Physics 4BL Final Project: Broadcasting Sound Using Arduino Piano and Speakers

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2. Physics
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Group 2

Motivation

- We wanted to be creative with the Arduino ➔ making a piano
- Multiple members have some background in music, would be interesting to see how Arduino music compares to more conventional sources
- Specifically, wanted to compare the frequencies of sounds played through traditional, everyday sources such as computer speakers and portable speakers
  - See if there's any difference in the listening quality

Introduction

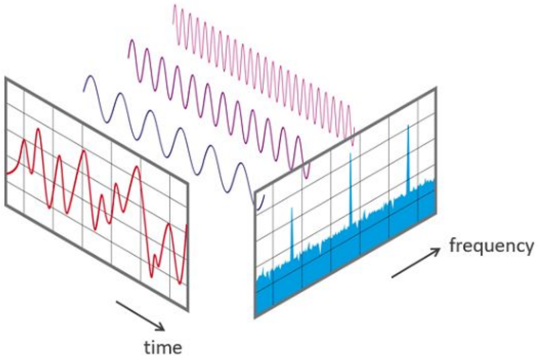
We constructed an **Arduino piano**. It uses push buttons to output notes of different frequencies. When the notes are played, we record the sound and make Fourier Transform plots and spectrograms to determine the dominant frequencies. We also did this for scales on other speakers and a real piano to compare.

Theory and Prediction

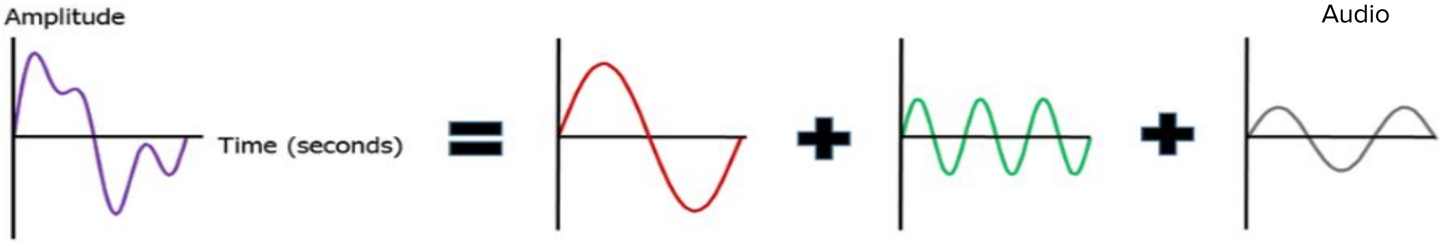
Our theory is based on the basic ideas of sound. Through this experiment we are testing the sensitivity and accuracy of our Arduino piano.

Fourier Transform

- Mathematical tool can decompose any sound wave
- Reveals dominant frequencies (Intensity v. Frequency)
- Compare plots across different devices



Fourier Transform (NTi Audio

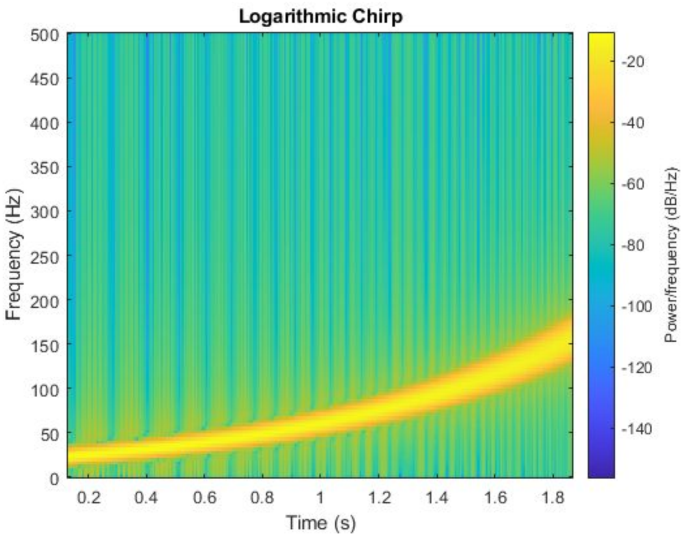


Fourier Transform (Siemens PLM Community)

Theory and Prediction

Spectrogram

- Frequency v. Time
- Highlights what frequencies are played at what times
  - Useful for music scales
- Compare plots across different devices



Example of Spectrogram (MathWorks)

Theory and Prediction

- Across all speakers, we will broadcast a C-major scale starting at the fourth octave ending at the fifth octave using the Arduino piano, piano recordings, and a regular piano.
- Our prediction is that the frequencies recorded from the **different speakers will vary slightly from those expected, with the variance dependent on the quality of speaker.**
- Specifically, we predict the differences should be marginal. **All devices and instruments should more or less produce the expected frequencies.**

Theoretical Values

Note	Predicted Frequency (Hz)
C4	261
D4	294
E4	330
F4	349
G4	392
A4	440
B4	494

Scale is tuned so that A4 = 440 Hz (https://pages.mtu.edu/~suits/notefreqs.html)

Experimental Set-up

Equipment:

