Cancelled

A FFT Characterization of Noise Canceling Headphones

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Introduction

There are multiple kinds of noise canceling headphones. There are passive noise canceling, which block noise physically with their presence - like ones you would find in the shop spaces. Then there is active noise canceling (ANC) which uses a variety of techniques to “digitally” cancel noise. These headphones do include passive noise canceling by nature - they go on/over your ears which blocks sound - but they also play white noise and/or “inverse” frequencies.

White noise is often played by noise canceling headphones to increase the “floor” of what you can hear (in terms of dB). This “covers” many quiet/small sounds because you will hear the white noise over whatever outside sounds are happening. This is useful because it masks many irritating irregular sounds such as typing, papers moving, and the like.

The other method of ANC is detecting a sound(wave) with a built-in microphone, determining the frequency, and producing this frequency, but shifted 180 degrees thus creating the inverse wave. This cancels out the sound. This prevents the user from hearing the outside sound created or at least greatly reduces it. The user does not hear the “inside” sound produced to counter the outside sound.

Noise canceling is used for hearing protection, medical, and sensory needs. Noise canceling headphones can be useful for these purposes, but are far from perfect and do not work in every application. Depending on the headphones, they will muffle human conversation (sometimes desired), miss bothersome ranges of frequency, and bother people with white noise. We intend to use DFT to better understand how these headphones work by dissecting the sound that can be heard through them.

Engineers who have designed noise canceling headphones have to design headphones that prioritize certain frequencies and block them out, but at the same time also created the problem of white noise in order to solve the greater problem of cutting out the major frequencies in a system. Engineers must prioritize cutting out certain frequencies while balancing out the amount of white noise that the headphones create.

How ANC headphones are able to do any detecting of the outside world is through microphones that periodically listen to outside sound waves, shift that sound, and play an “inverse wave” to cancel out the sound, all as shown in the system image below.

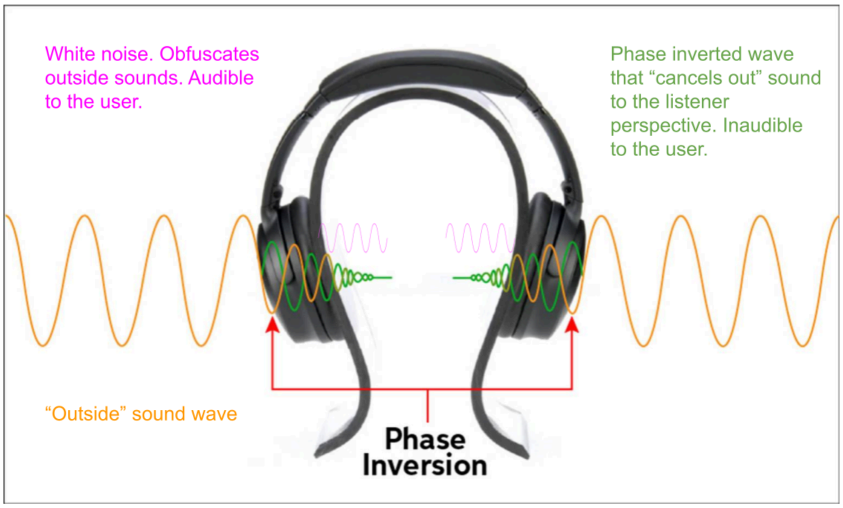

Figure 1: A graphic representing how ANC headphones work, and what they add and remove from a system. Edited from: https://www.sweetwater.com/sweetcare/articles/how-do-noise-canceling-headphones-work/

Data Collection and Analysis

We used the library sound studio and a mic pack in order to collect our data. We closed the microphone in a pair of noise canceling headphones, and plugged the receiver into the soundboard. We used the soundboard to minimize the noise inherent in the space, and adjust the gain of the microphone so it would “hear” similarly to human ears. We then created different sounds which would be picked up by the headphones. These sounds were in thoroughly different ranges of frequency to test the headphones over a wide range. We recorded what the microphone heard from these sounds and saved each of them to a .wav (uncompressed) file at a sampling rate of 44100Hz (standard rate for most audio sources).

For each sound, we recorded the audio with the headphones open (no noise canceling), headphones closed (passive noise canceling), and with the headphones closed with ANC on (passive and active noise canceling). This way we can compare how the different aspects of noise canceling affect the audio as well as how the headphones handle different kinds of sounds.

