not change more than ±5% over the specified temperature range.

4 Results

Specification	**Result**
Max Power Consumption	221mW
Minimum Battery Life	21.7hr
LED "On" Current	11.7mA
LED Time Adjustment	0.8-20s
Pulse Width Variation with Temperature	+1.74%, -1.86%

Table 1: Results/Figures of Merit

The final circuit topology includes 3 stages: microphone taking an input, a DC biased comparator circuit to process the input, and a 555 timer to generate the output pulse.

The figures of merit and results are shown in the table above. The maximum power consumption was found with analysis by looking at the datasheets and the maximum current draw of the supply. The battery life is less than the required battery life. An analysis for the worst case current was calculated, which may be different than the actual current draw due to lack of datasheet specifications. The LED "On" Current is an order of 10 larger than the requried "On" current. This amount of current is sufficient to light up the LED. The time originally required to be adjustable from 1-10s has gone beyond this range to be adjustable from as low as 0.8s to 20s. Finally, the output pulse will not vary more than +1.74% or -1.86%. This allows proper function of the device in the required temperature range. More on the analysis and design is listed in the next section. The results of the test plan can also be found in the Appendix **8**.

With all of these figures of merit, some issues arose. A few being the below requirement battery life and device triggering on power up. The battery life is due to an oversight when planning the project, further datahsheet inspection should be performed accounting for all requirements before submission. The issue with the device being triggered on power up is also a datahset oversight issue. In the future, the datasheets will be used more to create requirements rather than to just understand how a device functions.

