ANALYSIS OF CELL PHONE ADAPTIVE NOISE CANCELLATION FILTERS

by

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Analysis of Cell Phone Adaptive Noise Cancellation Filters

Thesis directed by Associate Professor Catalin Grigoras

ABSTRACT

When background noise compromises the quality of a cell phone call, adaptive noise cancellation filters can be used to increase call clarity. These filters are utilized by most major cell phone manufacturers to reduce background noise during calls through the use of a secondary microphone usually located at the top of the device [1]. Unfortunately, these filters use proprietary algorithms [2] which are unavailable to forensic examiners and scientists. In the fall of 2018, Anthony Nelson published a thesis paper which proposed a method for recording and analyzing the adaptive noise reduction filters found in cell phones [3]. Nelson used his proposed method of recording and analyzing these noise reduction filters to categorize and document specific aspects of the filters and sort them by make and model. This thesis is a continuation of that research on cell phone models not covered in Nelson's original work including the iPhone Xr, iPhone Xs Max, Samsung Galaxy S7, Samsung Galaxy Note 9, and Google Pixel 1. In addition to running Nelson's proposed method on these models, this thesis includes a test on an iPhone Xs Max using babble noise and a test on an iPhone 7, which was covered in Nelson's thesis, for comparison.

The form and content of this abstract are approved. I recommend its publication.

Approved: Catalin Grigoras

I would like to dedicate this thesis to all the teachers I've had throughout my academic career and to my loving parents, the best teachers of them all.

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CHAPTER I

INTRODUCTION

Over the last decade, noise cancellation has become effective and cheap enough to use in mobile phones [4]. Most smart phone manufacturers make use of the technology today and implement it in their products under setting names such as "noise reduction" or "phone noise cancellation" (as is the case in iPhones). These noise reduction filters have been an area of cell phones without much forensic research until Anthony Nelson's thesis "Proposed Method for Recording and Analyzing Cell Phone Adaptive Noise Reduction Filters" was published in the fall of 2018.

Nelson's proposed method recorded and documented aspects of noise reduction filters and categorized them by phone make and model. His testing method consisted of playing a broadband noise over loudspeakers while someone spoke into the cell phone being studied (cell phone A) and recording the call using a call recording application on the phone receiving the call (cell phone B) [3]. The caller using cell phone A was positioned in front of the loudspeakers so the broadband noise would trigger the threshold of the filter and activate the noise cancellation feature. The broadband noise consisted of a twenty second clip of white noise which was used because white noise evenly disperses noise across the audible sound spectrum [5]. The broadband noise clip also included impulses at the one and nineteen second marks for later synchronization. The recordings were made with the broadband noise played back at two different volumes: 70db(A) and 80db(A) which were measured using an SPL meter. Three recordings were made per cell phone with the noise cancellation feature turned on and then three more were made with the cancellation turned off for comparison. The recorded calls were then imported into Adobe Audition where they were trimmed down to the twenty seconds matching the broadband noise and analyzed via spectrograms, FFT frequency analysis, and Signal to Noise Ratios (SNR).

The work done in this thesis is comprised of three tests: the first uses Nelson's proposed method on newer models of cell phones, the second test involves a similar testing method to Nelson's but with babble noise (noise that is comprised of multiple simultaneous speech sources [6] which obscures any one source from being intelligible) instead of white noise, and the third uses a novel test on a phone covered in Nelson's original thesis for comparison. The makes and models of cell phones used in the first two tests include the following:

Apple iPhone Xr

Apple iPhone Xs Max

Samsung Galaxy S7

Samsung Galaxy Note 9

Google Pixel 1

The novel test was conducted on an Apple iPhone 7 running the newest version of iOS, 13.1.2.

Scope and Limitations

The scope of this thesis is limited to the phones studied from Apple, Samsung, and Google. This thesis does not attempt to discern or interpret the proprietary algorithms or code used in the noise reduction filters of these phones but instead records and interprets their unique impact on recorded calls made with these makes and models.

CHAPTER II

CELL PHONE LAYOUTS

While cell phones make use of a secondary microphone (sometimes more than two) for noise reduction filters to operate [1], the location of these additional microphones varies between cell phone makes and models. The following are the microphone layouts of the cell phones studied in this thesis.

Apple iPhone Xr, Xs Max and 7

While the different models of iPhones used for this test generally place their additional microphones in the same location, layouts for each iPhone used are included here as the dimensions vary between models.

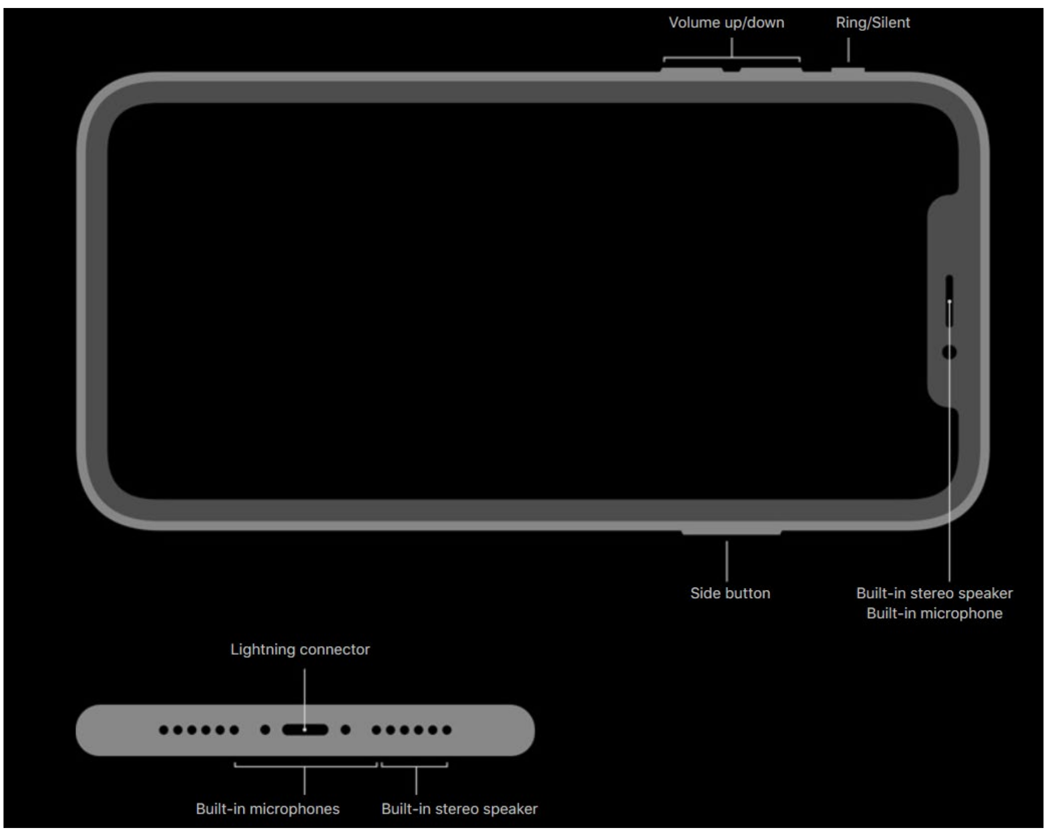

Figure 2.1 iPhone Xr layout [7]

Figure 2.2 iPhone Xs Max layout [8]