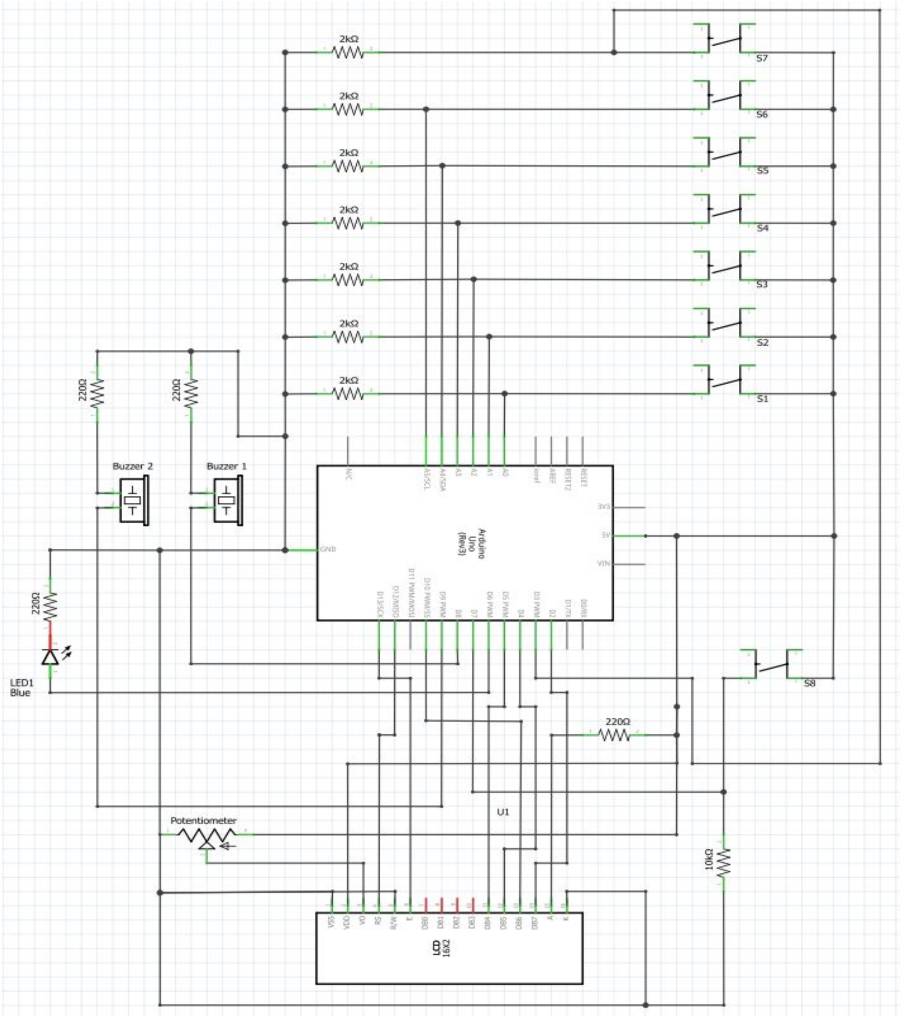
- 8 push buttons (7 used as keys, one for LCD control)
- Jumper Wires
- Breadboard
- Arduino Uno + Power source (laptop)
- Resistors (220Ω, 2kΩ, 10kΩ)
- Potentiometer
- Blue LED
- LCD Display
- 2 buzzers (outputs the sound)
- Speakers (OontZ Angle 3, iPad, laptop)
- MIDI piano

Arduino Buzzer (techZeero)

OontZ Angle 3 speaker (Amazon)

MIDI piano (Amazon)

We also had several files of code for the Arduino to process what frequencies needed to be played.

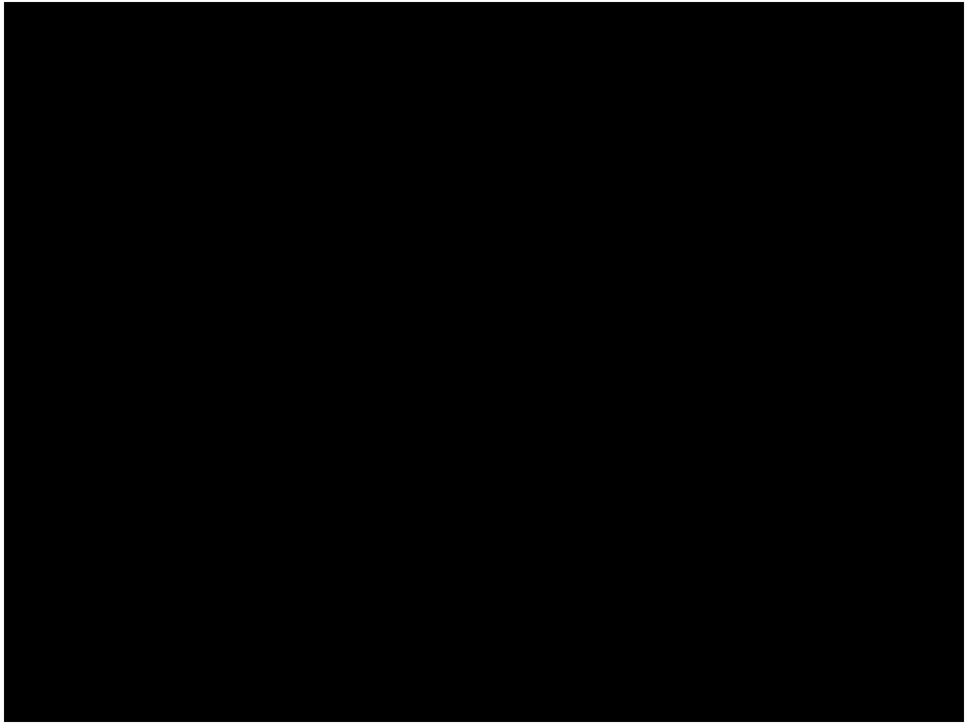


Circuit diagram (made on Fritzing)

```
int totalAnalog = C + D + E + F + G + A + (B*1023);
```

```
else if(totalAnalog < 1025)
{
  buzzer2.stop();
  lcd.display();
  if(C > 10){
    buzzer1.play(NOTE_C4);
    lcd.clear();
    lcd.setCursor(7, 0);
    lcd.print("C4");
  }
```

