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Working with Electrons

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Sound-and-Light-Combined Prank Box

1. Project Title (Tom)

Sound-and-Light-Combined Prank Box.

2. Project Statement of Purpose (Barry)

In this midterm project, we aim to not only utilize what we have learned in class but also more knowledge and techniques from outside the classroom to develop a project that can both demonstrate our deep understanding of the course material and show our thoughtful idea on the combination of technologies and art. One important factor of this our standing position is that we believe that the charm and beauty can be illustrated and presented better off with the methodology of art. To be more concrete, we would like to produce a project that maintains rigorous scientific level as well as generating an artistic or aesthetic pleasure to the audience. We fix on the purpose of brining an immediate and direct joyful experience once the product is delivered. To reach this point, we would like to take the path of adding meaningful interactions from acoustic and visual angles so that the audience get a meaningful and satisfied experience of interaction.

3. Literature and Art, Perspectives and Contexts (Harry)

Changtengguixiao, Chengdu, Sichuan, China.

Changtengguixiao is a famous ghost house in Chengdu. When I first went to this place with my friends, besides the frightening experience, the technology behind it also impresses me a lot. I remember, in one of the rooms of the ghost house, we were asked to move a candle on the desk. But as soon as my friend picked the candle up, a load screaming came from our back. While thinking of this project, I am wondering whether we could adapt this prank into an object common in our daily life. What's more, besides the weird sound, what makes the ghost house more real is the light effects. This design brings us to the idea of using LED light to simulate the light effect, with light shining one after another.

4. Project Description (Harry)

In our project, we will attempt to build a prank box. We are going to explore the function of the NE555 timer IC, CD4017 counter IC, the photoresistor, and their applications in the production of toys with sound and light. We are going to learn about their basic internal architectures, their different operating modes as well as utilizing other components including speakers, LEDs, and so on. In the process of making the prank box, a comprehensive understanding of each component and a skillful usage of breadboard or soldering tools are prerequisites. Furthermore, we also anticipate potential challenges such as finding the proper value of the potentiometers, combining different circuits together, etc. Thus, we also anticipate an educational process.

5. Project Significance (Tom)

Our project is significant, first and foremost because it will be an educational process to us. Our goal is to make a prank box combining both sound and light. In order to produce it, we will not only apply what we have learned in the past half semester, but also conduct necessary self-study. Through production, we are able to reinforce our understanding of the principle and effects of basic electronic components and gain an essential knowledge about the use and principles of some classic integrated chips such as NE555 and CD4017. The prank box we make will be a low-cost prop and toy. Unlike ordinary prank boxes with only one element, ours will be a blend of auditory and visual experiences. As a toy, its primary intended users will be young people. It can be used to play a little joke on a friend during special holidays like April Fool's Day, parties, or everyday life. It can bring more surprise and joy to an otherwise dull life, as well as promoting friendship among friends.

6. Project Design and Production

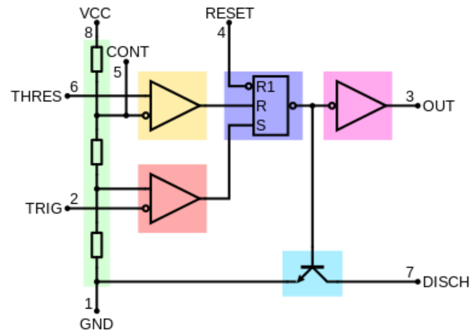
6.1. Research

6.1.1. NE555 Timer (Tom)

NE555 is a classic IC used in a variety of timer, pulse generation, and oscillator applications. The 555 can be used to provide time delays, as an oscillator, and as a flip-flop element. The specific model we are using for this project is the standard NE555, which has 8 pins. The name of each pin is as follows:

Pin#	1	2	3	4	5	6	7	8
Name	GND	TRIG	OUT	$\neg RST$	CTRL	THR	DIS	VCC

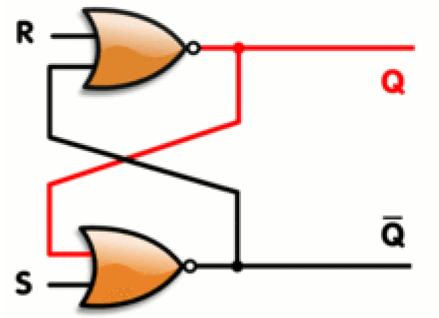
Here is the internal block diagram of a 555:



Typically, a 555 consists of three 5 kΩ resistors, two comparators, an SR flip-flop, a NOT gate, and a NPN transistor.

Before we understand how 555 works, we need to understand how SR flip-flop and comparators work.

