FINAL PROJECT REPORT

PHYS 319 – ELECTRONICS LABORATORY

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The project is titled '**AudioMotion Illuminate'** as it is a two-part project which activates LEDs based on both sound and motion.

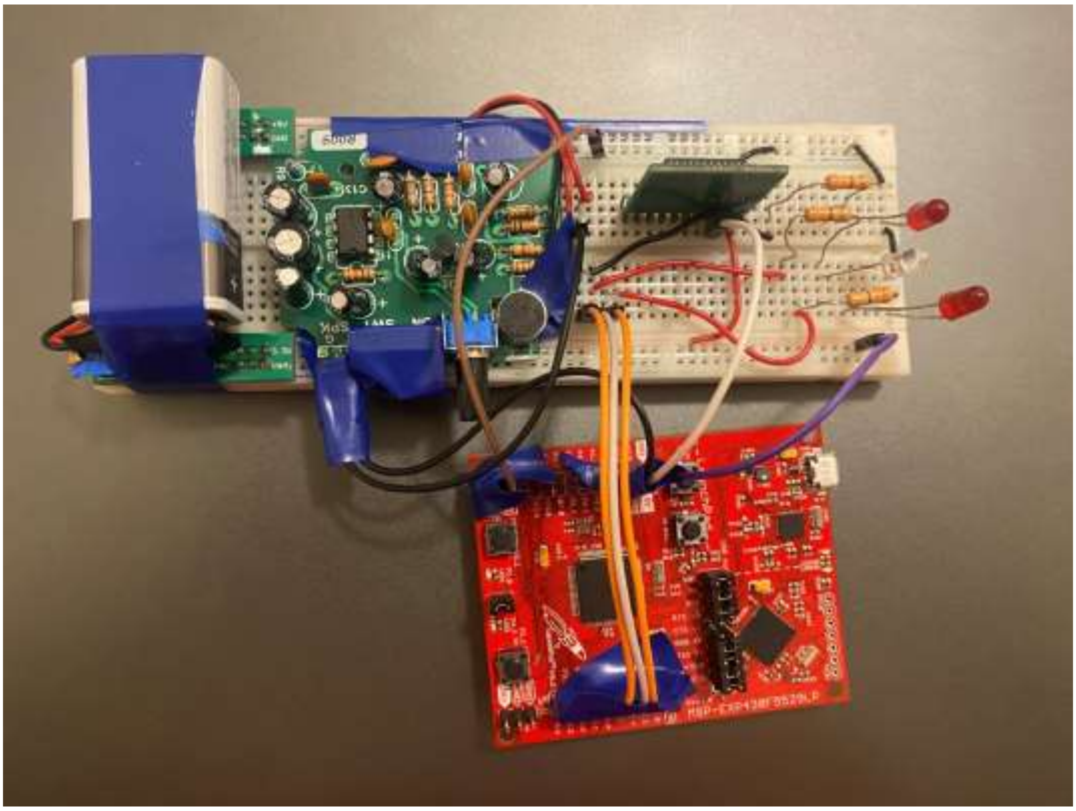

Figure 1: AudioMotion Illuminate: The Full Project

ABSTRACT

The project is a two-part project both of which use the 12-bit Analog-to-Digital conversion of the MSP430 microprocessor to control 3 separate LED lights: 2 red and 1 white. The first part is a clap controlled light switch which has 5 distinct settings (or modes) which can be cycled through by clapping your hands or snapping your fingers. These modes are: Each light on separately for 3 different LEDs, all three lights on together, and a Christmas light effect using all 3 LEDs.

The second part is an acceleration-activated LED indicator which activates a certain configuration of the 3 LEDs based on the measured results. The project measures the acceleration for a 5 second period and obtains the maximum acceleration observed in that

period. If no acceleration is detected, all 3 LEDs start blinking. If an acceleration is detected which does not meet our required threshold, the 2 red LEDs turn on. Finally, if the maximum acceleration crosses our required threshold, the white LED turns on.

