# MUSIC 258D FINAL PROJECT

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## ABSTRACT

The current project consisted of constructing a tenor ukulele fitted with a piezo pickup to be used to record the playing of the ukulele. The piezo pickup was then processed to sound similar to an external condenser microphone in order to improve the overall sound quality of the ukulele recordings.

## 1. INTRODUCTION

Piezo pickups are a convenient way of capturing the sound of certain acoustic instruments. While external microphones may provide a clearer and more detailed sound, piezo pickups may be fitted onto an instrument and then directly connected to a mixing console or computer via an audio interface. Piezo pickups may provide a more portable and convenient method of amplification, especially in environments with many other instruments requiring sound reinforcement. Piezo pickups are also relatively inexpensive in comparison to traditional microphones, however there is a pronounced trade-off in terms of audio quality, especially with lower-end pickups. Microphones also more accurately mimic the position at which we tend to hear the sound from an instrument, making them often feel more accurate in their representation of an instrument's sound. The current project attempts to mitigate this trade-off through the digital processing of a piezo pickup in order to get a clearer, more microphone-like sound, while maintaining convenience and affordability.

## 2. METHODS

The first part of this project consisted of assembling the tenor ukulele using a StewMac Ukulele Kit [1]. The StewMac kit provided the separated body components as well as instructions to assemble the various parts into the finished ukulele. Assembly required gluing together the body, followed by installing the neck and fretboard and finally stringing and tuning the strings. The pickup was installed by taping the two piezo components close to position 2 as depicted in Figure 1. The piezo used was the EP003K two-balanced passive piezo pickup from Journey Instruments. A hole was also drilled in the bottom of the ukulele to house the pickup cable.

The second part of this project consisted of processing the pickup signal. Recordings of the tenor ukulele being played were captured using the pickup, as well as with a condenser microphone placed in a similar position to that shown in Figure 2. Recordings were taken in order to capture the frequency response generated by playing the ukulele in C-tuning. A range of different material was recorded to span the range of frequencies likely to be manufactured in the playing of the instrument. The full recording used in the final processing scheme was 400 seconds in duration.

Figure 1: *Pickup placement diagram [2].*

Figure 2: *Microphone placement diagram [3].*

A short-time Fourier transform was then taken of both the microphone and pickup signals and averaged across the time samples to generate an approximate frequency response for each of the microphone and pickup in reference to the tones used by the ukulele. The two frequency responses were then smoothed using a Savitzky-Golay filter [4], depicted in Figures 3 and 4. A filter transfer function was then generated by dividing the mic frequency response by the pickup frequency response in order to transform

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a new pickup signal into a signal more similar to the microphone response [5] (Figure 5).

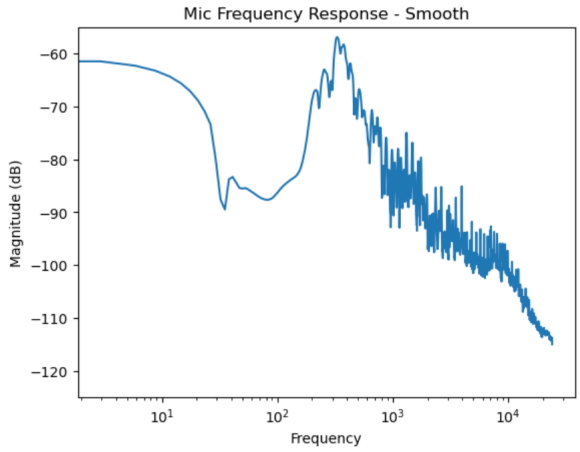


Figure 3: *Microphone frequency response smoothed using a Savitzky-Golay filter.*