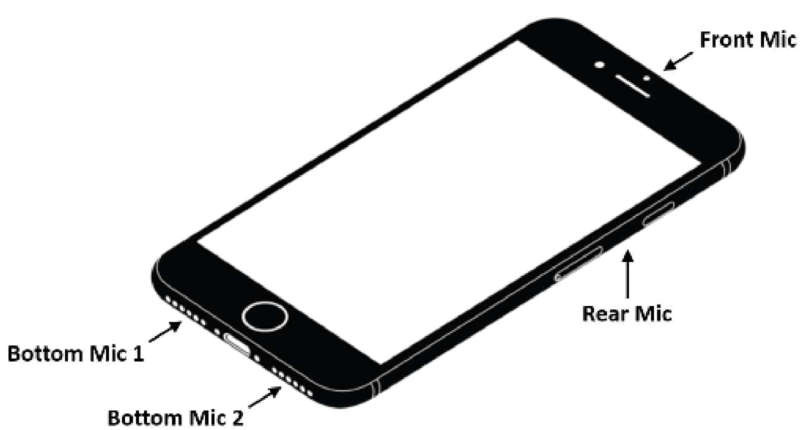

Figure 2.3 iPhone 7 layout [9]

Samsung Galaxy S7 and Galaxy Note 9

It is important to note that the Samsung phones used in this test do not allow the user to toggle the noise reduction setting on and off, noise reduction is always turned on in these phones by default. Samsung Galaxy smartphones used to allow the user to turn noise reduction off but since the Galaxy S6 model that option has been removed [3].

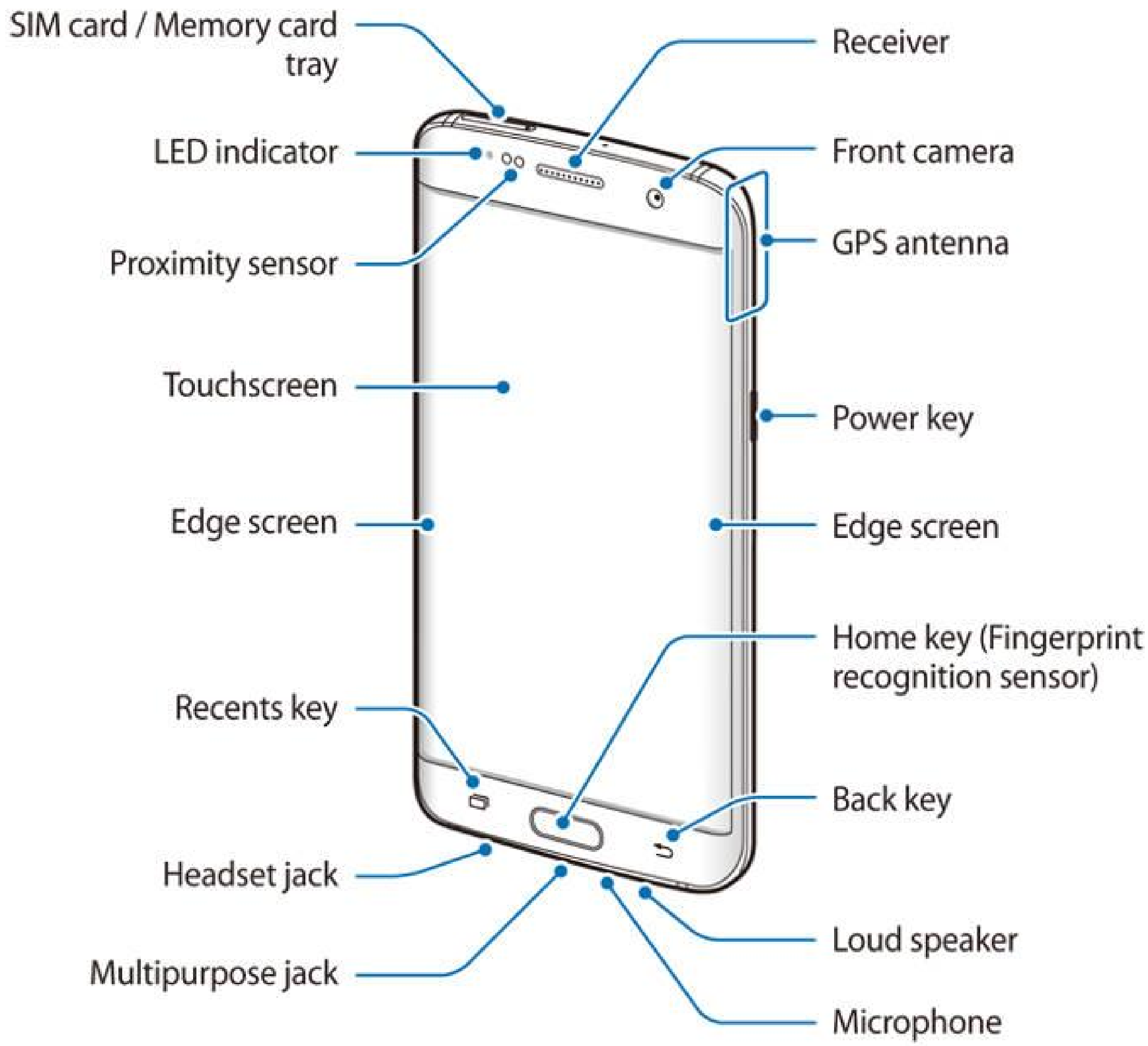

Figure 2.4 Samsung Galaxy S7 front view [10]

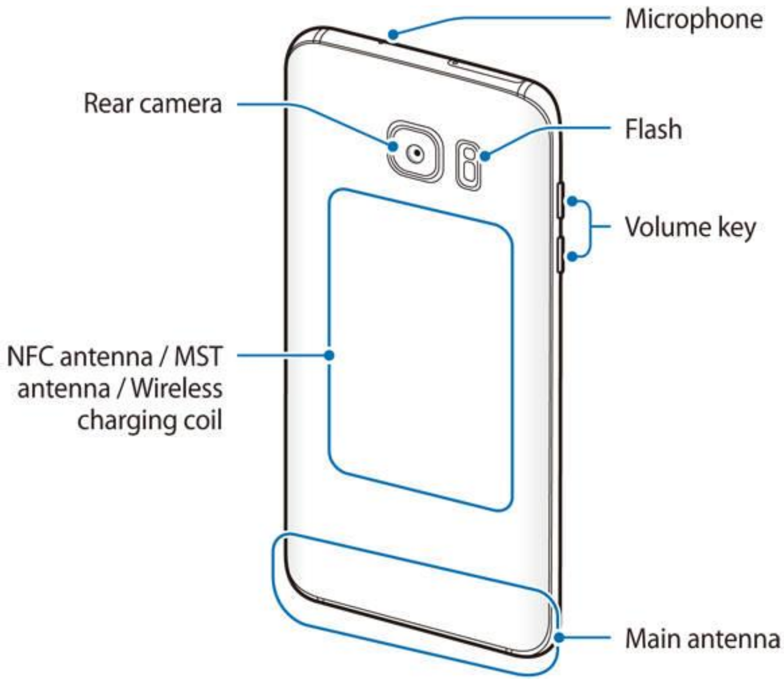

Figure 2.5 Samsung Galaxy S7 back view [10]

