EE 217 Continuous Linear Systems SP 2014

Final Project: “Hunt for Noise: Extracting Audio Information from Noisy Environment”

Table of Contents

Abstract……………………………………………………………………………………………1

Introduction……………………………………………………………………………………..2

Preliminary…………………………………………………………………………………...3-4

Data and Results………………………………………………………………………………5-31

Conclusion…………………………………………………………………………………….31

Appendix: MATLAB code…………………………………...………………………32-59

Abstract:

This project was intended to find a way to remove the noise from a noisy recorded audio signal. Filtering techniques can be used to filter the noise with frequencies outside of human voice frequency range. The experiment of this project will try to determine ways the noise within the human voice frequency range can be removed, so that the undistinguishable audio message can be identified.

Introduction:

Many times audio information is recorded in a noisy environment, making the audio message undistinguishable because of the noise interface. The recorded audio signal has a poor Signal to Noise Ratio (SNR). Filtering techniques can be used for eliminating the noise that is outside of the audio frequency range, but this does not remove the noise that lies in the same frequency range as the audio message. The noise power for this experiment was significantly greater than that of the audio, which results in a low SNR. The experiment was aimed to eliminate that overlapping noise with the audio signal, to improve the SNR and have a distinguishable audio signal.

The project began with finding noise sources and analyzing the noise sources. Then the audio signal was found and analyzed as well. Next, recordings were taken of the noise and audio signals playing at the same time. This process was repeated for each noise source for three different recording distances of one foot, two feet, and five feet.

The task of eliminating the noise frequency was taken on by trying multiple methods. The first method was to convert the noise only signal and the combination signal to the frequency domain. This was accomplished by taking the FFT of each signal. The FFT of the noise signal was then subtracted from the FFT of the combination signal. This new frequency signal was created and using the inverse FFT, it was converted back to the time domain. Method two was to add 180 degrees of phase to the FFT of the noise signal and invert the amplitude. This was then added back to the combination signal FFT in hope of cancellation between the noise spectrums. Additionally, a filter was used to see which of the noise sources could be filtered out from the audio signal.

Preliminary:

The preliminary for the project required finding a recording device, as well as, completing a few calibration tests. The recording device used was my iPhone 5, then iTunes was used to convert the recordings to wav files. Next, a single tone was recorded and the FFT was taken. Figure 1 shows that the FFT produced the single frequency component at the fundamental frequency. Lastly, the same audio recording was found and used throughout the experiment.

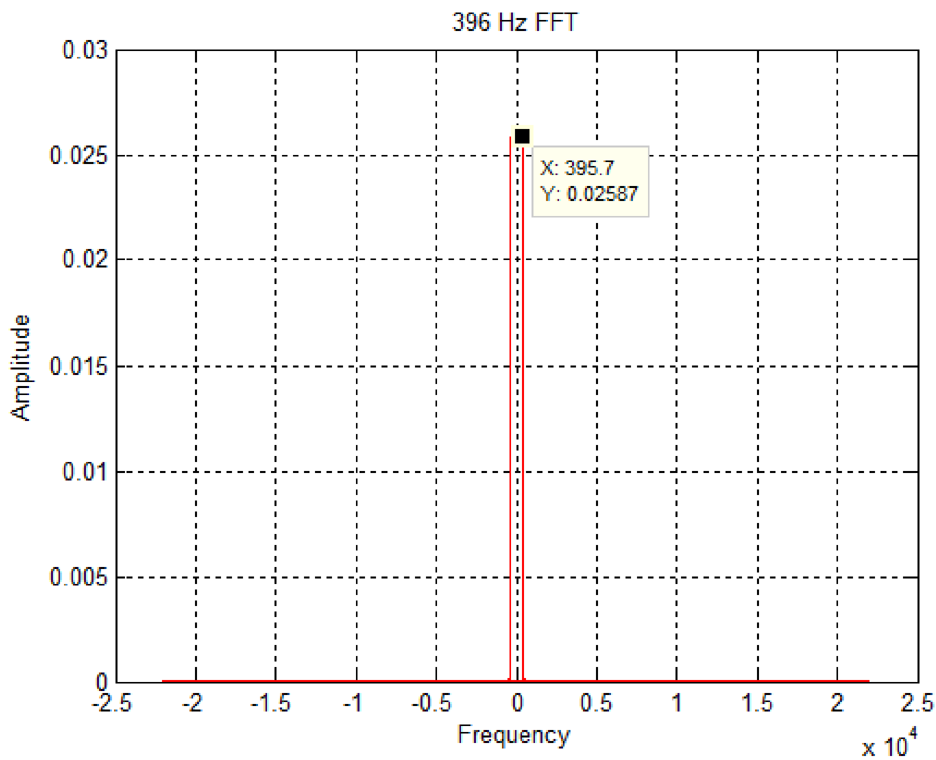

Figure 1: FFT of 396 Hz tone

396 Hz Tone.wav

396 Hz recorded tone used for preliminary calibration experiment.

Audio Signal:

The audio signal used was kept constant throughout the signal. The piece was a recording of President Obama's inaugural speech after being sworn in as president. The signal was recorded at the three distances and the FFT was observed for each.

Audio1.wav Audio signal at recording distance of one foot.

Audio2.wav Audio signal at recording distance of two feet.

Audio3.wav Audio signal at recording distance of five feet.

Noise Sources:

The noise sources used in the experimentation were a hand held beard trimmer, a hand held kitchen mixer, and a blow dryer. The sources all interfere with the audio signal such that in the recordings the audio signal cannot be heard well or distinguished.

Trim1.wav Trimmer 1 ft.	. Trim2.wav Trimmer 2 ft.	. Trim3.wav Trimmer 5 ft.
Dry1.wav Dryer 1 ft.	Dry2.wav Dryer 2 ft.	Dry3.wav Dryer 5 ft.
Mixer1.wav Mixer 1 ft.	Mixer2.wav Mixer 2 ft.	Mixer3.wav Mixer 5 ft.

Recording Samples of Audio and Noise

Recording File	Noise Signal	Recording Distance
Combo11x.wav	Beard Trimmer	1 ft.
Combo12x.wav	Beard Trimmer	2 ft.
Combo13x.wav	Beard Trimmer	5 ft.
Combo21x.wav	Hair Dryer	1 ft.
Combo22x.wav	Hair Dryer	2 ft.
Combo23x.wav	Hair Dryer	5 ft.
Combo31x.wav	Kitchen Mixer	1 ft.
Combo32x.wav	Kitchen Mixer	2 ft.
Combo33x.wav	Kitchen Mixer	5 ft.

Data and Results

Audio Signal Alone

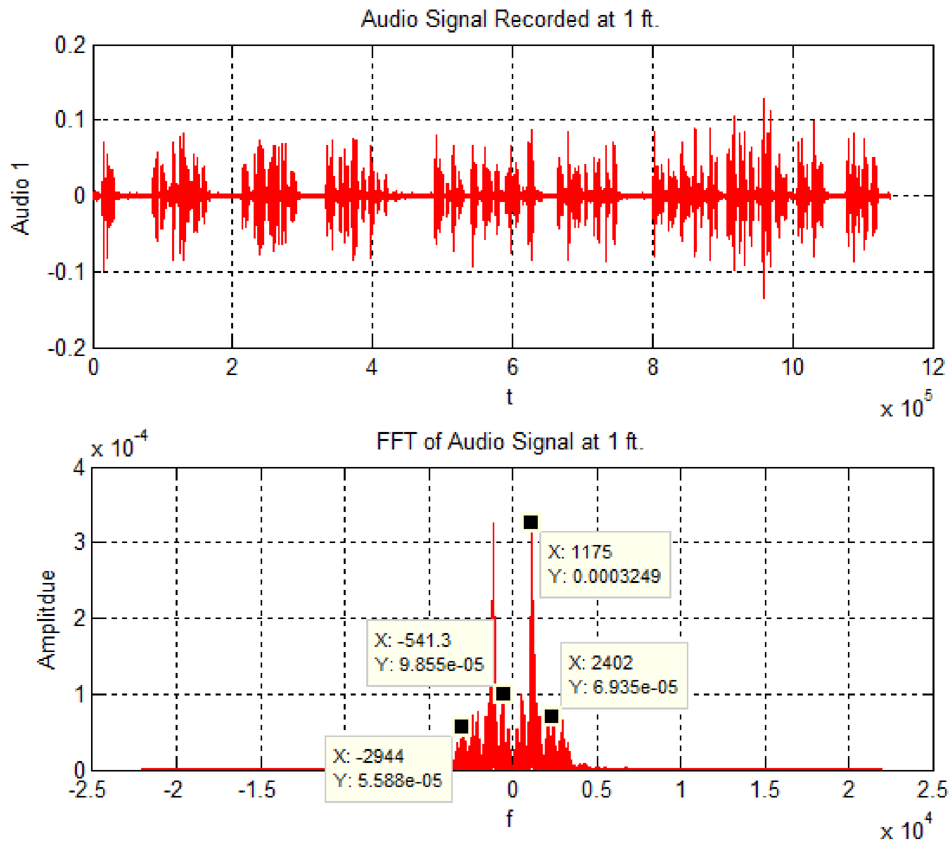

Figure 2: Plot of Audio signal in time domain and the FFT of the audio signal.

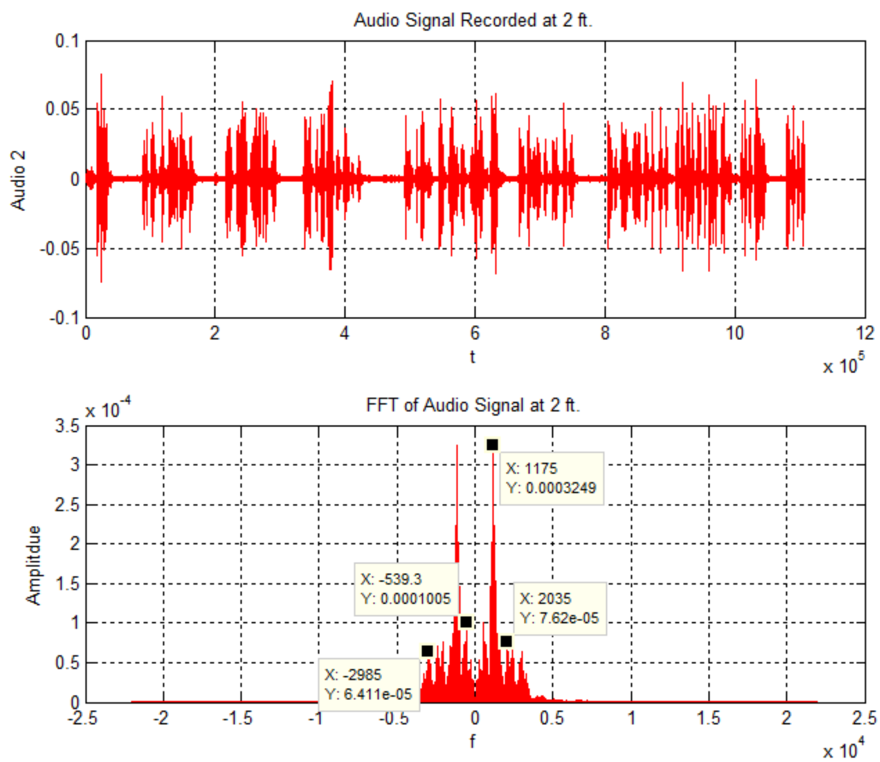

Figure 3: Plot of audio signal in time domain and FFT at recording distance of two feet.