Figure 2: All of the steps that we took in our experimental setup to record our data.

We attempted to minimize noise by using the Sound Studio. However, the Olin library is not a quiet space, so hints of Justin Bieber and Mariah Carey Christmas music permeate each of our tests. The HVAC is also rather loud in this room. It also turns out that noise is created by the minute shaking caused by a human holding the headphones closed. We could have found a clamp to hold the headphones shut, eliminating that source of noise. However, we realized this after taking most of our data and in the interest of time (for PIE) we decided not to retake the data.

We took the data that we collected from recording the microphone via Audacity, and we viewed the audio in MATLAB and used the FFT function on it to take our data and convert it into frequencies. To get the magnitude of each frequency, we take the absolute value of the output we get from the FFT and we square it afterwards, and then divide it by the length of our data.

$$|fft(\frac{data}{length(data)})|^2$$

Eq 1. How we calculate our magnitude.

Each frequency has a magnitude associated with it, resembling how much it shows up in the audio clip that we constructed in our system.

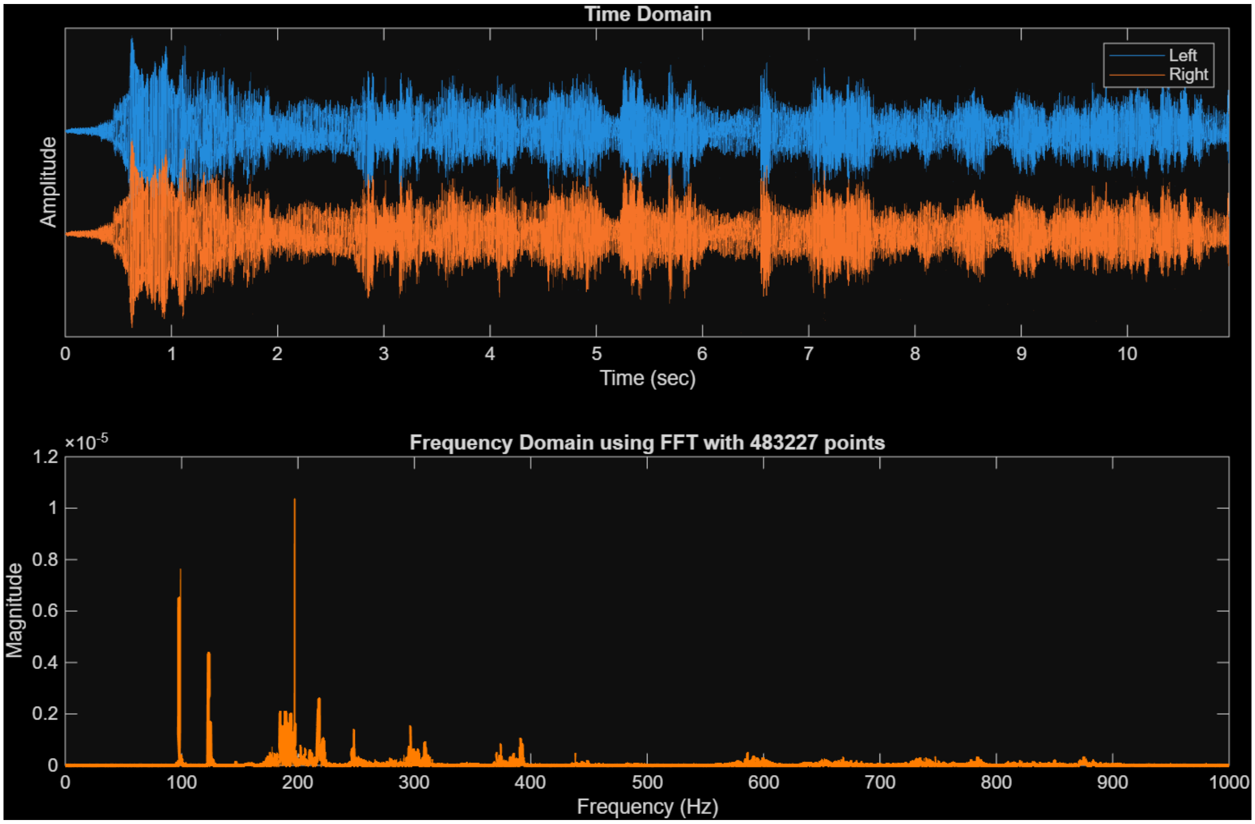

Figure 3: The original time to amplitude plot that you would see with sound recordings, and its accompanying DFT plot, to show the conversion from a sound to the frequencies that that sound has and their magnitudes.

