Piano Overtones

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Introduction

Let's talk about background knowledge

What is the Goal of Our Project?

Assess Overtone Spectra of a Piano

Compare Overtone Spectra for Various Instruments

Create a Program and Use an Addalogger to Gather Data

The Piano We Used: Yamaha 'Super U1' (U10BL) 48" Premium Upright Piano

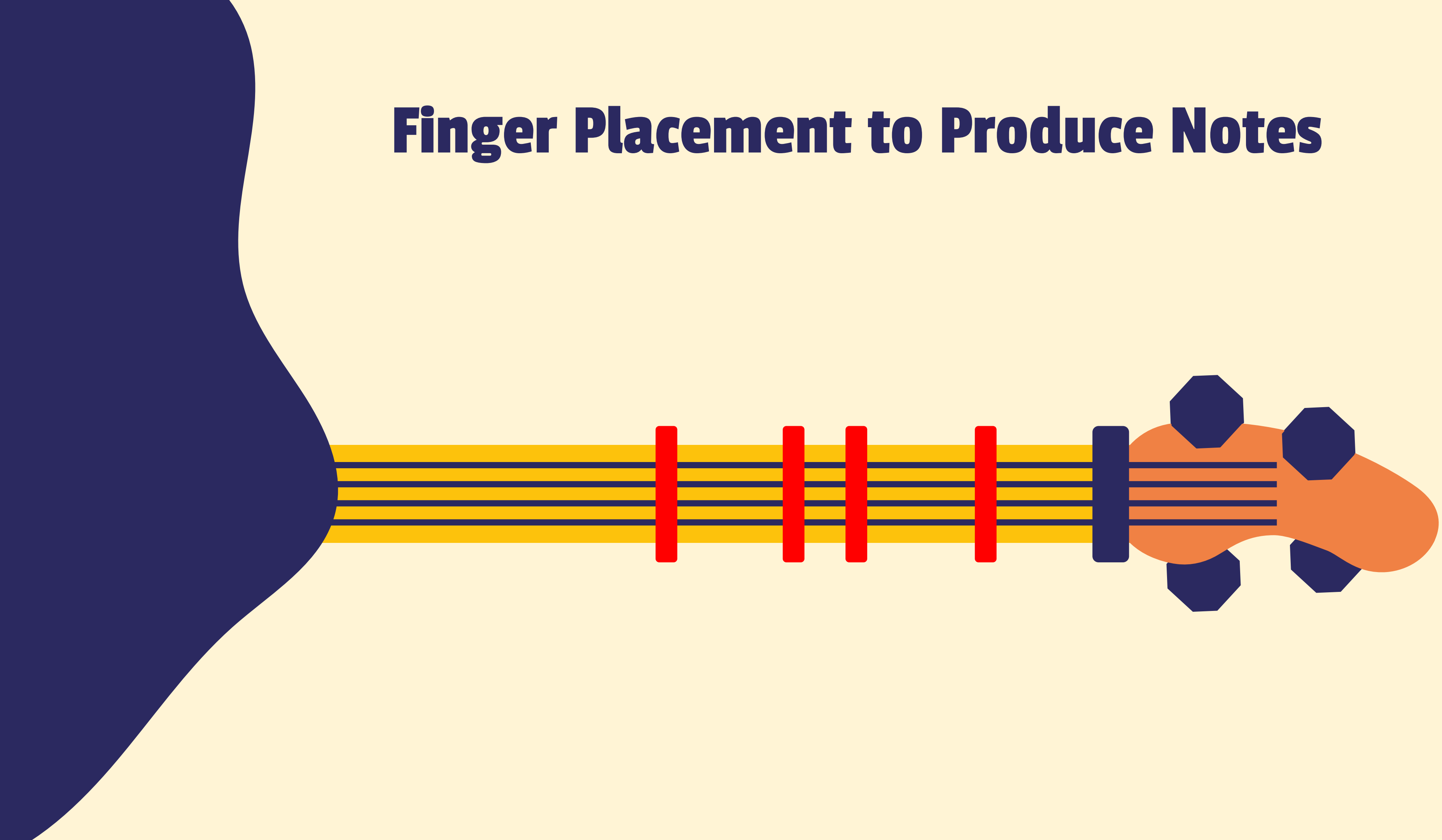
- Donated and in Kavita and Lalit Bahl Smart Bridge "CEE Bridge"
- Hammer strikes strings when a key is pressed
- 88 keys attached from soundboard to bridge and resonates through the soundboard
- 2/3 sections of the piano have more than one string per key
    - Get the same volume output with higher notes

Inside of the Piano

The Violin We Used: Full-Size Antonius Stradivarius Copy

- Strings attached from neck to bridge - 4 strings
- Hollow body where reverberations of strings can resonate through the f-holes
- Notes that we recorded were strictly bowed
- Notes produced by 4 fingering pattern
- Bow is made of horsehair

Finger Placement to Produce Notes



The Clarinet We Used: Refurbished Wooden Student Clarinet - Brand Unknown

- Wind instrument
- Reed (1) vibrations when air is blown through the mouthpiece
- Sound resonates through inside
- Opening and closing keys produce notes
- Wooden produces more accurate frequencies than plastic
- Often used for tuning in band

Frequency- Fundamental,Overtones and Harmonics

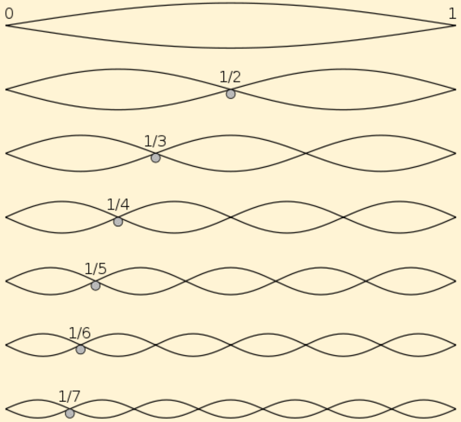
~a brief review~

$$f_n = nf$$

Fundamental: lowest frequency of a periodic waveform. The pitch of the note and lowest perceived frequency

Overtone: any resonant frequency that is present that is higher than its fundamental

Harmonic: resonant frequencies that are integer multiples of the fundamental



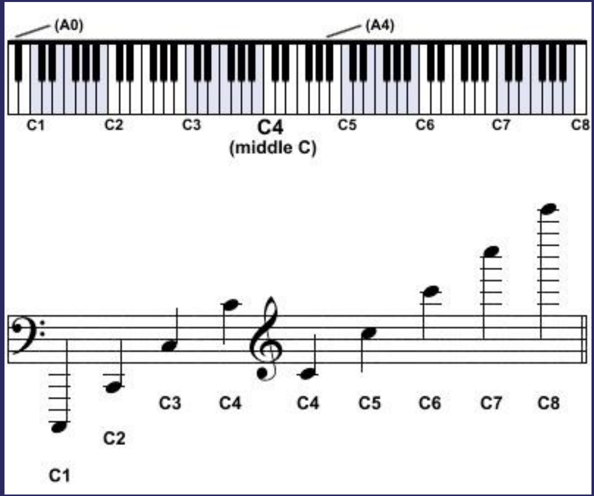
Timbre

- Instrument sound depends on material, shape, type of instrument, way string is struck or blown etc..
- Other frequencies beside the fundamental may also be produced (overtones!)
- If we listen to a pure tone with a singular frequency, it sounds very “dull” or “flat” to our ears because there is one frequency being produced.
- instruments sound pleasant to our ears when single notes are played because there are other frequencies present

Timbre: the particular blend of harmonics in an instrument’s tone, or in the tone of a single note.