Both projects shared the caveat that they worked extremely well while testing in a controlled environment indicating that the fundamental functionality of each was implemented correctly. However, inconsistencies were observed when we went out of the controlled environment and during demonstrations. Future steps to tackle these inconsistencies and steps for further improvements have also been discussed below.

INTRODUCTION

The two different functionalities of this project have different motivations and purposes for each, even though both eventually control the LEDs. Given the structure of the project, these can be used separately for the purposes mentioned below but also for many different ideas and projects further building on the current project.

For the clap controlled light switch, the purpose was to eventually set up LED lighting in my dormitory which can be controlled by clapping. The current project controls simple LEDs but can be built upon to control and LED light strip which can be put up as a lighting system in any room. The primary motivation here was to create an aesthetic lighting system which is controlled by clapping. Currently, most of the clap controlled light switches consist of single bulbs and also only focus on turning the lights on and off. The motivation in my project was to control multiple LEDs (or circuits) and also create design patterns using the LEDs.

For the acceleration-activated LEDs, the purpose is to measure the maximum acceleration detected in a short time period and turn a white LED on if a certain threshold is met. The motivation comes from sports and athletics, but again, the same fundamental design can be easily used to measure the maximum acceleration for different purposes.

The maximum acceleration that athletes can achieve in a short burst of time has a significant impact on their performance, specially in sports like basketball, football etc. This maximum acceleration has also been correlated with other important fitness parameters like endurance and the average velocity and acceleration that athletes present over longer durations. Hence, testing whether athletes reach a minimum acceleration threshold can be useful in many cases.

THEORY

For the first part, I have used an electret microphone amplifier which not only amplifies the input voltage but also eliminates noise and disruptions in the output signal. An electret microphone is a type of electrostatic capacitor-based microphone which eliminates the need for a polarizing power supply. Even though audio signals are detected by just the electret microphone, the output signal is too weak to use without an amplifier. The image shown here is the simplest circuit for an electret microphone. The resistor shown sets the gain and the capacitor blocks DC signals at the output.

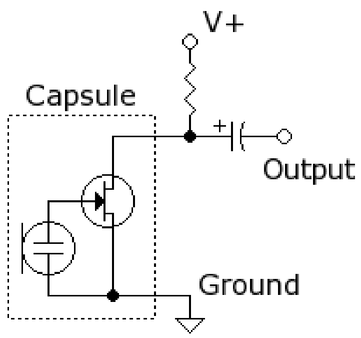

Figure 2: Electret Microphone Circuit

The amplifier uses multiple transistors, resistors, diodes and capacitors to obtain the maximum amplification of the output signal from the electret microphone. The transistors (usually an NPN transistor) amplify the signals, the capacitors block DC signals, and the resistors and diodes are used for biasing the circuit and preventing reverse voltage in the circuit respectively.

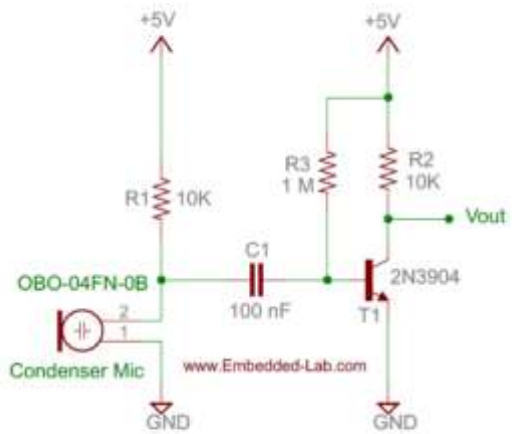

Figure 3: Electret Microphone with Transistor Amplifier

In the figure above, a simple transistor amplifier for an electret microphone can be seen. The output from the microphone through a DC blocking capacitor goes into the base of the transistor. Then, by connecting the collector to a power source, the output signal can be observed at the collector which is an amplified version of the microphone output. An extended version of this with more amplification and better DC blocking is seen in the integrated circuit amplifier I have used.

Therefore, to detect a clap, the output voltage from the amplifier will be continuously observed and if it meets certain conditions (threshold, peak time etc.), the LEDs will be triggered.