We saved all of the magnitude data and its associated frequency list and used them to plot each of the scenarios (open, closed, and closed with ANC on) against each other to see what changes between the scenarios and how effective ANC is at doing its job.

Results

We split the plots into 3 different scenarios, with each of them being their own DFT plot showing the magnitude of each particular frequency. We put the 3 scenarios next to each other to show the changes that each stage makes to the frequencies received by the microphone, but also to show the effectiveness of passive and active noise canceling. We had 5 scenarios, but we want to show 3 in this report that emphasize the changes that ANC makes to background noise.

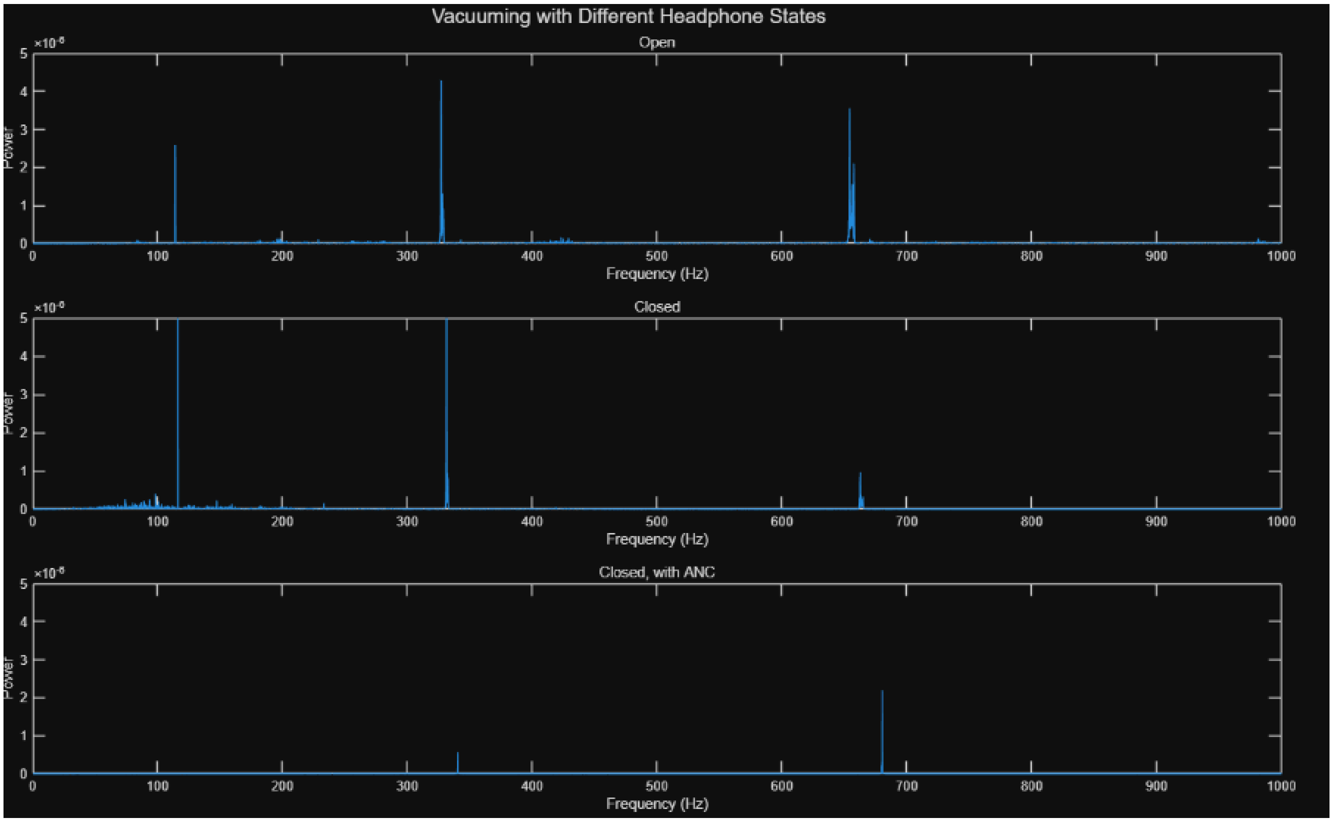

Figure 4: Magnitude over frequency graphs for the vacuuming sound. The plots for the different headphone states (open, closed, ANC) are shown for comparison.