- what makes instruments sound different from another, even when a note at the same fundamental frequency is played.

Notes We Are Analyzing ♫



- 88 keys on a piano
  - 1st 12 octaves (comprising 12 half-tones) are repeated over 7 ¼ times.
- Every repeated octave is an integer multiple harmonic of the previous octave.
- These notes are:
  - C, C-Sharp, D, D-sharp, E, F, F-Sharp, G, G-Sharp, A, A-Sharp, and B
  - We will not be using sharp notes.
- The overtones will be observed for middle C (C4-C5) and the upper octave (C7-C8) to compare the overtone spectra.

Fundamentals We Are Analyzing

- Are recorded notes representative of these fundamental frequencies?
- What other overtones are present and are they harmonics?
- What are reasons for out results?

C4-C5 Notes	Frequency (Hz)	C7-C8 Notes	Frequency (Hz)
C4	261.63	C7	2093.00
D4	293.66	D7	2349.32
E4	329.63	E7	2637.02
F4	349.23	F7	2793.83
G4	392.00	G7	3135.96
A4	440.00	A7	3520.00
B4	493.88	B7	3951.07
C5	523.25	C8	4186.01

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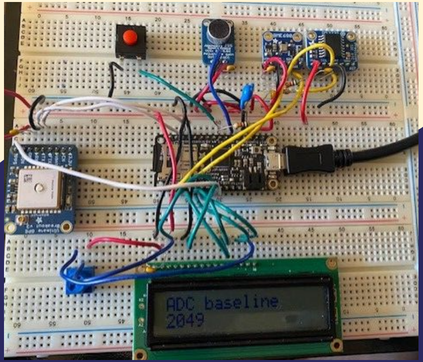
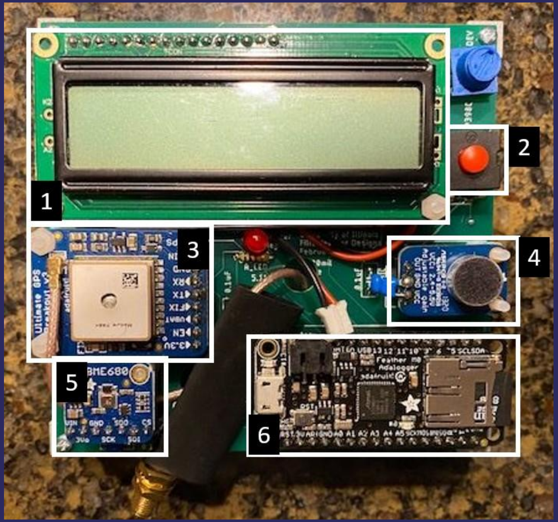
Procedure

How did we go about assessing overtones?



Original Breadboard



Final PCB

Our Device

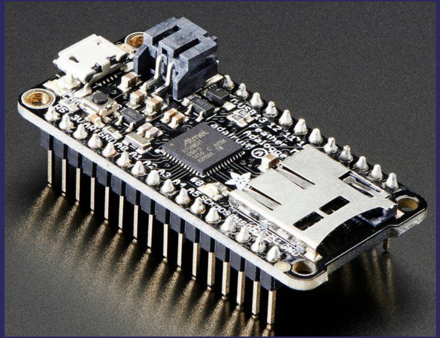
Component Breakdown

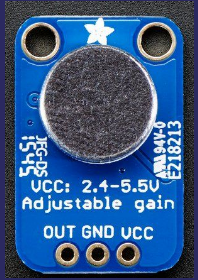
- LCD
  - Display "codes"
- Push Button
  - Start recording
- Ultimate GPS
  - Time keeping
  - Future Extension?
- Electret Microphone
  - Pick up audio
- BME 680
  - Environmental information
  - Future extension?
- Adalogger M0
  - "Powerhouse"

PCB Alterations

- Microphone power by battery pack
  - Reduced noise
- RTC moved
  - Removed spontaneous 1 kHZ Frequency
- Capacitor
  - Placed on microcontrollers analog reference pin

Adalogger Feather M0 and Electret Microphone MAX4466





Adalogger Benefits

- Faster than Arduino
  - 48 MHz clock speed
  - 350,000 samples per second
- Simplified our board
  - Replaced arduino and Micro SD card breakout - convenient

Analogger Purpose

- Control Device

Microphone Benefits

- Noise reduction
- Meant for FFT
- 20 - 20,000 Hz frequency range
- Inexpensive and available

Microphone Purpose

- Pick up voltages
  - Adalogger then convert to digital
  - Gave us our data

Recording Procedures

1. Wrote DAQ

DAQ - set up all the boards - waited for button push - made 20 audio files each with 20,000 bytes

2. Trial Recordings

Sinusoidal and Clarinet - informed DAQ worked

3. Recorded on Breadboard

Notes C4-C5 and C7-C8 on Piano in Newmark

4. Recorded on PCB

Notes C4-C5 and C7-C8 again on same piano in Newmark

5. Recorded Violin

C scale on breadboard and PCB

6. Recorded Clarinet

Notes D4-F#4 (Piano C4-E4)

7. Python Data Analysis

Python Analysis Breakdown

Read File

Loaded array with file bytes – last four removed -> gave sampling

Perform FFT

Performed FFT on this array – gave us function of frequency

Peak Findings

Used algorithm to find peaks – gave requirements – if requirements met – peak!