For the second part of the project, I used an accelerometer to measure the maximum acceleration. There are a few different types of accelerometers, but the one used in the project is a MEMS (Microelectromechanical Systems) inertial sensor which uses differences in capacitance to measure acceleration. It is manufactured using a proprietary process to create a surface micromachined accelerometer. The figure below shows the structure of the sensing element of such a device. It consists of a movable plate with fingers (white) and two sets of fixed fingers (black and grey) for each finger on each side. All components are made of doped polysilicon on the surface of a silicon wafer using surface micromachining technology. The movable plate is mechanically anchored onto the surface of the silicon wafer through a pair of polysilicon flexures. These flexures allow the plate to move along its central line while maintaining mechanical stability. Both the fingers and the plate are electrically isolated from the device

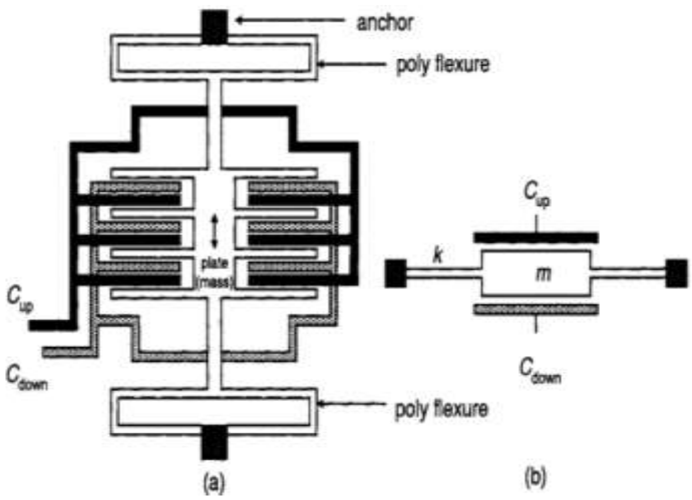

Figure 4: MEMS Capacitor Accelerometer

(substrate), but all fingers are connected into two groups: one on each side of the movable fingers. Figure 4(a) shows the full structure and 4(b) shows a simplified version.

The movable plates form two capacitors, C_{up} and C_{down} with two groups of fixed electrodes. When the device moves with acceleration along the central line of the movable plate, the plate moves due to inertial force. This changes the capacitances of the two capacitors and the acceleration is measured using the difference in capacitance.

Both the amplifier circuit and the accelerometer output voltage signals which need to be converted to bits to be useful in programming the microprocessor. This is done using the inbuilt ADC conversion of the MSP430. Since we are using the 12-bit conversion, the output can be calculated as

$$\text{Number of Bits} = 4095 * \frac{V_{in}}{3.3\text{V}}$$

Where V_{in} is the voltage from the sensors.

APPARATUS

The main component of the first part of the project uses an older version of the UK009 electret microphone amplifier, which is designed around the LM386 amplifier integrated circuit. The schematic diagram of the LM386 is shown to the right.

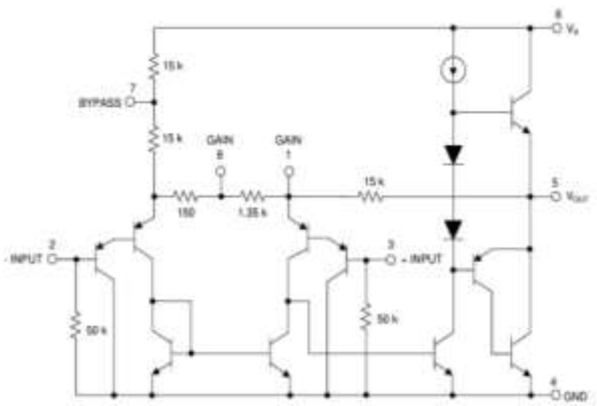

Figure 5: LM386 Schematic

The LM386 simply receives an input voltage which is amplified internally by multiple transistors and diodes configured as amplifiers. As seen in the schematic, the gain is variable can be controlled by Pin 1 (also present externally on the UK009). The device also includes a feedback loop which compares the output signal to a portion of the input and adjusts the amplification accordingly to maintain stability.

