ECE3161 Analogue Electronics Project

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Introduction

In smart home designs, there are many applications that support hand-free control modules. Using sound signals in order to control electronic devices are an example of hands-free control devices. In this project, a clapping switch module is designed.

Application

The switch uses clapping sound as an input signal and outputs to an LED using a DC voltage signal that lasts for a particular duration that is set by the user using a potentiometer. The clapping sound can also be replaced by any other sounds that have the same amplitude or higher. The volume of the sound that the circuit takes as input and the time the circuit is switched on due to that sound can be adjusted by the user to an extent by using potentiometers. References contain inspiration of the circuit concept.

High level block diagram

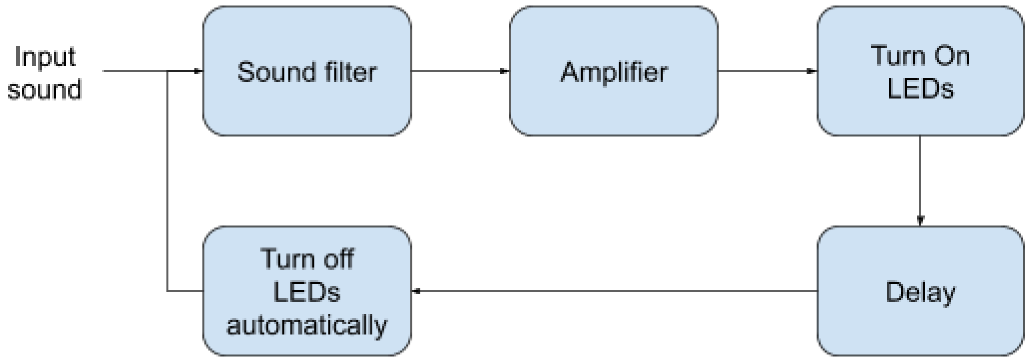


Figure: Block diagram.

The blocks will be sectionalised as follows in this report:

1. Sound filter
2. Amplifier
3. Turn On LEDs, Delay, and Turn off LEDs automatically

This represents the practical function blocks, which will be translated into analogue circuitry. The categorisation of these blocks are based on the analogue circuitry interpretation of the functions of each block. Appendix 1-4 shows the output of each relevant sectionalised block diagram.

Circuit Design:

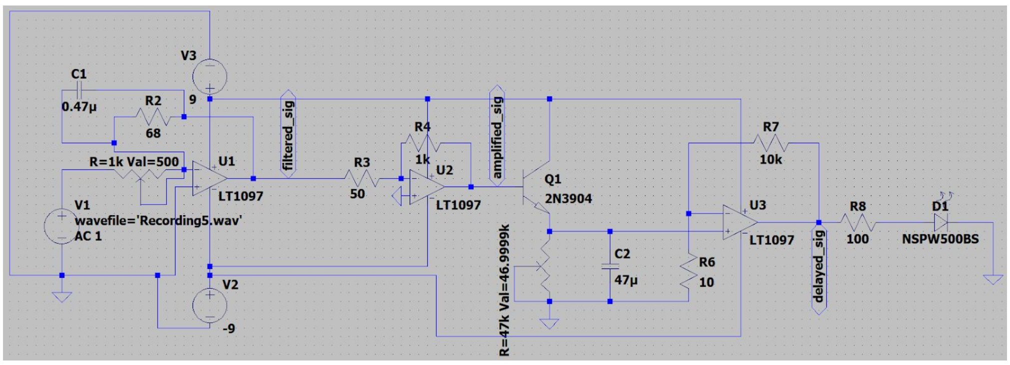


Figure: Complete circuit diagram.

This is the complete circuit design of the clapping switch.The overall power consumption of the circuit is 72mW for the clapping input audio that was used to test this circuit, this value can be used as an estimate and will be different for different inputs. The power measurement throughout this project is measured in the maximum performance (longest delay time). The individual block diagram explanations below will explain the workings of the circuit in detail.