5 Design and Analysis

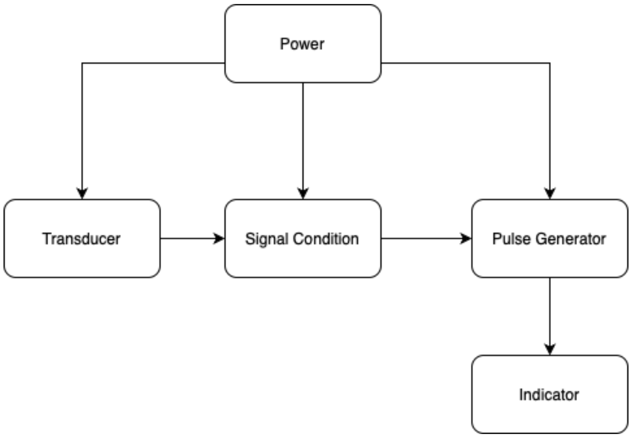


Figure 1: Device Topology

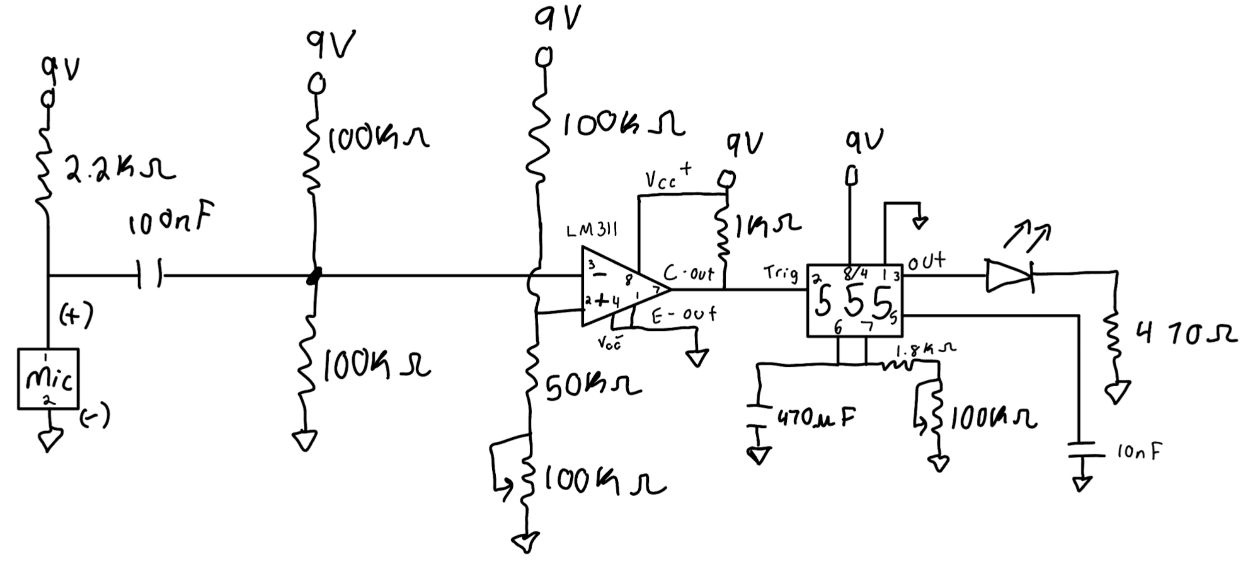


Figure 2: Circuit Schematic

5.1 Design Process

Figure 1 shows the device's basic topology. The transducer is a microphone, the signal condition is a comparator, the pulse generator is a 555 timer, and the indicator is the LED. Figure

This design process was iterative in that the datasheet was read to gain intuition and understanding of each device, then each device was tested individually. The process started with getting an output from the microphone. The microphone was attached to the oscilloscope and set up according to the datasheet. An oscilloscope reading was extracted after a clap was performed, paying careful attention to the peak voltage of this signal.

Next, the 555 timer was explored by again reading the datasheet. The device has two modes: Monostable and Astable. Monostable was chosen here because a pulse with a length controller by a resistor and a capacitor roughly obeying equation **1** is outputted when the device is triggered with a negative pulse.

$$t_{pulse} = 1.1 R_A C \tag{1}$$

This part was again wired up per the datasheet. Once the output produced a pulse when triggered, the next stage of design was started.

The final component the comparator was then explored. The comparator took the longest to understand. This particular comparator has a BJT on the output with both the emitter and the collector available as pins. This was used advantageously to pull the output low when the comparator was triggered which will later be used to trigger the 555 timer.

Combining all of these components was the final step in the design process. The microphone output was AC coupled to the inverting input of the comparator so only the AC microphone signal could pass through to the comparator. The non-inverting bias point is adjustable with a potentiometer. With the non-inverting bias point set, the inverting terminal was biased at a point around 100mV below the non-inverting terminal. This was accomplished with two resistors with a high impedance as to deliver a majority of the signal to the comparator. The 100mV difference comes from the peak voltage of the microphone signal when triggered by a sound of around 100dB (as measured by the decibelX app on iPhone 12 Pro). The microphone signal is added to the DC bias point of the non-inverting terminal which sends the inverting terminal voltage over the non-inverting voltage, triggering the output.

The output of the comparator is high with no trigger as the BJT output is leveraged to act as an inverter driven by a resistor. When the output is triggered, the output gets pulled to ground which is the negative pulse that the 555 timer is triggered by. The 555 timer then sends a pulse of length in correspondence to equation **1**. The output is connected to a current-limiting resistor and an LED.

5.2 Analysis

To ensure satisfaction of all requirements, further analysis was performed. All analysis can be found in Appendix **8.2**

To satisfy the power requirement, an analysis was performed in which the maxixmum supply current draw for each stage of the device was found. The sum of these currents and the maximum voltage of a 9V battery accounting for variance were used in equation **2** to find the maximum possible power consumption.

$$P = VI \tag{2}$$

To get the minimum battery life, research was performed to find the minimum battery life of a battery, this came out to be 500mAh. This value along with the current drawn from the power supply were used to calculate the minimum hours of operation. The current draw variations from each component were also accounted for to get the absolute worst-case minimum time the device would last.

To vary the pulse width, or the time that the LED is on, a capacitance and a resistance had to be chosen. The pulse width follows equation **1**. These values had to be chosen carefully to achieve a width of 1 and 10 seconds. When testing, the time was fixed around 1 second with a 470μF capacitor and a 2.2kΩ resistor. This provided a baseline pulse width that could be increased with a potentiometer. Any potentiometer that could create a pulse of at least 10 seconds could be used in series with the resistor.

To ensure the output pulse would stay within ±5% with temperature, the datasheets of the resistor, capacitor, potentiometer, and 555 timer were analyzed. These are the components that affect the pulse width of the output. Further online research was necessary to find information about these components. Using the variance of each of these components lead to the maximum pulse width variation.