The UK009 passes the input signal through a separate set of capacitors, transistors and current limiting resistors before passing it to the LM386 to provide an additional layer of filtering and amplification and also to provide a stable power supply voltage. An image of the complete schematic for the UK009 has been attached in the appendix. Both the LM386 and UK009 have their own bypassing capacitors which prevent noise.

The UK009 is connected to a 9 V battery for the power supply and the V_{CC} pin is connected to pin 6.1 on the MSP430 for the analog input which is subsequently converted to digital by the 12-bit ADC. The ground is of course connected to the ground of the circuit.

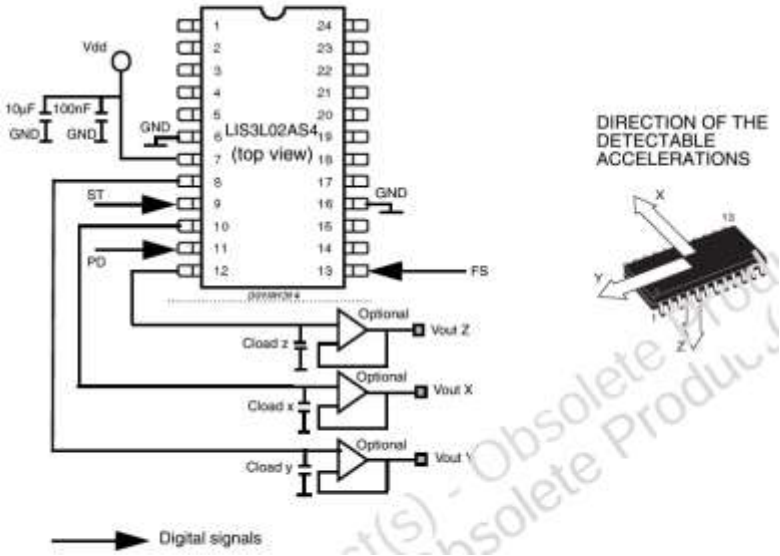

Figure 6: LIS3L02AS4 Electrical Connections

For the second part of the project, an LIS3L02AS4 3-axis accelerometer on a mounting board was used to measure acceleration. In this particular case, the y axis acceleration is enough to measure the horizontal acceleration, so the only output received from the accelerometer was from V_{OUT} Y which is connected to pin 6.0 on the MSP430 for the analog to digital conversion. Connections of the device and directions of axes are shown in image above.

The accelerometer has a sensitivity which is the gain in voltage if 1 g acceleration is applied. For this device, the sensitivity is about 0.66 V. The zero-g level describes the output signal if no acceleration is present. Ideally, this is supposed to be 1650 mV for a 3.3 V power source, but due to mounting the circuit on a PCB, extra stress sometimes reduces the zero-g level and the deviation is called the zero-g offset. The offset in our case was 150 mV and the new zero-g level was 1500 mV. Further, if the accelerometer is placed flat on the surface with z axis upwards, the X and Y outputs would be equal to the zero-g level but the Z output will have a +1g output (1.5+0.66 = 2.26 V). This is because it experiences the acceleration due to gravity (-9.8 m/s^2) in the negative z-direction.

Both sensors are connected to the microprocessor which reads the voltages from pins 6.0 and 6.1 and uses the ADC conversion to use them in the program. On the microprocessor, we have also connected the 3.3 V pin to the 3.3 V on the protoboard so that the microprocessor does not need a separate power source. Pins 1.2, 1.4 and 1.5 of the MSP430 are connected to the LEDs through current limiting resistors and are configured as output pins to control the LEDs.

How the project is used?

The two parts of the project are activated by two different interrupt service routines (ISRs) which are also part of the MSP430. The button at 2.1 is configured to have an ISR which activates the clap controlled light switch. The button at 1.1 on the other hand is configured to have an ISR to activate the acceleration-activated LEDs.