Peak Baseline

Used algorithm to calculate baseline – allowed us to verify peaks w/ peak/baseline

$$\tilde{f}(\omega) = \int_{-\infty}^{\infty} f(t) \exp(-i\omega t) dt$$

Fundamental Finding

Gave "expected" fundamental – function search array for closest value

Ratio Calculation

Took fundamental, divided each value of peak array by this

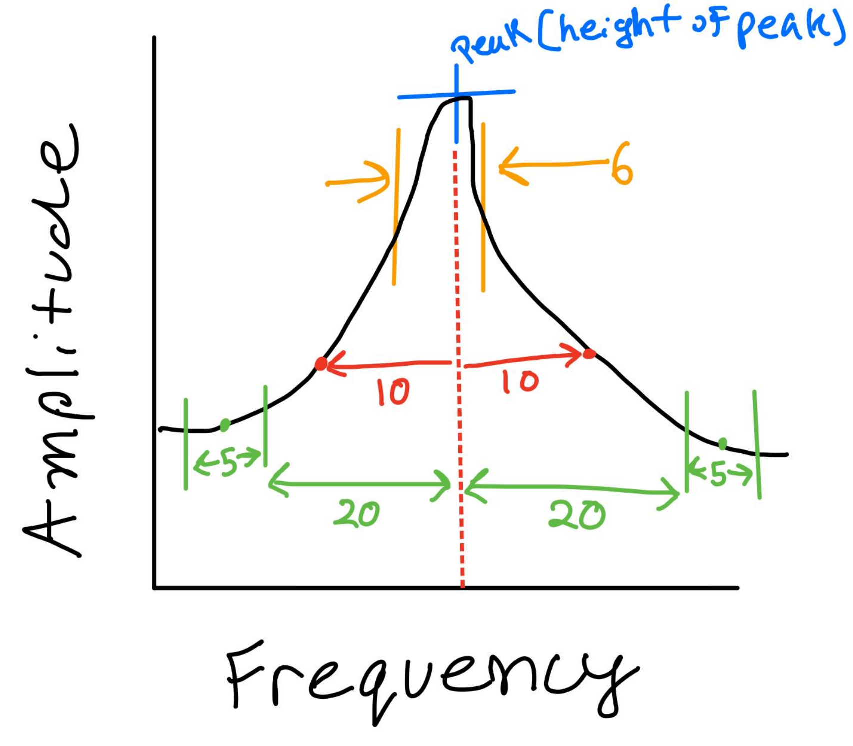
Deviation Calculation

Subtracted calculated ratios from expected integer ratio

Plots and Tables

Made plots of frequency spectrum, ratios and deviation and table of all numbers

Peak Finding and Baseline Algorithm Breakdown



Peak Finding

1. Find max amplitude – look only at points greater than 1/500th of this
2. Amplitudes plus or minus 10 from peak must be at least 1/5th of peak – ensures fast fall off and shape
3. Bins plus or minus 3 from peak must have magnitudes lower than peak – ensure true maximum
4. If all met, index and magnitude are saved – index divided by recording duration gives our peak frequencies

Baseline Calculation

1. Went to bins 20-25 away from peak on either side
2. Calculated sum of bins for each side
3. Calculated average of sum for each side
4. Average for each side summed with the other then divided by 2 – Baseline!

Summary of Procedure

1. Constructed Recording Devices
2. Wrote and tested DAQ
3. Performed first set of piano recordings on Breadboard
4. Performed second set of piano recordings on PCB
5. Recorded additional instruments
6. Performed offline python data analysis that involved varies steps

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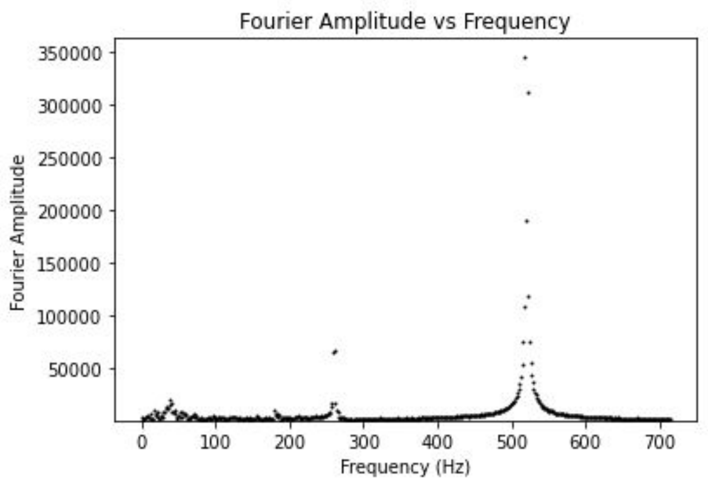
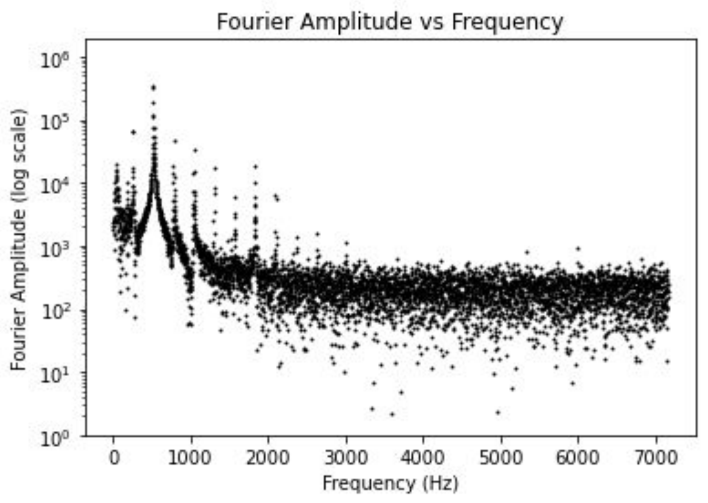
Results and Discussion