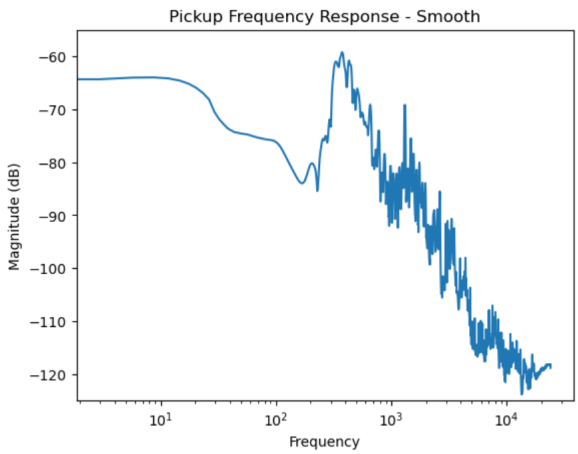


Figure 4: *Pickup frequency response smoothed using a Savitzky-Golay filter.*

This transfer function was converted to a minimum phase filter using the Hilbert transform, in order to preserve the original phase. The equation to transform the existing filter into a minimum phase filter is shown in Equation 1 [6].

$$H_{min} = e^{\log|H(\omega)| - j\mathcal{H}\{\log|H(\omega)|\}} \tag{1}$$

After taking the inverse Fourier transform of this transfer function, the end was cut off, generating a 1000 sample long FIR filter (Figure 6). The frequency response of the resulting filter is shown in Figure 7.

A new signal from the pickup could then be convolved with this filter to make the spectrum more similar to that recorded using

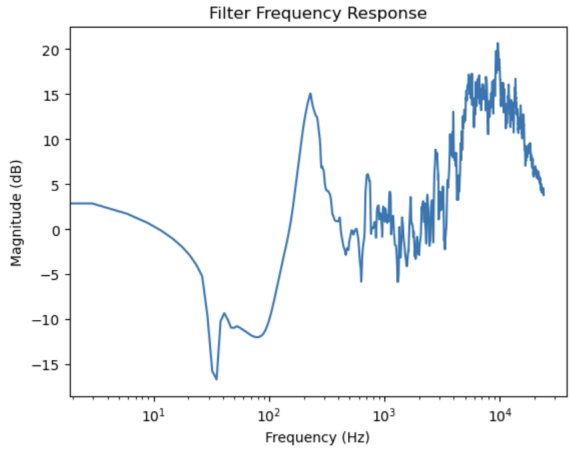


Figure 5: *Filter frequency response after dividing the microphone frequency response by the pickup frequency response.*

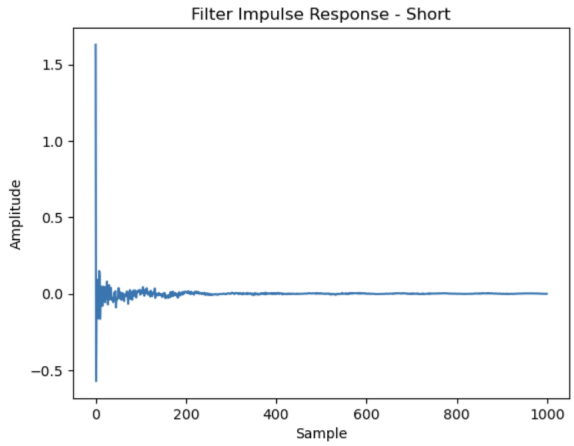


Figure 6: *Filter impulse response.*

the microphone. Finally, two notch filters were added after this initial processing scheme to further improve the sound quality. These filters were IIR filters created with a center frequency of 27Hz and 450Hz, both with a quality factor of 5. The filter frequency responses are shown in Figures 8 and 9. The parameters for these two filters were chosen to improve the quality of two different test signals consisting of the ukulele being strummed, as well as by comparing these test signals in the frequency domain.

## 3. RESULTS

Figure 10 shows the completed tenor ukulele build with the pickup installed.