Here is the internal diagram of a SR flip-flop:

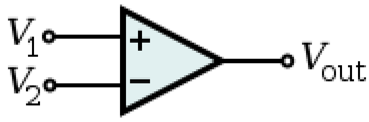


It consists of two NOR gates. When S=1 and R=0, the output of the lower NOR gate is 0, thus setting $\neg Q$ to 0. And the output of the upper NOR gate is 1, thus setting Q to 1. When S=0 and R=0, the two NOR gates and be seen as two NOT gates that are connected in a loop, therefore the equation $\neg Q = Q$ remains true. When S=0 and R=1, the output of the lower NOR gate is 1, thus setting $\neg Q$ to 1. And the output of the upper NOR gate is 0, thus setting Q to 0. We can use the following table to conclude the behavior of a SR flip-flop:

S	R	Q_{next}	Action
0	0	Q	Hold state
0	1	0	Reset
1	0	1	Set
1	1	X	Not allowed

Note: X means don't care, that is, either 0 or 1 is a valid value.

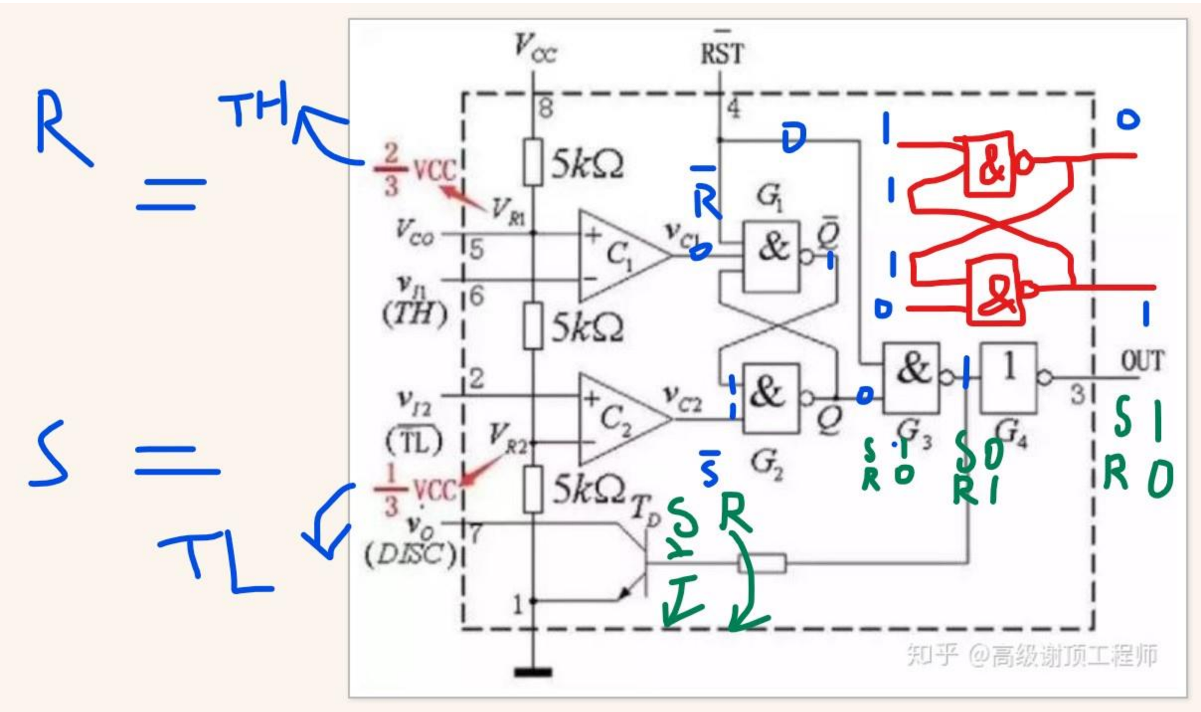
And here is the symbol of a comparator:



The V_{out} depends on the difference between V_1 and V_2. Its behavior can be described as:

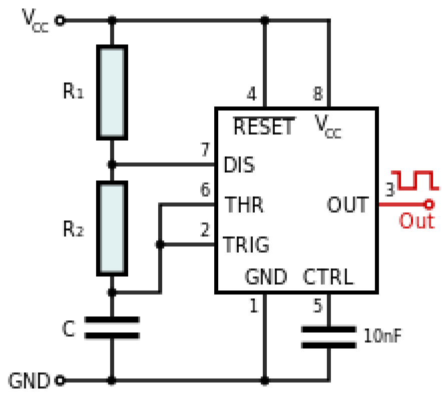
Condition	V_{out}
$V_1>V_2$	1
V1<V2	0

Now we have a basic knowledge about the SR flip-flop and comparator, and we can move on to understand how 555 works. Here is a draft that illustrates how we interpret the principle of 555:



To describe it, pin 6 and pin 7 respectively controls R and S of the SR flip-flop. When R gets higher than $\frac{2}{3}V_{CC}$ (or V_{CO}), R=1 and Q is reset. When S gets lower than $\frac{1}{3}V_{CC}$, S=1 and Q is set. Furthermore, when Q is 0, the output pin is 0 and the discharge pin (pin 7) is connected to the ground; when Q is 1, the output pin is 1 and the discharge pin is disconnected from the ground.

