# Final report: Building a theremin

TRA320 - Music Engineering


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# Introduction

The theremin is a unique electronic musical instrument that is controlled entirely without physical contact, making it both technically and artistically exciting. This project aims to build one functional theremin each, based on a previous project, with improvements in component selection, construction, and usability. The project is carried out as part of an 80-hour project plan and includes electronics, construction, and creative performance.

# Aim

The goal is to build three fully functional theremins and to perform a musical piece using them. The project also aims to deepen our understanding of electronic systems, sound generation.

# Methods and materials

## Time plan

The time allocated for the project is 80 hours and is allocated accordingly in the time plan.

| | | Mar | April | | | | Maj | | | | Juni | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Activities** | **Duration** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| Intro | 2 | ■ | ■ | | | | | | | | | | | |
| Buying components | 3 | | ■ | | | | | | | | | | | |
| Consultation | 3 | | | ■ | | ■ | | ■ | | | | | | |
| Project planning | 8 | | ■ | | | | | | | | | | | |
| Construction | 50 | | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| Demo & Troubleshoot | 16 | | | | | | ■ | ■ | | | | | | |
| Report writing | 5 | | | ■ | | | | ■ | | | | | | |
| Presentation | 2 | | | | | | | | ■ | ■ | | | | |
| Final report | 1 | | | | | | | | | | | ■ | | |
| | | | | | | | | | | | | | | |

*Table 1: Project plan*

## Budget

The budget for the project is 1391 kr for each Theremin and might be adjusted due to resources at TRACKS. The whole budget in detail is presented in Appendice 1 Thermin budget.

## Method

The method of proceeding with the project could be summarized in the following stages.

1. Planning and design
2. Component acquisition
3. Construction and assembly
4. Testing, troubleshooting and tuning
5. Report writing and presentation preparation

Planning the project consists of desktop study primarily on Theremin world and discussing with students who have completed the project in earlier courses. Acquiring the components will be done by reviewing what is present at FUSE electronics lab and complementing with components to be bought at a suitable electronics store. Construction and assembly will be done at FUSE electronics lab, wood workshop, and other suitable workshop access at the FUSE environment. If certain competencies or tools will be needed that will be sourced externally in the network. This stage will be done at the electronics lab in order to operate in a controlled environment with state of the art equipment. Both for high accuracy but also for safety reasons. Lastly, the presentation and report will be done throughout the project and naturally mainly at the end stage of the project.

Throughout the project, we will have guidance from our supervisor Palle Dalerstedt.

# Results

We based the work on previous theremin projects in the course and tried to make improvements and integrate our ambitions into the project. We ended up to adjust the current plans along with the LCD screen and making the body of wood.

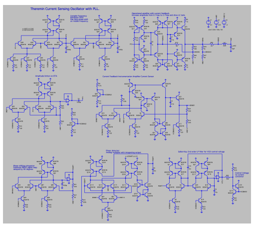

*Fig 1: PCB layout*

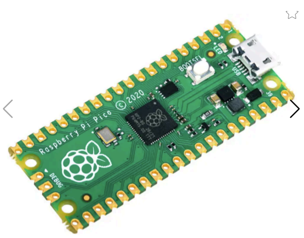

*Fig 2:Micro processor*

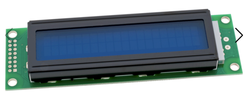

*Fig 3: LCD screen*

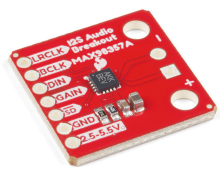

*Fig 4: Sound card*

However, the struggle emerged when creating the circuit for controlling the output voltage of each antenna. The project was halted in order to gain further insight and understand how the control circuit could be designed.

In parallel, we had to do a mapping of resources at the FUSE lab in order to know what to purchase or not, and secondly, and more importantly, obtain access to the lab.

After a couple of iterations, we decided to build an ultrasonic theremin as a proof of concept prototype in order to get the understanding and knowledge of building the control circuit with an easier sensor to work with.