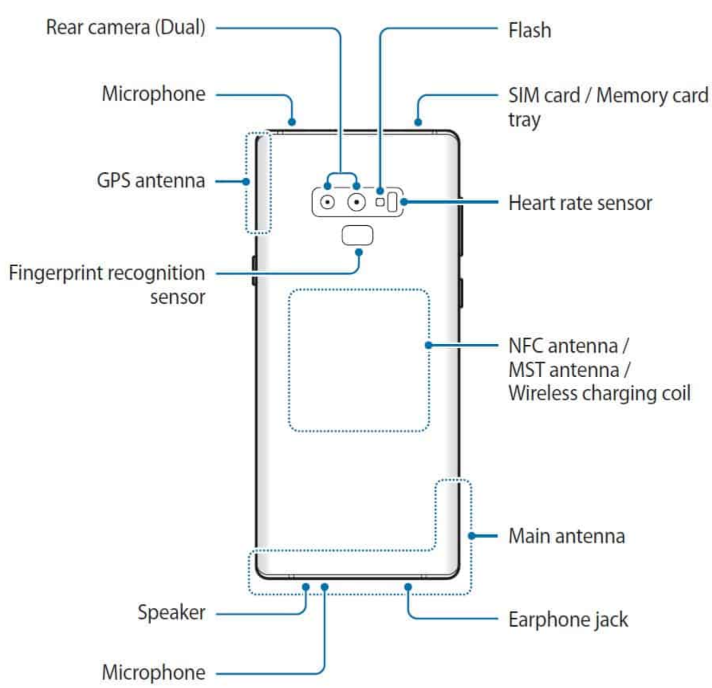

Figure 2.6 Samsung Galaxy Note 9 layout [11]

Google Pixel 1

Like the Samsung Galaxy smartphone, the Google Pixel also does not allow the user the option to toggle noise reduction on or off.

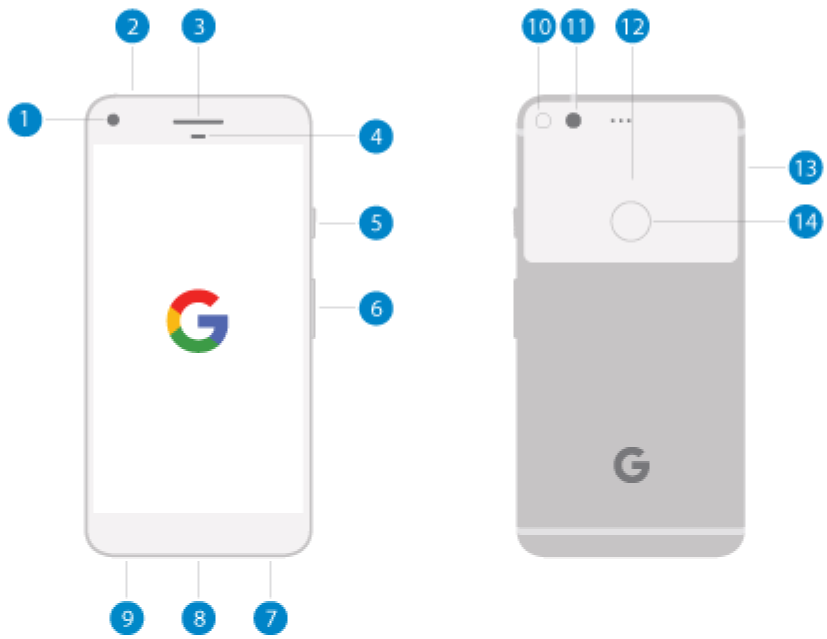

Figure 2.7 Google Pixel 1 where point 7 is the primary microphone and the secondary microphone is located to the right of the rear facing camera at point 11 on the diagram [12]

CHAPTER III

TESTING

Test 1

The first test was modeled after Nelson's original test and involved playing a clip of white noise over loudspeakers in front of cell phone A while a call was made from cell phone A to cell phone B. Noise cancellation filters work to improve signal intelligibility during a phone call and thus calls from cell phone A to cell phone B were necessary to capture the signal for comparison between the filter being turned on and off. This call was recorded on cell phone B using the application TapeACall which recorded the phone calls at an 8kHz sampling rate (this is the default setting for TapeACall as cell phone signals only transmit at an 8kHz sampling rate [13]). The white noise clip included impulses at the one and nineteen second marks for later synchronization and was played back over the loudspeakers at 70db(A) and 80db(A) (both measured using an SPL meter). Each cell phone was recorded three times with its noise reduction filter on and three times with its noise reduction filter turned off (if applicable). The recorded phone calls were then trimmed down using Adobe Audition to the twenty seconds matching the noise playback and analyzed via spectrograms, FFT charts, and SNRs.

The Fast Fourier Transform, or FFT, is an algorithm that can be used to convert the time domain of an audio signal into the frequency domain [14], allowing a recorded signal to be viewed on a graph where the x-axis is the frequency in Hz and the y-axis is the gain in dB. This produces an FFT spectrum which displays the loudness level of each frequency present in the entire signal. In addition to the FFT spectrum, spectrograms were also produced of the recorded calls which show time in seconds along the x-axis and frequency along the y-axis. These graphs display the frequencies present at each moment in time in the signal and also show loudness via a heatmap style display where the brighter colors are louder and the darker colors are quieter.

Test 2

The second test involved repeating the method of the first test but using babble noise instead of white noise as the controlled noisy signal. This test was run on an iPhone Xs Max and was conducted to simulate a more realistic noisy condition for noise cancellation than white noise.

Test 3

The third test consisted of recording an iPhone 7 running the latest version of iOS (version 13.1.2) in front of an oven blower with the “phone noise cancellation” setting turned on and then off. The spectrograms of the two recordings were captured and compared.

CHAPTER IV

ANALYSIS AND RESULTS

The trimmed, recorded clips were analyzed via spectrograms, FFT charts and SNRs and compared to each other. The idea behind these comparisons is that there should be a discernible difference between the results when the noise cancellation filters are turned on and off, therefore allowing for documentation of what a particular phone's noise cancellation looks like on a recorded call. However, when listening back to these recordings very little difference, if any at all, existed between the filter being turned on or off in the settings. Furthermore, since Samsung and Google manufactured smartphones do not allow the user to toggle this setting, getting a picture of the effect that noise reduction had on these phones becomes difficult. Without the option to turn the filter on and off, comparison between the filter affecting the signal and not affecting it is not possible.

Spectrograms

When observing the spectrograms of the recorded calls, it was expected that there would be a difference in the level of background noise present in between the spoken words of the caller. However, this was not the case and the background noise appeared to be reduced whether or not the noise reduction setting was turned on. The following are the spectrograms of the iPhone models from Test 1 which allowed for the noise reduction setting to be turned off.