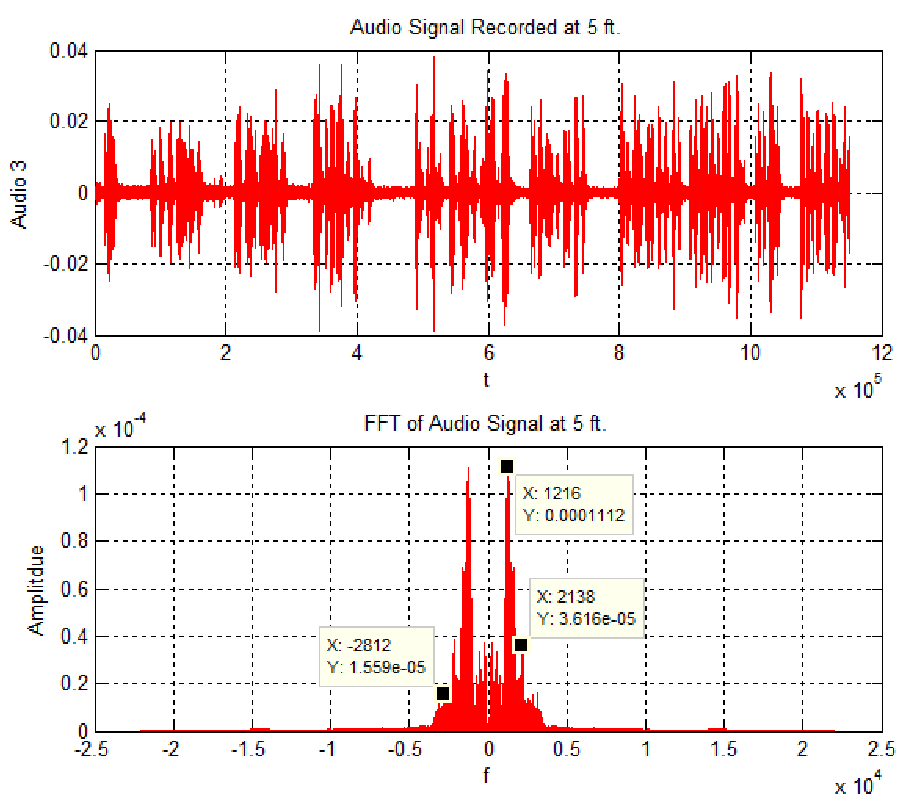

Figure 4: Plot of audio signal in time domain and FFT at recording distance of five feet.

The FFT analysis of the audio source showed that at recording distances of one and two feet, the fundamental frequency was 1175 Hz. The frequency changed to 1216 when the recording distance was extended to five feet. Also, the amplitude of the time domain signal decreases as the recording distance increases.

Noise Signals Alone

The noise sources were plotted in the time domain, as well as, in the frequency domain after the FFT had been done. Also, each noise source was recorded at the three different recording distances.

Noise Signal 1: Beard Trimmer

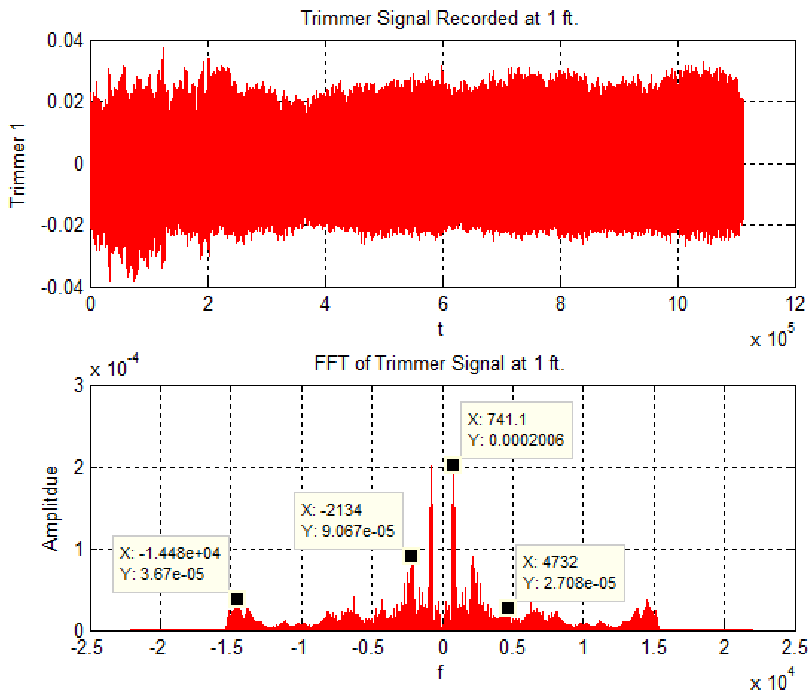

Figure 5: Plot of trimmer noise signal in time domain and FFT at recording distance of one foot.

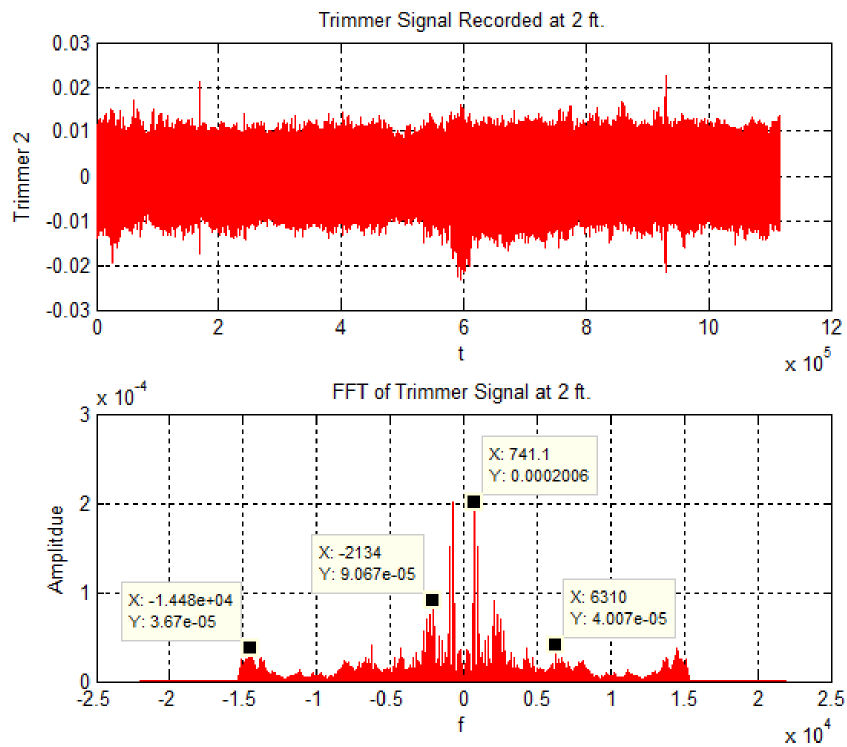

Figure 6: Plot of trimmer noise signal in time domain and FFT at recording distance of two feet.

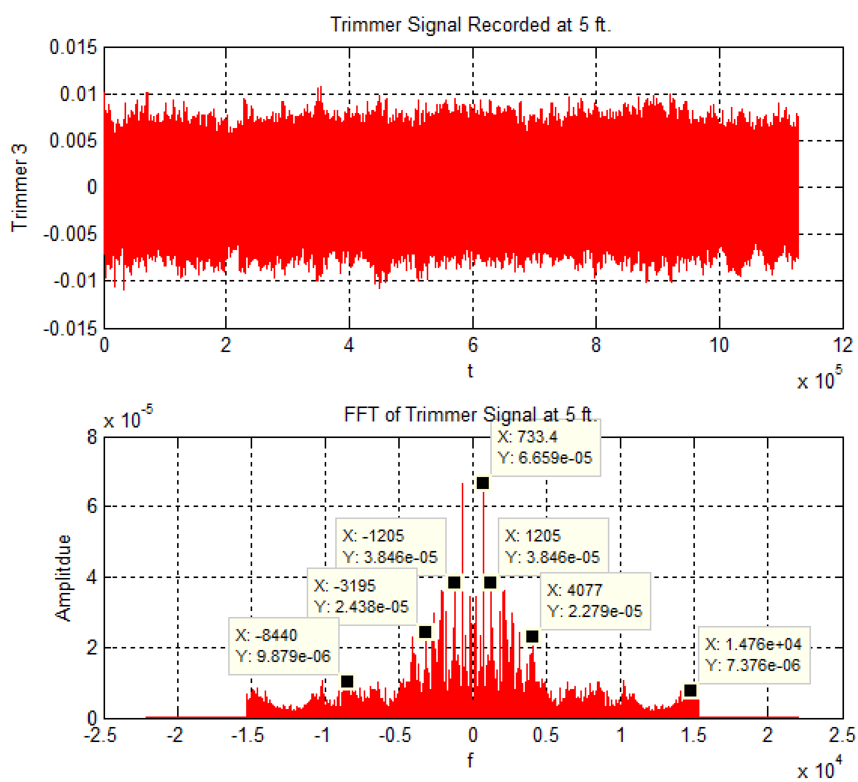

Figure 7: Plot of trimmer noise signal in time domain and FFT at recording distance of five feet.

Noise Signal 2: Hair Blow Dryer

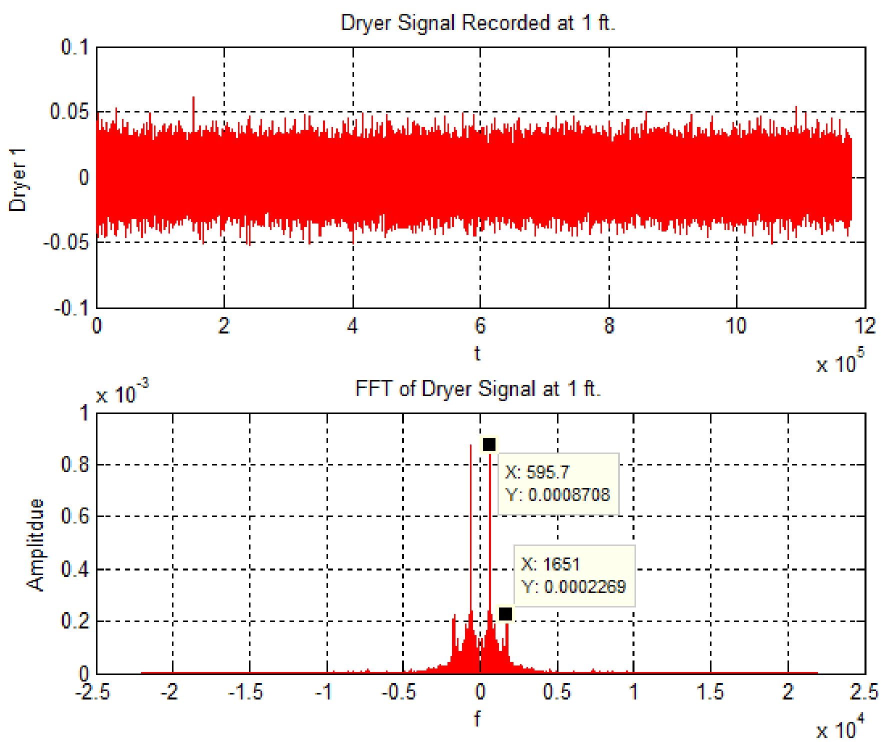

Figure 8: Plot of blow dryer noise signal in time domain and FFT at recording distance of 1 foot.

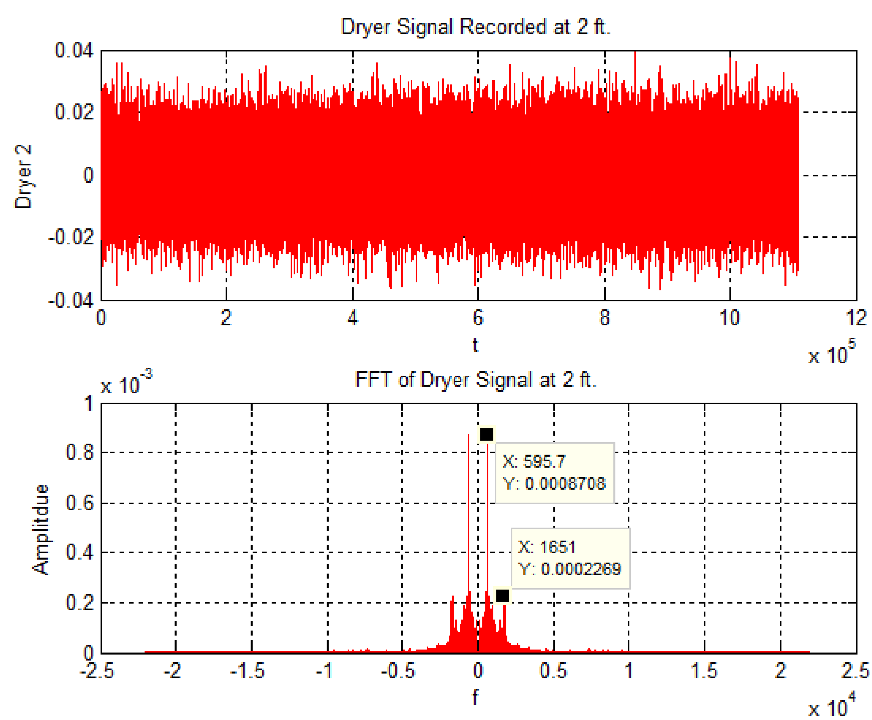

Figure 9: Plot of blow dryer noise signal in time domain and FFT at recording distance of 2 feet.