Design considerations

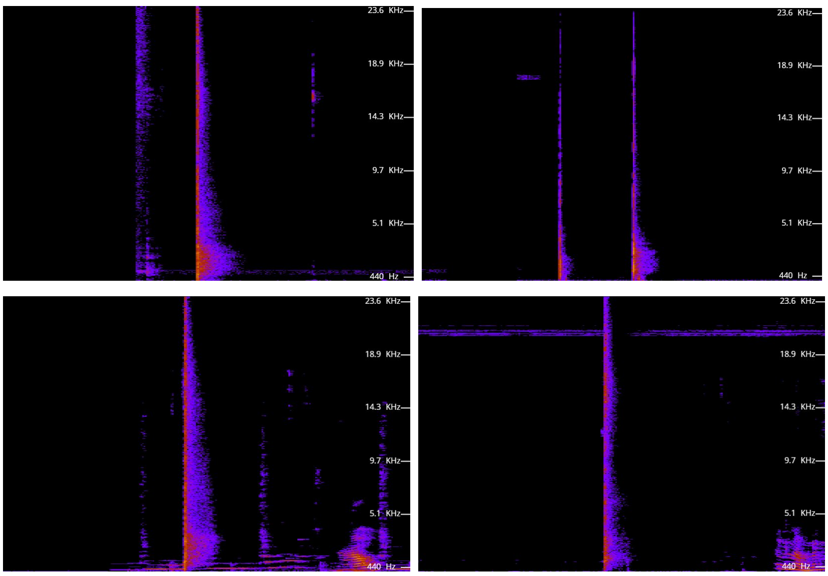
- Clap frequency range: High amplitude signals located at 0Hz-5kHz. Therefore a low pass filter is required to retain most of the clap signal. Frequencies were measured with an online spectrum analyser, and can be found in the references.
- Voltage value from the initial input needs to be amplified so it can turn on a switch.
- A switch is needed to turn on for a few seconds. A transistor is used to forward the signal, a resistor-capacitor circuit is used for the delay, and the amplifier allows the delayed voltage waveform to be clipped at a sufficient voltage to power the LED that is safely under the breakdown voltage of the LED.
- Resistors can be used in this design, as considering practical implications, this does not have to be small enough to fit in an integrated circuit.
- Common resistor values are used within this circuit.
- Potentiometers are used to control the signal attenuation into the low pass filter and output duration of the LED.

Block 1: Sound Filter

Components and Values:
Amplifier: LT1097
Resistors: 68Ω
Potentiometer: 500Ω
Capacitor: 0.1uF

Simulation results and analysis:

1. **Choosing Cut-off frequency:**



Figures: Frequency plots of different samples of sound recordings.

As can be seen at the plots, the main frequency of the sound recordings is smaller than 5kHz. Therefore, the cut-off frequency of the signal should be 5kHz in order to get rid of the noise whilst retaining the majority of the clap signal. Frequencies were measured with an online spectrum analyser, and can be found in the references.

2. **Low-pass filter circuit:**

The circuit for low-pass filter in this project is first-order low-pass filter with one pole at s = $\frac{-1}{RxC}$. The purpose is to get rid of noises and only keep the main smooth sounds.

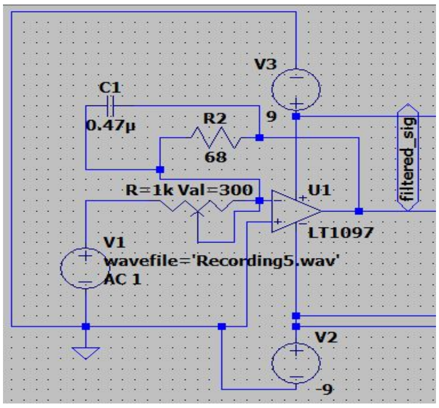


Figure: Low-pass filter block circuit.

The cut-off frequency is determined by R_2 and C_1. The capacitance is 0.1uF and resistance R2 is 30Ω. In order to set cut-off frequency at 5kHz, the resistor value is R_2=68Ω (f= $\frac{1}{2\pi*(R2)*C}$ = 4979.82(Hz)). The gain of the output signal is: G=-68/R_{pot} (with R_{pot}=300Ω, the gain is -0.2267). Lower potentiometer values (higher gain) will make the system more sensitive to sounds in terms of their volume and higher values (lower gain) will make the system less sensitive to sounds.

Power consumed by the measured Low-pass filter block is 6.3106mW.

3. **Frequency Response:**

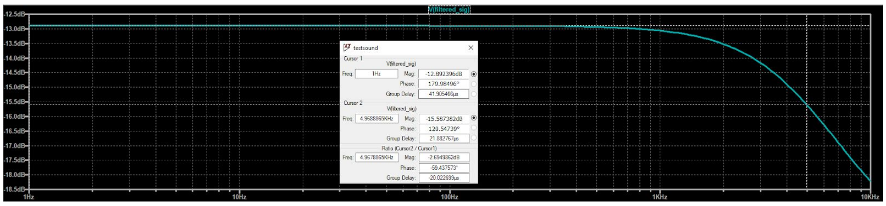


Figure: frequency response for output low-pass filter ($f_{cut\text{-}off}$=5kHz).