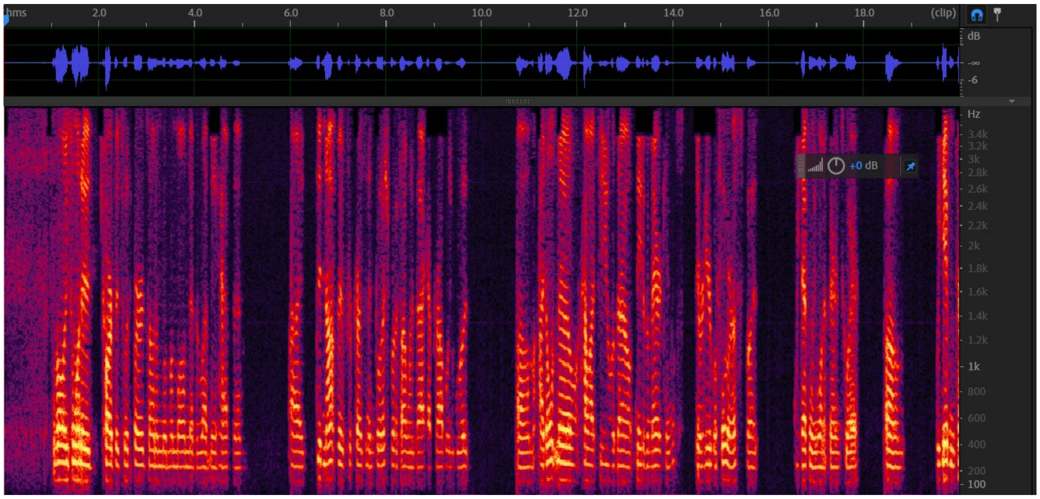

Figure 4.1 iPhone Xr with Noise Cancellation off, white noise playback at 70db(A)

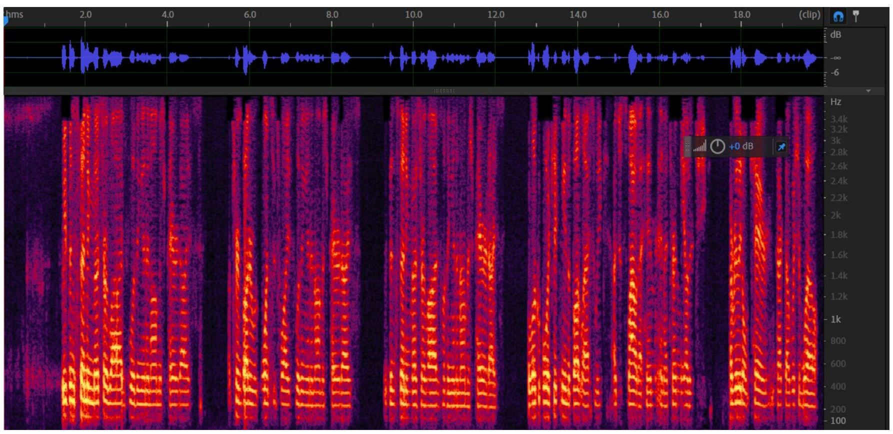

Figure 4.2 iPhone Xr with Noise Cancellation on, white noise playback at 70db(A)

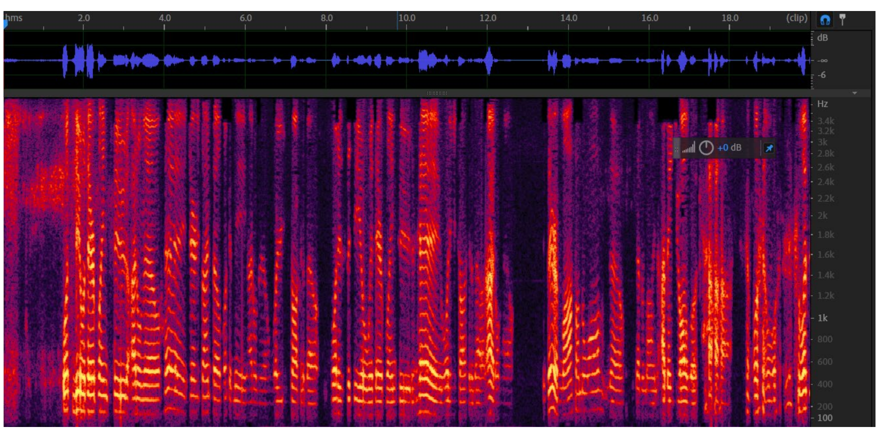

Figure 4.3 iPhone Xr with Noise Cancellation off, white noise playback at 80db(A)

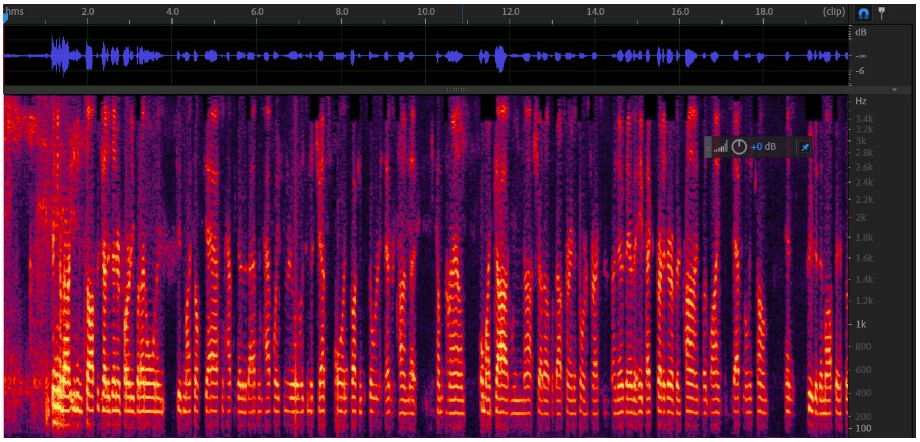

Figure 4.4 iPhone Xr with Noise Cancellation on, white noise playback at 80db(A)

Figure 4.5 iPhone Xs Max with Noise Cancellation off, white noise playback at 70db(A)

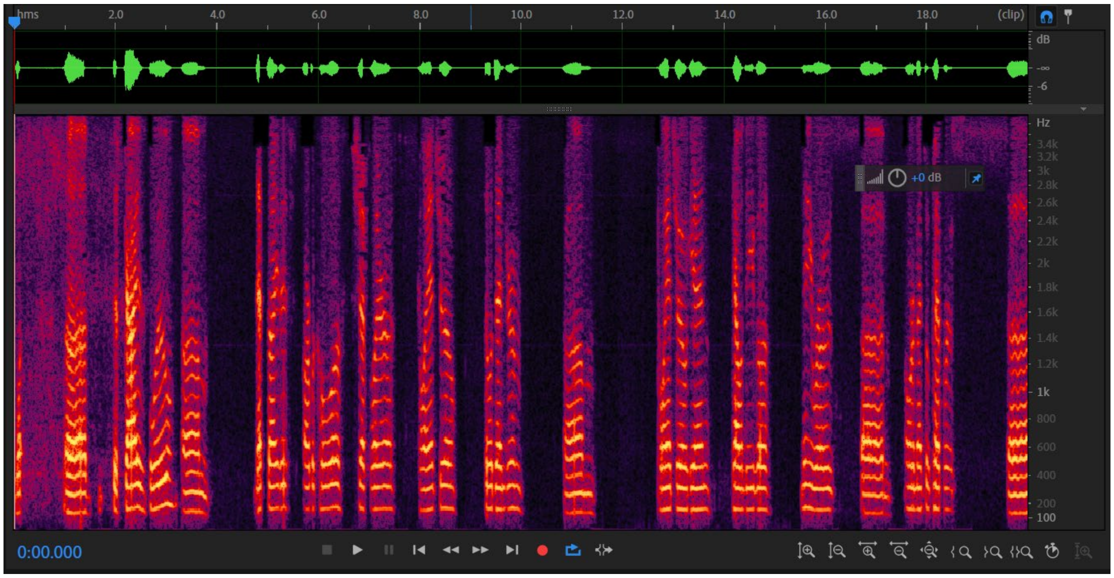

Figure 4.6 iPhone Xs Max with Noise Cancellation on, white noise playback at 70db(A)