6 Limitations and Issues

There were not many limitations in this design process and the final product. The few limitations in the design process present include time and interference with work from other courses.

The final design does have its issue and limitations. The first issue with the circuit is that the output is triggered on power up. This is because when the device is powered on, the trigger pin of the 555 timer transitions from low to high which the component interprets as a trigger, so the output becomes active. The cause of this issue was lack of full understanding of the datasheet and general oversight. The device was not powered on and off very often so this issue went unnoticed because of lack of consideration of the power up transient. Several fixes could be implemented to prevent this issue. The problem can be solved with use of the reset pin on this device, which effectively prevents the output from triggering regardless of the device being triggered. Using a capacitor and resistor tied to the supply voltage to hold this pin low while the device is being powered up will solve this issue. The pin will be held low until the capacitor is charged, preventing an output pulse, then after the capacitor is charged, the output will be able to trigger.

The minimum battery life being below requirement is another limitation of this device. While the voltage supply current at 15V was used for the comparator and the 555 timer because of lack of specification for 9V in the datasheet, the minimum battery life would still be outside of the requirement. A solution for this could include using a smaller current limiting resistor for the LED, using different comparator and or 555 timer with a lower current draw, or using a different method of power supply such as a buck boost circuit, but this may cause issues with other components. In the future, the datasheet will be inspected further to understand the requirements of the device before constructing the requirements.

Another limitation of the design is the comparator having no hysteresis. This could cause unexpected behavior when the inverting terminal of the comparator voltage is close to the non-inverting terminal voltage when a clap is detected such that there is oscillation just above the threshold of triggering. This may cause unexpected outputs that are not at either of the power supply rails of the comparator. This could cause improper triggering of the 555 timer as the negative pulse needs to be less than 1/3 of the power supply. This was seen during testing, when adjusting the bias point of the non-inverting terminal of the comparator, when the voltage at both terminals was very similar, the LED began flashing, which is not the intended function. This could be fixed in the future by adding some resistors to the output of the comparator feeding back into the non-inverting input to provide hysteresis for potential noise or an edge case signal causing oscillation above and below the threshold voltage.

The specifications included a clap triggered the output, but this design does not account for any noise louder than a clap. To account for this in the future, another comparator could be used to detect if the sound goes above a certain threshold of something louder than a clap and this would lead to the reset pin on the 555 timer being triggered to stop the output, effectively disregarding the sound that is louder than a clap.

A final limitation of this design is that the threshold may need to be adjusted depending on the environment. Sound may be more amplified or absorbed better in different environments causing the device to trigger or not trigger when not desired. The potentiometer was included in the design process to dynamically adjust the threshold of when the output was triggered, but this can be tedious to adjust and an automated system would be more ideal. Some sort of sensor to detect and provide feedback about the ambient noise or the way that a certain sound acts in a room would solve this issue.

7 Conclusion

The design and analysis process brought forth a device that satisfies most requiremts with a few exceptions. Some figures of merit of the device include power consumption, stability with temperature, and output pulse width variance with temperature. The design process went relatively smoothly and benefited from starting early and looking at device applications on the datasheet. The final device fell short of the battery life requirement and also triggers on power up. In future iterations, these discrepancies will be fixed and more function mentioned in section **6** will be implemented. What can be taken out of this design process is to properly examine the datasheet and understand each device before writing requirements, and if an issue arises communicate with the client.

8 Appendix

8.1 Test Plan

Sound Activated Switch Test Plan

Test Plan

1010. (Verifies 1010, 1050, & 1100) Connect a 9V power supply to the circuit and perform a clap. Measure the current through the LED with a multimeter confirming it is at least 1mA.

1020. (Verifies 1020) Using a standard US ruler, measure the circuit's length, width, and height. Multiply these measurements to get the volume, ensuring this volume remains below 216 in^3.

1030. (Verifies 1030) Place the device on a scale, ensuring that the device does not exceed a weight of 2 lbs. If a scale is not available, use the volume measurement from Test 1020 and rule to eliminate weights that would be too heavy for the device's volume and materials. This confirms that the weight of the device remains under 2 lbs.

1040. (Verifies 1040) Measure the current drawn from the power source with a multimeter while in the active state. Divide the mAh capacity of the 9V battery by the current drawn, this value is the amount of time in hours the device would last when constantly in the "active" state. Confirm that this value is at least 24 hrs.