A test signal was used to assess the results of the pickup processing. Figures 11-13 show the frequency domain plots of the test signals, both processed and unprocessed, depicting the output behavior of applying the filtering methodology. The test signal used in the depicted plots consists of a few different chords being strummed. These plots demonstrate how the processing of

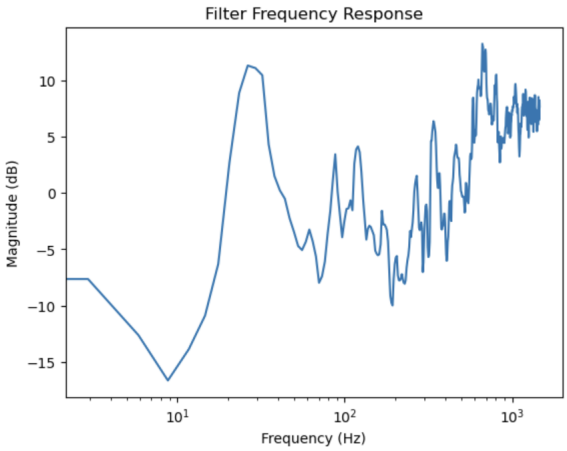


Figure 7: *Filter frequency response.*

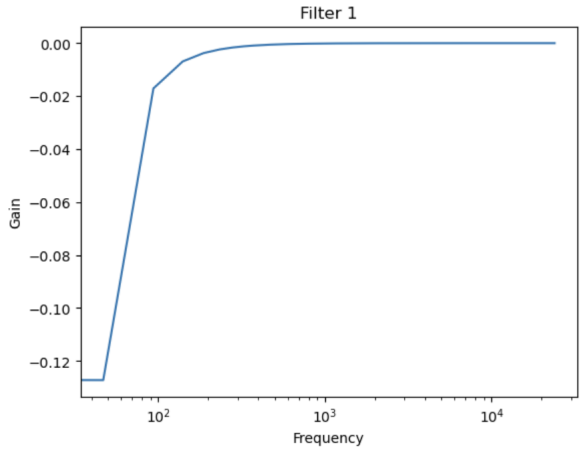


Figure 8: *IIR notch filter 1 frequency response.*

the piezo pickup succeed in achieving a frequency response that is more similar to that of the same content recorded with the microphone. However, the processed signal still maintains distinct characteristics of the original pickup frequency response and is unable to completely match the microphone response.

## 4. DISCUSSION/CONCLUSIONS

The tenor ukulele created in this project is fairly effective at producing accurate tones and a relatively clear sound. The choice of a tenor ukulele, as opposed to a concert or soprano, may have also proved beneficial given that the pickup succeeds more in reproducing lower tones in comparison to higher ones. However, there were some issues that arose in the building of the ukulele that likely impacted the quality of sound. Most notably, there were some gaps in the sides and the top and the back of the ukulele. In retrospect, the assembly and gluing procedures could have been refined to ensure components did not slide to become out of alignment as pieces were attached together. With additional time, using a less stiff top plate material may have improved the sound of the ukulele as well.

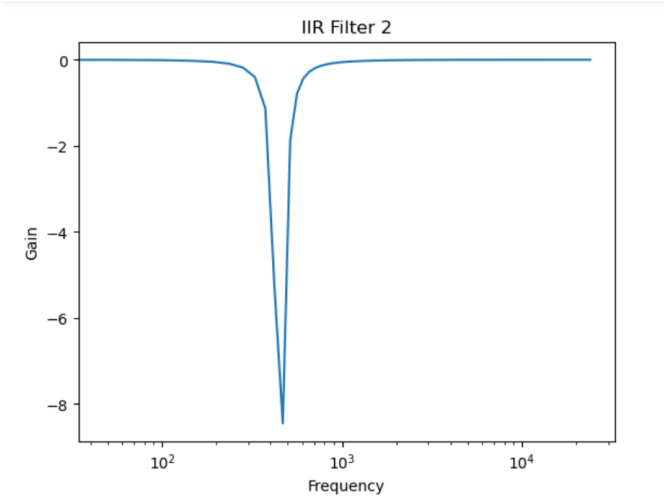


Figure 9: *IIR notch filter 2 frequency response.*

Figure 10: *Ukulele build.*

Another issue arose in the installation of the pickup, which would likely sound best arranged in position 1 as shown in Figure 1. In reality, it is placed more closely to position 2, yet the pickups are also somewhat out of alignment and asymmetrical due to the difficulty in installing the pickups after assembling the ukulele. In retrospect, the pickups may have been able to be placed in a more desirable fashion by attaching them before gluing the top plate.