Figure 4.7 iPhone Xs Max with Noise Cancellation off, white noise playback at 80db(A)

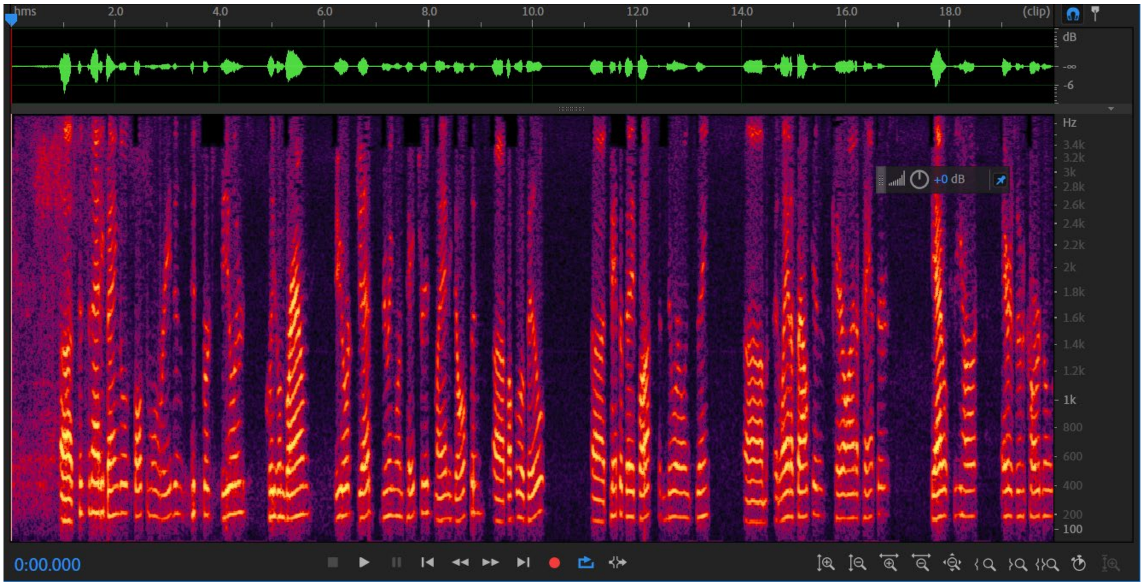

Figure 4.8 iPhone Xs Max with Noise Cancellation on, white noise playback at 80db(A)

As can be seen from the Test 1 spectrograms of the iPhones with noise reduction turned on and off, there is no major difference between the amount of noise in between the spoken words. The dynamic range of the signal with the filter turned on is 58.34dB as calculated by Adobe Audition while the dynamic range of the signal with the filter turned off is 59.97dB. A higher dynamic range would be expected in the signal with the filter turned on as it should reduce the noise therefore lowering the signal in certain sections. This prompted Test 2 and Test 3, which used babble noise on an iPhone Xs Max and an oven blower on an iPhone 7, respectively. Here are those spectrograms:

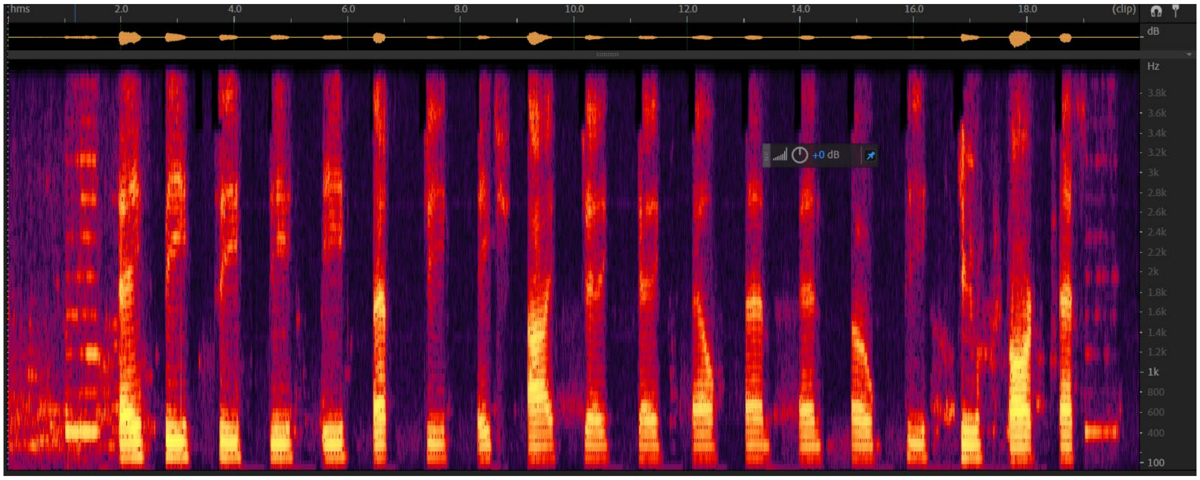

Figure 4.9 iPhone Xs Max with Noise Cancellation off, babble noise playback at 70db(A)

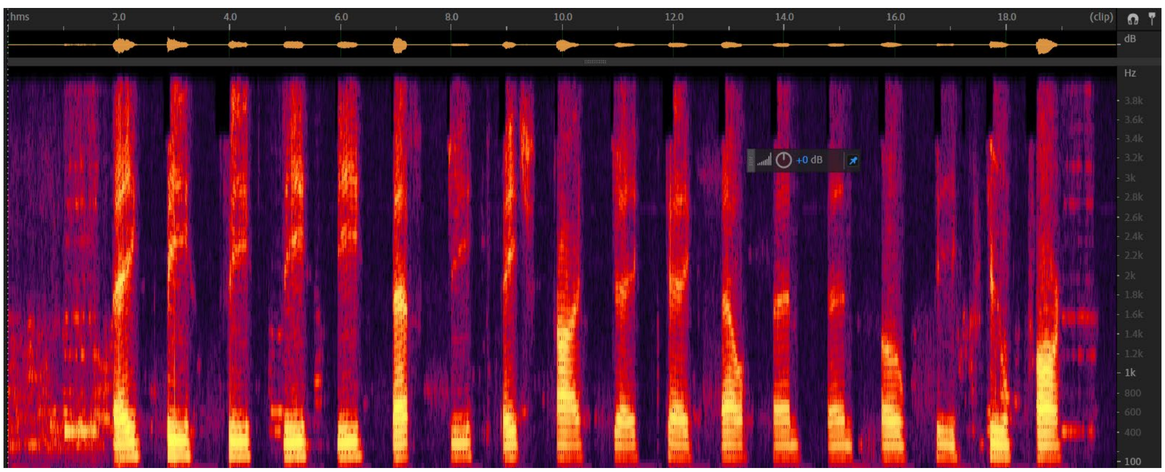

Figure 4.10 iPhone Xs Max with Noise Cancellation on, babble noise playback at 70db(A)