Vacuuming has a straightforward frequency signature, so it is very clear how vacuuming is affected by passive and active noise canceling. With the headphones open, we can see that there are 3 main peaks of magnitude of a frequency that show up, and closing the headphones over the microphone reduces them somewhat. When ANC gets turned on, we can see that the large majority of frequencies get cut out almost entirely, showing that the “inverse wave” effect is really effective for simple frequency signatures.

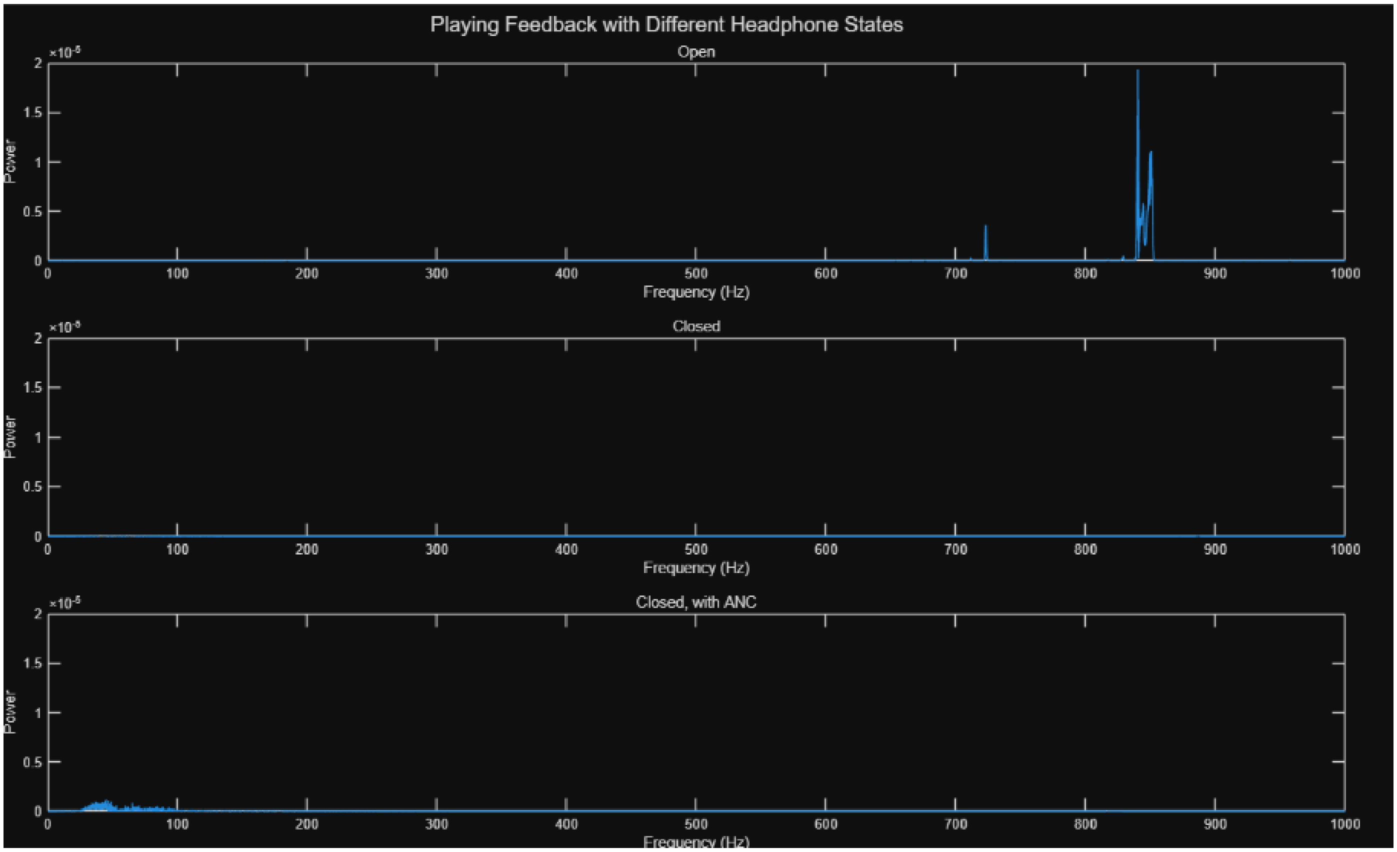

Figure 5: Magnitude over frequency graphs for the feedback sound. The plots for the different headphone states (open, closed, ANC) are shown for comparison.