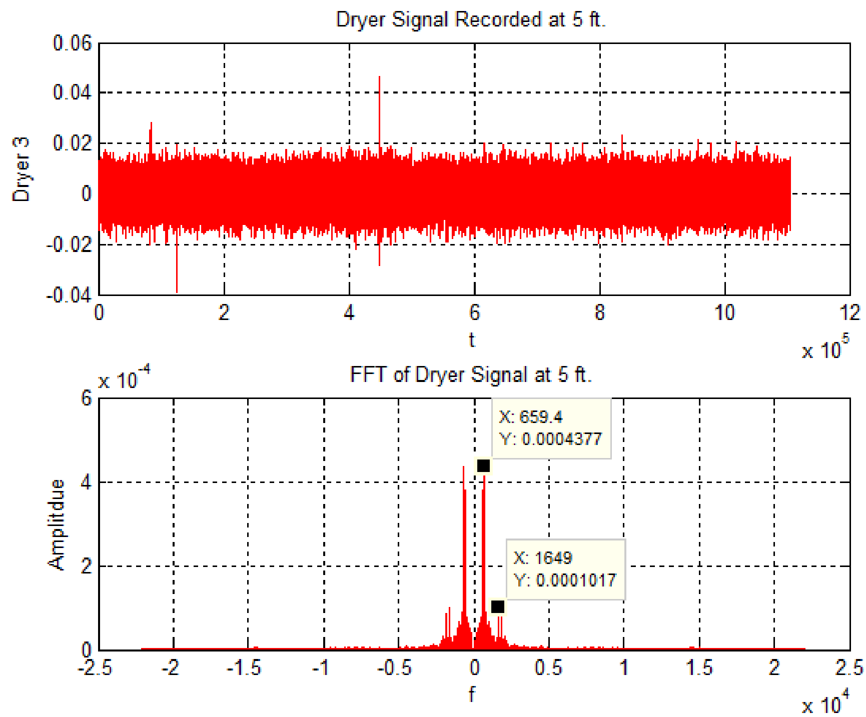

Figure 10: Plot of blow dryer noise signal in time domain and FFT at recording distance of 5 feet.

Noise Signal 3: Hand-held Mixer

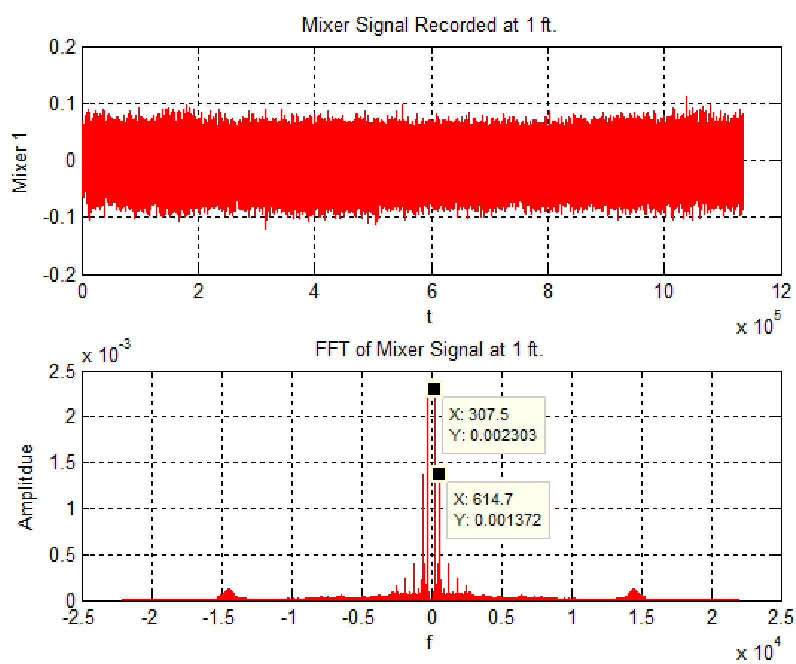

Figure 11: Plot of blow dryer noise signal in time domain and FFT at recording distance of 1 foot.

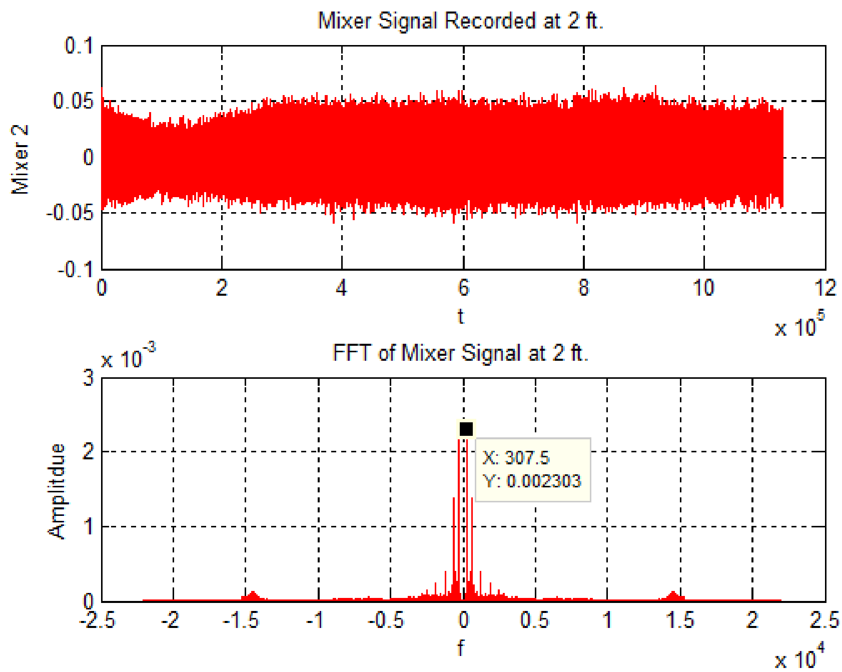

Figure 12: Plot of mixer noise signal in time domain and FFT at recording distance of 2 feet.

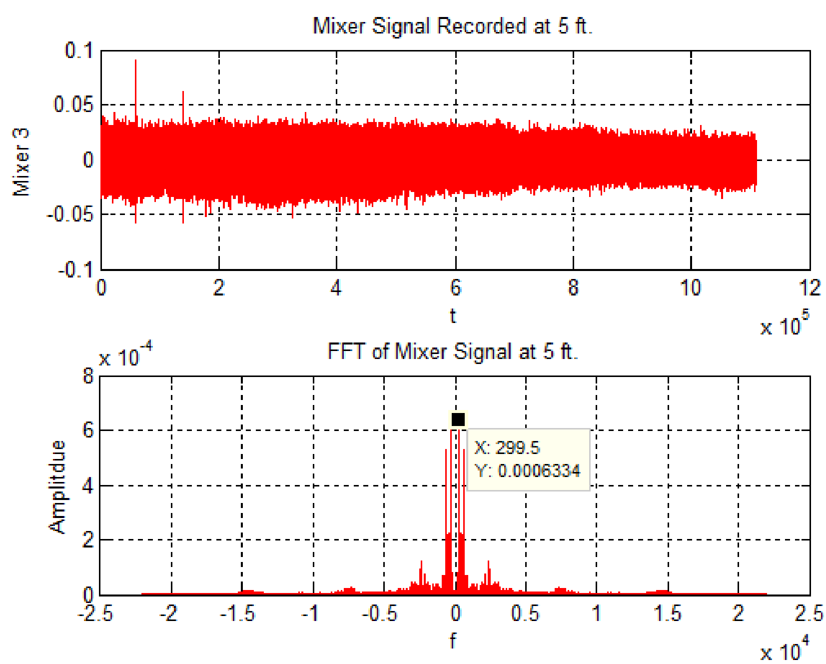

Figure 13: Plot of mixer noise signal in time domain and FFT at recording distance of 5 feet.

The FFT analysis of the noise signals was very similar for each one. The beard trimmer had a frequency of 741 Hz, the blow dryer had a frequency of 595 Hz, and the mixer's frequency was 307 Hz. The recording distances of one and two feet yielded the same results, but the recording distance of five feet had a lower fundamental frequency for each noise source.

Filtering Noise/Audio Signals:

The combination recordings which included the audio signal, as well as, the noise were analyzed and passed through a band pass filter in MATLAB. The aim was to determine if any of the noise sources would have frequencies out of the human vocal spectrum. The results below show the time domain function outputted from the filter and the FFT of that function to show the fundamental frequency.

- Noise Signal 1: Beard Trimmer at Recording Distance 1: 1 ft.

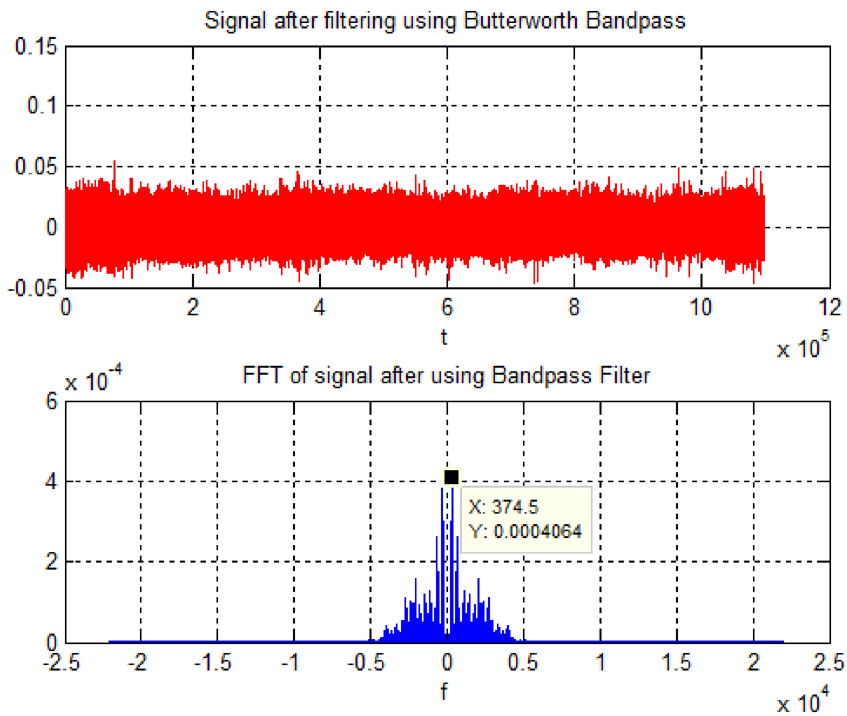

Figure 14: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 1: Beard Trimmer at Recording Distance 2: 2 feet.

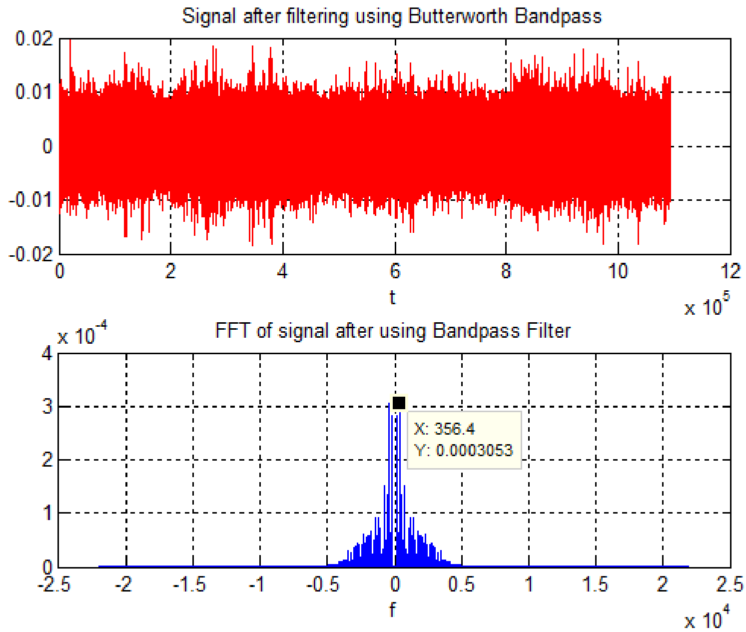

Figure 15: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 1: Beard Trimmer at Recording Distance 3: 5 feet.