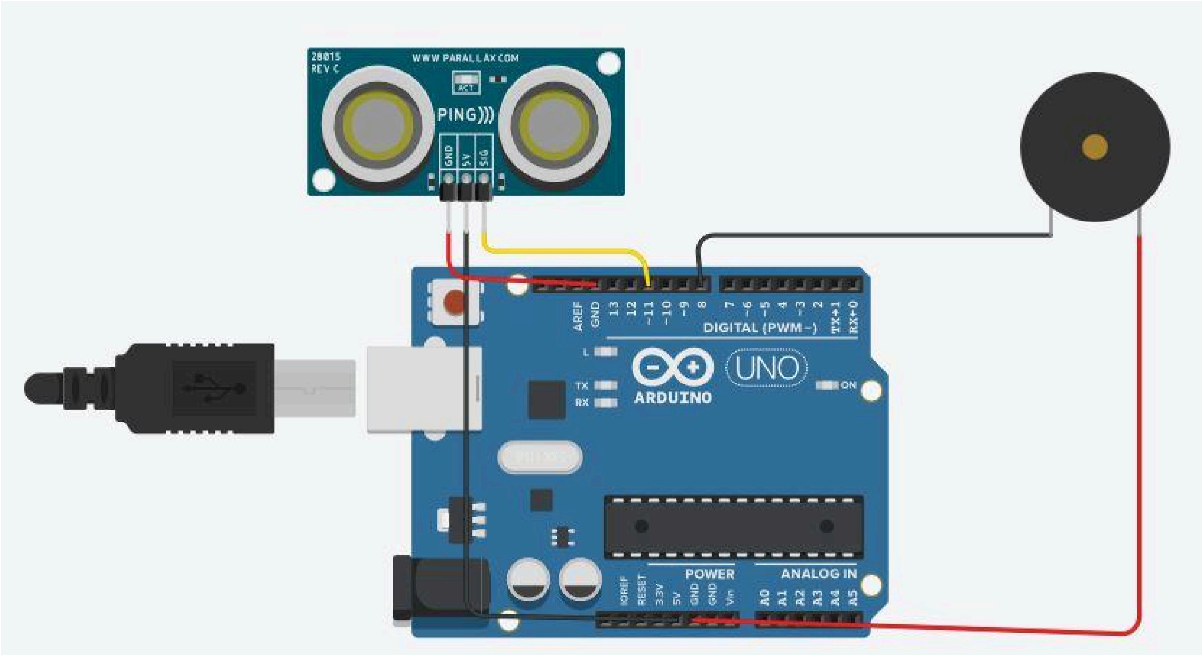


*Fig 5: Concept ultrasonic theremin*

The needed parts were Arduino, an external speaker, an ultrasonic sensor, and a circuit of a low pass filter and amplifier. We complemented the components with an AC module and a VCO module in order to modify the signals.

When building the LPF and AMP circuit we also discovered that the resistance in the circuit was too low which then was exploratively iterated.

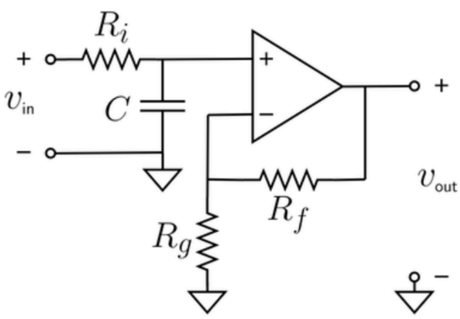


*Fig 6: LPF circuit schematics*

Arduino has a pre-built ping software that can be used for sensor signals. The software was modified to work for the setup and adjusted to modify the signals and give the correct output. The software code is attached in Appendix 2: Arduino IDE Ping code.

The final result was more impressive than thought when initiating the proof of concept prototype ultrasonic theremin presented below. The box was made in FUSE and laser-cut, and likewise the “playing” pick.