To have a sound that was consistent, we decided to record some feedback from a microphone hearing the speaker it’s sound came from. We replayed that to get a very specific frequency and see how the system behaves. Passive noise canceling cuts out the frequency as a whole, but then you can see that ANC still cuts out all of the noise, but also adds a small bit of noise, which we can theorize is the white noise floor that is created by ANC headphones.

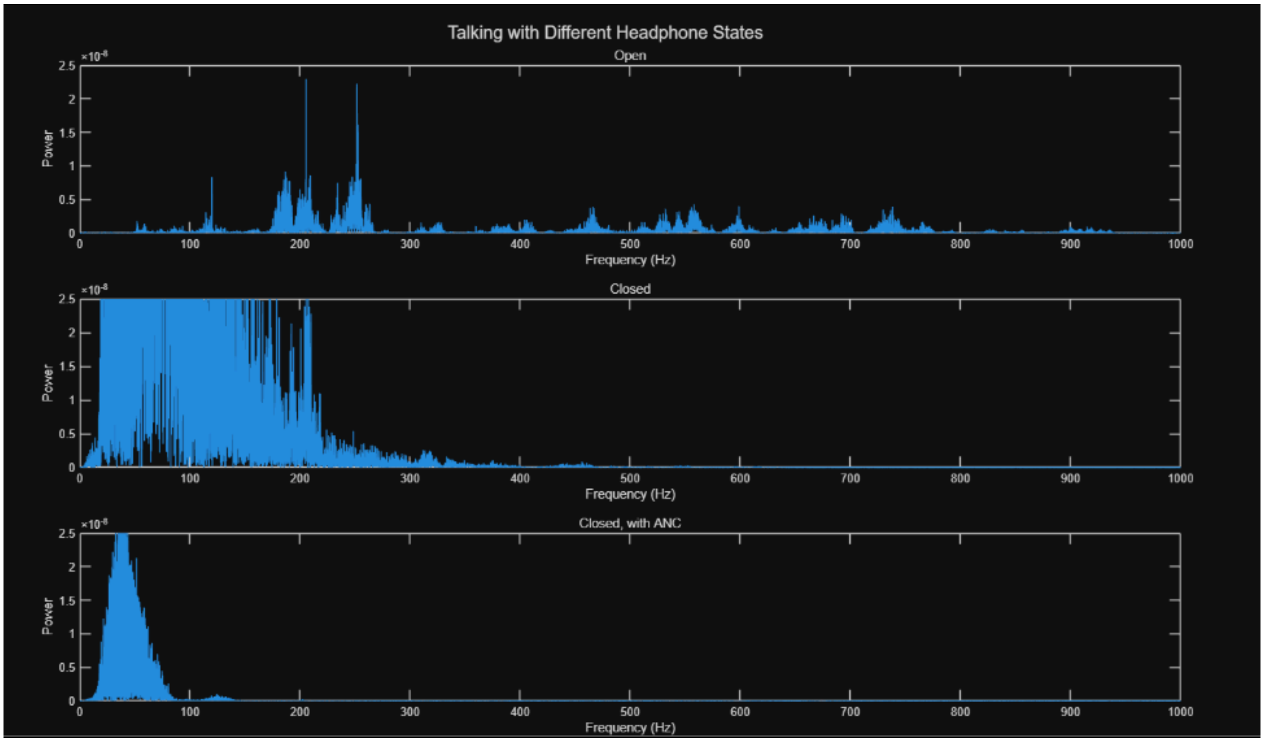

Figure 6: Magnitude over frequency graphs for the talking sound. The plots for the different headphone states (open, closed, ANC) are shown for comparison.

For the last example, we wanted to show how the way that we ran this experiment may have messed with our data. When collecting data, there was the sound of muscles shaking that slightly rattled the headphones. When we had the headphones open for this experiment where we just talked in the background, the noise was reasonable. But you can see that there was a significant amount of noise added, but the sounds that were originally there were cut off. ANC did a lot of work to cut out that noise but that noise was still there even after noise canceling. The scale is quite different for this point, but it is worth it to show that in some cases we *did* add some noise to the system.