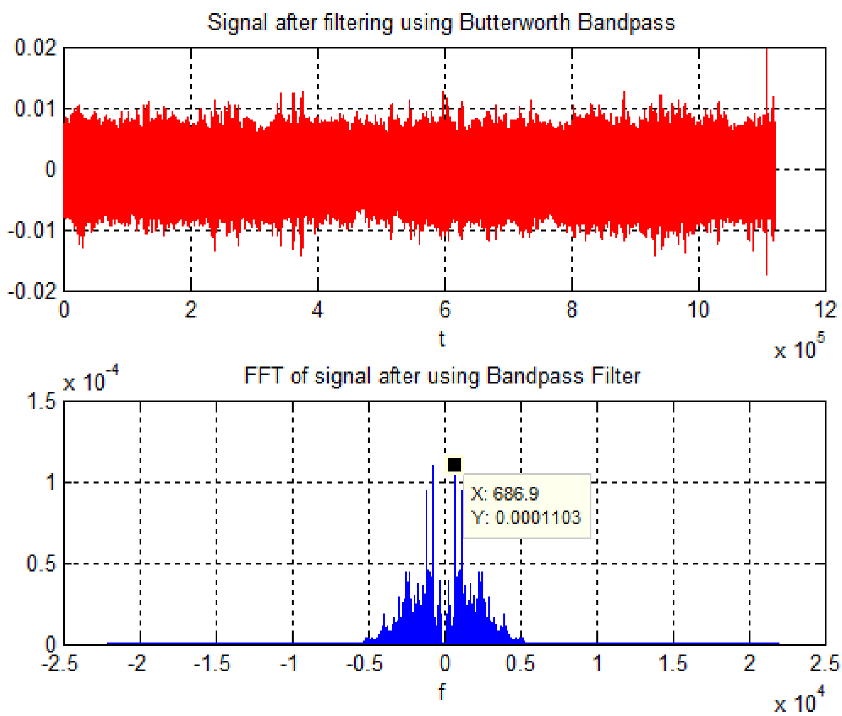

Figure 16: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 2: Hair Blow Dryer at Recording Distance 1: 1 foot.

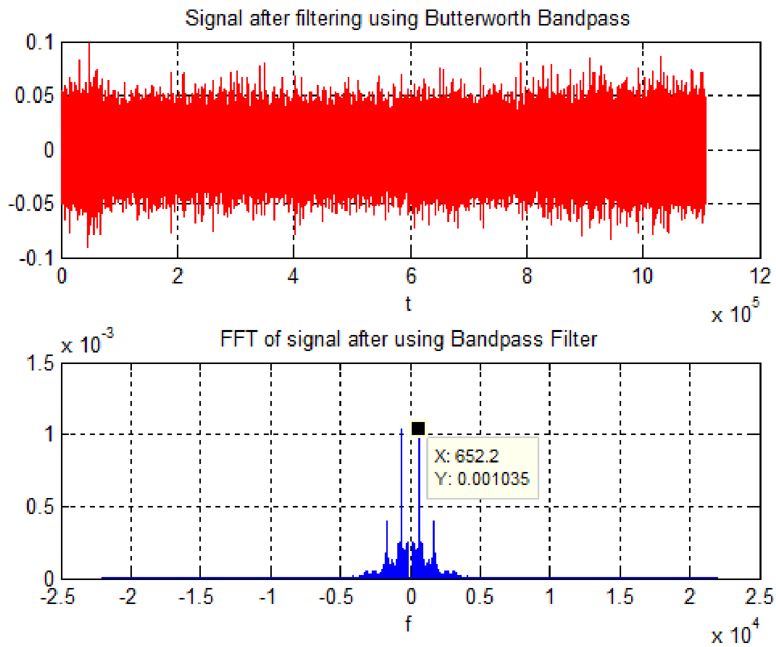

Figure 17: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 2: Hair Blow Dryer at Recording Distance 2: 2 feet.

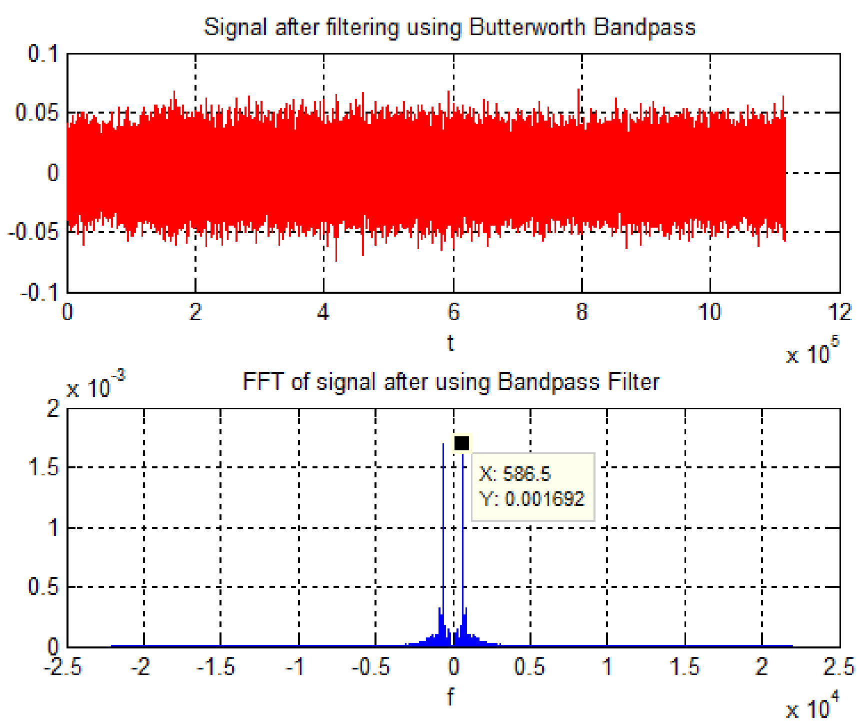

Figure 18: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 2: Hair Blow Dryer at Recording Distance 3: 5 feet.

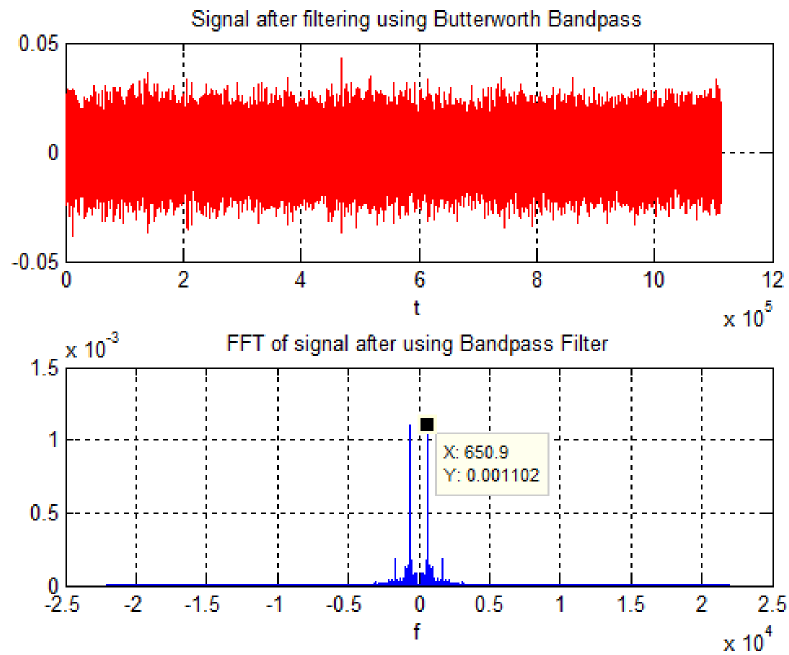

Figure 19: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 3: Kitchen Mixer at Recording Distance 1: 1 foot.

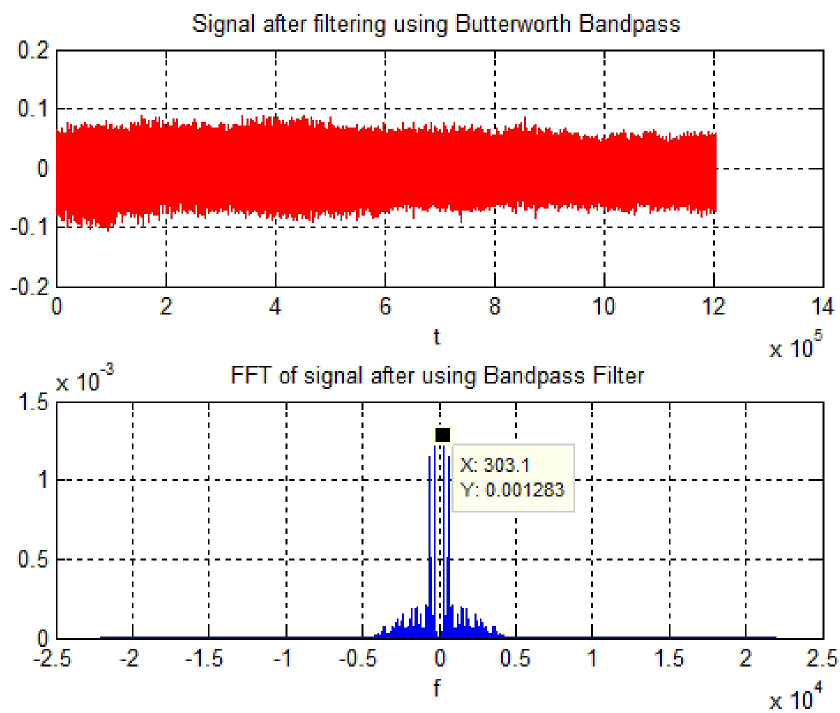

Figure 20: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 3: Kitchen Mixer at Recording Distance 2: 2 feet.

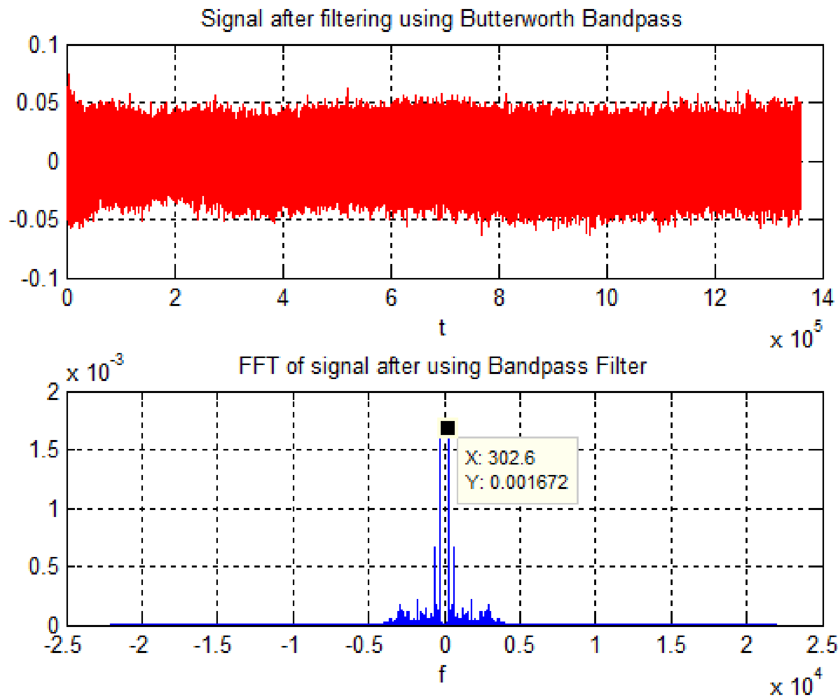

Figure 21: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

- Noise Signal 3: Kitchen Mixer at Recording Distance 3: 5 feet.

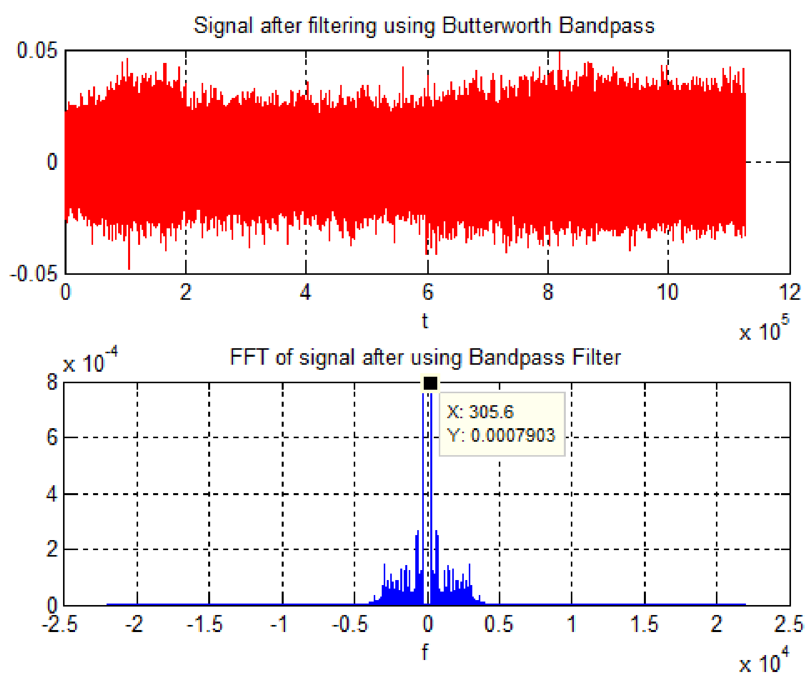

Figure 22: Resulting time domain and FFT of signal after passing through band pass filter with limits of the human audio range.