*Fig 7: Theremin above*

*Fig 8: Theremin from side*

*Fig 9: Playing “pick”*

The prototype is a theremin using an ultrasonic sensor. The sensor is mounted on the side of the wooden body, and the instrument is played by moving a reflective surface back and forth in front of it. We found that the theremin sounded best when the lowest pitch was produced at close range, and the frequency increased as the distance grew. This is the opposite of how traditional theremins usually behave.

The sensor is connected to an Arduino, which in turn is linked to a circuit board that can be considered a digital-to-analog converter. The signal is then sent to a voltage-controlled oscillator (VCO), where both the base frequency and timbre can be adjusted. The VCO is powered by a 12 V supply. It features an output that can be connected to any speaker. In our project, we used a small, battery-powered guitar amplifier.

# Discussion and conclusion

Initially, we thought it would be possible to study the circuits and projects from earlier course projects and iterate based on suggestions and recommended upgrades from that. But as we studied other projects, we also realized that there are several solutions to create the control circuit. This made it challenging to decide how to map and write the whole circuit of the theremin since our electronic knowledge was limited. Furthermore, we found it important to coordinate the ambitions with FUSE personnel and the electronics lab as we would get guidance and also want to minimize the need to buy components from other places.

By doing so the initial schematic was iterated many times as we tried to get a full schematic of the theremin. Throughout the project was iterated and several additional steps were made in order to build knowledge and get us steps closer to the final theremin.

The proof of concept decision was crucial in order to narrow the schematics and learnings as it was much easier to create the control circuit for an ultrasonic sensor. However, it has very limiting functionality but helped us gain insights and know-how of how to write and build the control circuit for the final theremin that we still intend to finalize.

Anyhow when reflecting on the method we believe that it would have helped us to understand the initial problem and need if we could have gotten a clear schematics of the modules and components of the theremin from the beginning. This would have helped us understand what type of constraints and signals we need to create for input and output.

This is something that will be iterated when writing the schematics for the control circuit of the theremin.

But concluding with the proof of concept prototype theremin we believe that we reached impressive results as we didn't think it would create as good sound as it now does.

# Group members´ contributions

Each member has contributed to all aspects of the project and naturally, Waleed could not contribute to the intro and planning report due to joining the project afterwards.

| | **Sebastian** | **Gustav** | **Waleed** |
|---|---|---|---|
| Intro | x | x | |
| Buying components | x | x | x |
| Consultation | x | x | x |
| Project planning | x | x | x |
| Construction | x | x | x |
| Demo & Troubleshoot | x | x | x |
| Report writing | x | x | x |
| Presentation | x | x | x |
| Final report | x | x | x |

*Table 2: Group members´ contribution*

# Appendice 1: Thermin budget

| Budget 1 Theremin | | | | |
|---|---|---|---|---|
| **Component** | **Price** | **Piece** | **Amount** | **Link** |
| Raspberry Pi Pico | 69 | 1 | 69 | https://www.electrokit.com/raspberry-pi-pico |
| LCD 2x20 tecken JHD202C STN blå/vit LED | 99 | 1 | 99 | https://www.electrokit.com/lcd-2x20-tecken-jhd202c-stn-bla/vit-led |
| Förstärkare klass-D 3.2W mono I2S | 99 | 1 | 99 | https://www.electrokit.com/forstarkare-klass-d-3.2w-mono-i2s |
| Rattar | 28 | 2 | 56 | https://www.electrokit.com/ratt-metall-24x14mm |
| Av/på knapp | 36 | 2 | 72 | https://www.electrokit.com/vippomkopplare-med-skylt-1-pol-on-off |
| Laddkabel | 39 | 1 | 39 | https://www.electrokit.com/usb-c-till-usb-a-kabel-usb-2.0-15w-1m-svart |
| Strömkabel + mikro usb | 79 | 1 | 79 | https://www.electrokit.com/usb-laddare-5w-1a-med-micro-usb-svart |
| USB C | 8 | 1 | 8 | https://www.electrokit.com/usb-c-hona-6-pin-pcb-vinklad |
| RCA svart | 39 | 1 | 39 | https://www.electrokit.com/rca-jack-rean-guld-svart |
| RCA röd | 39 | 1 | 39 | https://www.electrokit.com/rca-jack-rean-guld-rod |
| RCA kabel | 19 | 1 | 19 | https://www.electrokit.com/rca-kabel-stereo-1.5m |
| Antennkontakter höger | 92 | 1 | 92 | https://www.hornbach.se/p/vatette-vinkelkoppling-1147-15xr15-forkromad-1948082/5139156/ |
| Antennkontakter vänster | 64 | 2 | 128 | https://www.hornbach.se/p |