555 has three different working mode, namely astable mode, monostable mode, bistable mode, and Schmitt Trigger mode. Since in this project we only use astable mode, our research is mainly about astable mode. Here is a typical schematic of a 555 astable circuit:



In order to avoid high-frequency interference, pin 5 is connected to ground with a 10nF capacitor. In the beginning, the voltage on pin 2 and pin 6 is low, Q is set to 1, thus the output pin is 1 and the discharge pin is disconnected from the ground. The capacitor is then charged, with its voltage gradually increases. The voltage remains increasing until the voltage on pin 2 and pin 6 gets larger than $\frac{2}{3}V_{CC}$. Q is then reset to 0, thus the output pin is 0 and the discharge pin is connected to the ground, causing the capacitor to be discharged. When the voltage drops below $\frac{1}{3}V_{CC}$, another loop starts. And so on, we can get a square wave signal on the output pin.

Worth mentioning, the oscillating cycle and the duty cycle can be controlled by changing the value of the two resistors and the capacitor. The value of C determines how much electricity it could storage, thus determining the time interval of charging and discharging. R_1 controls the speed of charging by limiting the current. Similar is R_2, but it controls the speed of both charging and discharging. More specifically, the high time interval of each pulse is:

$$t_{high} = \ln(2) \times (R_1 + R_2) \times C$$

And the low time interval of each pulse is:

$$t_{low} = \ln(2) \times R_2 \times C$$

6.1.2. CD4017 Counter (Harry)

CD4017 is a decimal system IC counter which can give 10 outputs under certain circumstances.

A CD4017 IC has 16 pins, 10 of which are outputs, their orders are as follows:

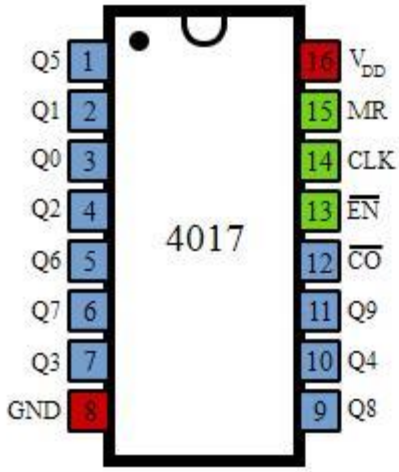
Output	0	1	2	3	4	5	6	7	8	9
Pin	3	2	4	7	10	1	5	6	9	11

Regarding Pin CP, EN, and RST, the counter output is as below:

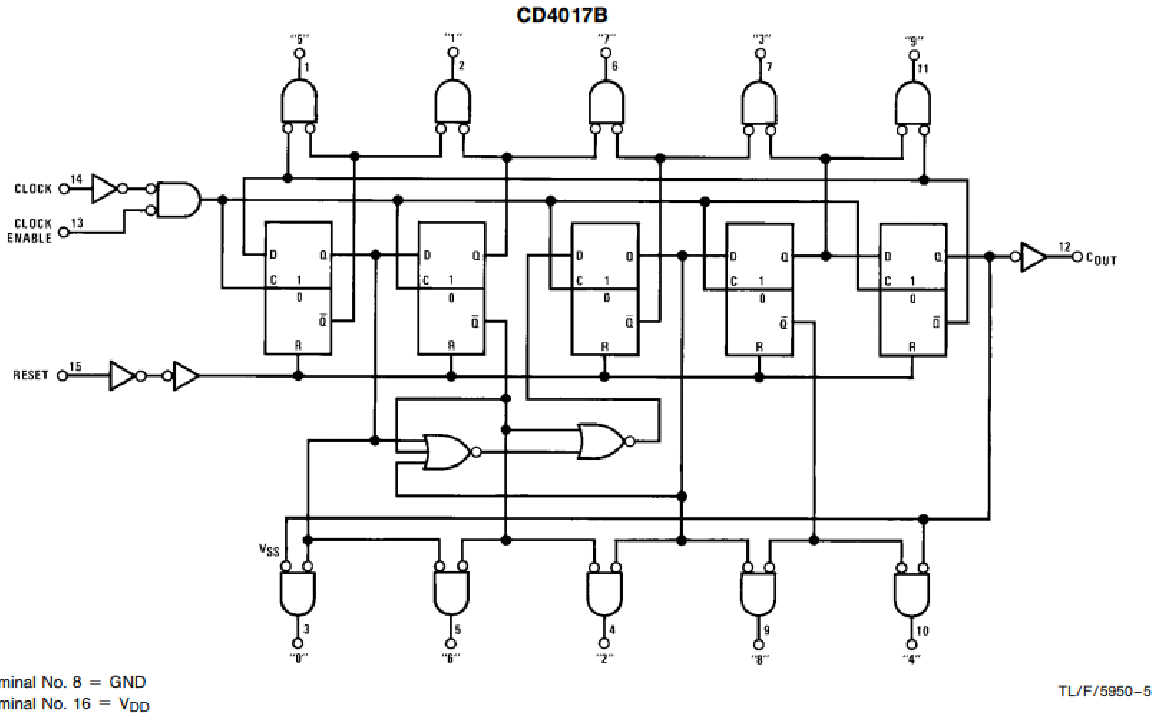
Input			Output	
CP	EN	CR	Q0~Q9	CO
×	×	1	Q0=1 (Reset)	When the counter output is between 0~4 (see above), the output of this pin is 0, when the counter output is between 5~9, the output of this pin is 1.
↑	0	0	Count	
1	↓	0		
×	1	0	Stay on, stop counting	
0	×	0	Stay on	
↓	×	0		