The results from using the band pass filter showed that the noise sources all fell in the same frequency range as that of the human voice. The FFT analysis showed the frequencies of the noise/audio recording sources as well. The noise was not easily filtered, so additional methods to remove it will be tried.

Method 1: FFT Subtraction

The first method for extracting the audio signal from the combined noise and audio recording was FFT subtraction. The FFT was taken of both the combined recording and the noise recording. The FFT of the noise recording was subtracted from that of the combined recording FFT. Lastly, the new FFT was converted back to the time domain, where it was plotted and played for listening. The logic was that this would yield the FFT of just the audio signal. The results of FFT subtraction are shown below. The method was not successful in extracting the noise from the audio recording.

- Noise Signal 1: Beard Trimmer at Recording Distance 1: 1 ft.

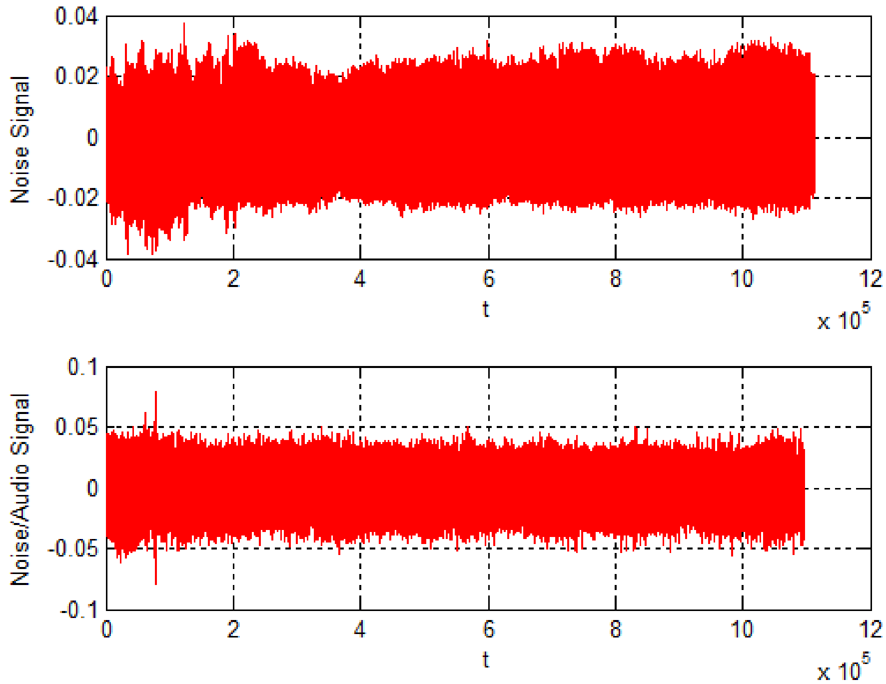

Figure 23: The time domain plots of the noise signal and the noise/audio signal at recording distance of 1 foot

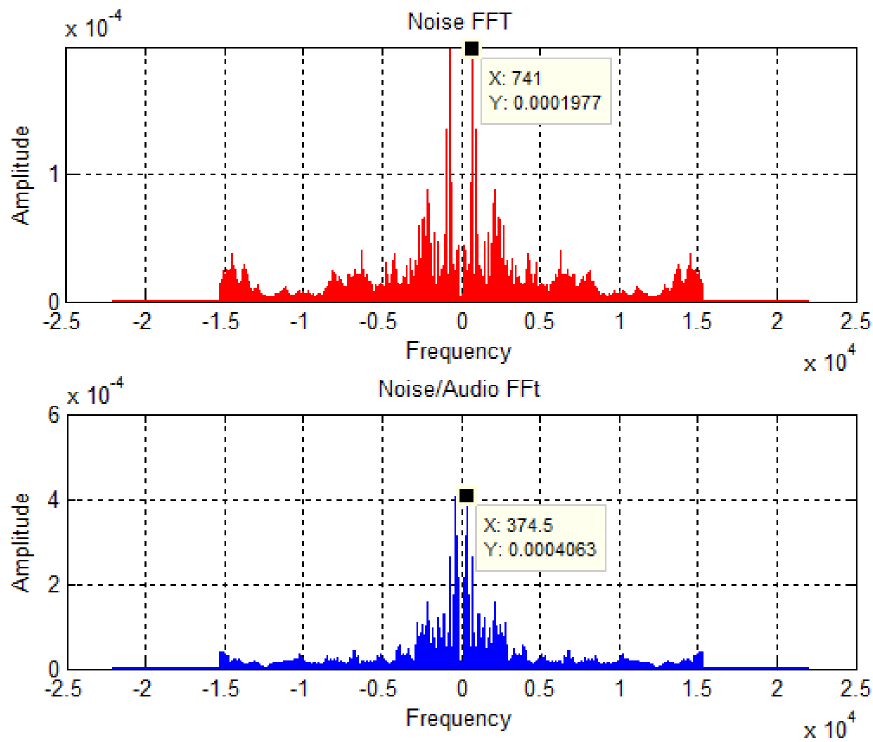

Figure 24: FFT of both the Noise signal and the combination of the noise/audio signal at recording distance of 1 foot.

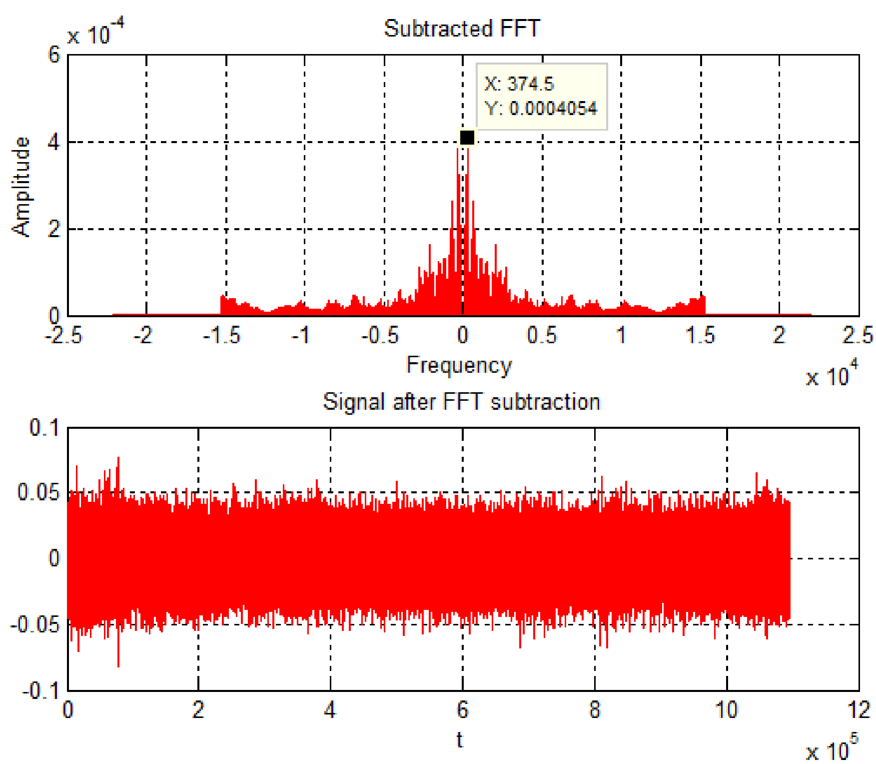

Figure 25: FFT and time domain signal produced from subtracting FFTs.

- Noise Source 1: Beard Trimmer at Recording Distance 2: 2 ft.

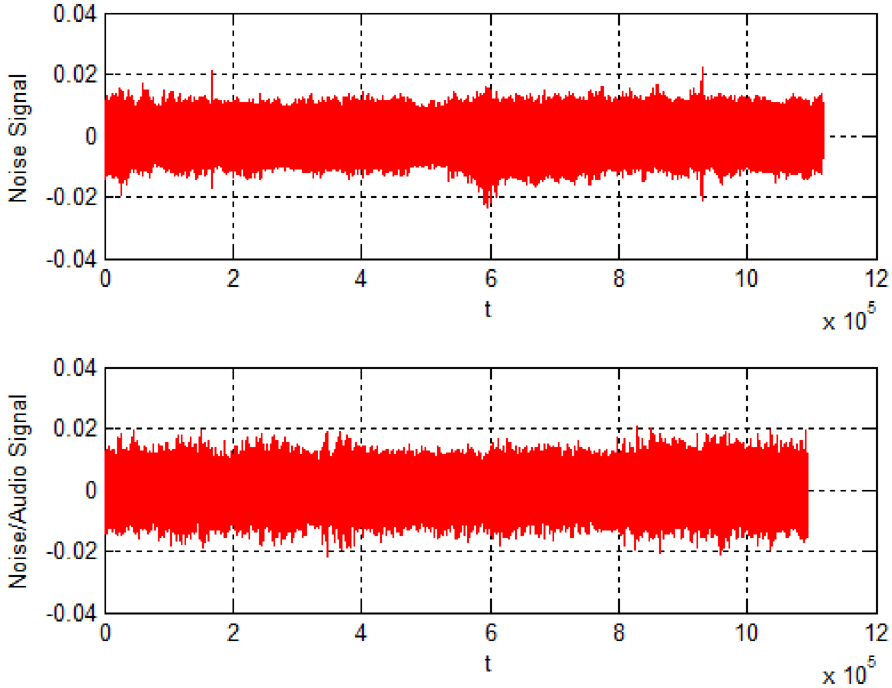

Figure 26: The time domain plots of the noise signal and the noise/audio signal at recording distance of 2 feet.

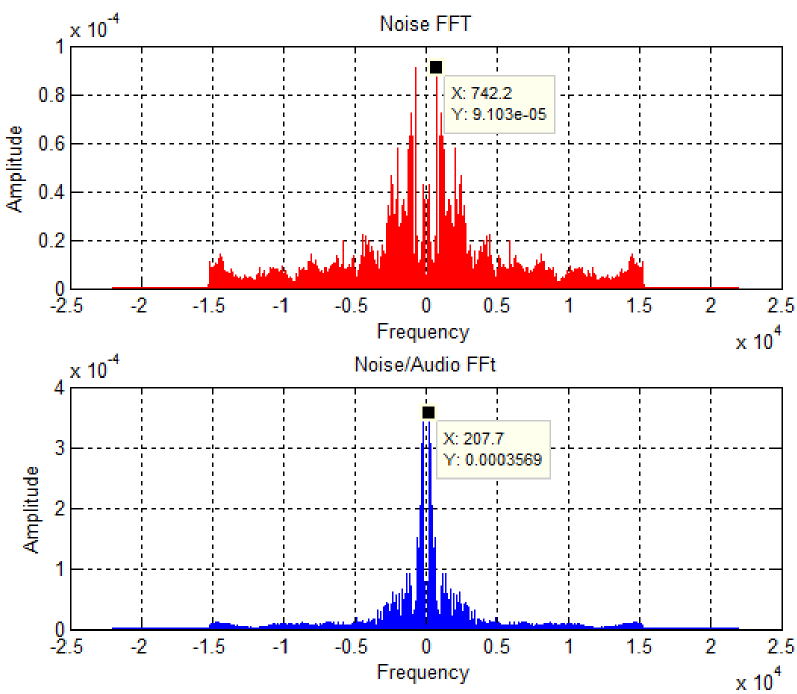

Figure 27: FFT of both the Noise signal and the combination of the noise/audio signal at recording distance of 2 feet.