The frequency response of this block shows the effect the circuit block has on the input. With a cut-off frequency at 5kHz, the majority of the clap signal is retained, whilst filtering out (attenuating) any high frequency noises. The majority of the clap signal can be defined as the frequencies which have the higher amplitudes that contribute to the clap signal. This is around the 0-5kHz range. Although the noise is also around the low frequency ranges, this block also attenuates the signal enough so that only noises as that have a voltage equivalent amplitude as large as the clap register within the circuit. Due to this, other low frequency loud noises will also work as inputs to this circuit.

Block 2: Amplifier

Components and Values:

Amplifier: LT1097

Resistors: 50, 1k

Simulation results and analysis:

1. **Amplifier circuit**

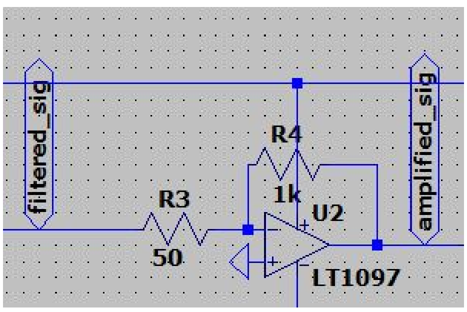


Figure: Amplifier block circuit.

Since the filtered signal is inverted, it can be reversed back by applying an inverse amplifier with the gain of G=-1000/50 = -20.

2. **Gain of amplifier**

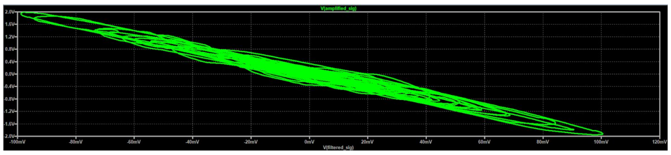


Figure: X-Y plot of input and output.

It shows a linear relationship between input and output with a small phase shift which can be neglected in this scenario

Power consumed by the Amplifier block is 6.3041mW.

Block 3: Turn on LED, Delay, & Amplifier

Components and Values:

Transistor: 2N3904

Amplifier: LT1097

LED: NSPW500BS

Resistors: 10Ω, 100Ω, 10kΩ.

Capacitor: 47uF

Potentiometer: 47kΩ

Simulation results and analysis:

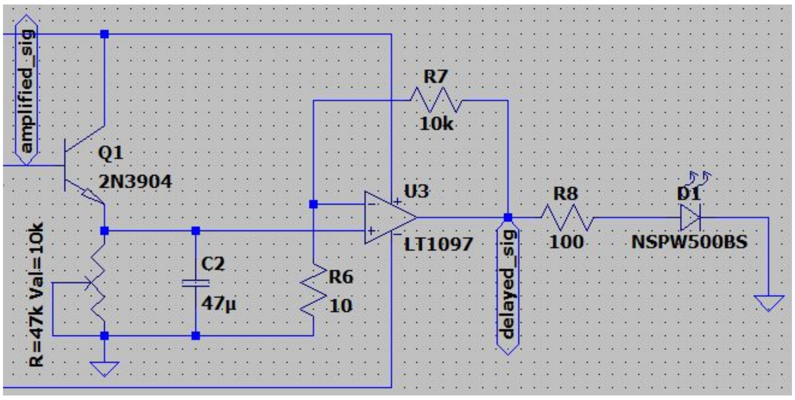


Figure: Delay block circuit.

After inversely amplifying the signal, it is then passed to an emitter follower (common emitter) circuit. The emitter of the transistor is connected to a potentiometer in parallel with a capacitor in order to create a delay pulse of the signal. An amplifier will then be applied to make the pulse become a square wave signal with rail to rail voltage of 9V and -9V. The amplifier outputs DC voltage of 4.7V to the series of resistor and LED (break down voltage: 5V, forward current: 0.03A). The users can vary the delay time using a potentiometer.

1. **Common Emitter.**
   Common Emitter provides the high current gain to the output current (about 111 gain) and keeps voltage gain at unity.
2. **Delay.**
   RC circuit at the emitter is delay circuit with time constant of t=R*C. The time to turn on the light can be vary by the potentiometer (increase resistance for longer delay and decrease for shorter on time)
3. **Amplifier.**
   The amplifier in this delay circuit is used to convert the pulse/sawtooth signal (created by the delay circuit) to a square pulse with the same delay to the RC delay. The gain of the amplifier is G = 10k/10 = 1000. The DC current is created by clipping the pulse at 4.7V.