Video



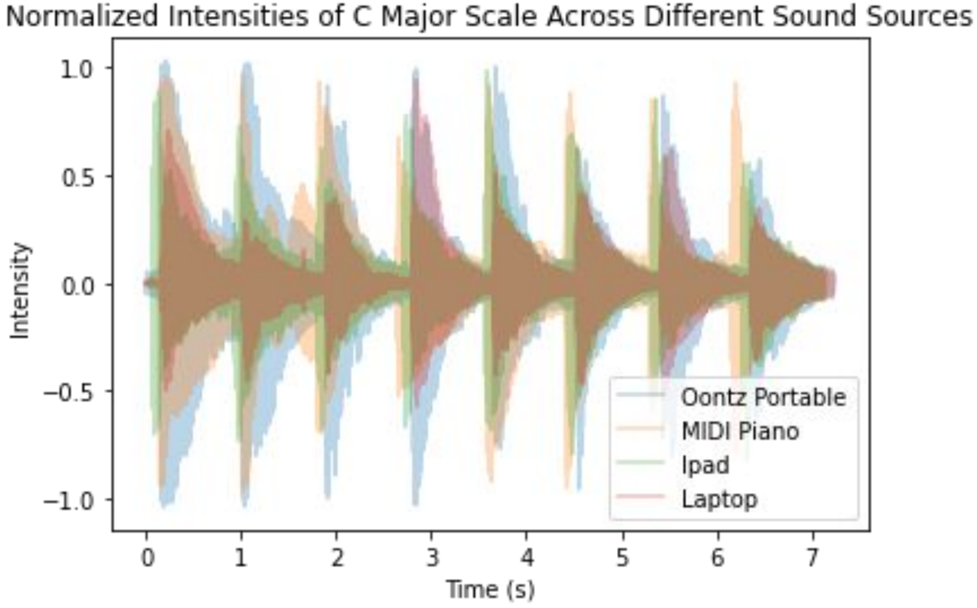
Data taking and Analysis

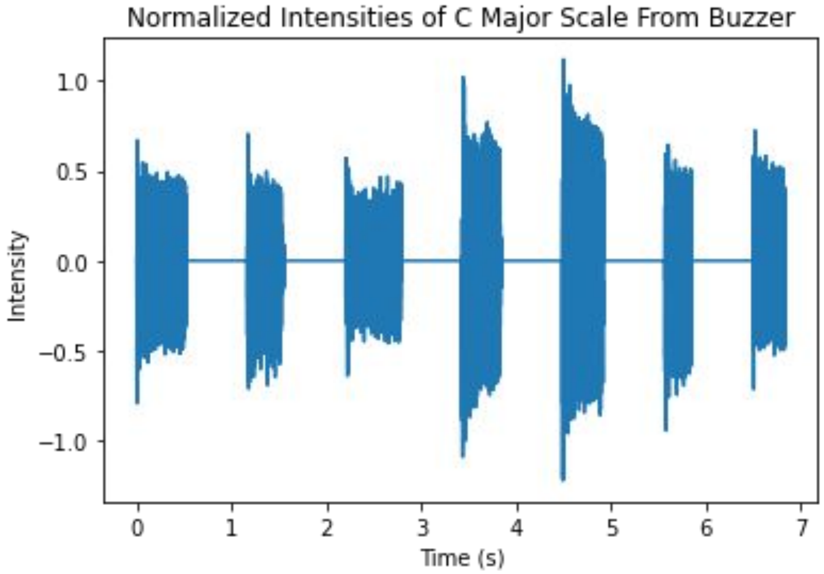
The main data we are collecting is sound data that is then converted to a .wav file for analysis. This data is collected **using smart phones as recording devices** and then an online converter. We also printed out data on the serial monitor that specified time elapsed between the pushing of the button and the output sound to determine reaction speed of the circuit.

The data is analyzed in python **using spectrograms, Fourier transform plots, and the matplotlib module** in order to compare collected data with expected. We first converted the sound file into useable frequency data, then plotted this data against expected frequencies to determine percent error.

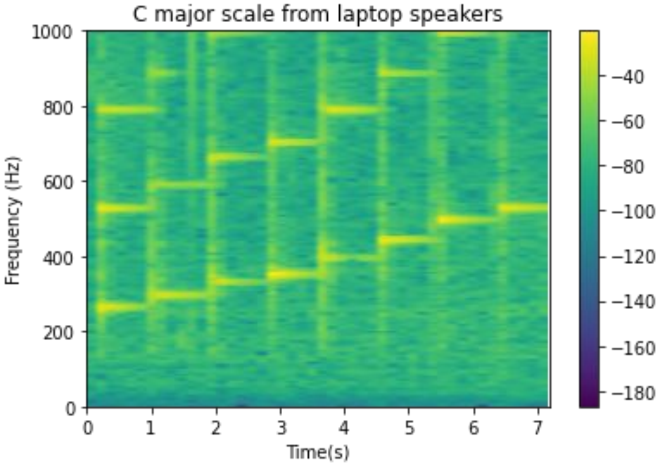
Analysis of Different Sound Sources (Exclude Buzzer)

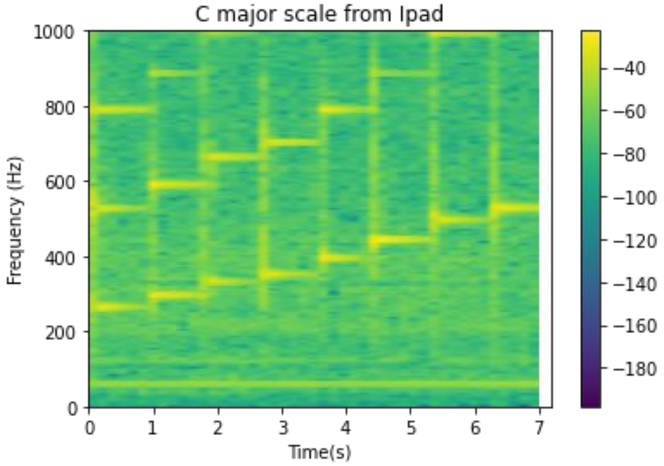
From this initial analysis of speakers, we get an idea of what the waveform of a C Major scale should look like on the buzzer, with each peak representing one note on the scale.