| | | | | |
|---|---|---|---|---|
| | | | | /vatette-rak-koppling-1138-12xr10-forkromad-1947316/5139157/ |
| Klämmring 10 | 8 | 3 | 24 | https://www.hornbach.se/p/klamring-10-mm/5125288/ |
| Mutter | 10 | 3 | 30 | TRACKS |
| Rör (120 cm) | 99 | 1 | 99 | https://www.hornbach.se/p/kopparror-forkromad-glodgad-10x0-8mm-1-2-m-8564122/8377124/ |
| Träkropp | 100 | 1 | 100 | TRACKS |
| Stativ + montering | 300 | 1 | 300 | https://www.amazon.com/gp/product/B0002MJTZ8/ref=as_li_tl?ie=UTF8&camp=1789&creative=390957&creativeASIN=B0002MJTZ8&linkCode=as2&tag=thereminworld&linkId=XU5ABIRS7RCXTDFD&th=1 |
| | | | | |
| Total | | | 1391 | |

# Appendice 2: Arduino IDE Ping code

```
/*
 Ping))) Sensor med PWM-output

 Läser PING)))-sensorn på D7/D8 och skickar en PWM-signal på D9.
 PWM-medelvärdet är proportionellt mot det filtrerade avståndet (0–96 cm).
*/

const int trigPin   = 7;   // PING))) Trig
const int echoPin   = 8;   // PING))) Echo
const int outputPin = 9;   // PWM-utgång till lågpassfiltret

#define A 0.1              // Filterkonstant
const long maxDistanceCm = 200;                    // Max användbart avstånd i cm
const long maxDuration   = maxDistanceCm * 29 * 2;  // Max µs tur-retur för 96 cm

uint32_t lastOutputTimeStamp = 0;
float x = 0;  // Filtervärde i µs

void setup() {
 Serial.begin(9600);
 pinMode(trigPin, OUTPUT);
 pinMode(echoPin, INPUT);
 pinMode(outputPin, OUTPUT);
}

void loop() {
 // 1) Skicka trig-puls
 digitalWrite(trigPin, LOW);
 delayMicroseconds(2);
 digitalWrite(trigPin, HIGH);
 delayMicroseconds(10);
 digitalWrite(trigPin, LOW);

 // 2) Läs echo-puls
 long duration = pulseIn(echoPin, HIGH);

 // 3) Uppdatera filtervärdet x (glättat värde av duration)
 x = A * duration + (1.0 - A) * x;

 // 4) Skala x (µs) → 0–255 PWM med multiplikation och klippning
 int pwmValue = (int)( x * 255.0 / maxDuration );
 pwmValue = constrain(pwmValue, 0, 255);
```

```
 // 5) Skriv ut PWM
 analogWrite(outputPin, pwmValue);

 // 6) Debug-utskrift varje 100 ms
 if (millis() - lastOutputTimeStamp > 100) {
   long cm     = microsecondsToCentimeters(duration);
   char buf[100];
   sprintf(buf, "%3ld cm\tPWM: %3d\tµs: %5ld\tx: %.1f\n",
           cm, pwmValue, duration, x);
   Serial.print(buf);
   lastOutputTimeStamp = millis();
 }
}

// Hjälpmetod: µs → cm
long microsecondsToCentimeters(long microseconds) {
 // 29 µs per cm tur-retur → dela med 29 och med 2
 return microseconds / 29 / 2;
}
```