×	↑	0		

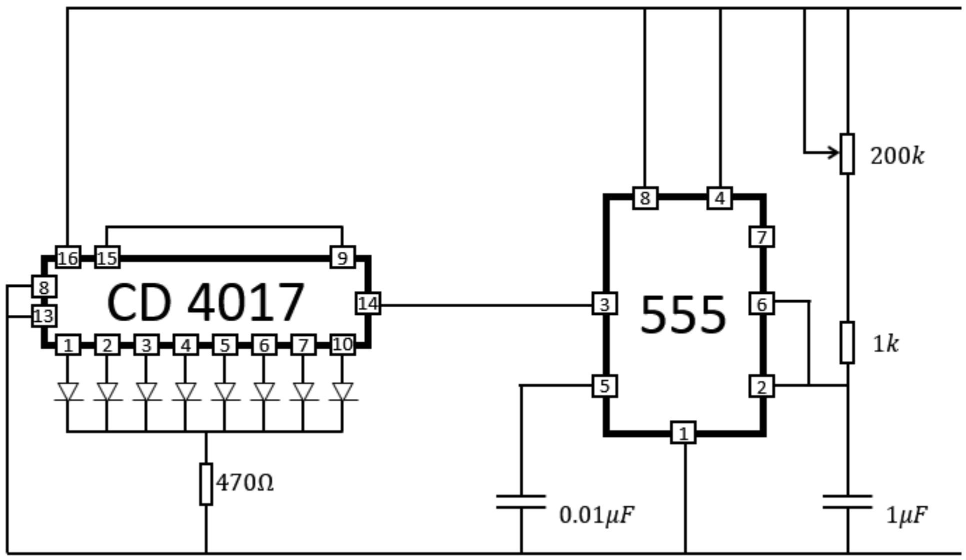
Note: "×" means an arbitrary value, "↑" means rising edge, "↓" means falling edge, "1" means high voltage, "0" means low voltage.



And below is the logic diagram of CD4017. It consists of a decimal counter circuit and a sequential decoding circuit. Every time when it receives a signal from the combination of clock and clock enable, the counter increase by 1, when it receive a signal form reset, the counter returns to 0.

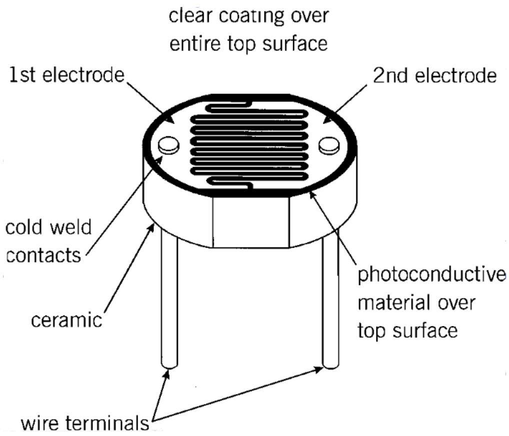


In our project, as shown in the picture below. For output, we connect 8 LEDs with pin 1, 2, 3, 4, 5, 6, 7, 10. Since the output has 10 pins while we do not want the 8 LEDs to be all off at some time, we connect pin 9 with pin 15 – when it comes to the 9th output, we deliver high voltage to the RST pin. In that case, the counter would return to its start. We also connect pin 13 (EN/INH) to the ground and pin 14 (CLK/CP) to pin 3 (OUT) of the NE555 timer. Thus, every time when OUT pin of NE555 timer delivers a rising edge signal to pin 14 of CD4017, the counter increases by 1 and the next LED light is turned on. After the 8th LED lights, the reset pin is activated, the counter returns 0 and the first LED light is turned on again.