Upon loading the program, the MSP430 starts in an idle mode where no program is activated which is indicated by the red LED at 1.0 on the microprocessor. If button 2.1 is pushed, the 1.0 LED turns off and the clap controlled light switch is activated. If a clapping sound is detected, the first of three LEDs (red) turns on. Another clap turns the first one off and the second (white) on. A third clap turns the white LED off and the other red LED on. If a fourth clap is detected, all three LEDs turn on together. Finally, a fifth clap activates a flickering LED effect which resembles Christmas lights flickering. To stop the program after this, another clap is needed, which return the microprocessor to the idle state. It can also be returned to the idle state in the middle of the program simply by pressing the reset button the microprocessor.

If button 1.1 is pressed when the program is in idle mode, the acceleration-activated LED program is activated. Again, the red LED (1.0) turns off. After 2 seconds, the green LED at 4.7 on the microprocessor turns on automatically which means acceleration measurements have started. This buffer time is to ensure there is enough time to stabilize before starting measurements. The acceleration is detected for 5 seconds and the maximum acceleration is stored. Based on the result, the LEDs turn on in the following manner – if no acceleration detected, all three LEDs flicker; if a small maximum acceleration is detected but it does not meet the threshold, the two red LEDs turn on; if the threshold is met, the white LED turns on.

RESULTS

Clap Controlled Light Switch

The performance of the device slightly varied in a controlled environment (quiet, no disturbance or noise) compared to an environment where there was external noise. In the controlled environment, the device worked almost perfectly and turned the LEDs on and off as expected. Some inconsistencies however were observed in the lab environment where there was more noise. Due to the compact nature of the project, it was difficult to capture an exact waveform of the results, but a representative example of what a clap looked like during testing can be seen to the right.

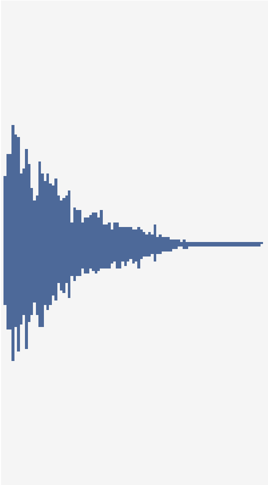

Figure 7: Example Waveform

As seen above, loud enough claps had a specific waveform which first peaked at the maximum and minimum output and input (3.3 V or 4095 bits, 0 V or 0 bits) and an exponentially decreasing oscillating waveform following the peak. Other noise and even regular sounds around the microphone did not usually go above 2.5 V. To make the clap detection as robust as possible, I incorporated checks in the code to ensure that LEDs were triggered only when the peak went above 3 V or below 0.3 V and maintained a waveform similar to the one above. Even with the checks however some false positives and false negatives were observed, more so in a noisy environment.

Acceleration-Activated LEDs

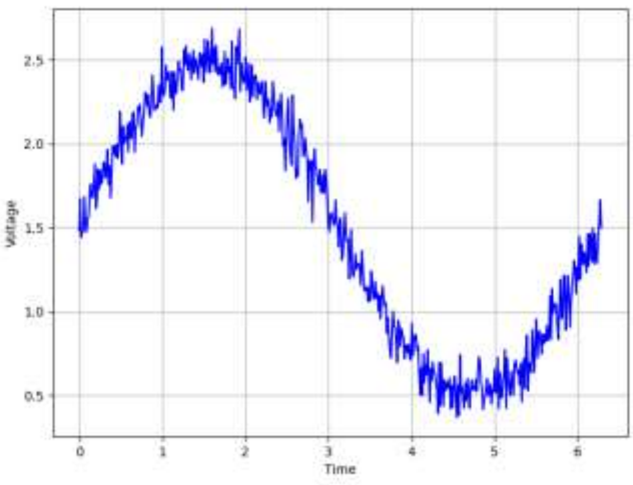

Figure 8: Example Waveform

The second part of the project, the acceleration activated LEDs worked well for short distances and for testing where the protoboard was being accelerated by hand in the y direction of the accelerometer. However, it proved to be very inconsistent when actually using it while running. It did work as expected in some cases, but it also showed inconsistent results in other.