1050. (Verifies 1080) Look up the components or similar components used in this device on Digikey and ensure the sum of the components does not exceed $20.

1060. (Verifies 1130) Connecting one probe of the oscilloscope to the output of the the comparator. Connect another oscilloscope probe to the output pin of the pulse generator. Perform a clap and inspect the oscilloscope to confirm that the output of the pulse generator is triggered within 500ms of a clap being detected.

1070. (Verifies 1100) Using a multimeter, measure the current draw of the power supply while the device is in the active state. Multiply this value by the voltage supplied by the power supply to get the power consumption. Confirm this value does not exceed 9W.

1080. (Verifies 1120) Ensure the date that the device is being tested is 4 weeks after the assignment date of the device.

1090. (Verifies 1090) Connect an oscilloscope probe to the output pin of the pulse generator set to trigger on a single waveform. Set the circuit to have a pulse of at most 1 second. Perform a clap and inspect the waveform confirming that the pulse was on for at least 1 second. Repeat this process setting the output for at least 10 seconds.

1100. (Verifies 1070 & partially verifies 1090) Set the output to a previously measured length. Perform two claps in a row with less than a 1-second delay between each clap. Use an oscilloscope connected to the output of the pulse generator to confirm this output pulse is the same as when one clap was performed.

1120. (Verifies "clap" & "non-clap" definition) Position the bottom microphone of an iPhone 12 Pro within 2 inches of the device microphone. Open the DecibelX app and inspect decibel meter as a clap is performed. Set a multimeter to measure the current through the LED confirming that the device does not enter the active state for sounds below 85 dB and that the active state is entered for sounds above 95 dB.

1130. (Verifies 1060) Inspect each component's datasheets to ensure operation over the specified temperature range.

1140. (Verifies 1140) Inspect each components' datasheets and perform an analysis to ensure the pulse remains within ±5% of the original value over the specified temperature range.

Test Results

Student Signature________________ **Instructor/TA Signature**________________

Test Num	Description	Pass (Y/N)	Measurements/Notes
1010	Connect a 9V power supply to the circuit and perform a clap. Measure the current through the LED confirming it is at least 1mA.	✓	11.7mA 9V
1020	Using a standard US ruler, measure the circuit's length, width, and height. Multiply these measurements to get the volume, ensuring this volume remains below 216 in^3.	✓	2.1 x 6.5 x 3.5 47.775 in^3
1030	Place the device on a scale, ensuring that the device does not exceed a weight of 2 lbs. If a scale is unavailable, use the volume measurement from Test 1020 and rule to eliminate weights that would be too heavy for the device's volume and materials. This confirms that the weight of the device remains under 2 lbs.	✓	Dr. K forgot the scale
1040	Measure the current drawn from the power source with a multimeter while in the active state. Divide the mAh capacity of the 9V battery by the current drawn, this value is the amount of time in hours the device would last when constantly in the "active" state. Confirm that this value is at least 24 hrs.	✓	16.6mA 500mAh = 30.12 hrs
1050	Look up the components or similar components used in this device on Digikey and ensure the sum of the components does not exceed $20.	✓	Breadboard ~$2-3 everything else less than $ each, Total ~$8
1060	Connecting one probe of the oscilloscope to the output of the the comparator. Connect another oscilloscope probe to the output pin of the pulse generator. Perform a clap and inspect the oscilloscope to confirm that the output of the pulse generator is triggered within 500ms of a clap being detected.	✓	no change in output
1070	Using a multimeter, measure the current draw of the power supply while the device is in the active state. Multiply this value by the voltage supplied by the power supply to get the power consumption. Confirm this value does not exceed 9W.	✓	9V 16.6mA = 149.4mW
1080	Ensure the date that the device is being tested is 6 weeks after the assignment date of the device.	✓	
1090	Connect an oscilloscope probe to the output pin of the pulse generator set to trigger on a single waveform. Set the circuit to have a pulse of at most 1 second. Perform a clap and inspect the waveform confirming that the pulse was on for at least 1 second. Repeat this process setting the output for at least 10 seconds.	✓	Potentiometer vary linearly