6.1.3. Photoresistor (Barry)

A photoresistor is essentially a light dependent resistor (LDR), which means that the resistance is positively relevant to the light that is applied on the component. It is critical to our basic feature in our project. The feature of it enables it to control the duty ratio of the 555 time that is connected to it. To start explaining the mechanism, we shall take a look at the structure of it

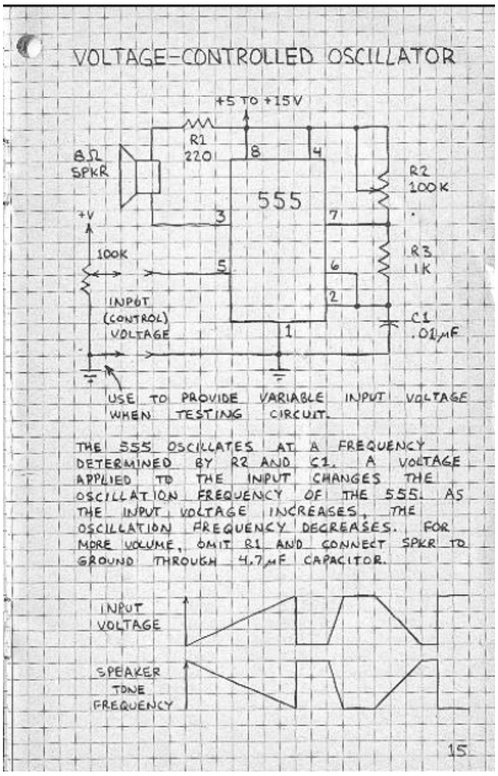


As we can observe from the figure above, the light goes through the clear coting and shine on the photoconductive material. As the frequency of the light reach a certain threshold, then the valence electrons on the photoconductive material start to gain enough energy from the photons of and break through the bonding with the parent atoms, jumping into the conductive band. In this process, free electrons and electron holes, which are conductive, are also generated. They move freely in the material and being able to carry a number of charges. As the intensity of light increases, the amount of charge carriers increases, thus causing the conductive rate of the resistor to increase and the resistance to reduce.

6.2. Design and Production

6.2.1. Breadboard (sound only version) (Tom)

As a first version, we made a prank box that screams when the lid is opened, and the frequency varies with the intensity of the light. We referred to the “voltage-controlled oscillator” from Mims’ *555 Circuits* as a starting point. Here is the diagram:

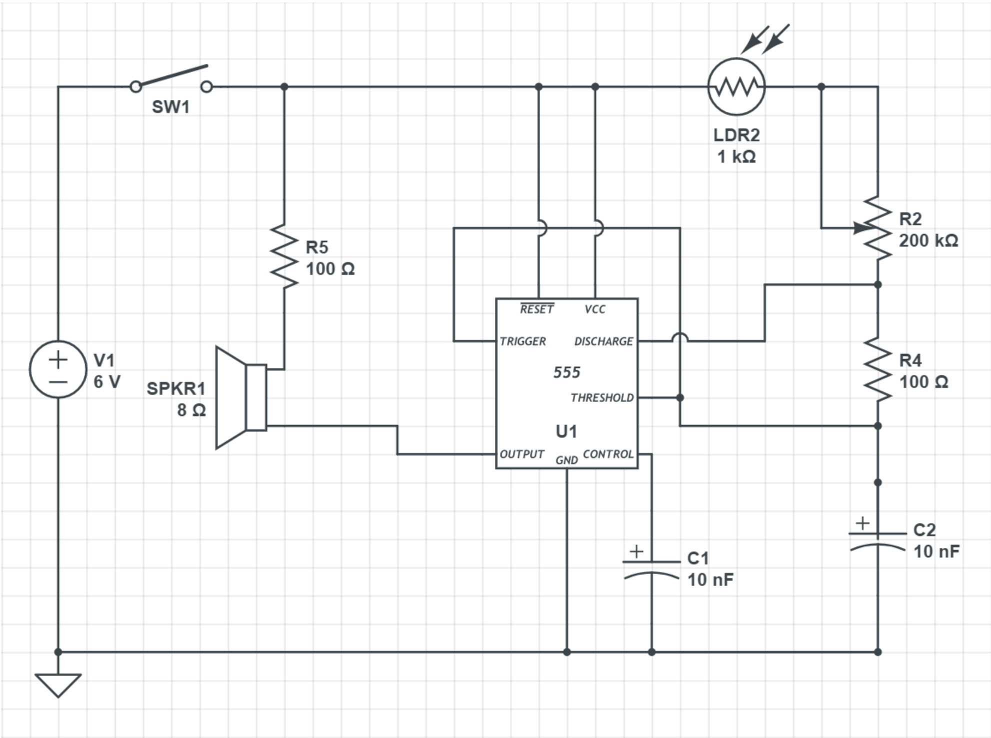


In order to implement our goals, we did a few modification and adaptation to the circuit.

