Project Assignment: Audio Signal Processing for Bird Sound Isolation

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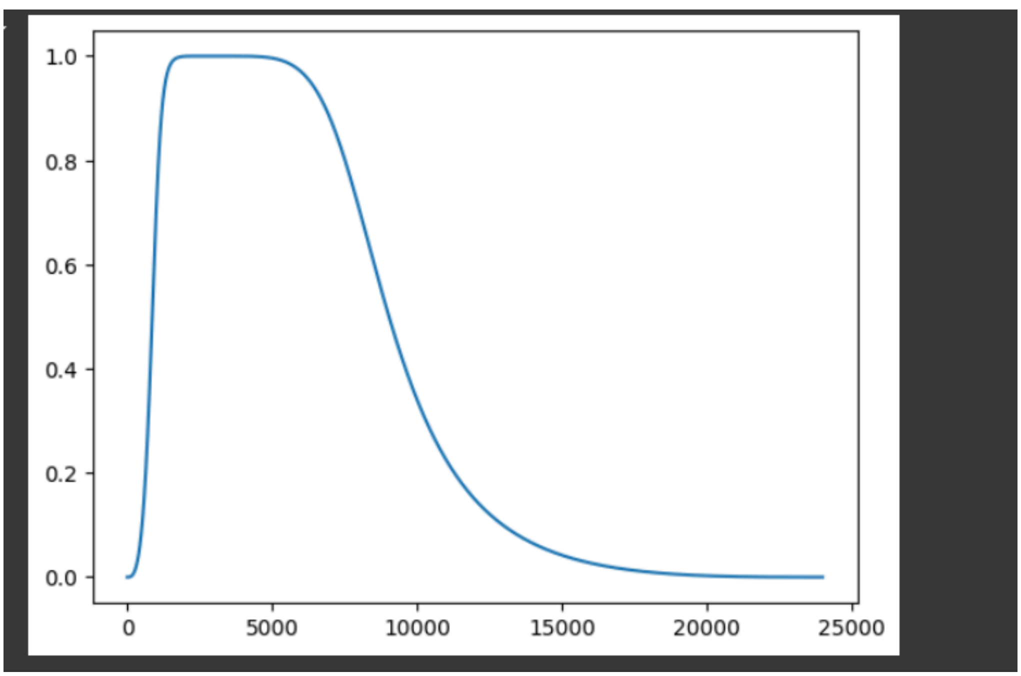
Objective:
The goal of this project is to analyze an audio recording to identify and isolate the sounds of birds and a plane. This involves plotting time and frequency representations of the signal, applying filtering techniques to isolate the bird sounds, and removing the bird sounds to isolate the plane sounds.

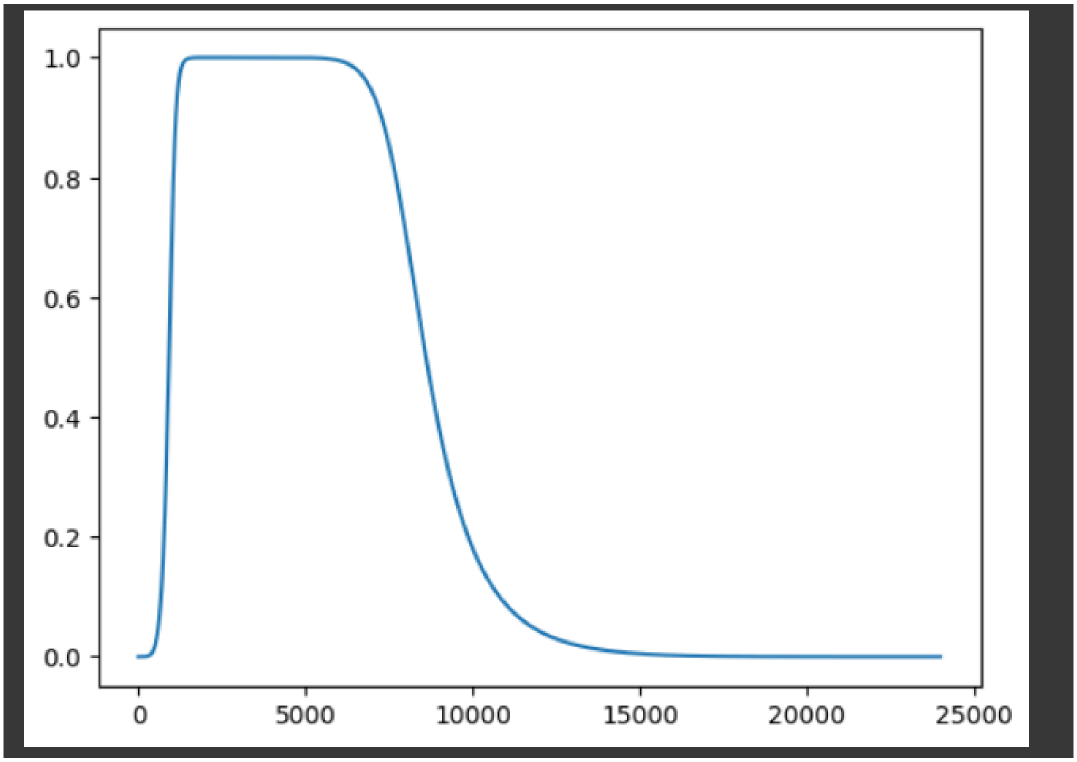
<u>Isolating the bird sound:</u>
To use a bandpass filter to capture the signal between a specific period of frequency. Because the bird sound is normally between 1000 and 8000 Hz. Therefore to use this filter for the original signal and to get a voice only has the bird sound. This process containing the following steps:

1. Designing the bandpass filter and applying the different order numbers (3,5,and 7) to observe its difference based on the graph we plot.
2. Applying the filter to the original one
3. To save the filtered audio and transform it into audio
4. Overlay the fft of filtered signal to the original one and analyze its domain and the response.

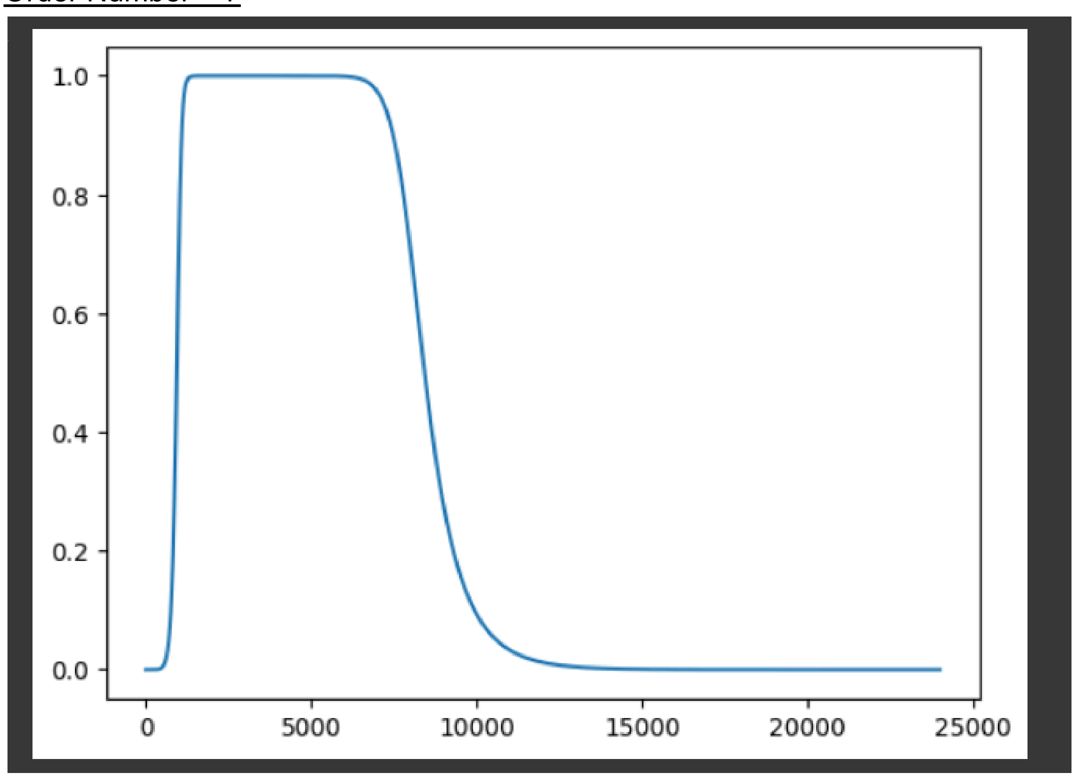
<u>Observation of Different Number of Orders:</u>
<u>Order Number = 3</u>