For the pickup processing component of the project, there are a few aspects that may have further improved performance. The use of the filters to transform the pickup signal into more of a microphone-like signal was able to alter the frequency components of the pickup signal to increase some clarity and brightness.

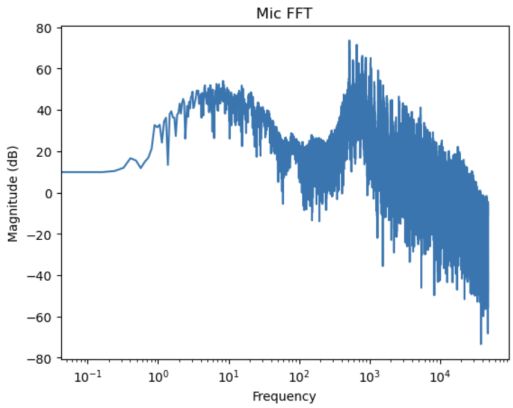


Figure 11: *Frequency domain representation of the test signal recorded using an external condenser microphone.*

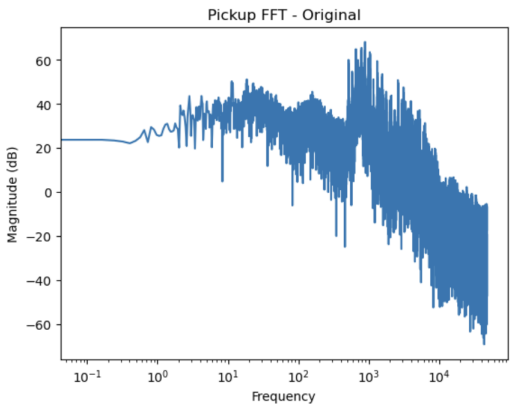


Figure 12: *Frequency domain representation of the test signal recorded using the piezo pickup (without any additional processing).*

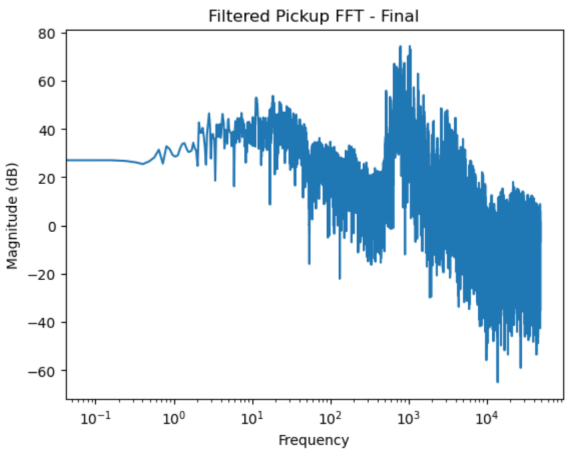


Figure 13: *Frequency domain representation of the processed piezo pickup signal.*

However, there is still a significant difference in the quality of the microphone signal and the pickup signals. The filtered signals still remain pretty muddy in the low frequencies and the high frequency components are not as bright and clean as the microphone signal. There also seems to be some added noise in the high frequencies. More investigation into the low frequency components of the signal may yield some insight into ways to improve this initial design. However, given that the pickup does not capture much of the high end of the ukulele to begin with, further boosting the high frequencies would likely degrade the signal quality.

Further work could expand on this investigation by comparing different types of pickups to see which may be optimal for capturing more of the desired high end. In addition, due to timing constraints, the input signal used to generate the frequency responses for the microphone and pickup were only about 400 seconds in length, containing significant silence, and may not have captured all of the desired frequency range, including those introduced with different tunings. Expanding the range of input content may have been able to more appropriately capture the desired frequency response and thus generate a better overall filter. The method employed in the pickup processing also fails to consider any time varying effects that may differ between the microphone and pickup responses, as well as any frequency components of the pickup signal, which may be attenuated through this procedure which may worsen the sounds quality. A more nuanced approach might focus on specific frequency bands and employ different filters or degrees of change based on different bands of frequencies.

## 5. REFERENCES

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