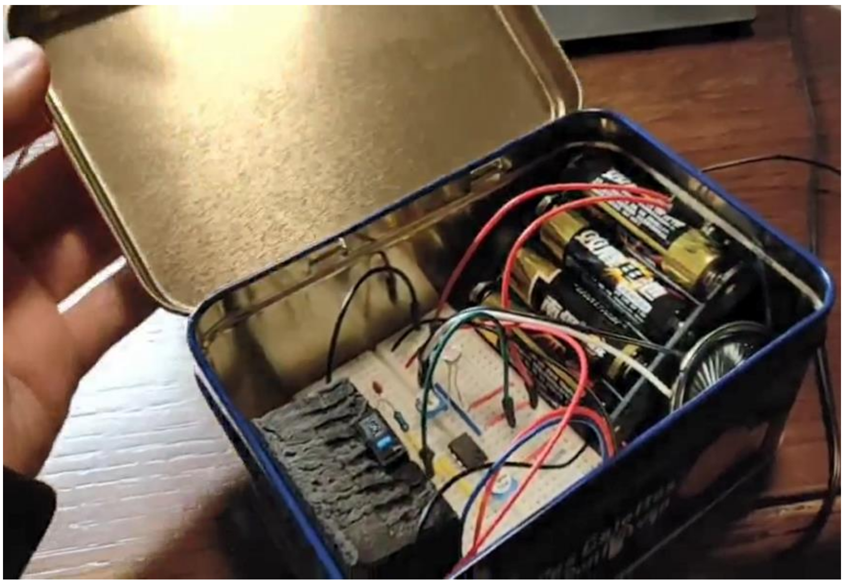
Firstly, for the sake of simplicity, we got rid of the potentiometers on pin 5 and used a 10nF capacitor to connect it to the ground instead.

The pitch of the sound is indeed determined by the oscillating frequency. In order to let the pitch changes according to the intensity of light, we add a photoresistor in series with R_2. Consequently, when the ambient light is strong, the photoresistor's value gets smaller, thus the oscillating frequency is higher; and vice versa.

However, when the lid is closed, the whole circuit is still oscillating. We did not want the battery to run out of power quickly, thus a switch seemed to be necessary. Then we came up with the idea of adding a microswitch. A microswitch has a very small travel distance and can be triggered with a very small action. We dissembled a few microswitches from some discarded mice. They all have three pins, and when they are released, the ground and a certain pin are connected; when they are pressed, the ground and another pin are connected. We connected them to the circuit in series with the battery pack. As a result, the whole circuit stops working when the lid is closed and the microswitch is pressed down. Here is the diagram of the adapted circuit:

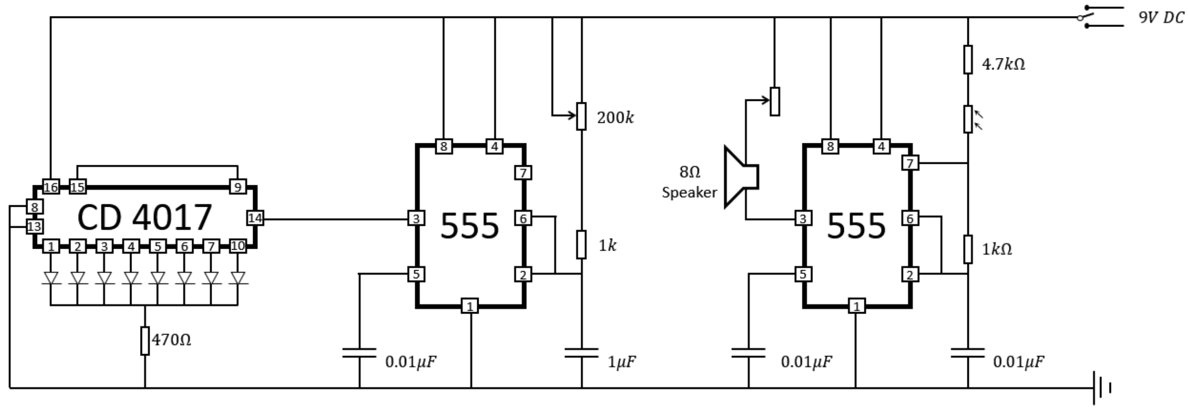


And we built this circuit with out breadboard kits and tested it. Here is what we got:

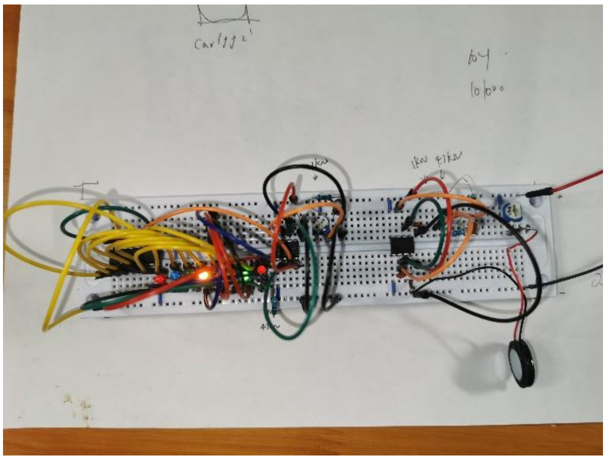


6.2.2. Breadboard (sound and light version) (Barry)

To better orient at our goal of integrating technology and art, we continue on developing further in the possible ways of improving the project. As stated in the project purpose and project descriptions section, we consider the prank box with only acoustic effect is way too boring. So, we improved it by adding more visual elements (LEDs) to it. To start off, a new diagram was designed first.