Just like for the first part, it was difficult to save the resultant waveform. A representative waveform of the output signal when acceleration is observed in the positive y-direction is shown above. At rest, the voltage is stable at 1.5 V (Zero-g value), but when the protoboard is accelerated and stopped, the acceleration and deceleration (acceleration in negative y) are observed as positive and negative deviations as seen above. In the example above, similar to testing, the voltage reached is about 2.5 V (1 V increase) which is equivalent to about 1.5g of acceleration.

For the actual demonstration with running, the threshold was set to be about 0.24 V (300 bits) which corresponds to an acceleration of about 0.36g or 3.5 m/s^2. As said before, the results for this proved to be inconsistent.

DISCUSSION

HIGHLIGHTS OF SUCCESS – WHAT WENT WELL?

For the clap controlled light switch, using the integrated circuit (IC) amplifier for the electret microphone greatly enhanced the quality of results observed. The original plan was to use a regular transistor amplifier designed on the protoboard itself to keep the project as compact as possible. It was important to keep the project compact largely due to the acceleration-activated LED illuminator which required physical movement of the entire setup to detect acceleration. The structure of the amplifier is such that initially it seemed impractical to use while keeping the project compact because of the requirement of a separate 9 V DC power source and the location of the V_{CC} and ground pins on the amplifier.

However, the transistor amplifier circuit proved to be extremely inefficient due to the fact that large amounts of noise detected in the output signal kept triggering the LEDs even in case of no clapping. This was observed in a relatively quiet environment and it was assumed that the noise issue would be much worse in a classroom / lab environment. If the threshold for activation was set to be so high that it could never be affected by noise, it stopped detecting even clap sounds and hence the LEDs did not trigger at all. Hence, the integrated circuit amplifier proved to be a much better choice in the end since it suppressed most of the noise and correctly detected around 90% of the clap sounds. The issue of compactness was partially solved by securing the amplifier and 9 V battery to the protoboard and the wiring between the microprocessor, the amplifier and the protoboard using electrical tape.

For the acceleration-activated LED, the project worked very well for short distances and smooth movements of the whole structure. During testing, to the extent of the limits of our equipment, the waveforms observed were according to what theory dictated and those observations ensured that the basic structure and functionality of the device was working as expected. It also allowed us to get a better indication of how the output voltage changed due to different changes in acceleration getting a better idea of setting our thresholds.

Again, just like for the light switch, making the project compact and secure by using electrical tape greatly improved both the structure of the entire project and also the ability to test both projects simultaneously without worrying about loose wire connections or hanging parts. It also allowed testing and demonstrating the acceleration-activated LED by physically running to induce acceleration which would not have been possible without a secure setup.

LIMITATIONS AND POTENTIAL REMEDIES

Even after using the IC amplifier for the clap controlled light switch, one of the biggest limitations was that the device was missing about 10% of the claps and was also detecting some false positives if there was a sudden loud noise detected (for example from talking too loud, construction etc.). As depicted in the example waveform of a clap above, I observed that clap sounds had a very specific waveform with a small sustained peak (about 50 microseconds) and tried to modify the code to only trigger the LEDs if a peak is maintained for that amount and also to ignore peaks which occur very close together to prevent rapid triggering. While this did result in a slight improvement in the number of false positives detected, it still wasn’t perfect and had little to no effect on the claps it was missing. Further modifications to this part of the project will definitely include enhancing the code to make the clap detection mechanism more robust and reliable.

For the acceleration-activated LED, there were a couple of limitations. First, with the equipment available, testing was a difficult process especially due to size of the oscilloscope. The resulting waveforms could only be observed for small distances and smooth movements, for which the device performed well. However, for the main purpose of the project which involved running, it was not possible to observe the resulting waveform.

As a direct consequence of the above, it was difficult to troubleshoot problems in the program that were observed when the final functionality was tested. Even with carefully selected threshold values, the device was inconsistent in the results shown when I tested it by running. The base case of no acceleration detected almost always showed blinking LEDs as expected. However, for minimal accelerations below the threshold and large accelerations above the threshold, the device only showed corrected results about 50% of the time. Possible ways to overcome these limitations are to use a compact version of an oscilloscope which can store waveforms and also to use multiple accelerometers instead of 1 to get an average value of the result to ensure a balanced measuring process.