Here's what we got and what it means



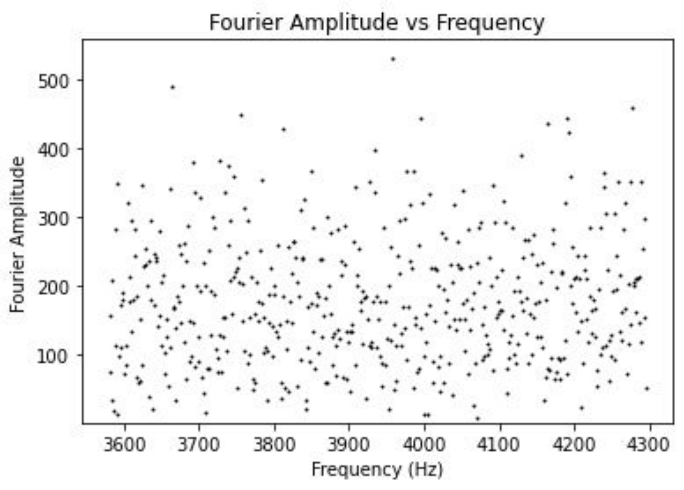


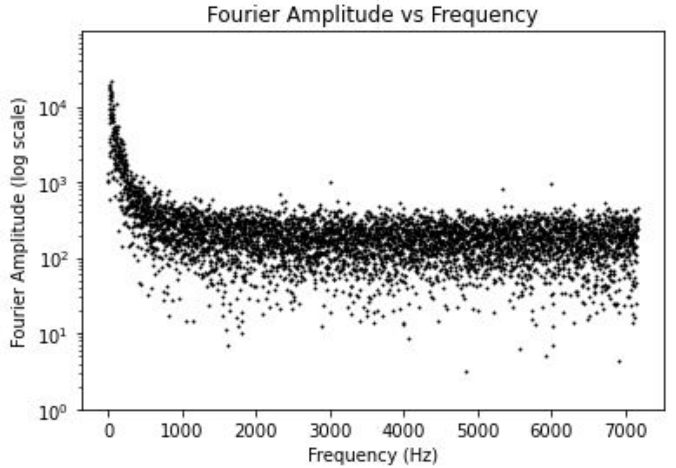
Piano Notes C4-C5

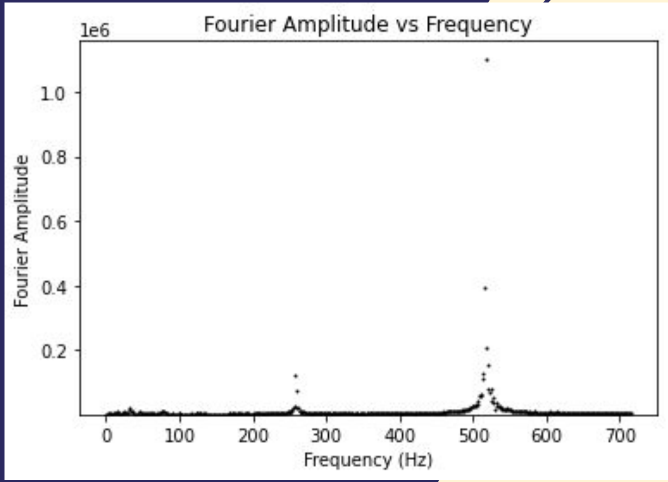
- The first peak (fundamental) is at 260.66 Hz and the second is at 518.46 Hz. The expected fundamental frequency of C4 is 261.63 Hz.
- The peaks are apparent on the frequency spectrum for each note and the fundamental frequency of each note within the C4-C5 scale in our data is relatively true to the expected fundamental frequency.
- The overtones of each note are also visible on the frequency spectrum with their respective amplitudes being higher than the amplitudes of the fundamental frequencies.
- We found it interesting that the overtones are relatively close multiples of the fundamental frequency.

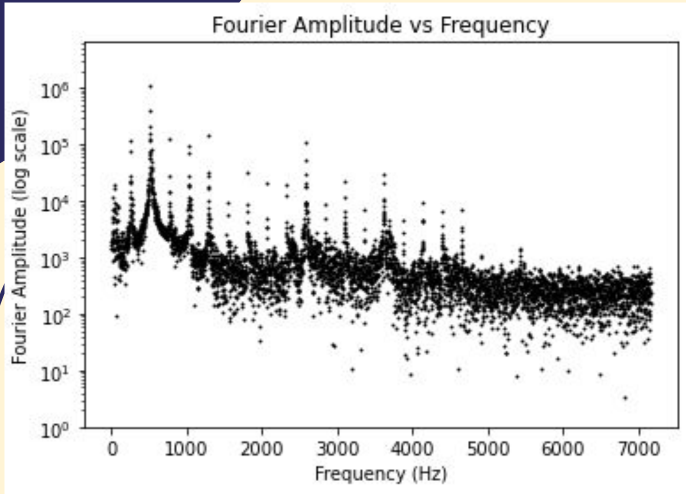
Piano Notes C7-C8

- The peaks are apparent on the frequency spectrum; however, they are not as clear.
- The overtone frequencies are less accurate than those in the C4-C5 scale.
- The first peak (fundamental) is at 4052.07 Hz. The expected fundamental frequency of C8 is 4186.00 Hz.
- As the notes increase in each scale, the further off the frequency certainty is.
- With the recorded frequency being 133.94 Hz less that the expected fundamental frequency, this is an implication of the note being flat.





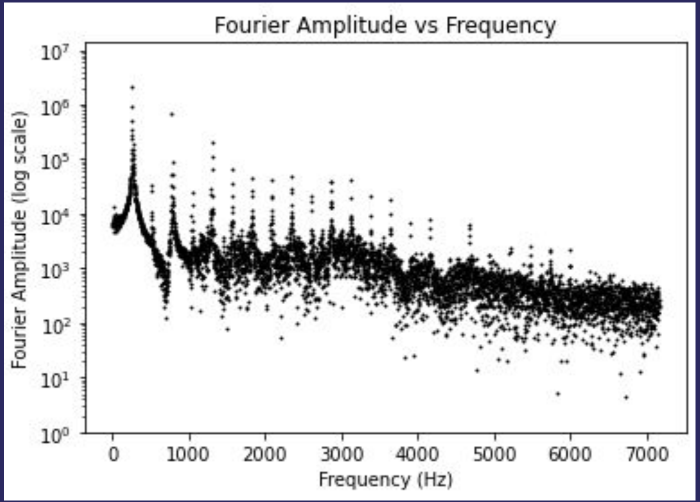


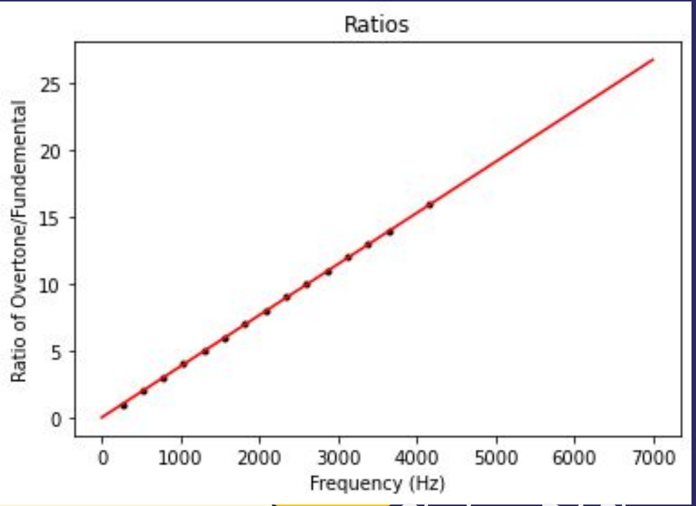


Violin Notes C4-C5

- The notes for C4-C5 on the violin behaved very similarly to the notes for C4-C5 with the peaks being extremely identifiable.
- The first peak (fundamental) is at 257.84 Hz and the second is at 517.10 Hz. The expected fundamental frequency of C4 is 261.63 Hz.
- It is important to note that with the violin, the overtones are greatly pronounced, meaning that when any note in the C4-C5 scale is bowed on the violin, these notes are more intense than what would be seen in the piano figures for the same C4-C5 scale.