Order Number = 5



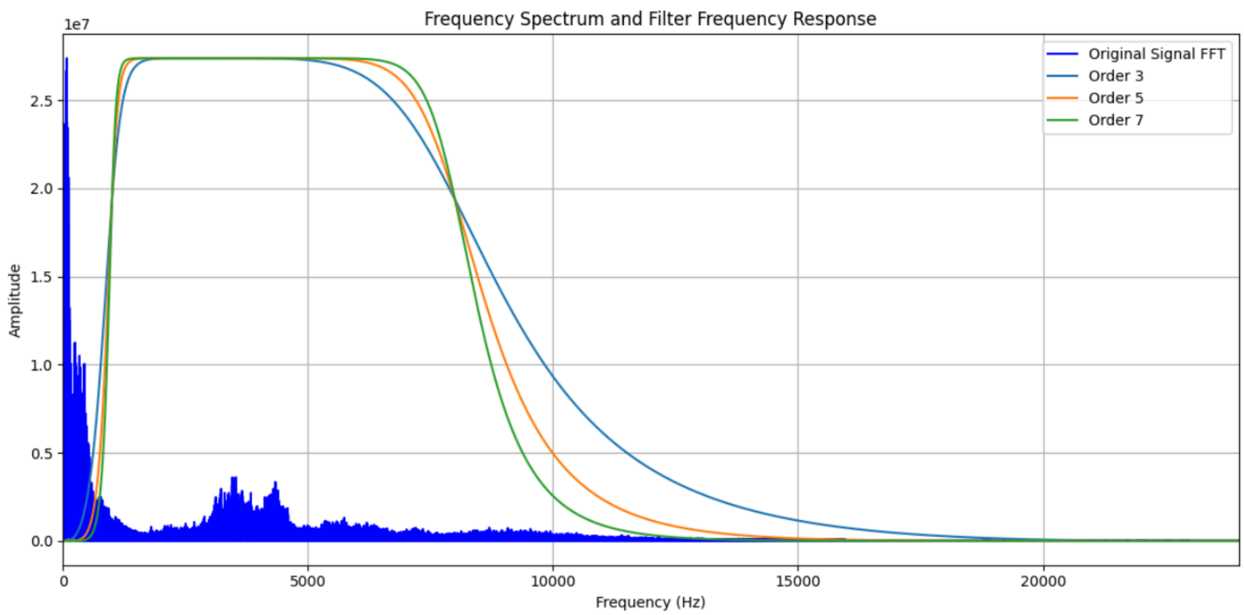
Order Number = 7



Observation

Based on the three graphs above, we can see that as the number of orders increases, the sharpness of the signal is increasing also. Normally, as the sharpness increases, there will be more sound to be filtered. But if we set the order number extremely high, which makes the wave almost vertical to the x-axis, that will make the filtered signal to be exactly between 1000 and 8000 Hz. This is inappropriate to use in real life.

To check the performance of the filtered signal, we overlay these three signals into the original one and show the graph below:



Observation

Because of this audio, its amplitude is relatively low.The sharpness of the filter does not that much affect its performance. We have generated the audio based on these three order numbers, to be honest, we did not hear the difference between them. But we did the test once we setted the order number to be very large like 40, it will have less sound than the lower order number ones. This means although the order number larger can have better filter performance, there will be the problem of sound quality.

Based on the investigation, it is necessary to find the order number to balance the sound quality and the filter performance. To achieve this goal, we think it is better to adjust the number and listen to the audio at the same time. Once you have the comparison between all possible numbers of orders, at least we can choose a range of it which can be seen as the acceptable range and then try to focus on.

Isolating the plane sound:

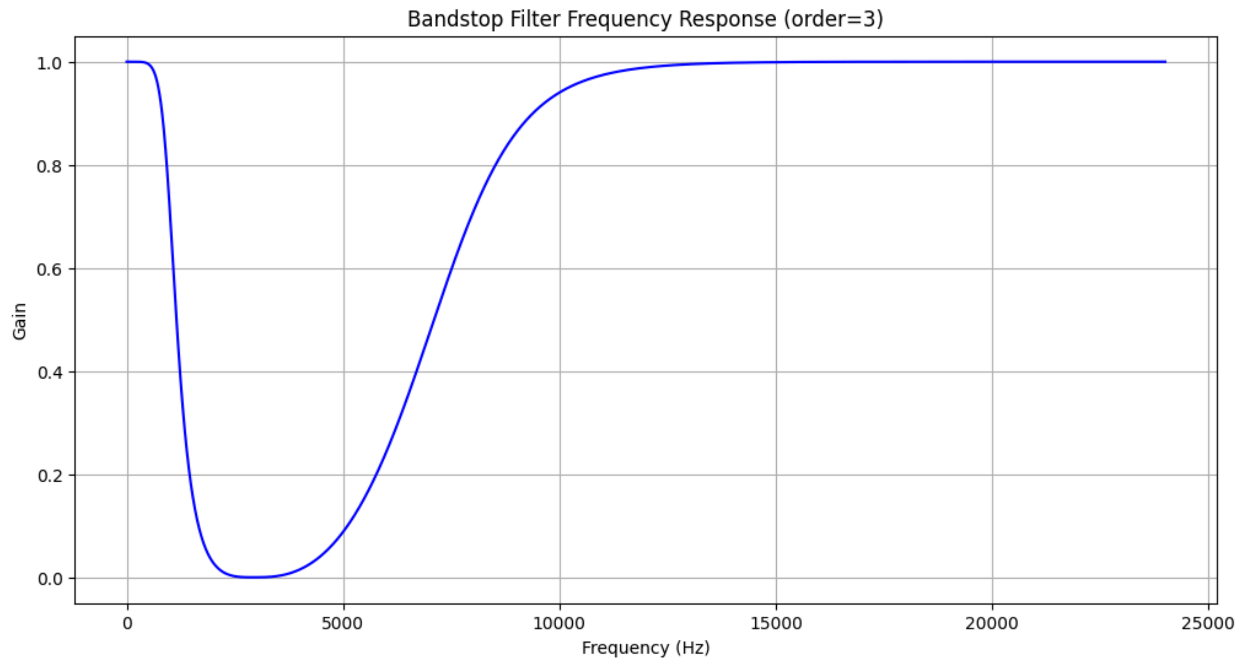
The goal of this part was to apply a bandstop filter to an audio signal containing both bird and plane sounds, aiming to isolate the plane sounds by attenuating a specific frequency band. The bandstop filter was designed to remove frequencies between 1000 Hz and 8000 Hz. This process involved the following steps.

1. **Designing the Bandstop Filter**: The bandstop filter was designed using the Butterworth filter design method, which is known for its smooth frequency response. The filter was applied with three different orders (3, 5, and 7) to observe the impact of filter order on the filtered signal.
2. **Applying the Filter**: The filter was applied to the audio data using the `filtfilt` function, which performs forward and backward filtering to eliminate phase distortions.
3. **Saving and Playing Filtered Audio**: The filtered audio signals were saved as new WAV files and played back to allow auditory inspection.
4. **Frequency Domain Analysis**: The frequency responses of the original and filtered signals were analyzed by plotting their FFTs, along with the frequency responses of the designed filters.

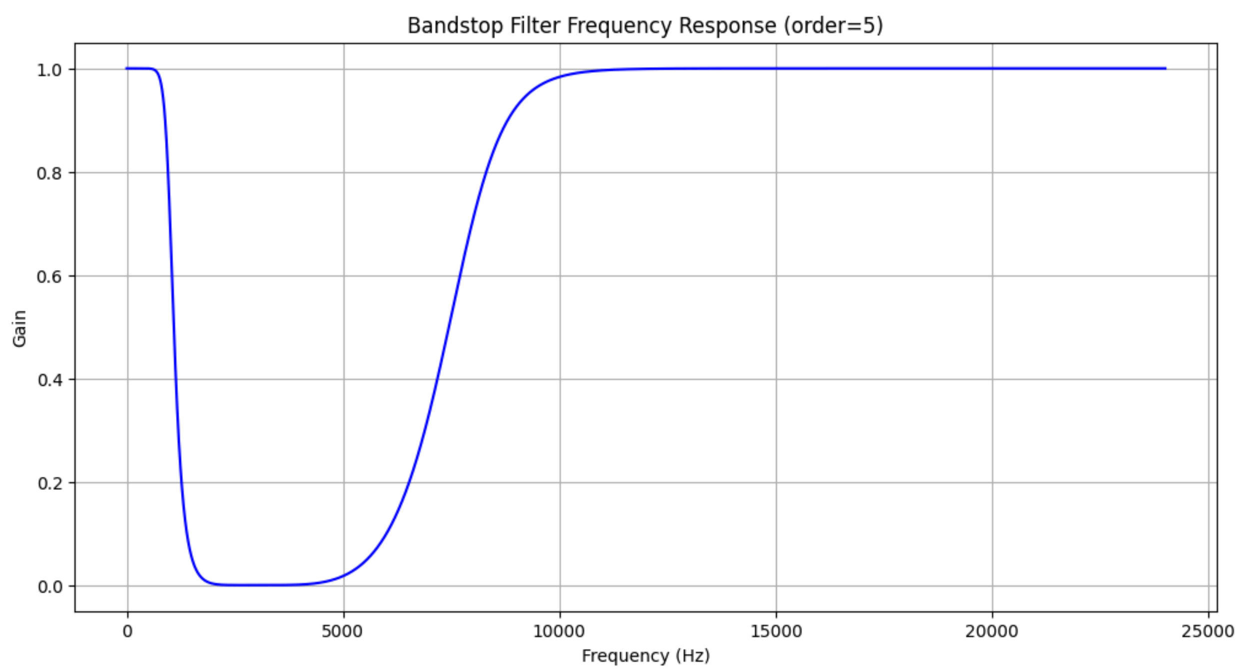
Impact of Different Filter Orders on the Audio Signal