Analysis of Different Sound Sources (Exclude Buzzer) cont.



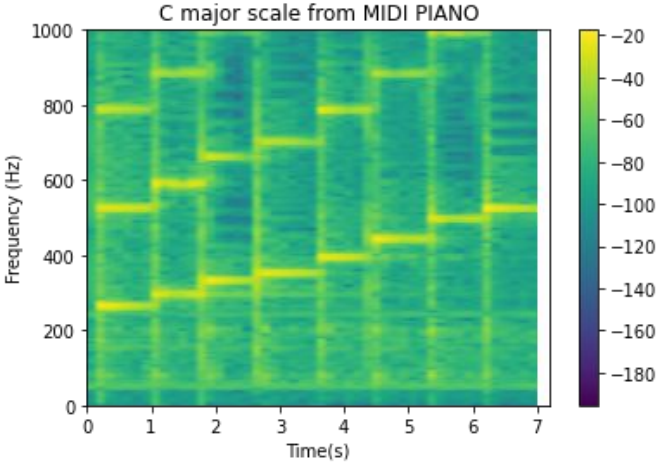


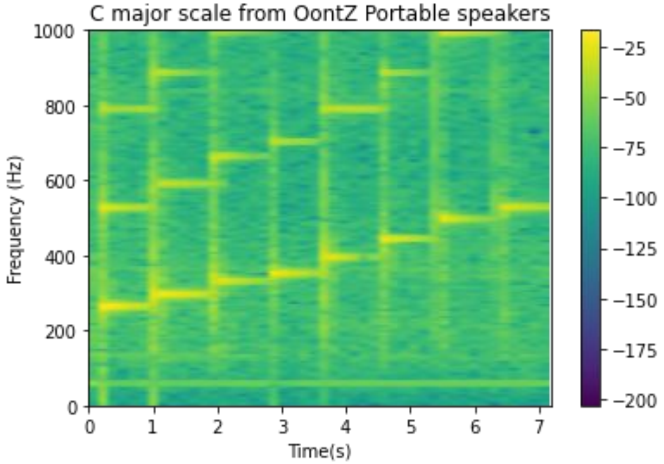
Some things to consider:

Overall grain of spectrograms

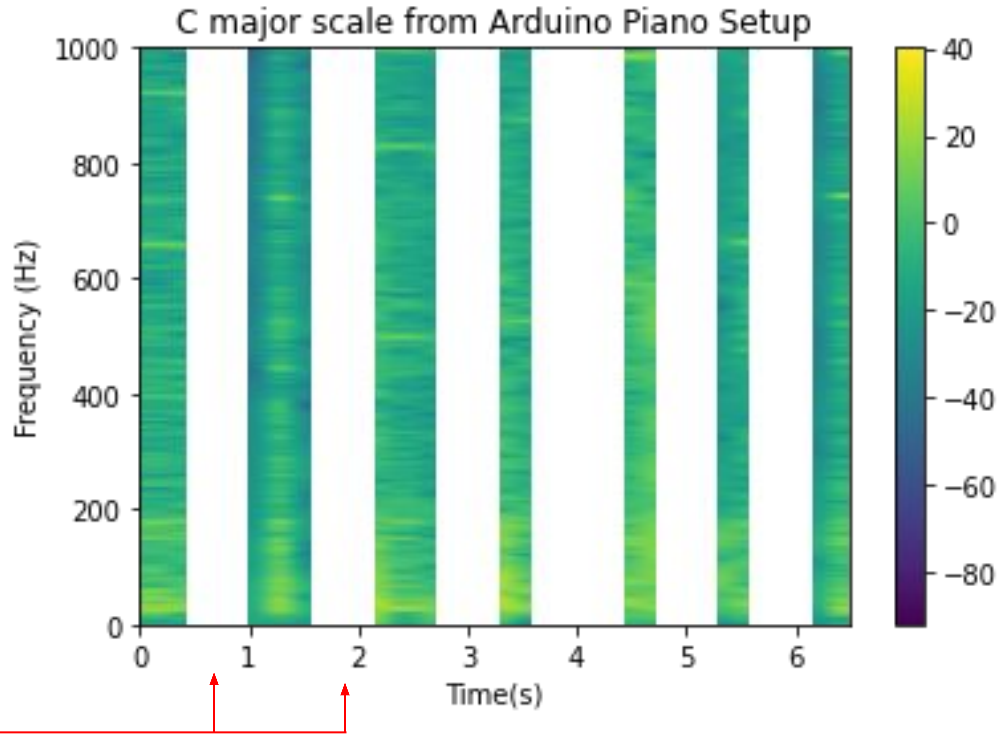
Distinctness of notes

Vertical streaks that appear at the start of each note





Spectrogram Analysis of Buzzer Scale



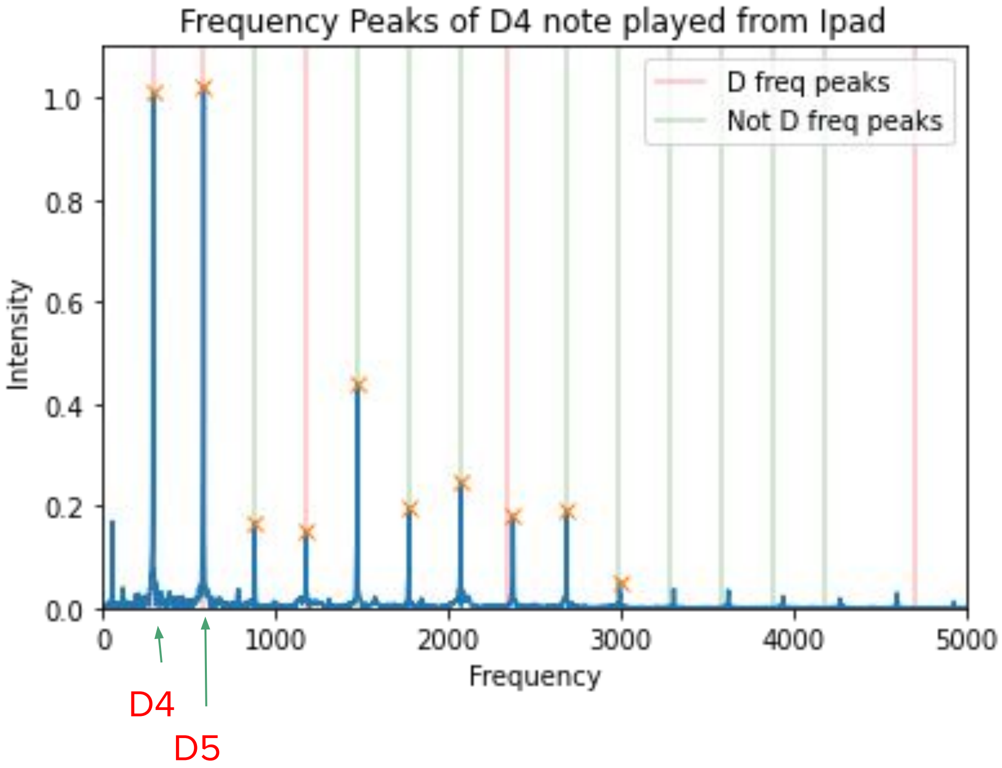
Results are “cut” to create a distinction between notes not seen without it

Profiles of Resonant Frequencies in Single Notes

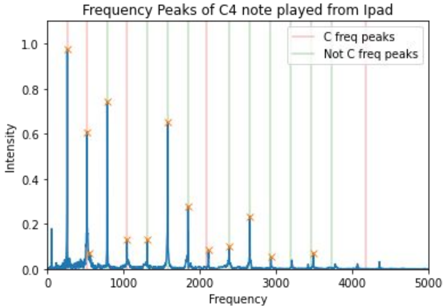
Across all recorded scales, the FFT of each note revealed a composition of overtones that accompany each single note.

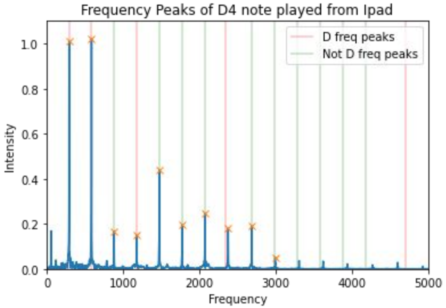
Each peak is found at a multiple of the base freq.

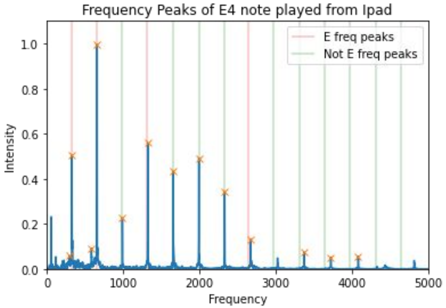
Ex. D4 = 294Hz, D5 = 588Hz, etc.

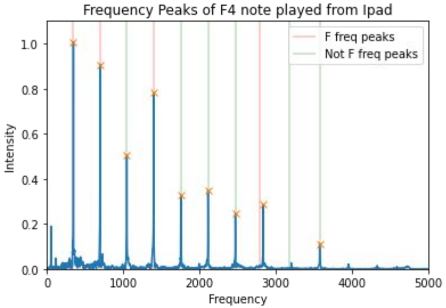


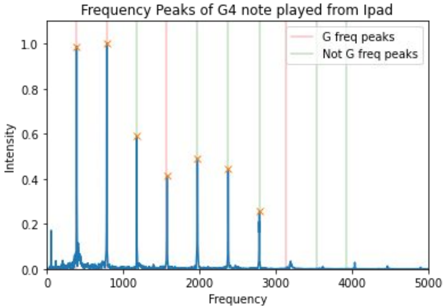
Resonant Frequencies in Single Notes (Full Scale, Ipad Speaker)