Clarinet Notes D4-F#4 (C4-E4 Equivalent)



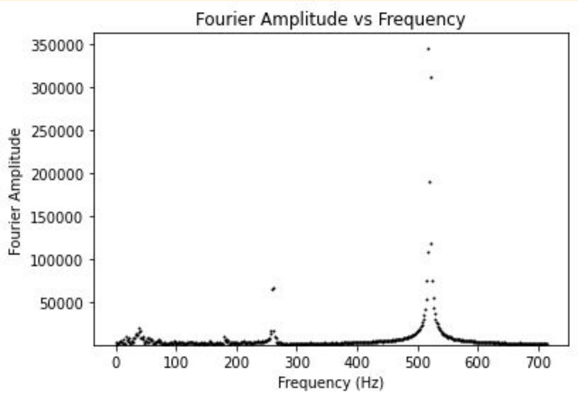


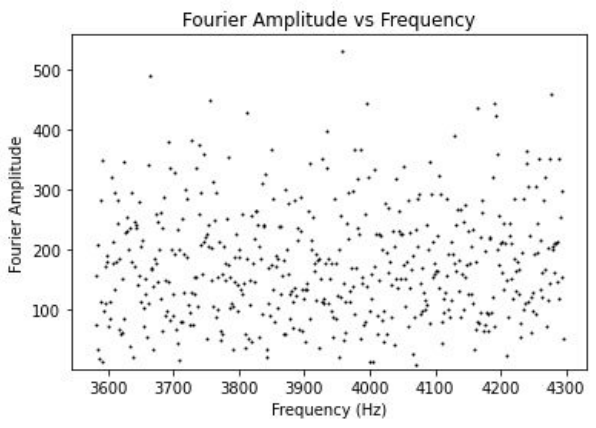
Clarinet D4 Plots

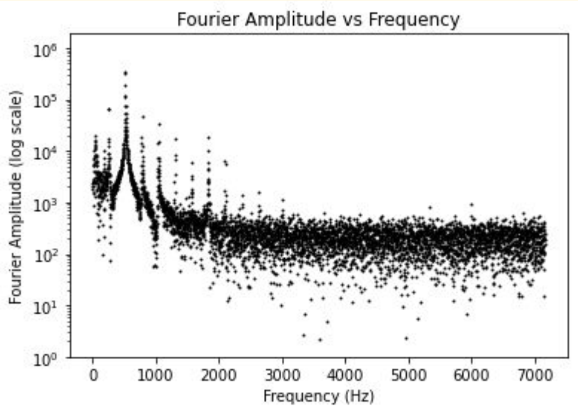
- Can easily see peaks in each spectra
- Fundamental for each note was within 1.5 Hz of expected - not much deviation here
- The fundamental frequency for each note had the highest amplitude
- Fundamental dominates spectrum - first harmonic dominates for piano and violin
- Amplitudes slightly higher than either of the other instruments - string wind difference
- Deviation of ratios, most of them were within 0.01 and max was 0.07
- The overtones were almost purely harmonics - little to no deviation of this - nothing was really that unexpected here

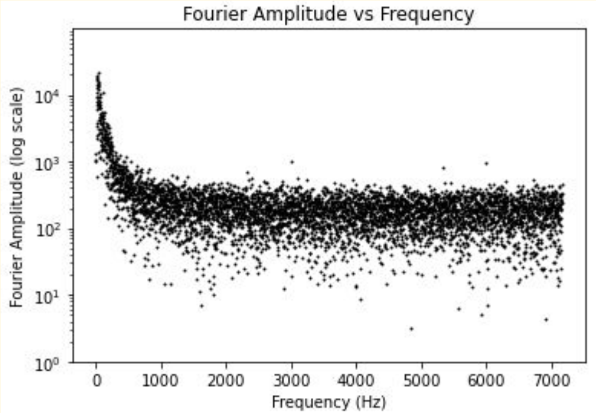
Piano C4-C5 vs Piano C7-C8

- When analyzing the overtones of each octave either qualitatively or quantitatively, we can see that the overtones are not exact multiples of the fundamental frequencies.
- With the higher octave, it is also detectable that the overtones are less clear in our figures because the higher overtones are the most inaccurate, making them more dissonant compared to the fundamental frequency.
- This means that more frequencies will be picked up and displayed in the figure because the higher notes on the piano produce overtones that are immensely out of tune with the fundamental.