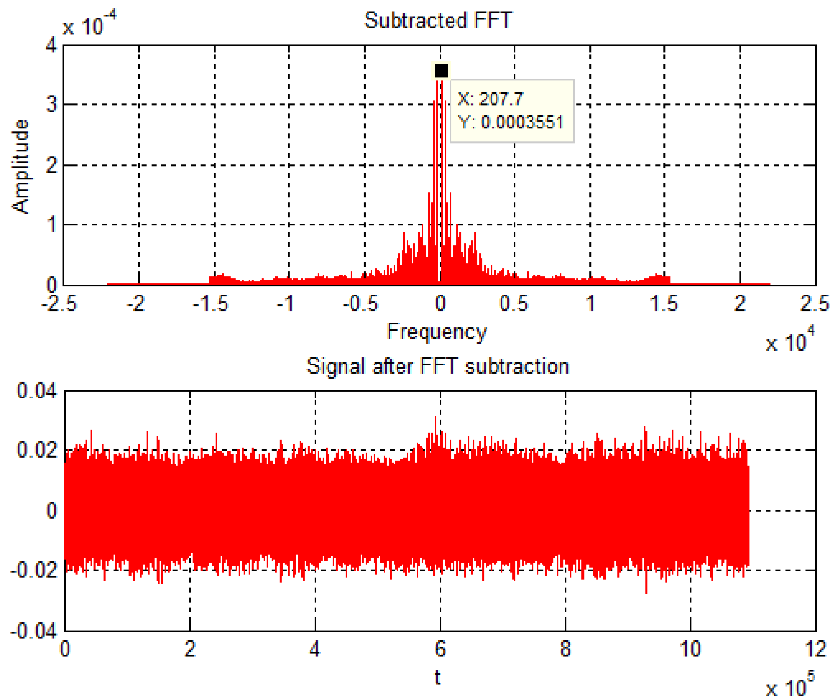

Figure 28: FFT and time domain signal produced from subtracting FFTs.

- Noise Source 1: Beard Trimmer at Recording Distance 3: 5 ft.

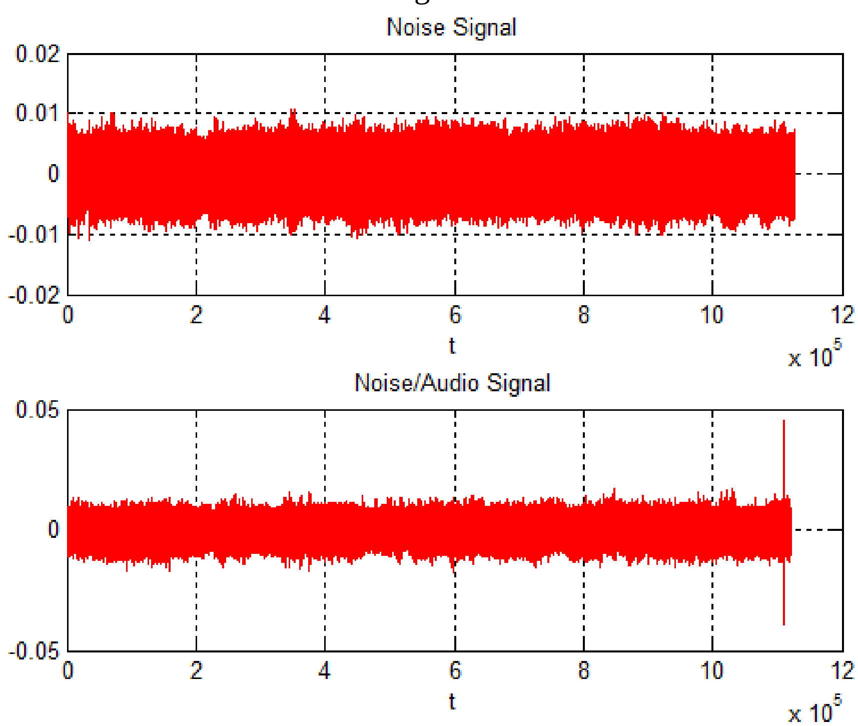

Figure 29: The time domain plots of the noise signal and the noise/audio signal at recording distance of 5 feet.

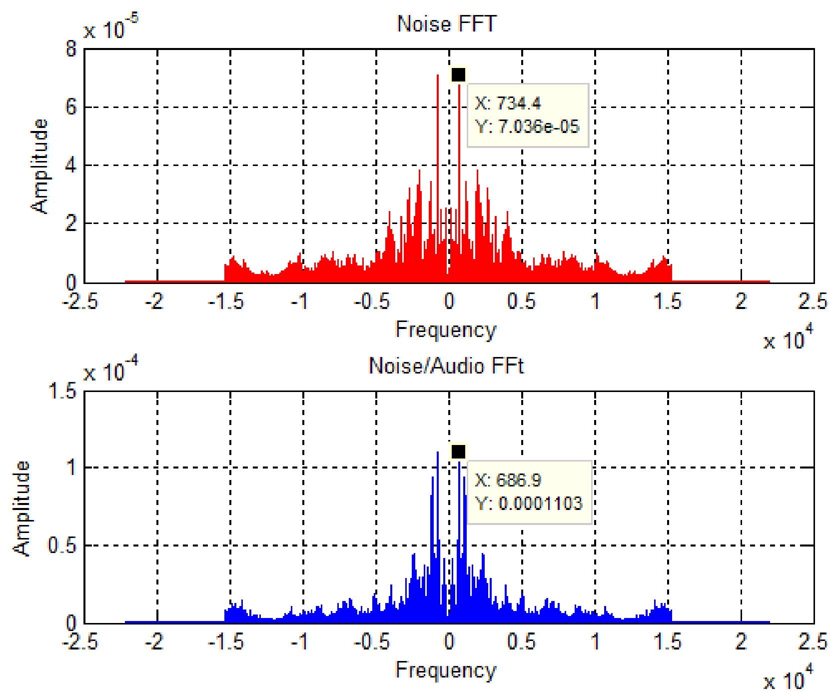

Figure 30: FFT of both the Noise signal and the combination of the noise/audio signal at recording distance of 5 feet.

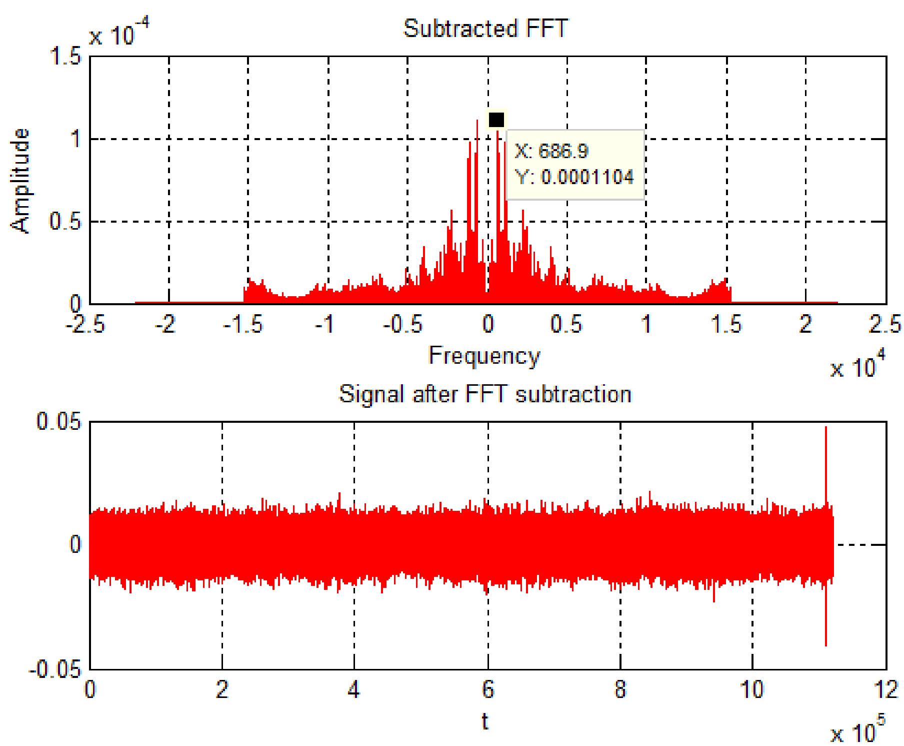

Figure 31: FFT and time domain signal produced from subtracting FFTs.

- Noise Signal 2: Hair Blow Dryer Recording Distance 1: 1 foot.

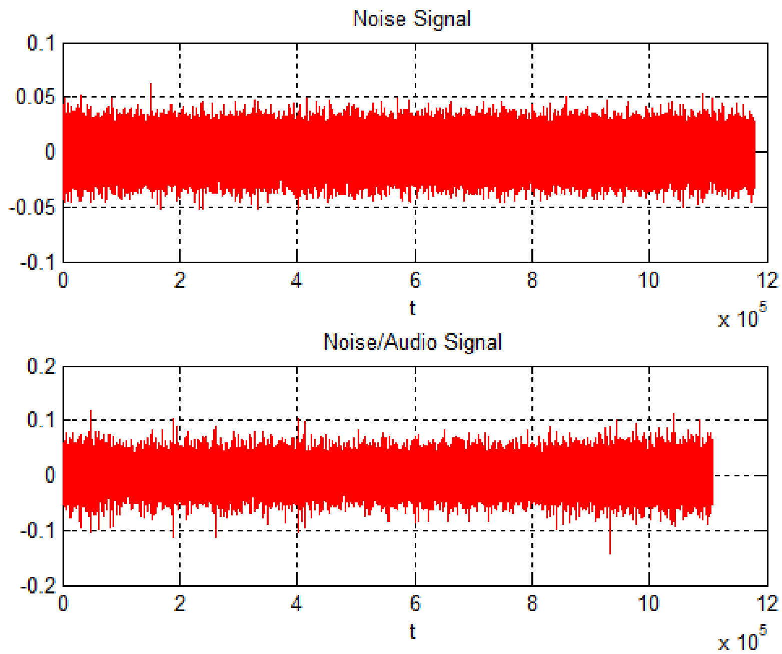

Figure 32: The time domain plots of the noise signal and the noise/audio signal at recording distance of 1 foot.

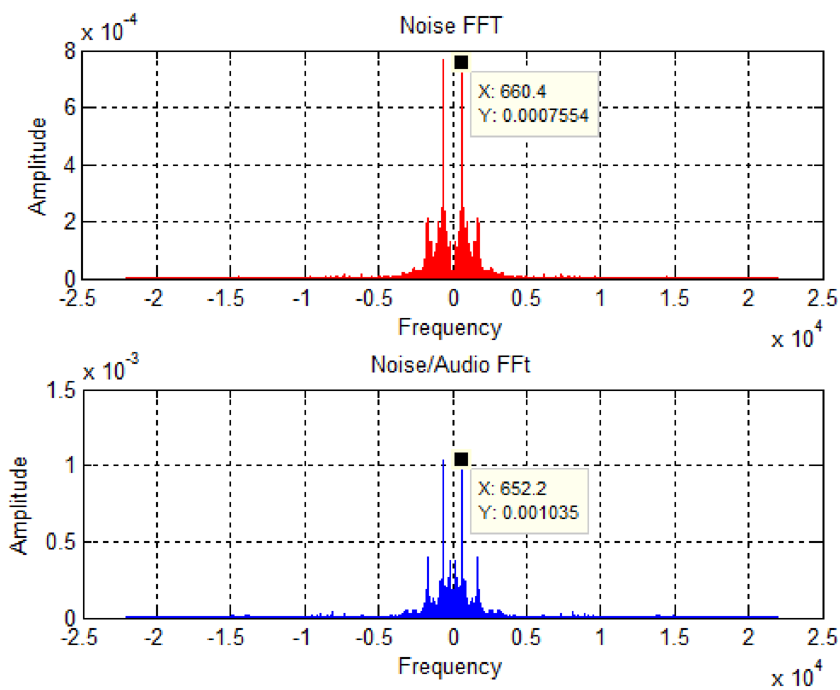

Figure 33: FFT of both the Noise signal and the combination of the noise/audio signal at recording distance of 1 foot.