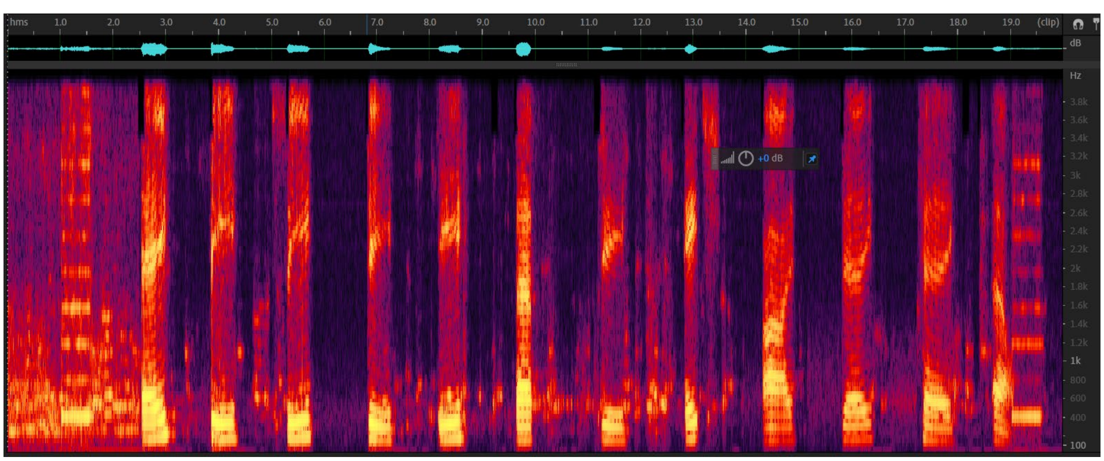

Figure 4.11 iPhone Xs Max with Noise Cancellation off, babble noise playback at 80db(A)

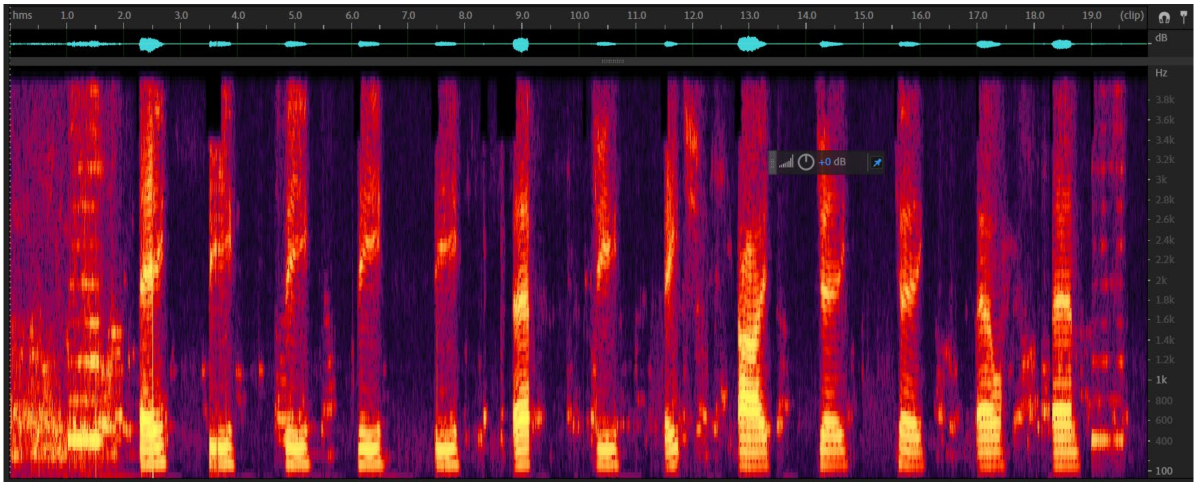

Figure 4.12 iPhone Xs Max with Noise Cancellation on, babble noise playback at 80db(A)

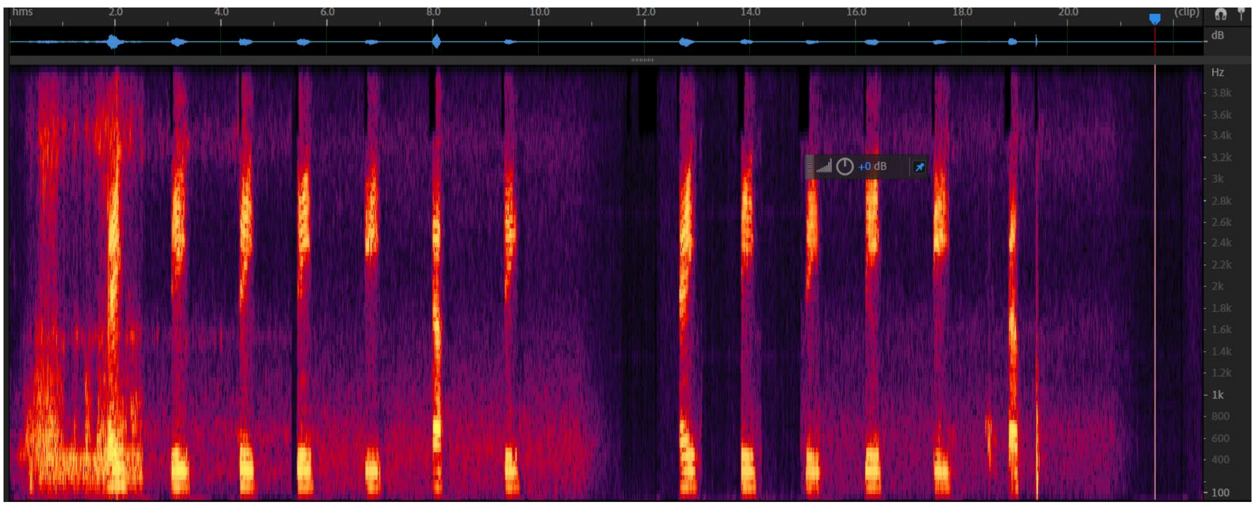

Figure 4.13 iPhone 7 with noise cancellation off recorded in front of oven blower

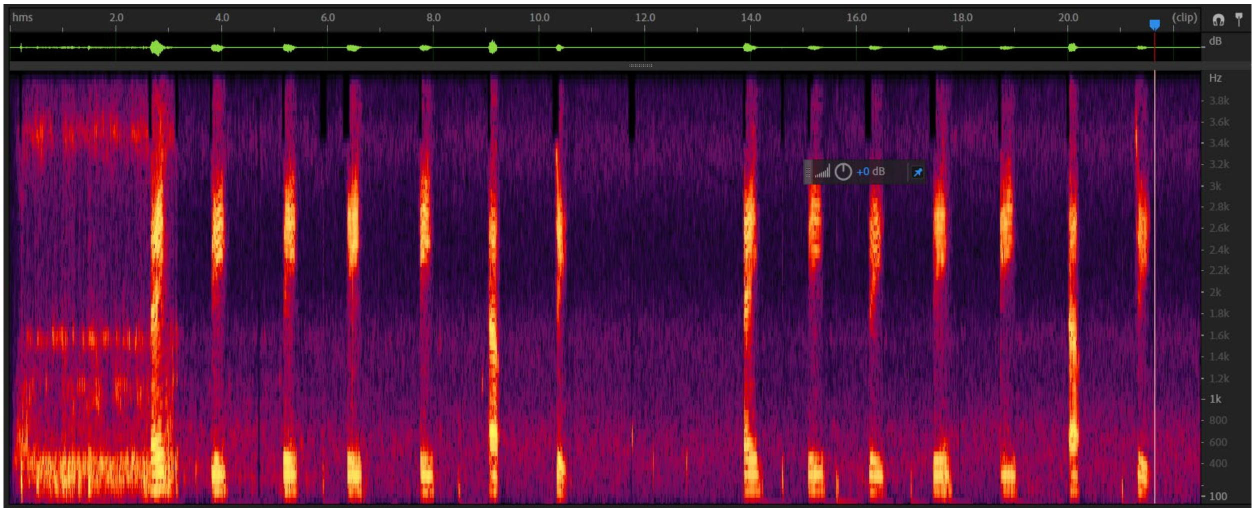

Figure 4.14 iPhone 7 with noise cancellation on recorded in front of oven blower

Again, no discernable difference in background noise can be noted with the noise reduction filter turned off in the iPhone's settings. In fact, the noise seemed to be reduced even when the noise cancellation setting was turned off.