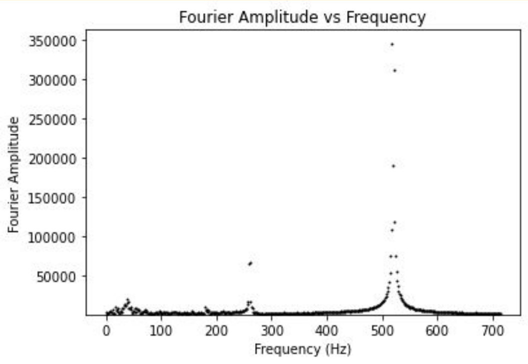


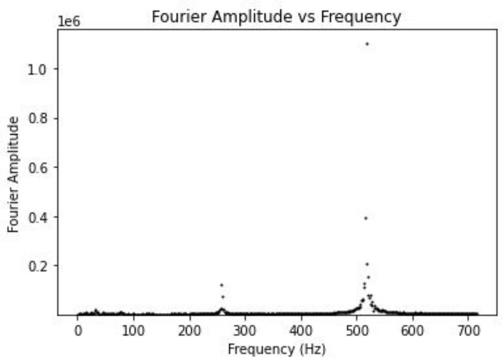


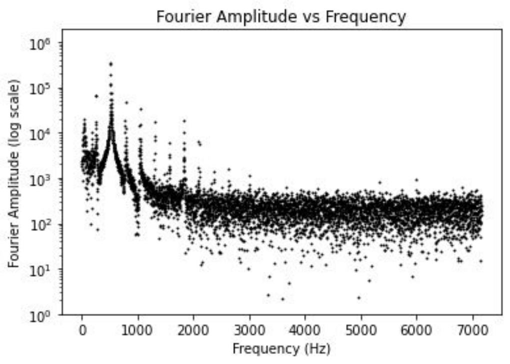


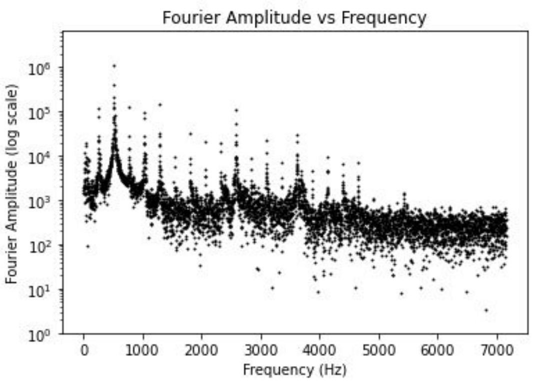


Piano C4-C5 vs Violin C4-C5





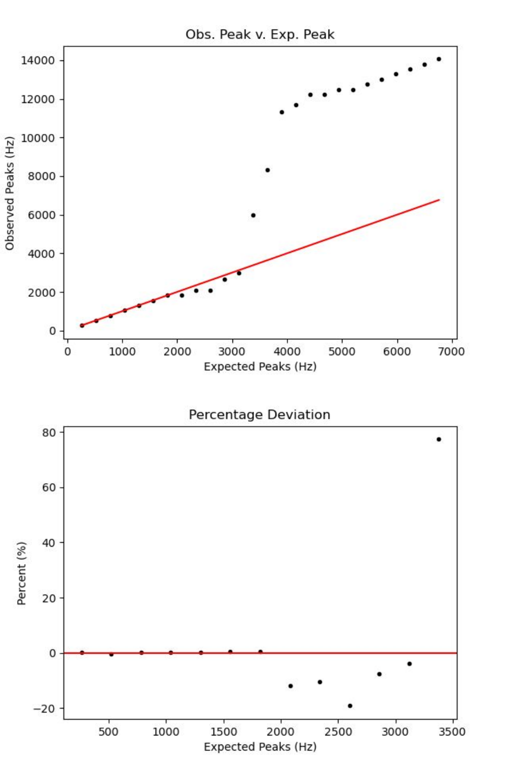




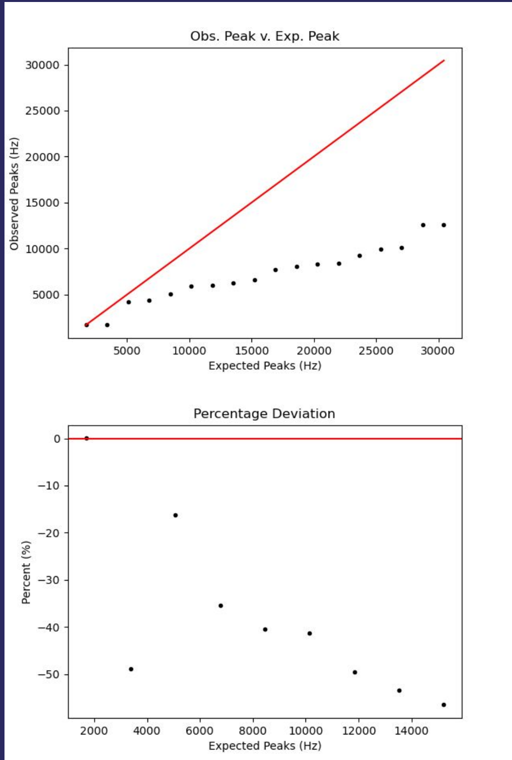
- We can see that the peaks of the fundamental frequencies, as well as a few of the preceding overtones from the violin, behave very similarly to the peaks displayed from the piano.
- This is probably due to the fact that they are both string instruments; however, it is worth noting that the violin's qualitative and quantitative data show that the violin produces much more overtones than the piano.
- The most reasonable explanation for this is that when a note is played on the piano, there is less sustained vibration because a hammer is striking the piano string once and then is released from the string, whereas when a note is played on the violin, the note being played is bowed continuously meaning there is more sustained vibration.

ADC File Comparison: C4 (Middle C)

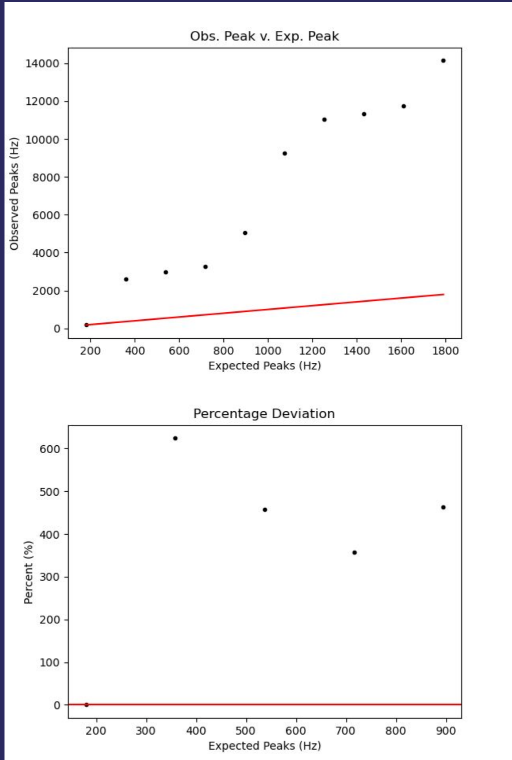
ADC0 (t=0s)



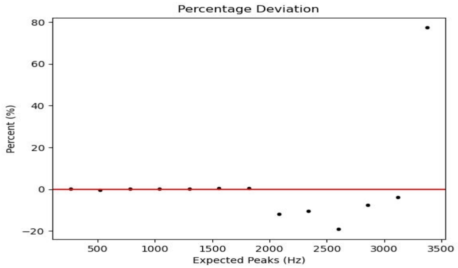
ADC10 (t=6s)



ADC19 (t=12s)



ADC File Comparison: C4 v. F4 v. G4



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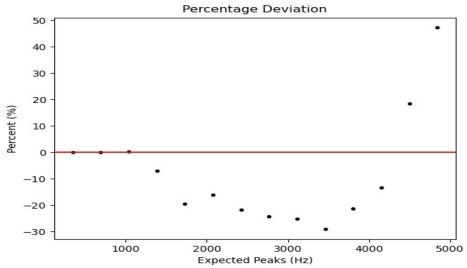

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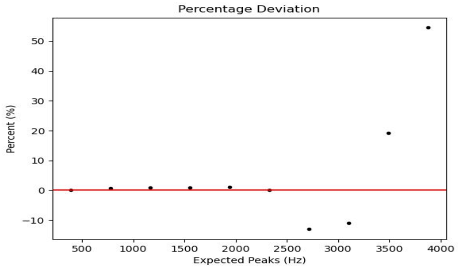