CONCLUSION

Overall, despite the limitations observed, the fundamental functionalities of the project worked just as expected, especially in controlled environments. The project was definitely worth constructing and allowed me to utilise a lot of the knowledge I acquired throughout the course. Specifically, I learned a lot about reading datasheets of electromechanical devices such as amplifiers and accelerometers and combining that information with the 12-bit ADC conversion of the microprocessor to achieve my desired functionality.

More generally, I also gained a lot of insights into troubleshooting electronic devices and debugging code. Since this was a two-part project, one of the decisions I had to make was how to incorporate both parts into a single microprocessor program while retaining the original functionality of each separately. This was one of the decisions that not only challenged me creatively, but also challenged my technical skills to implement the hardware and software to make both projects work together.

Looking forward, there are a few enhancements that could be made to the project both in terms of tackling limitations and increasing usability. The ideas to tackle different limitations have already been discussed above in the discussion section above and will improve the functionality in more general environments. Further, improvements related to usability are listed below:

1. The IC amplifier could be replaced with a different, more compact amplifier which can be powered with the other components while maintaining the same level of accuracy as the IC amplifier. This would make the project more compact as intended originally and make it easier to test and use the acceleration-activated LEDs.
2. The wiring and electrical components could be stored inside a 3-D printed structure with only the LEDs exposed externally, making the project easier to use and store.
3. The 3 LED lights can be replaced with an RGB LED light strip to make the clap controlled light switch usable for practical purposes and to also allow the acceleration-activated controller to control the light strip which can be integrated with athletes' fabrics to make it more accessible and aesthetic.

REFERENCES

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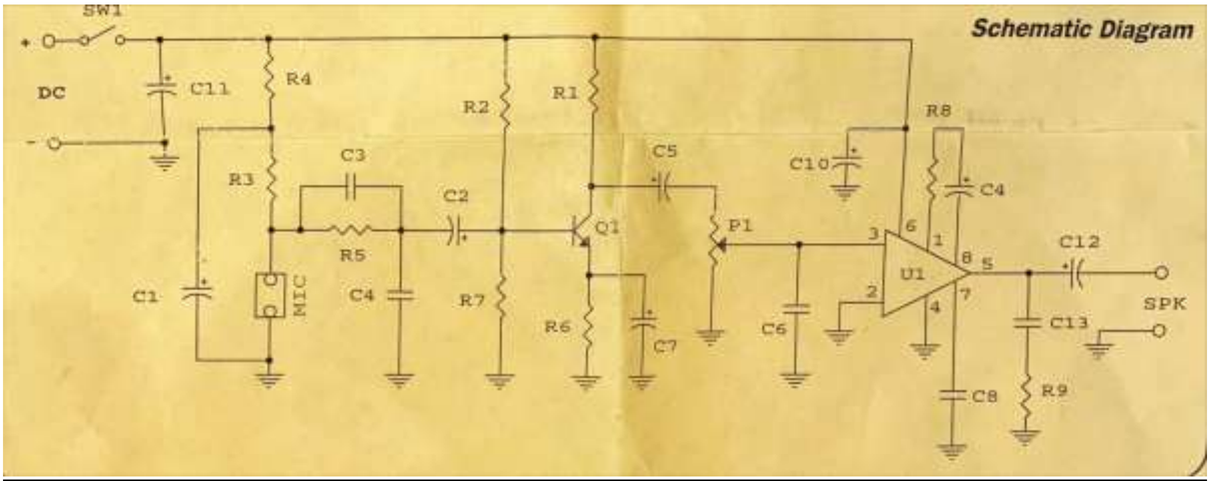
3. STMicroelectronics, "LIS3L02AS4 MEMS INERTIAL SENSOR: 3-Axis - ±2g/±6g LINEAR ACCELEROMETER," LIS3L02AS4 datasheet.
4. R-B (2012, Nov. 25). Making a Simple Clap Switch, *Embedded Lab*. https://embedded-lab.com/blog/making-a-simple-clap-switch/

APPENDIX

1. Full Schematic of Amplifier circuit



2. Source code for the program

https://github.com/tanaym12/audio_illuminate/tree/master