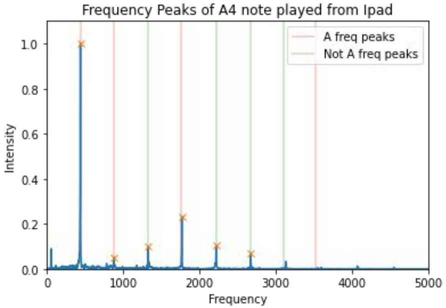


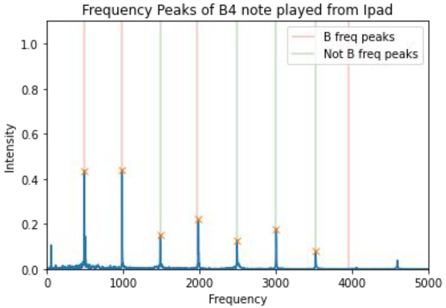








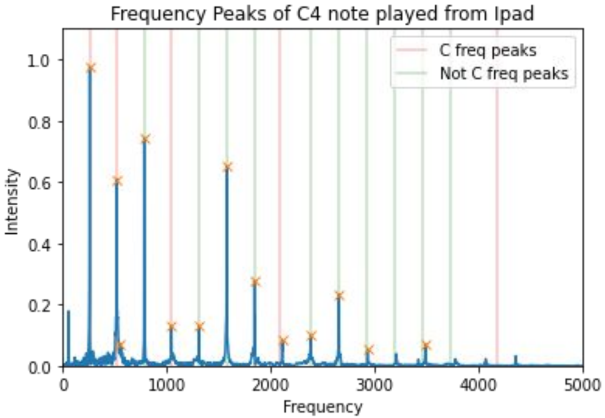


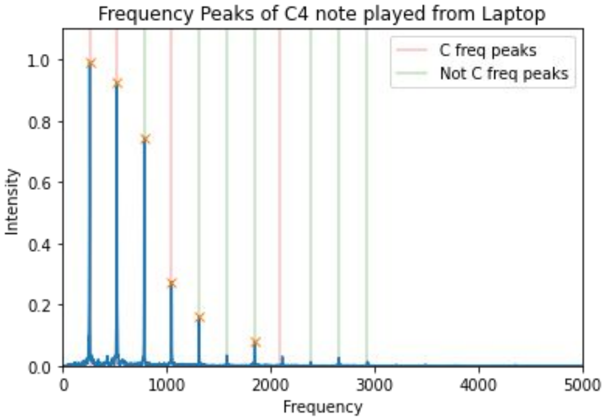


Note: Gaps between peaks grows as they are dependent on the base frequency of each note

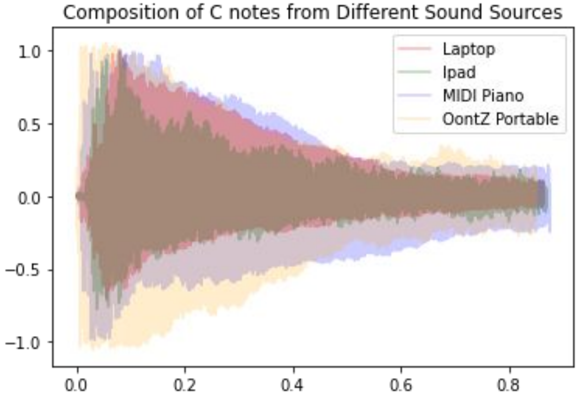
Due to the localization of frequencies towards the base freq., we see less peaks as the notes get higher

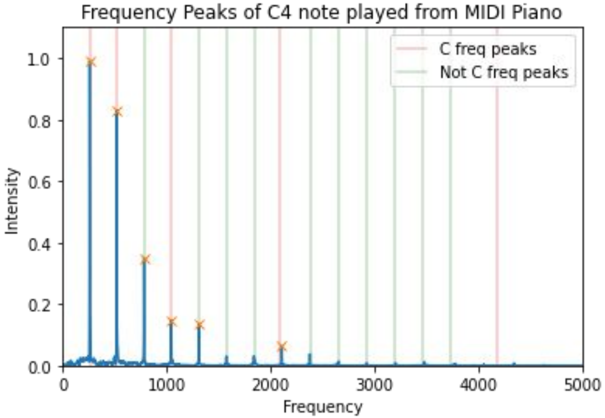
Fourier Analysis of C4 Note

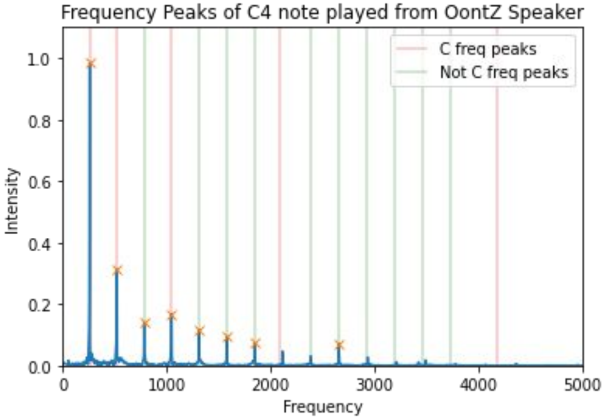




Visual comparison of C4 note waveforms, all trials have distinct and expected frequencies (C4 = 262 Hz)