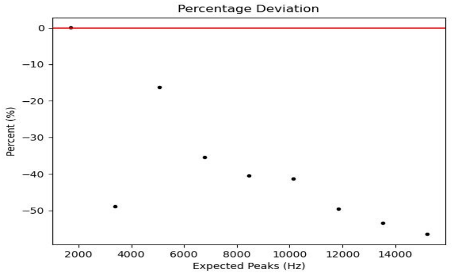

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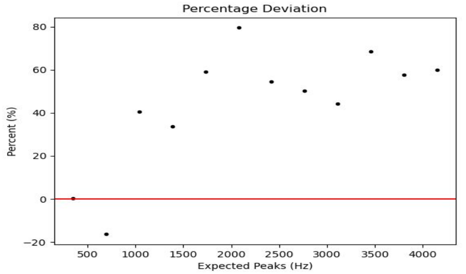

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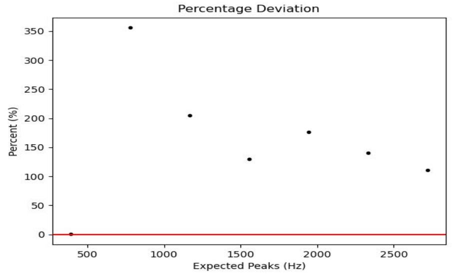

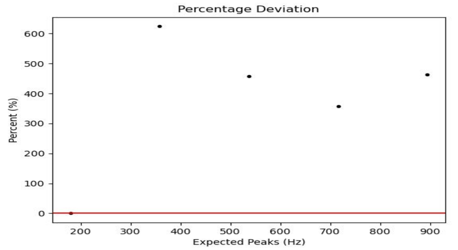

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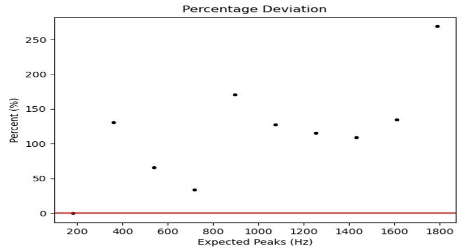

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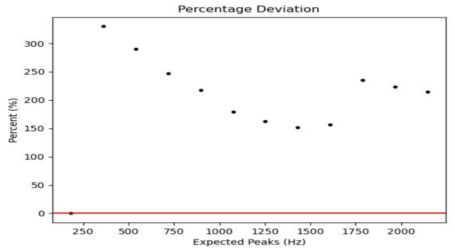
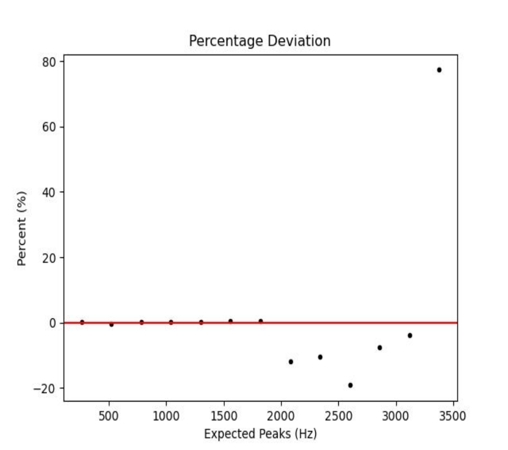


ADC File Comparison: C4 v. F4 v. G4



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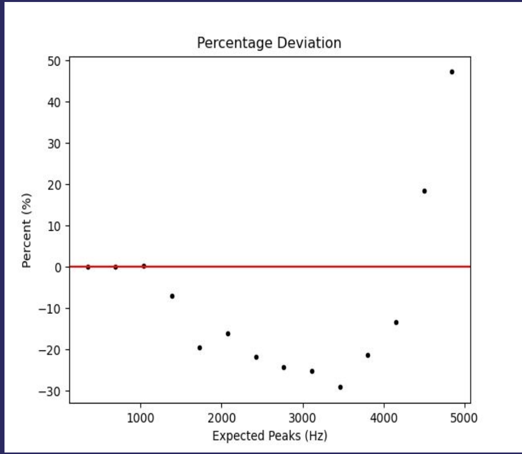

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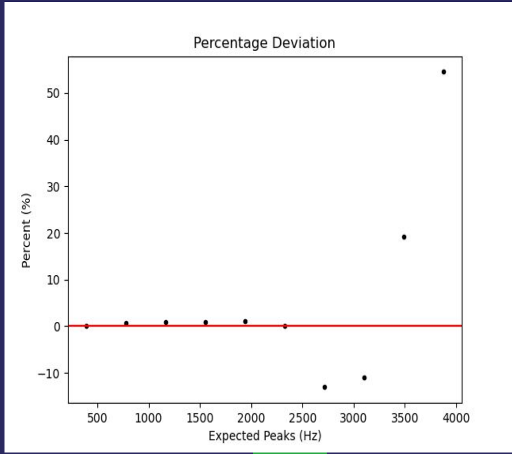
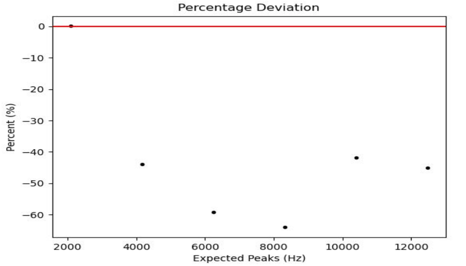
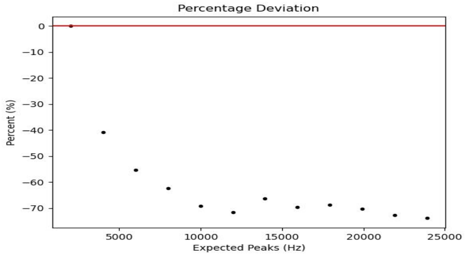
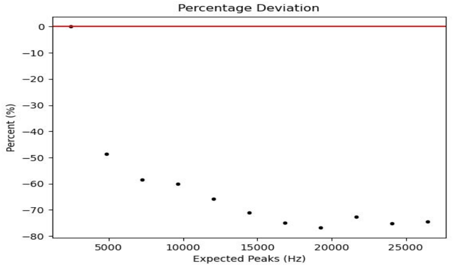
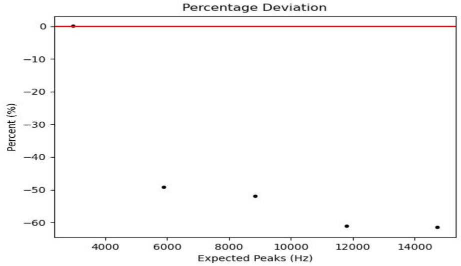