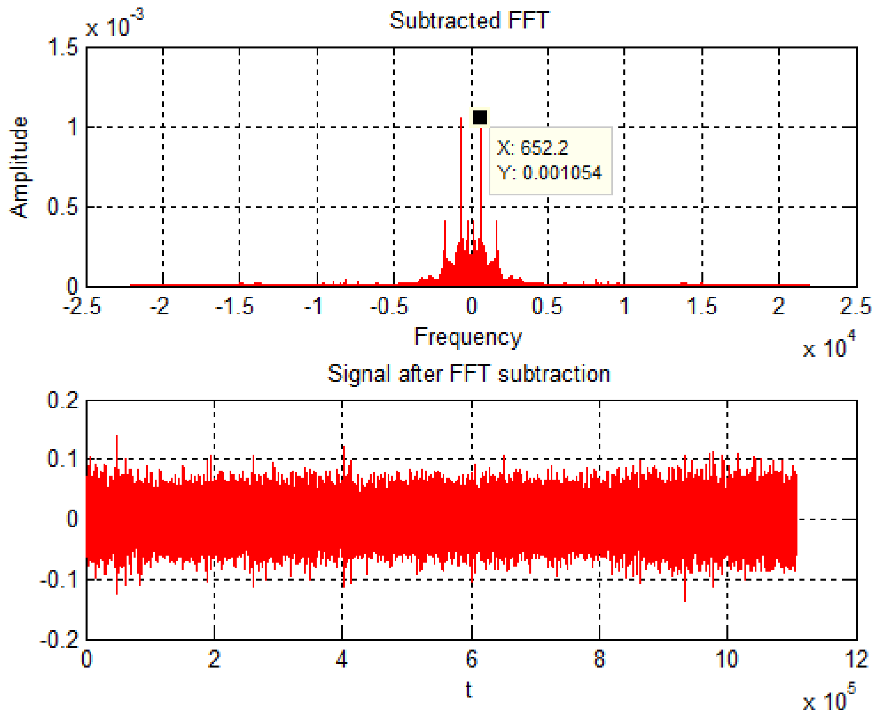

Figure 34: FFT and time domain signal produced from subtracting FFTs

The FFT subtraction method was also done for the recording distances of two and five feet. The results followed the same pattern as noise source one. The new frequency signal was always the same frequency as that of the combination of noise and audio.

- Noise Signal 3: Hand-held Kitchen Mixer Recording Distance 1: 1 foot.

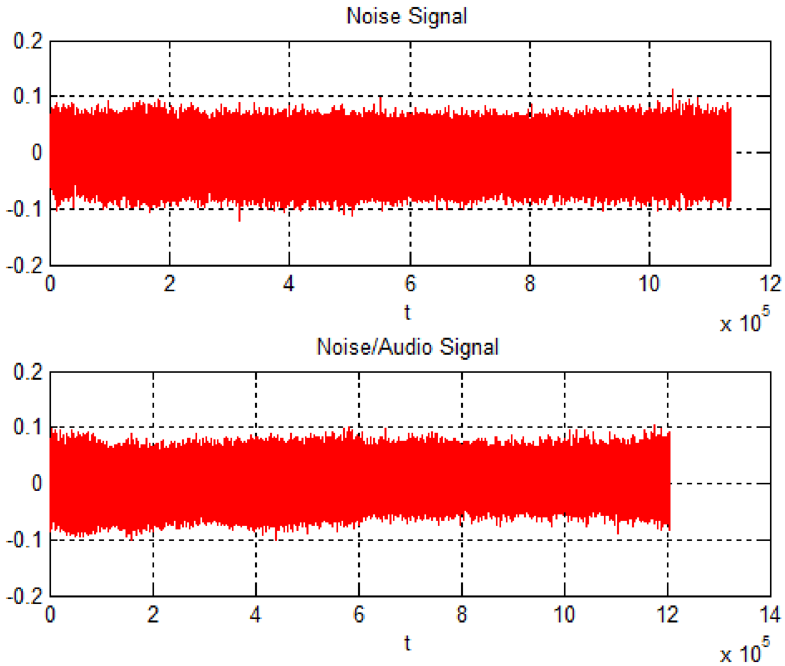

Figure 35: The time domain plots of the noise signal and the noise/audio signal at recording distance of 1 foot.

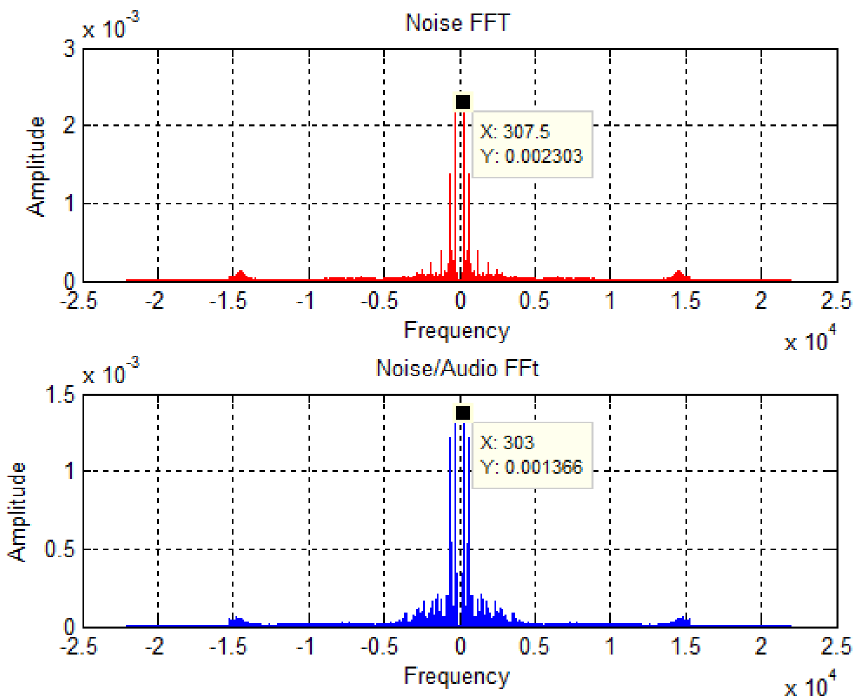

Figure 36: FFT of both the Noise signal and the combination of the noise/audio signal at recording distance of 1 foot.

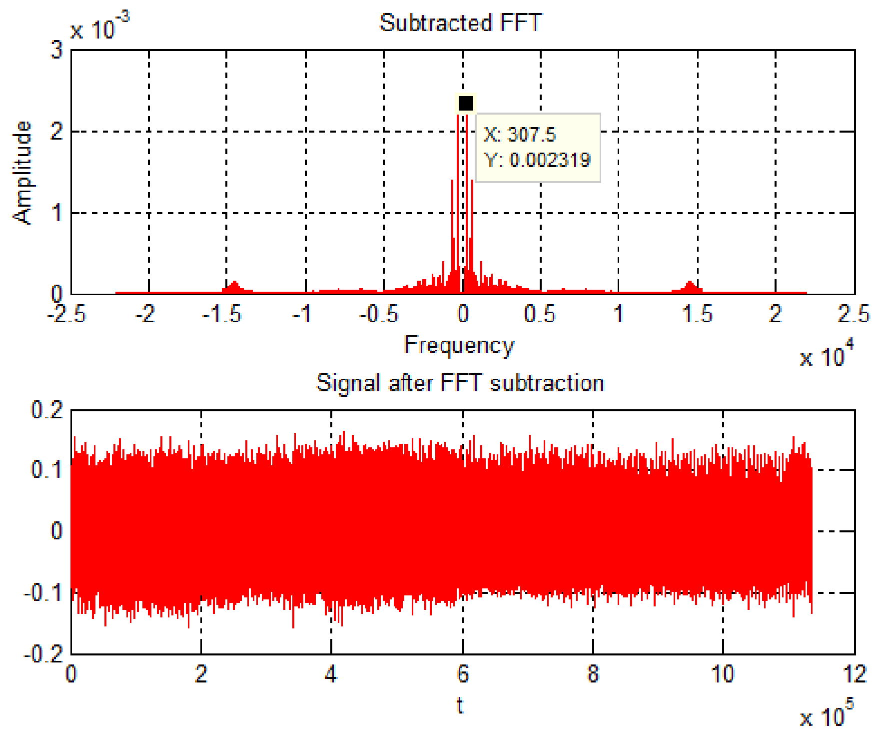

Figure 37: FFT and time domain signal produced from subtracting FFTs

Again, the FFT subtraction method was also done for the recording distances of two and five feet. The results followed the same pattern as with noise source one. The new frequency signal was always the same frequency as that of the combination of noise and audio.

Method one did not yield the results that were hoped for. The noise signal was still present, and the audio signal was still undistinguishable when the time domain signal was played. It was noted that the subtracted FFT had the same fundamental frequency as the combination signal, for each noise source.

Method 2: Noise phase cancellation

The second method was to find the conjugate of the noise only FFT then add this to the FFT of the noise and audio recording. The idea for this method stemmed from active noise control, which is used in noise cancellation speakers. The phase of the noise only FFT signal was inverted such that when combined with the combination FFT, the signals would be in antiphase. Adding phase in the frequency domain translates to time shift in the time domain. If the two signals meet at a point where they are in antiphase, then destructive interference will occur. The hope was for complete phase cancellation.

- Noise Signal 1: Beard Trimmer Recording Distance 1: 1 foot

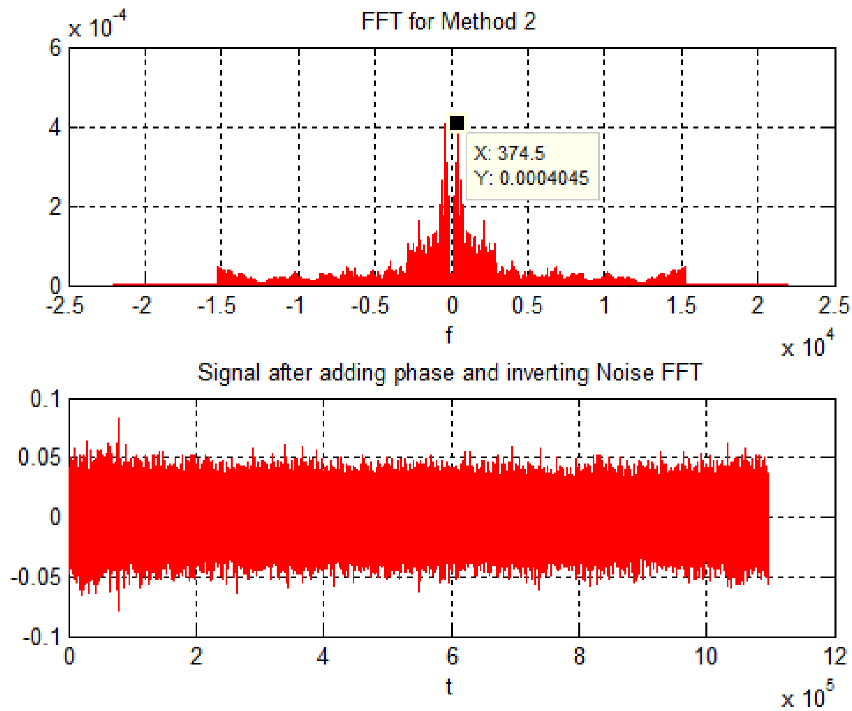

Figure 38: FFT and time domain function for phase cancellation method.

- Noise Signal 1: Beard Trimmer Recording Distance 2: 2 feet

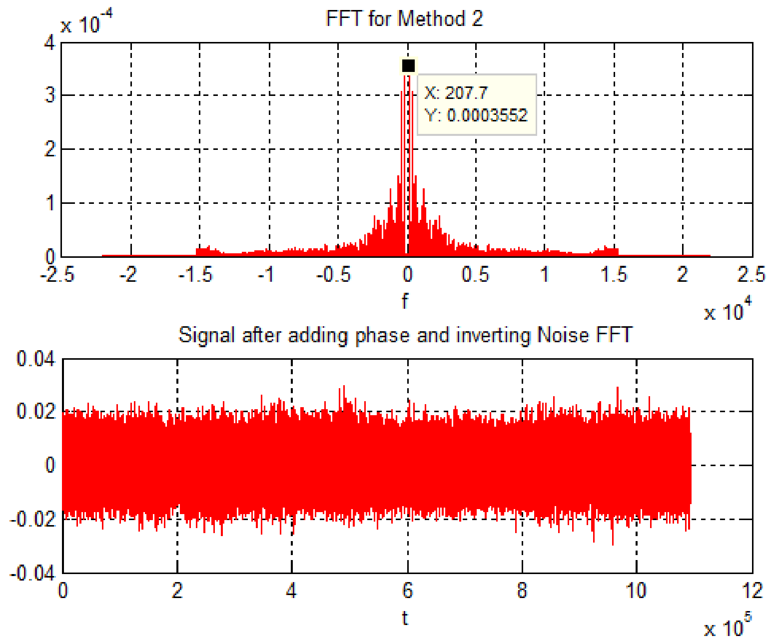

Figure 39: FFT and time domain function for phase cancellation method.