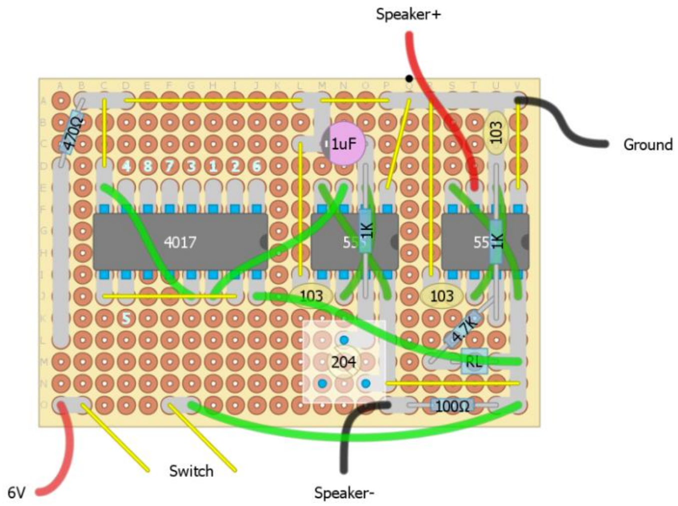
Another 555 + CD4017 is parallelly connected with the previous circuit. To make sure the



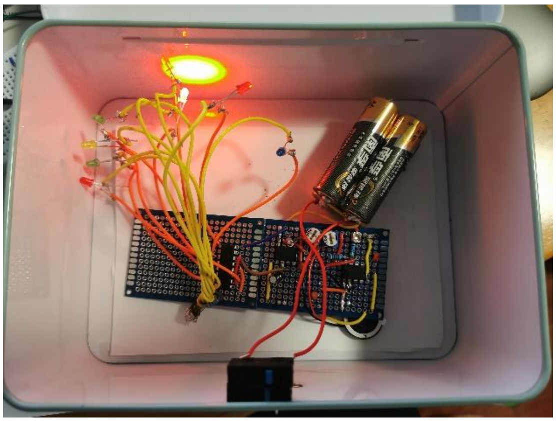
circuit works stable and works in the way we expect, we tuned the values of resistors and capacitors until it reaches a perfect point. During this process, we encountered a problem that in one circuit we built, the two 555s are interfering with each other, which is not supposed to happen. Having checked through every component and rebuilt the whole circuit, we found out that the issue is due to the control pin of one 555 is not properly grounded, probably because of the loose contact on the breadboard. With this issue solved, we made more tests to make sure there are no exception conditions. Next, we moved to soldering and setting the circuit into an actual prank box.

6.2.3. Soldering on Perfboard (Harry)

To make our project smaller and more durable, we decided to solder the circuit. Firstly, we brought electric soldering iron, soldering tin and relevant materials. Then, we used the DIY Layout Creator to design the following perfboard.



After that, we started the soldering work. While working on the project, we found it really hard to precisely connect the pins. Oftentimes, some of the connections are not tight thus causing the breakpoints, or some of the connections are mistakenly connected, making the circuit a short cut. It takes a long time to solder and check out the mistakes. And while we are soldering, we found one perfboard is too small for the design, so we make a little change and used 2 perfboards and connect them together. Here is the final work.