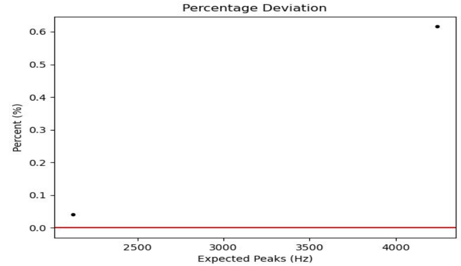
ADC File Comparison: C7 v. F7 v. G7

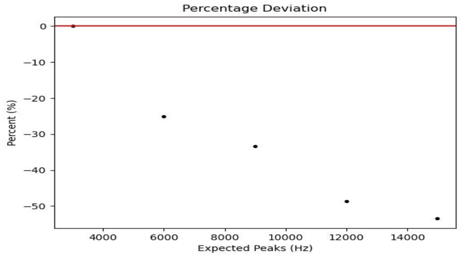


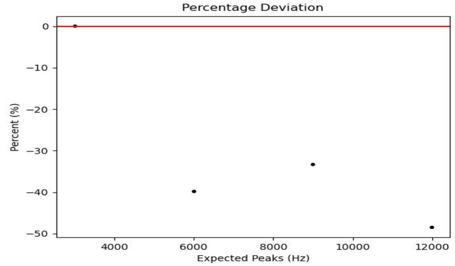


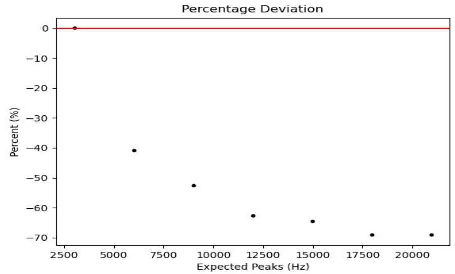


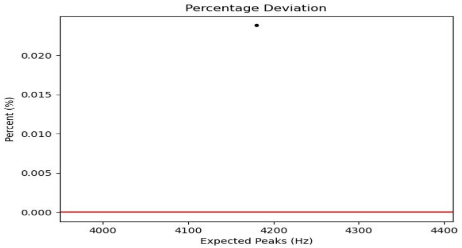




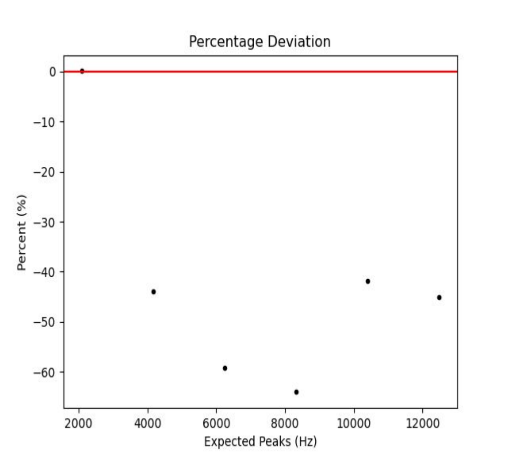








ADC File Comparison: C7 v. F7 v. G7



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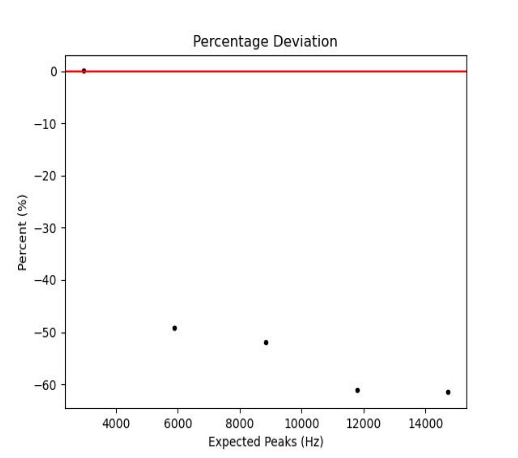
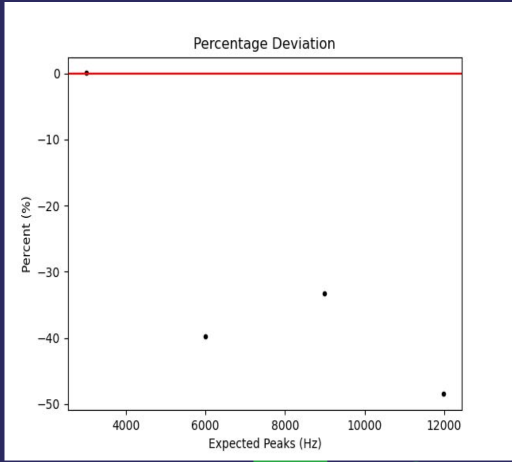
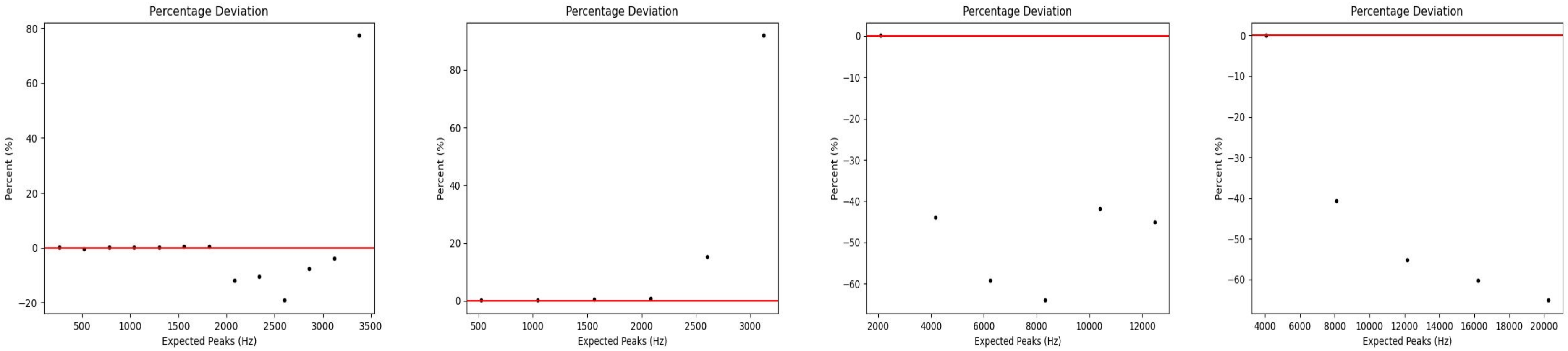


t=Os



ADC File Comparison: C4 v. C5 v. C7 v. C8



Conclusion

- Linear relationship between deviation of harmonic and fundamental ratios
- Deviation became more pronounced as octave increased on piano
- Rate of increase of deviation was higher for higher octaves

Future Directions

Many Potential Extensions

- Compare piano brands, shapes, or sizes
- Look at an Electric Piano
- Compare different types of electric pianos
- Look at environmental factors effects on overtones
- Compare more instruments
  - Woodwind to woodwind
  - Woodwind to brass
  - String to brass
  - Etc.
- Compare octaves for other instruments e.g. the clarinet

Thanks for Listening!

Do you have any questions?

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