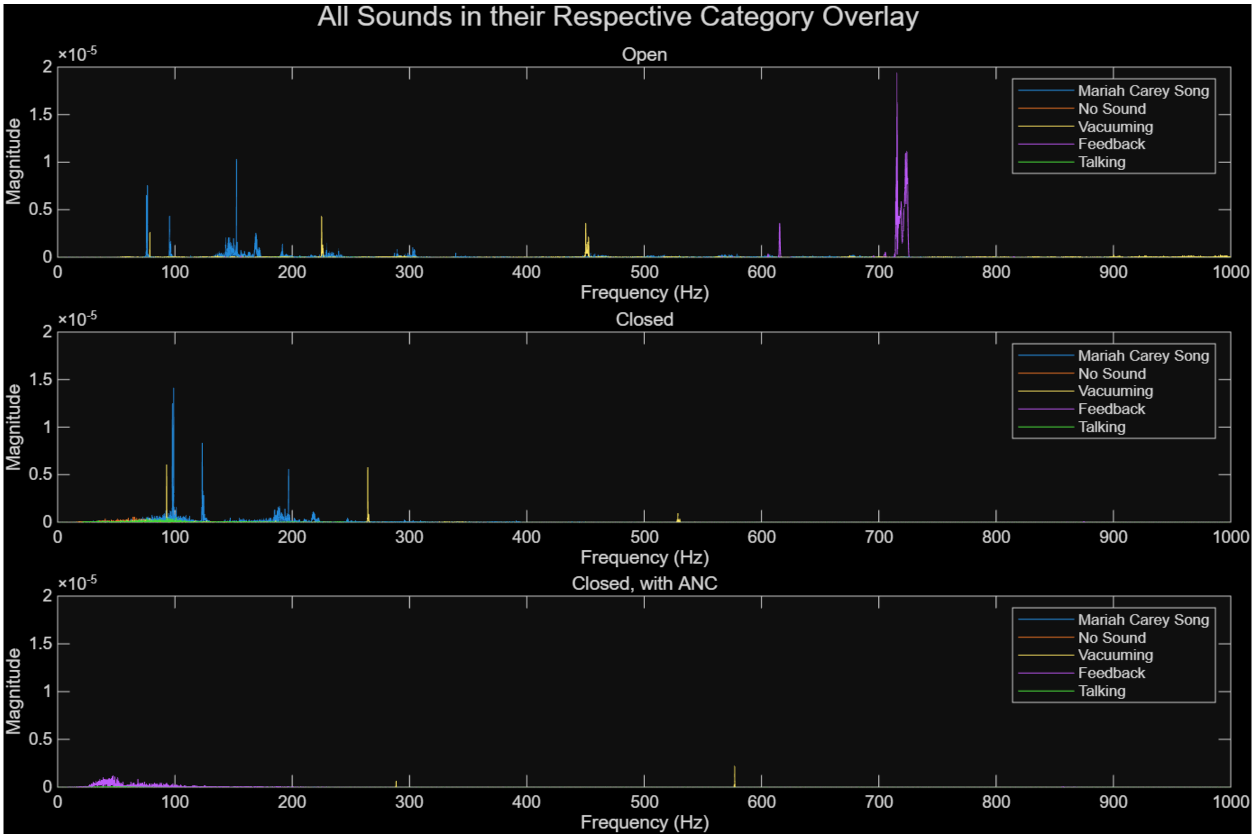

Figure 7: Full magnitude over frequency graphs for each state of the headphones (open, closed, ANC) with all the sounds for each case plotted on the same graph. This shows what frequencies each state of the headphones blocks in comparison to the other states.