Power consumed by the delay circuit with the maximum value of potentiometer (47kOhms) is $P_{transistor}+P_{amplifier}$=59.29mW. This block consumes most of the supplied power.

Conclusion

The Clapping Switch module in this project is expected to light up the LED whenever there is a high amplitude low frequency sound (in this case we use clapping sound). This circuit can be used as a standalone circuit, or be implemented as a function of other applications other than an LED light.

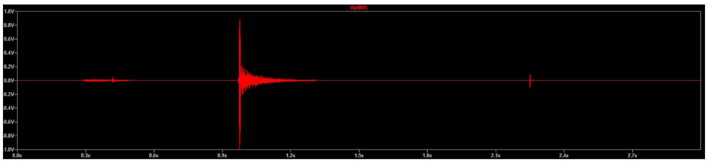
References

Clap switch inspiration:
https://www.homemade-circuits.com/make-simple-electronic-clap-switch/
https://www.instructables.com/id/Simple-illustrated-Clap-Switch/
LT1097 Amplifier:
https://www.analog.com/media/en/technical-documentation/data-sheets/1097fas.pdf
Spectrum Analyzer: https://academo.org/demos/spectrum-analyzer/
2N3904 Transistor datasheet:
https://www.onsemi.com/pub/Collateral/2N3903-D.PDF
Electret Condenser Microphone datasheet:
https://www.cuidevices.com/product/resource/cma-4544pf-w.pdf
LED datasheet:
http://search.alkon.net/cgi-bin/pdf.pl?pdfname=15190.pdf

Appendices

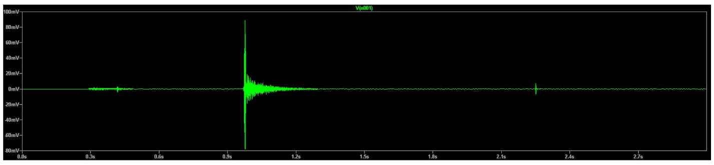
Appendix 1:

Input sound



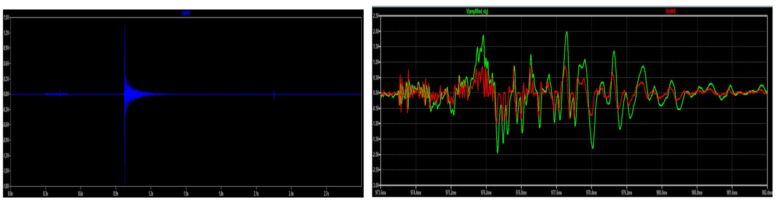
Appendix 2:

Sound filter



Appendix 3:

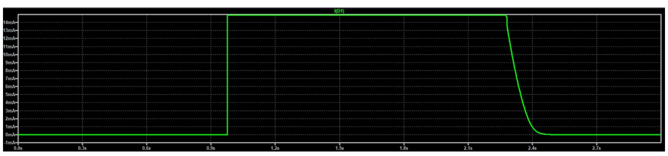
Amplifier



Amplified signal and zoom in clapping section(input- red, output-green)

Appendix 4:

Switch, delay and amplify switch/delay signal for LED



Voltage across LED

Work distribution:

Work Plan	Work distribution
Broad research: Circuit inspiration	Ba Dung Nguyen
Specific research: Specific design requirements/optimisation	Ba Dung Nguyen & Max How Li
LTSpice: circuit design sound filter and amplifier	Ba Dung Nguyen
LTSpice: circuit design delay and LED function	Max How Li
LTSpice: circuit analysis	Ba Dung Nguyen & Max How Li
Report: Skeleton	Max How Li
Report: Circuit design details - Sound filter and amplifier	Ba Dung Nguyen
Report: Circuit design details - Delay and LED function	Max How Li
Report: Circuit analysis results - Graphs for sound filter and amplifier	Ba Dung Nguyen
Report: Circuit analysis results - Graphs for delay & LED function	Max How Li
Report: Circuit analysis results - Explanation for sound filter and amplifier	Ba Dung Nguyen
Report: Circuit analysis results - Explanation for delay and LED function	Max How Li
Report: Review	Ba Dung Nguyen & Max How Li