1100	Set the output to a previously measured length. Perform two claps in a row with less than a 1-second delay between each clap. Use an oscilloscope connected to the output of the pulse generator to confirm this output pulse is the same as when one clap was performed.	✓	oscilloscope used
1110	Using a multimeter, measure the current through the LED in the active state. Ensure this current is at least 1mA.	✓	11.7mA
1120	Position the bottom microphone of an iPhone 12 Pro within 2 inches of the device microphone. Open the DecibelX app and inspect decibel meter as a clap is performed. Set a multimeter to measure the current through the LED confirming that the device does not enter the active state for sounds below 85 dB and that the active state is entered for sounds above 95 dB.	X	When device powered on, output triggered
1130	Inspect each component's datasheets to ensure operation over the specified temperature range.	✓	all at least 0-70°C
1140	Inspect each components' datasheets and perform an analysis to ensure the pulse remains within ±5% of the original value over the specified temperature range..	✓	+1.74% -1.857

8.2 Analysis

Power

$I_{555} = 15mA$ (@ 15V, no info on 9V)

$I_{microphone} = 0.5mA$ (max)

$I_{comparator} = 7.5mA$ (from V_{CC}^{+}, V_{CC}^{-} is ground so not used)

max 9V battery voltage = 9.6V

$$P = \underset{\substack{\swarrow \\ 9.6V}}{V_{MAX}} \cdot \underset{\substack{\downarrow \\ 23mA}}{\sum I_{max}} = 220.8mW$$

Battery Life

Lowest 9V battery mAh rating found was 500mAh

worst case is when output is active

$$\text{battery duration} = \frac{500mAh}{23mA} = \underline{21.7hrs}$$

Choosing Pulse Width components

equation : $t_{pulse} = 1.1RC$

choose for 1 second

$$1.1RC = 1$$

$$RC = .909$$

choose $R = 1.8\,K\Omega$

$C = 470\,\mu F$

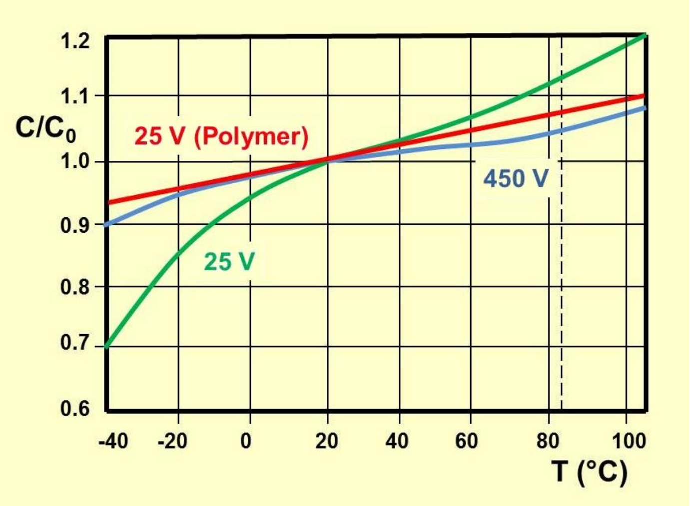
real min time $= 1.1(1.8k)(470\mu) = 0.936\,s$

add 50k potentiometer to get

$1.1(50k + 2.2k)(470\mu F) = 26.987\,s$

maximum

Pulse Width Variation w/ Temperature



Wikipedia article for cap

10°C – 40°C

		10°C	40°C	
cap	C/C_0	.99	1.01	→ ±1%
resistor	100 ppm/°C			$\frac{100 \cdot 30}{10^6} = \pm .3\%$
pot	150 ppm/°C			$\frac{150 \cdot 30}{10^6} = \pm .45\%$
NE555	150 ppm/°C			$\frac{150 \cdot 30}{10^6} = \pm .45\%$

Ideal

R + Pot = 10k

C = 470uF

→ $1.1RC = 5.17\text{ s}$

555 = normal

40°C

$R + Pot = 2206.6 + 7835.1 = 1004.17$

$C = 474.7\,\mu F$

$t = 1.1RC = 5.24 \cdot 1.0045 = 5.26$

10°C

$R + Pot = 2193.4 + 7764.9 = 9958.3$

$C = 465.3\,\mu F$

$t = 1.1RC = 5.097 \cdot .0045 = 5.074$

$+1.74\%$ -1.857%