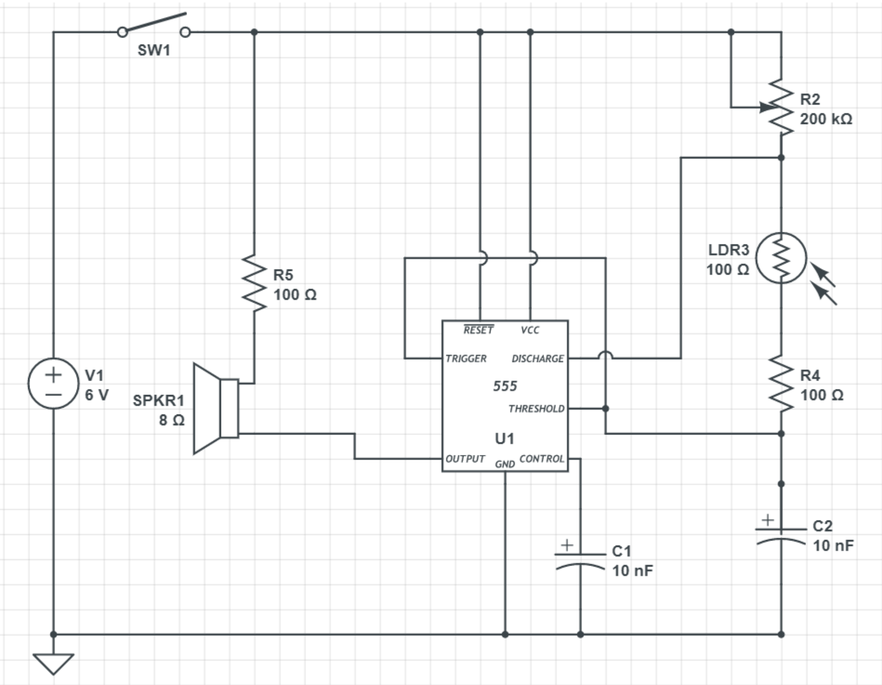
6.3. Reflection

Overall, we consider we did a great job. We utilized the course content and discovered more knowledge to finally come up with this project. The circuit is perfectly working, and we have added our own artistic considerations to it, to make it a more surprising box. All of these steps we made have definitely pushed the project forward to the purpose we aim to realize. However, this is definitely not a perfect project, there are more improvements we could make in the future development process. Some are listed below here.

6.3.1. Better-tuned R&C values and larger dynamic range of frequency (Tom)

Through the process of making this project, we found that different values of resistors and capacitors produce different frequencies of sound, with certain combination of values producing particularly loud sound and others causing the 555 to stop oscillating. In order to make the circuit more stable and reliable, we did not use the potentiometers in the final version, instead, we replaced them with constant resistors whose values are close to the optimal values that out previous tests on the breadboard have yielded. However, unfortunately, the values of the constant resistor are discrete and sometimes we had to use an approximate one. It introduces some error. And, it wasn't until the end that we realized that the same oscillating signal seemed to behave differently on different speakers. Therefore, rather than swapping 103 capacitors for 104 ones on the perfboard to tune the frequency, we would say better tuning can be done if time allowed.

Moreover, the dynamic range of the frequency can be larger. In our design, the photoresistor only controls the speed of charging of the capacitor. We later realized that if the photoresistor can controls both the speed of charging and discharging, the dynamic range of the frequency can be enlarged. Here is the diagram of the improved circuit, where the position of the photoresistor is changed:



6.3.2. More diverse and complex sound (Barry)

To make this whole project more surprising, we consider a various range of sounds, for example, the real screaming sound. Moreover, we can load the prank box with different sound presets and even allow the user to record the sounds as they wish. This will largely increase the playability and create a better user experience. To make this improvement, the key point is the storage to contain these sounds. The easiest way is to use a Arduino board, which provides a both support of direct output control through the PWM control pins and easy access to external storage such as SD cards.

6.3.3. A louder speaker (Harry)

We originally thought that as long as we adjust the resistor connected to the speaker, we would get a sound with enough volume. However, the specification of our speaker is 8Ω 1W, meaning that the maximum voltage given should be $\sqrt{8} \approx 2.83$V. During the experiment, when we tried to add more voltage, the speaker broken. As a result, for improvement, we could change our current speaker into a 8Ω 5W one.

6.3.4. More visual elements and physical motion (Harry)

With respect to the visual improvements, we think that one idea could be making the lights in a shape. But single LED lights may not work this time. So we may use the LED light set.

Also, for physical motion, we think it would be interesting if something such as a piece of paper would come out seconds after the box is open. We think doing some research on how the electromagnetic railgun works would help.

Works Cited

"555 Timer IC." *Wikipedia*, Wikimedia Foundation, 29 Mar. 2020, en.wikipedia.org/wiki/555_timer_IC.

"Comparator." *Wikipedia*, Wikimedia Foundation, 20 Feb. 2020, en.wikipedia.org/wiki/Comparator.

CD4017BM/CD4017BC Decade Counter/Divider with 10 Decoded Outputs CD4022BM/CD4022BC Divide-by-8 Counter/Divider with 8 Decoded Outputs, National Semiconductor Corporation, 1995.

"Flip-Flop (Electronics)." *Wikipedia*, Wikimedia Foundation, 12 Apr. 2020, en.wikipedia.org/wiki/Flip-flop_(electronics).

Hamblen, Jim, *Using a Photocell or Phototransistor to determine lighting levels,* MBED, 19 Apr. 2020, https://os.mbed.com/users/4180_1/notebook/using-a-photocell-to-determine-light-levels/

Mims, Forrest M. *555 Circuits*. Radio Shack, 1992.