FFT Spectrum

The Fast Fourier Transform, or FFT, is an algorithm that can be used to convert the time domain of an audio signal into the frequency domain [14], allowing a recorded signal to be viewed on a graph where the x-axis is the frequency in Hz and the y-axis is the gain in dB. The recorded calls were ran through Adobe Auditions' frequency analysis window which allows for an FFT view of the signal. The FFT spectrum was captured of a recording at either the 70db(A) or 80db(A) noise level playback with the filter turned off and then the FFT for the recording at the same noise level but with the filter turned on was captured and overlaid on the first graph. A red line was used for the filter turned off and a green line was used for the filter turned on. Here are those charts:

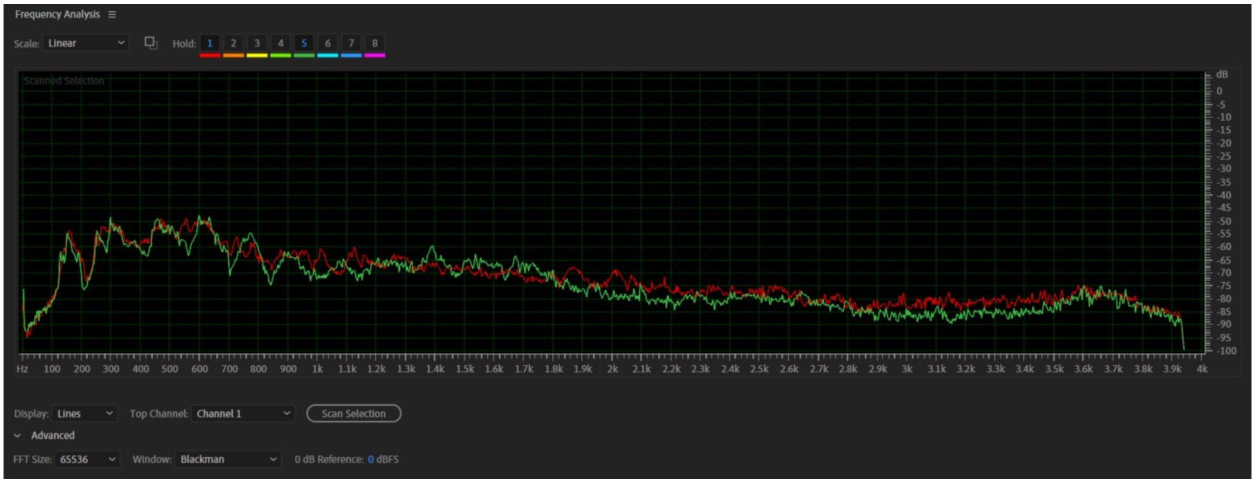

Figure 4.15 iPhone Xs Max white noise playback at 70db(A) FFTs

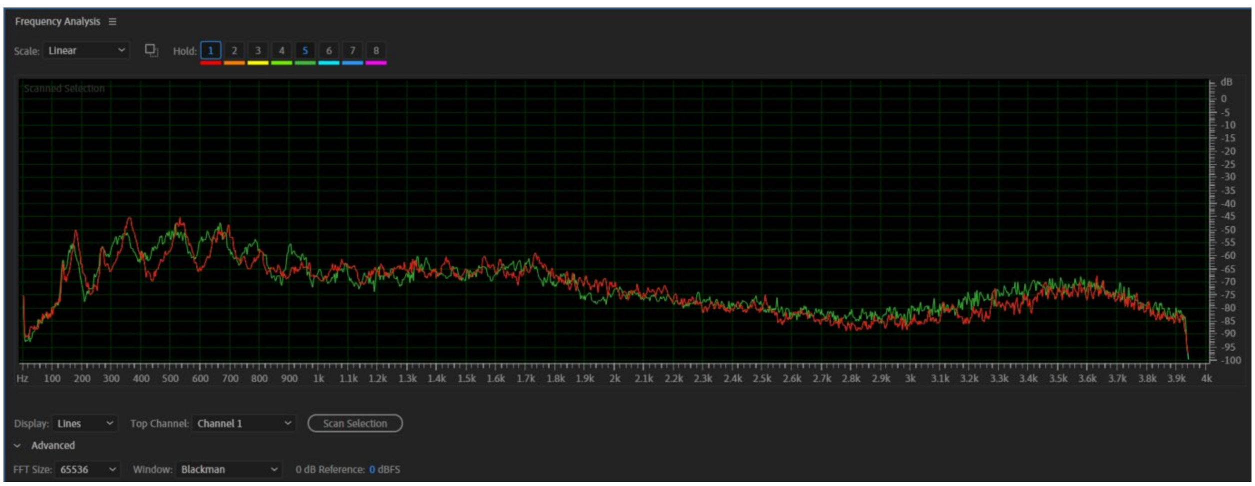

Figure 4.16 iPhone Xs Max white noise playback at 80db(A) FFTs

Figure 4.17 iPhone Xr white noise playback at 70db(A) FFTs

Figure 4.18 iPhone Xr white noise playback at 80db(A) FFTs

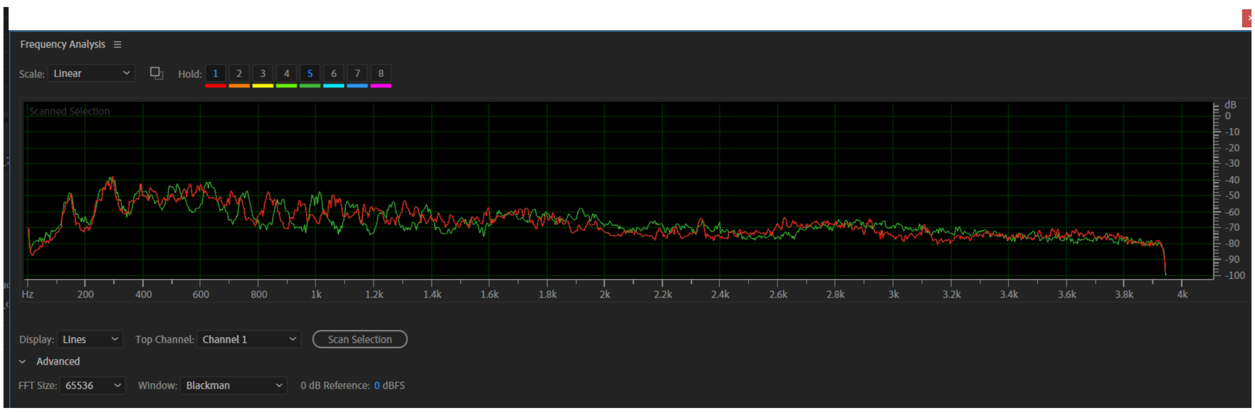

Figure 4.19 iPhone Xs Max babble noise playback at 70db(A) FFTs

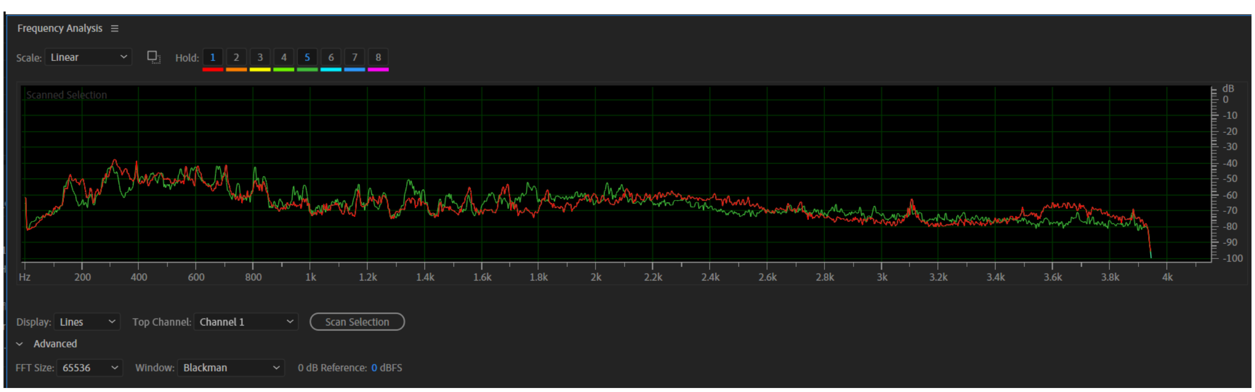

Figure 4.20 iPhone Xs Max babble noise playback at 80db(A) FFTs

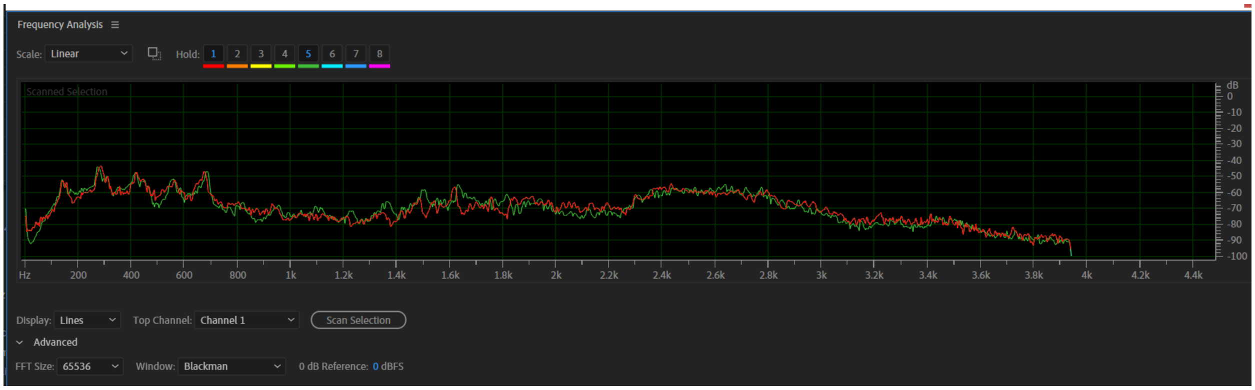

Figure 4.21 iPhone 7 oven blower noise FFTs

A difference in frequency response for the noise cancellation filter turned off and on was expected to be noticeable in the FFT charts of each recorded call. However, it can be seen in the graphs that this is not the case and that the iPhone models responded almost the same whether or not the noise cancellation filter was turned on or off. No frequencies were significantly reduced and the FFT spectrum responses were quite similar.

Signal to Noise Ratios

Signal to noise ratios, or SNRs, were found for each iteration of the tests based on phone model, noise type, noise playback volume and whether the filter was on or off. Since each iteration was recorded three times, the SNR for each of those was found using a Matlab script and then averaged. In the Matlab script the audio signal represented by "y" is the controlled noise signal, the generated white noise signal or the babble noise recording depending on the test. Here is the Matlab script and the results:

```
[name1, path1] = uigetfile
[x, fs] = audioread(name1)
[name2, path1] = uigetfile
[y, fs] = audioread(name2)
r = snr(x, y)
```

Table 4.1 SNR Results

	Average SNR of recorded call with noise reduction ON	Average SNR of recorded call with noise reduction OFF
iPhone Xr, white noise at 70db(A)	-4.343 dB	-4.278 dB
iPhone Xr, white noise at 80db(A)	-4.799 dB	-4.278 dB
iPhone Xs Max, white noise at 70db(A)	-4.812 dB	-4.323 dB
iPhone Xs Max, white noise at 80db(A)	-11.329 dB	-14.554 dB