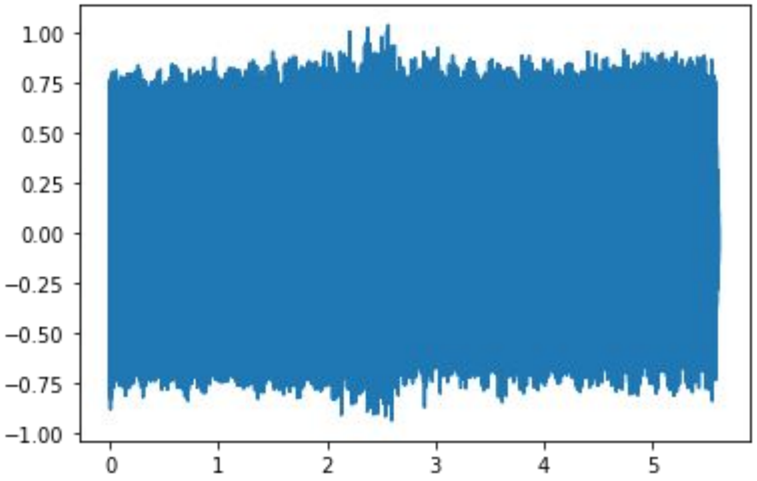




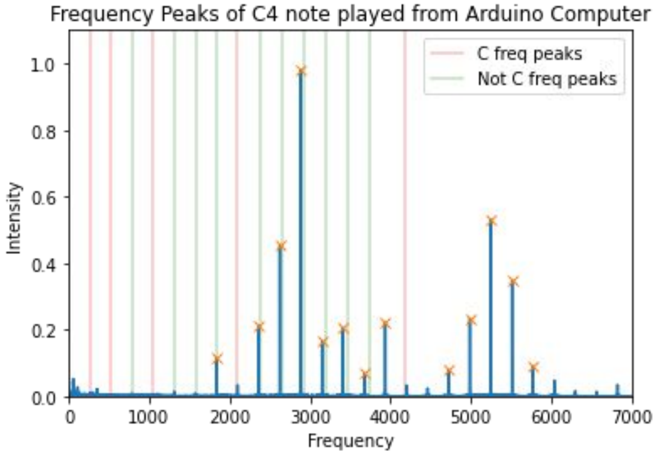


Analysis of Buzzer's C4 Note

Buzzer C4 Waveform

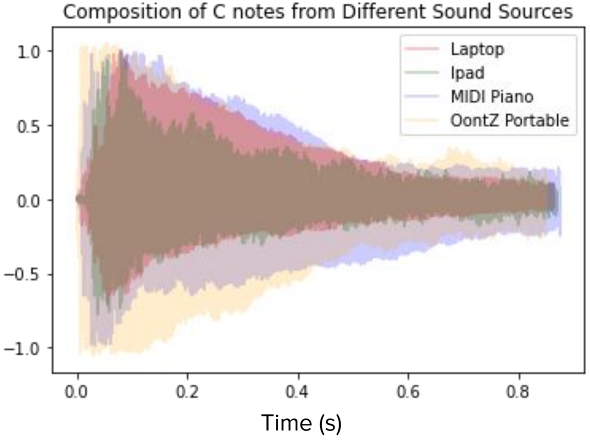


FFT of Buzzer C4

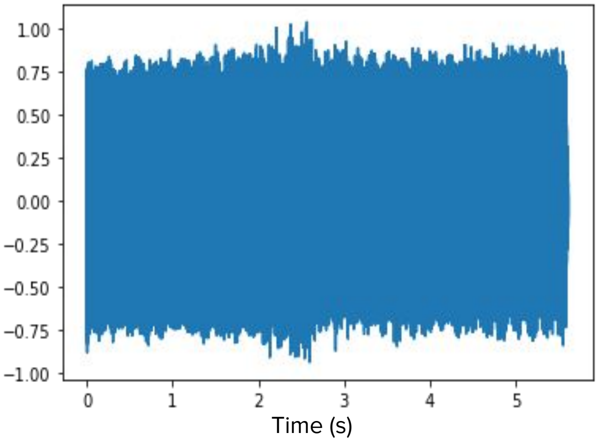


Comparison of C4 Waveforms

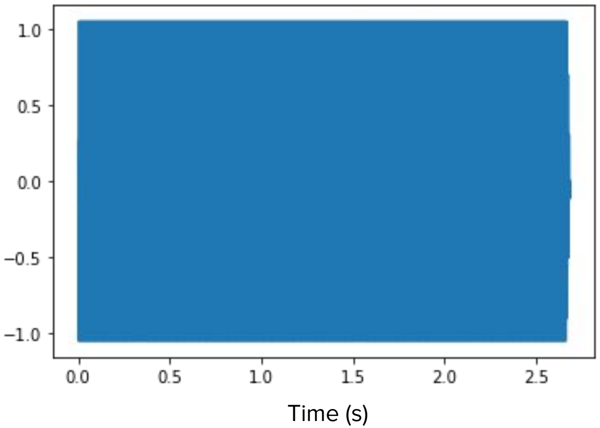
Various C4 Waveforms



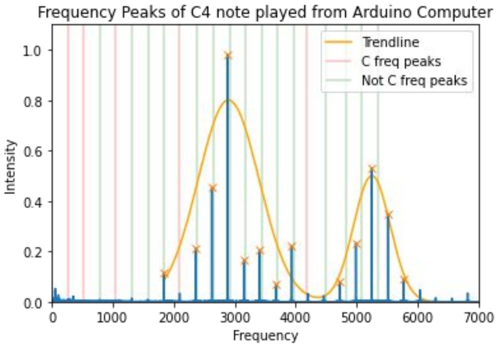
Buzzer C4 Waveform



Pure C4 Waveform (263 Hz)



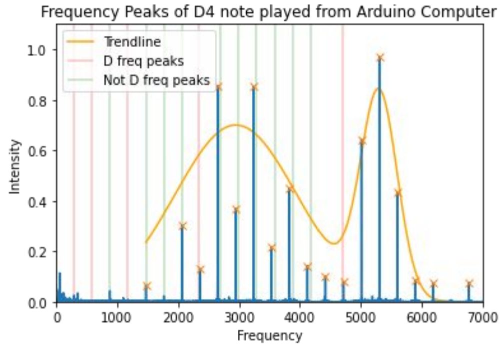
Comparison of Buzzer Sound Profile Through Scale