The order of a filter determines the steepness of the filter's transition band, which is the range of frequencies where the filter transitions from passband to stopband or vice versa. Higher-order filters have steeper transition bands, which means they can more precisely target specific frequency ranges. However, they also introduce more complex phase responses and can lead to greater computational complexity.

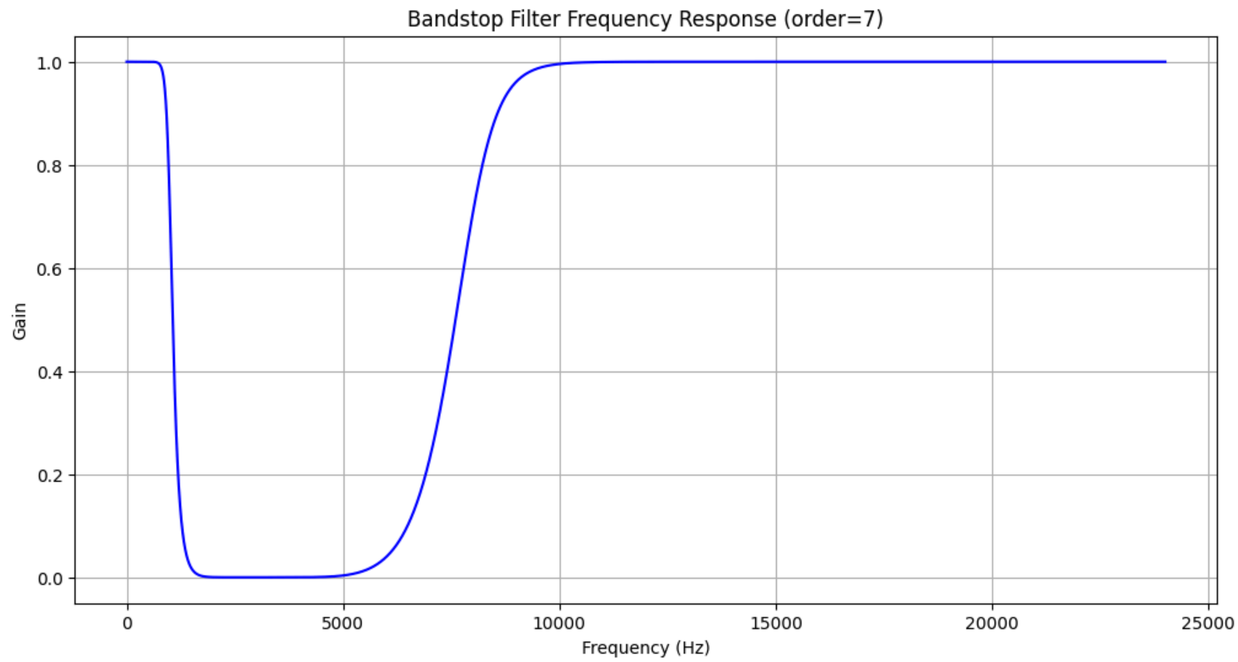
Observations for Different Orders:



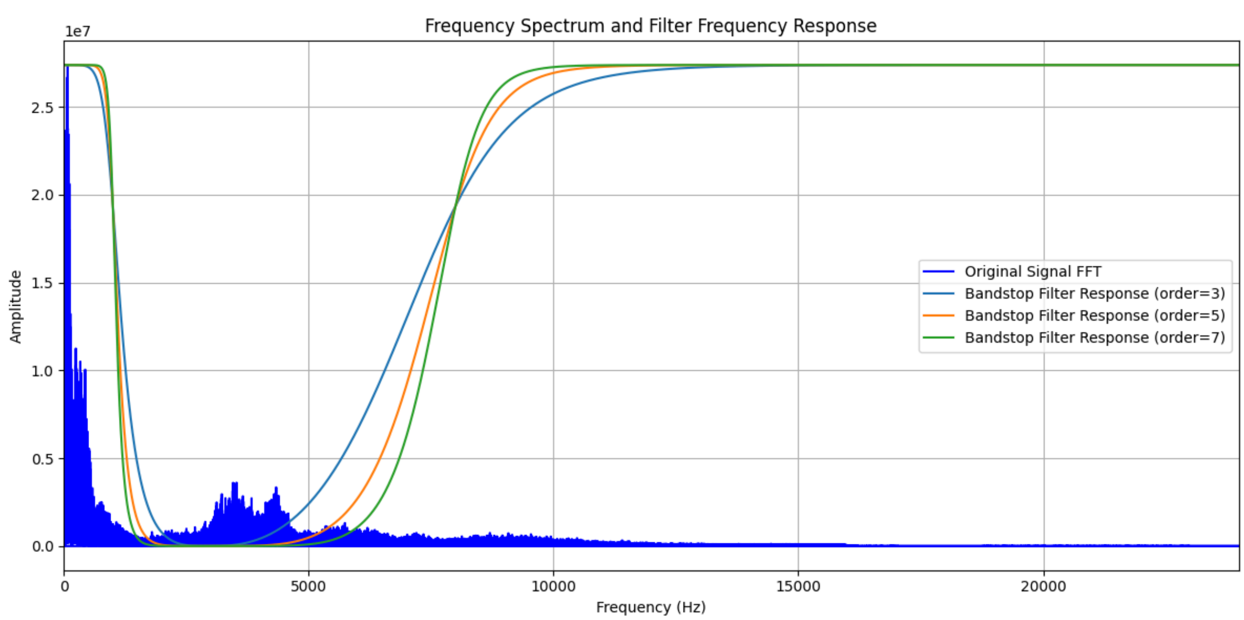
Order 3: The filter has a relatively gentle slope, meaning it starts attenuating frequencies slightly before 1000 Hz and doesn't fully attenuate until slightly after 8000 Hz. This results in a smoother transition but less precise filtering.



Order 5: This filter has a steeper slope compared to the order 3 filter. It more effectively attenuates the targeted frequency band while preserving the frequencies outside this range. This is a good balance between complexity and performance.



Order 7: This filter has a very steep slope, which means they can quickly and sharply attenuate frequencies around their cutoff points. This steepness makes them great for precise filtering tasks where exact frequency control is crucial. However, they can introduce more unwanted effects in the time domain, like echoes or ringing, and they require more computational power to process compared to lower-order filters.



Observations and Insights

1. **Effectiveness of Filtering**: The bandstop filter effectively attenuated the specified frequency range, which was evident from both the time-domain waveform and the frequency-domain FFT plot. The filtered audio files confirmed that the plane sounds, primarily within the targeted frequency band, were significantly reduced.
2. **Impact on Audio Quality**: Higher-order filters provide more precise attenuation of the targeted frequencies, but this can lead to ringing sounds or changes in how the sound is heard, affecting overall audio quality.
3. **Trade-offs in Filter Design:** Choosing the right filter order involves balancing how sharply the filter cuts unwanted frequencies with how much processing power it needs. Higher-order filters need more computing resources and can introduce unwanted sounds, whereas lower-order ones may not cut out enough of the unwanted frequencies.
4. **Practical Uses:** The filter order should match what's needed for the task. For instance, in communication systems where exact frequency control is crucial, a higher-order filter might be necessary. But for real-time audio processing where speed matters, a simpler filter might be better.
5. **Listening Tests:** Finally, listening to the filtered audio is essential. While graphs like FFT plots show us what the filter does visually, our ears can catch small changes that graphs might miss. In this project, listening tests confirmed that the airplane noises were reduced without making the bird sounds too distorted.

Conclusion

This project emphasized the need to select the right filter order, considering precision, computational demands, and maintaining good audio quality for different applications.