iPhone Xs Max, babble noise at 70db(A)	7.8159 dB	7.0566 dB
iPhone Xs Max, babble noise at 80db(A)	8.0167 dB	8.2357 dB
Samsung Galaxy S7, white noise at 70db(A)	3.246 dB	N/A
Samsung Galaxy S7, white noise at 80db(A)	5.902 dB	N/A
Samsung Galaxy Note 9, white noise at 70db(A)	-2.448 dB	N/A
Samsung Galaxy Note 9, white noise at 80db(A)	-2.441 dB	N/A
Google Pixel, white noise at 70db(A)	-1.319 dB	N/A
Google Pixel, white noise at 80db(A)	0.387 dB	N/A

It was expected that the SNRs would be noticeably higher when the filter setting was turned on due to the filter reducing noise and thus increasing the ratio of signal to noise, but as with the spectrogram and FFT spectrums the expected results were not the case. There was a minor difference between the SNRs of some of the filters turned on and off but the change was not consistent: some SNRs were higher when the filter was on and others were lower when the filter was on. For example, the SNR increased when the noise reduction filter was turned off on the iPhone Xs Max during the babble noise test at 80db(A) but it decreased from filter-on to filter-off during the babble noise test at 70db(A).

CHAPTER V

CONCLUSION

Based on the analysis of the test results, a discernible difference between the noise reduction filter turned on and off could not be found in those phone models which allow the user to toggle the noise reduction setting. Furthermore, the fact that most major phone manufacturers today such as Samsung and Google do not allow the user to toggle the noise reduction setting on and off makes documentation of the filter's effects on the call signal very difficult. This method might be useful in a select few cases but overall the study of noise cancellation filters does not seem like a very practical way of identifying the make and model of a cell phone based on a recorded call. The very small difference between the filter turned off and on is not always consistent and certainly not enough to confidently identify a particular cell phone.

CHAPTER VI

FURTHER RESEARCH

While noise reduction filters are used in most modern cell phones, the study of them in a forensic setting may not be the most practical way of identifying a make and model of cell phone. The fact that most phones do not give the user the option to turn this setting off is the key sticking point in this research and renders comparison nearly impossible for those models of cell phone. Out of the phone models studied, only the Apple iPhone models actually allowed the user to turn noise reduction off and even with that setting turned off it was apparent that some level of noise reduction was still present. Cell phones are very important area of research in forensics as their use becomes more ubiquitous across the world but perhaps noise reduction filters should not be the forefront of that research.

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