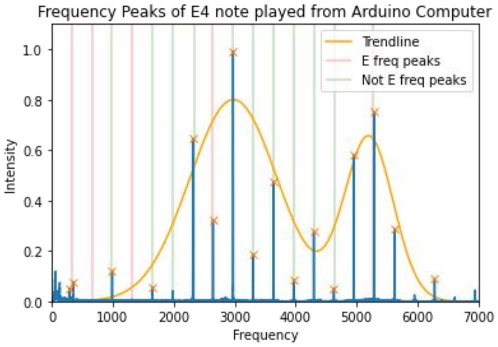


Approximate Dominant Frequencies

C4: 2900 and 5200

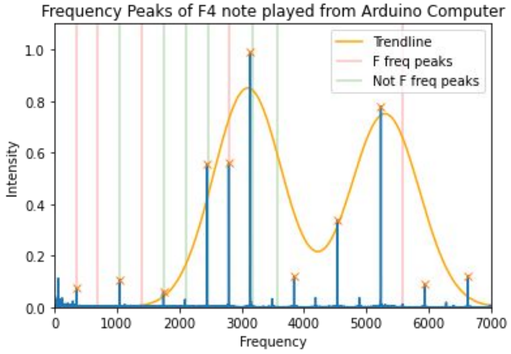
D4: 2600, 3300, and 5300



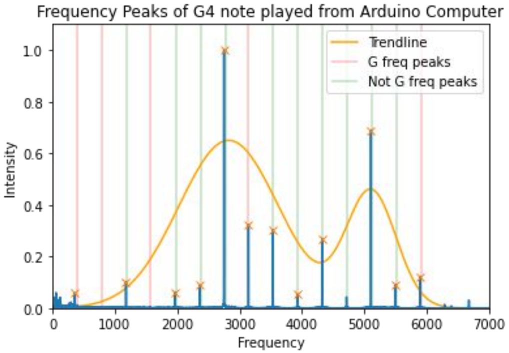


E4: 2900 and 5300

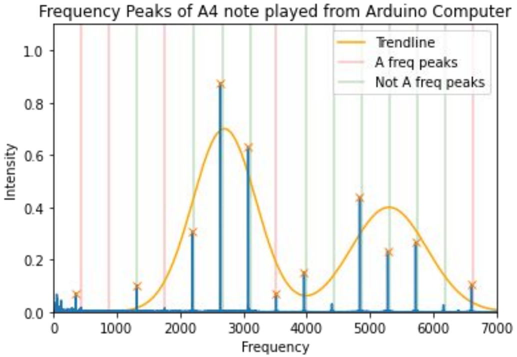
F4: 3000 and 5400



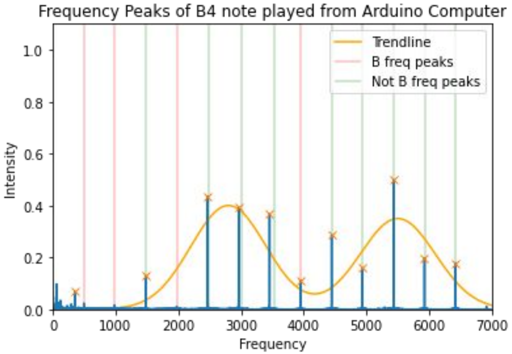
Comparison of Buzzer Sound Profile (cont.)



G4: 2800 and 5100



A4: 2500 and 4800



B4: 2500 and 5500

Discussion

Sources of sound

- Speakers and piano matched
- Buzzer different from expected
  - Most distinctive frequency 3000 Hz
  - Frequency peak distribution: double bell curve

Results

- Listening with ears vs. Python frequency analysis
  - Ringing noise from buzzer

Discussion

Buzzers

- Usually optimized to output one frequency or narrow range
- Relies on DC voltage due to built-in oscillator, internal circuit
- Small size (not big enough membrane) → designed to be energy efficient

Speakers

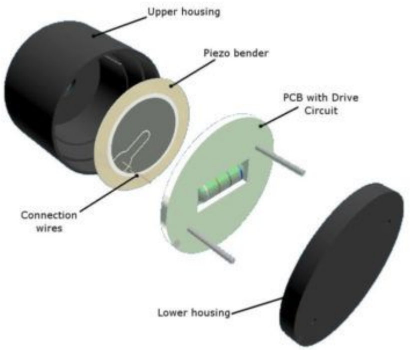
- Rely on AC voltage, alternating current → cone vibrates → pressure variations in air
- Reproduce the signal being sent to the speaker
- Larger membrane (cone) can produce wider frequencies

Piano

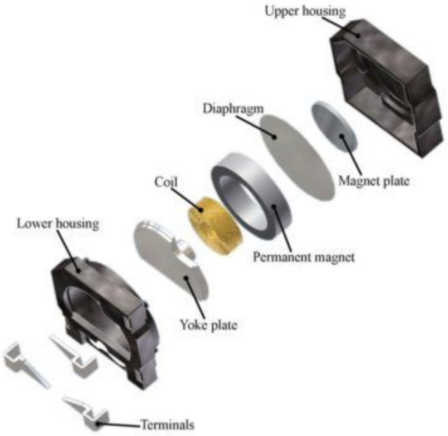
- Wooden hammer hits metal string→ string vibrates

Discussion

- **Piezo buzzer** (what we used)
  - Ceramic disk
  - Driven by voltage
  - Modeled as capacitor
- **Magnetic buzzer**
  - Wire coil driven by current
  - Produces a magnetic field (Ampere’s Law)
  - Modeled as a coil in series with a resistor



Piezo Buzzer Construction



Magnetic Buzzer Construction

Conclusion and Future Prospects

- Speakers and piano matched theoretical closely
- Buzzers were incredibly different and unexpected possibly due to hardware
  - Could have researched them before performing experiment
- Future Experiments
  - Investigating more with buzzer since that was the piece of greatest interest
    - Can test different types of buzzers against each other to see what factors have the most influence - different sized buzzers, different ceramic materials for the piezo buzzer, magnetic vs. piezo buzzers
  - Perform other scales/keys and even chords of multiple notes

References & Acknowledgements

- https://docs.google.com/presentation/d/1NVsZ_1Ht7NTQi9i0KP7_NCnXJobA9JmhLVM3kJHXmnw/edit
- https://pages.mtu.edu/~suits/notefreqs.html
- https://create.arduino.cc/projecthub/lindsi8784/electronic-piano-keyboard-with-preset-songs-74ee7c
- https://www.abcomponents.co.uk/buzzer-vs-speaker/
- https://www.bbc.co.uk/bitesize/guides/zpnc2nb/revision/9
- https://www.cuidevices.com/blog/buzzer-basics-technologies-tones-and-driving-circuits#magnetic-and-piezo-buzzers

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