Taking a look all of the sounds and the whole system, we can see that passive noise canceling does a really good job at cutting out a lot of the higher frequencies, but not the lower frequencies, whereas ANC cuts out all of the frequencies, but adds a bit of noise in the lower range to be able to cut out the lower frequencies. Let's zoom in and see a bit more at the lower magnitudes:

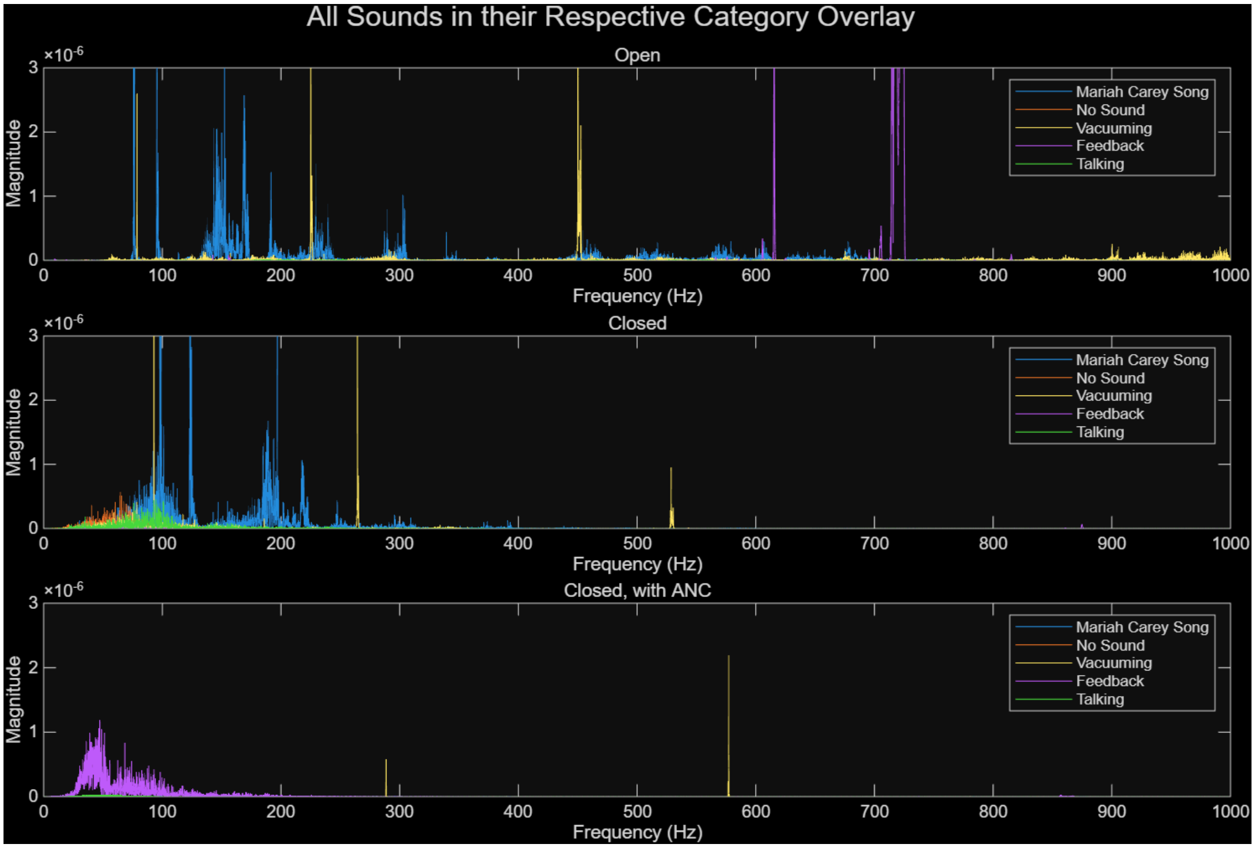

Figure 8: Zoomed-in magnitude over frequency graphs for each state of the headphones (open, closed, ANC) with all the sounds for each case plotted on the same graph. This shows what frequencies each state of the headphones blocks in comparison to the other states.

We can see here that the noise profile that is at the end, as shown in Feedback, is nowhere to be seen in other scenarios, which hints at it being an added white noise floor.

Takeaways

Engineers designed ANC headphones with the purpose of getting rid of the major frequencies that you would hear in a system. They take in the frequencies from the outside of the headphones and cut out the major ones that are in a system. Our microphone setup was very effective at picking this up, but it also made it difficult to make sure that it was completely soundproof due to various disturbances, but the effect was still clear. ANC headphones did cut out the majority of major frequencies in a system, as shown by using a DFT on all of the different scenarios we had.

The DFT allows us to see in the systems we created how much noise there was, how much noise was cut out, and even how much noise was added. We know that these headphones, despite how well they performed at their task, aren't perfect because we can see some of the white noise floor implemented by the headphones to make it easier to cut out the frequencies heard around the headphones.