- Noise Signal 1: Beard Trimmer Recording Distance 3: 5 feet

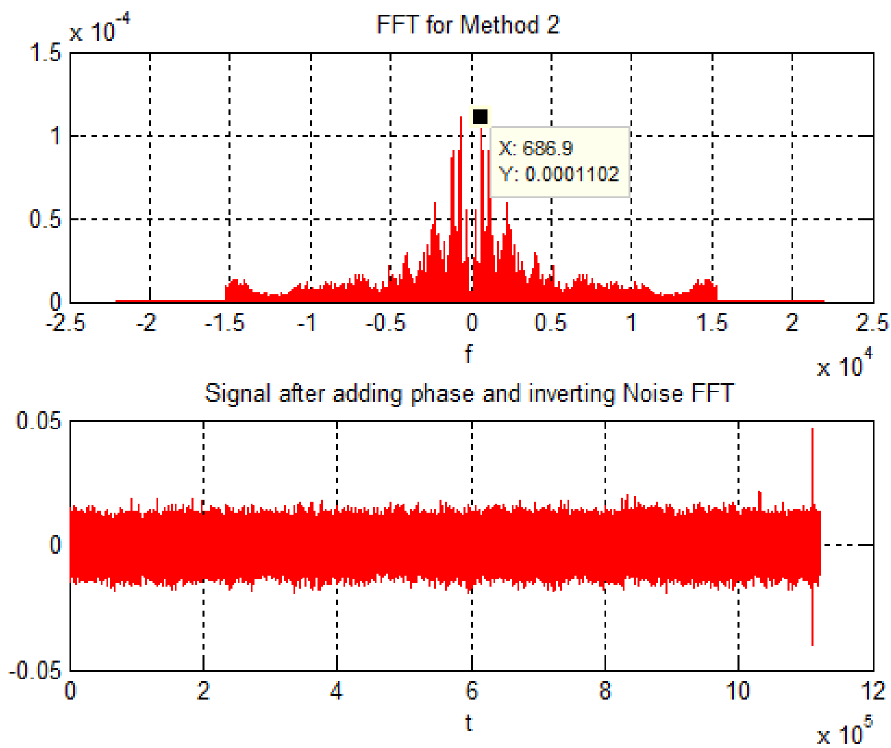

Figure 40: FFT and time domain function for phase cancellation method.

- Noise Signal 2: Hair Blow Dryer Recording Distance 1: 1 foot

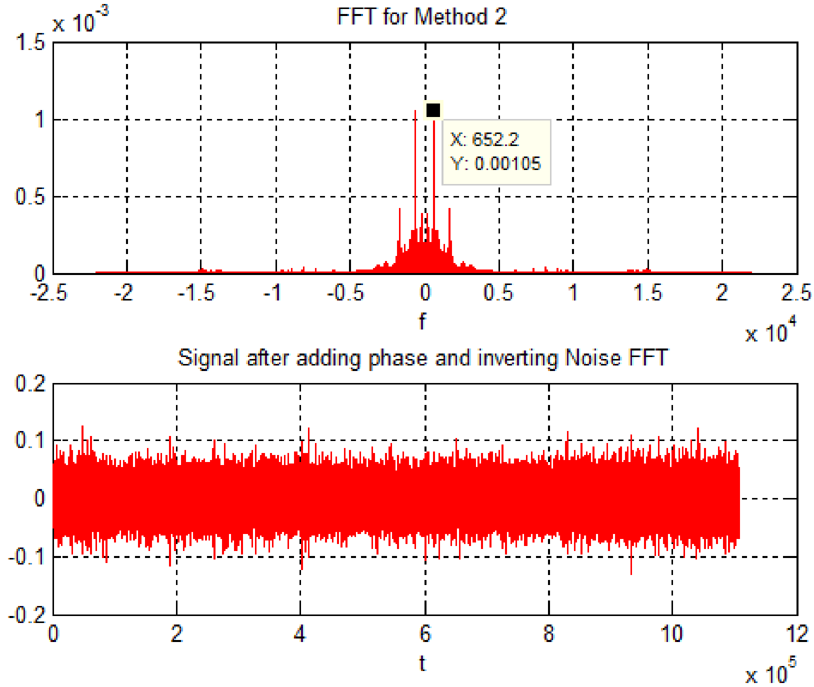

Figure 41: FFT and time domain function for phase cancellation method.

- Noise Signal 2: Hair Blow Dryer Recording Distance 2: 2 feet

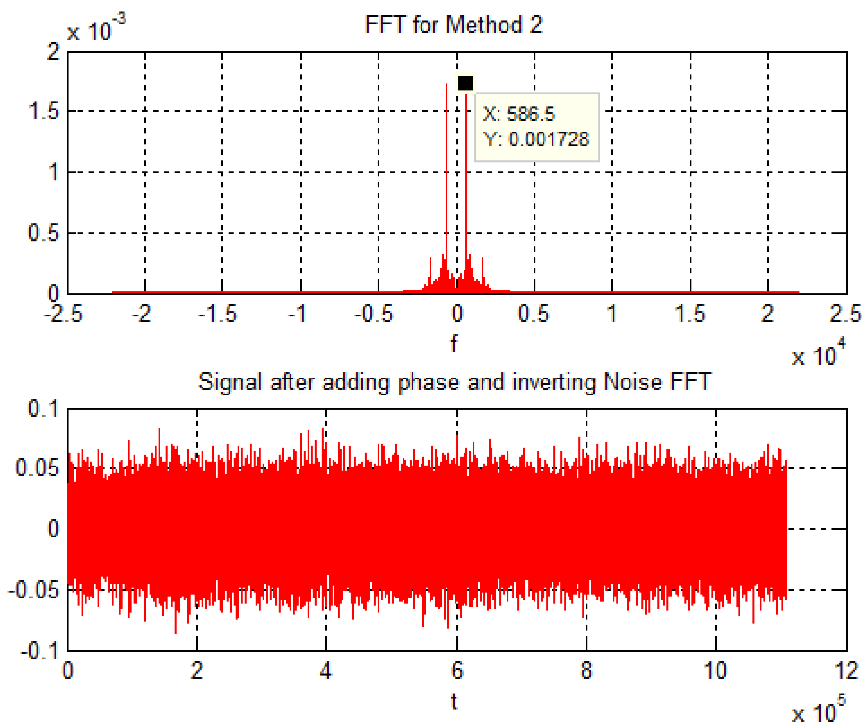

Figure 42: FFT and time domain function for phase cancellation method.

- Noise Signal 2: Hair Blow Dryer Recording Distance 3: 5 feet

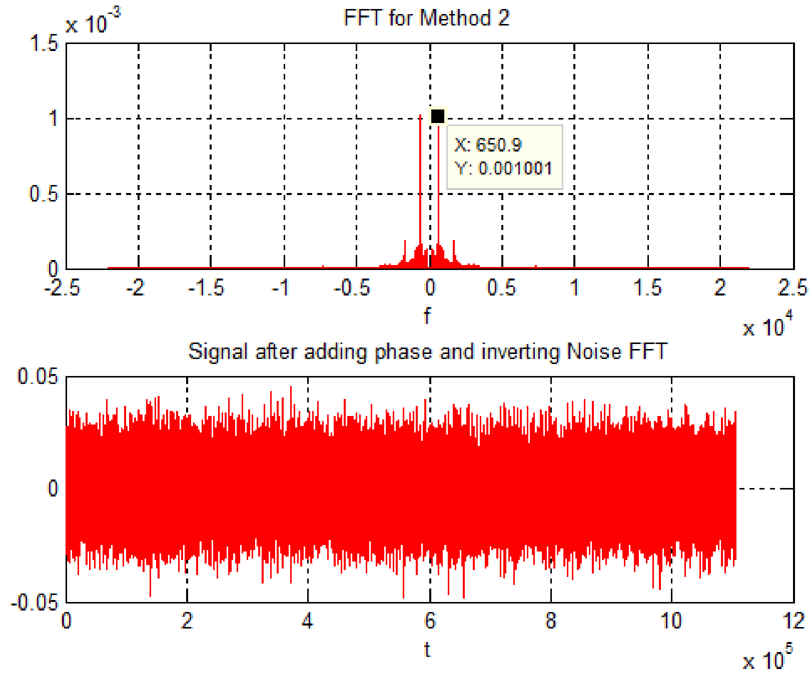

Figure 43: FFT and time domain function for phase cancellation method.

- Noise Signal 3: Kitchen Mixer Recording Distance 1: 1 foot

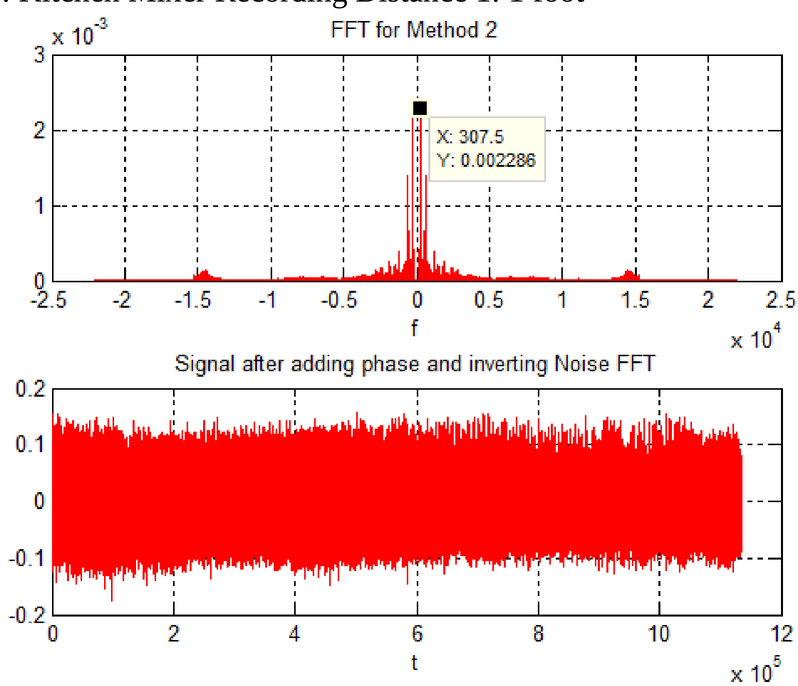

Figure 44: FFT and time domain function for phase cancellation method.

- Noise Signal 3: Kitchen Mixer Recording Distance 2: 2 feet

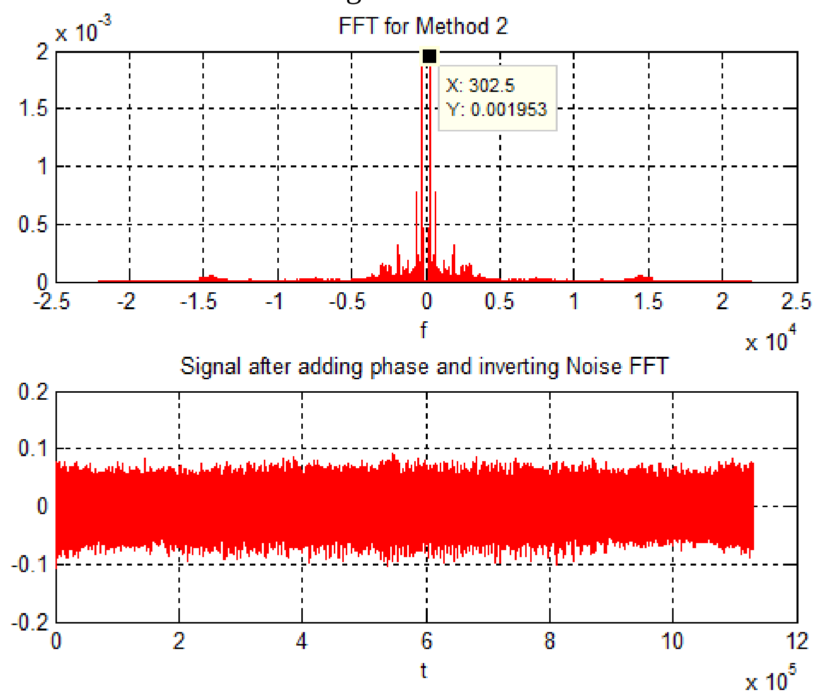

Figure 45: FFT and time domain function for phase cancellation method.

- Noise Signal 3: Kitchen Mixer Recording Distance 3: 5 feet

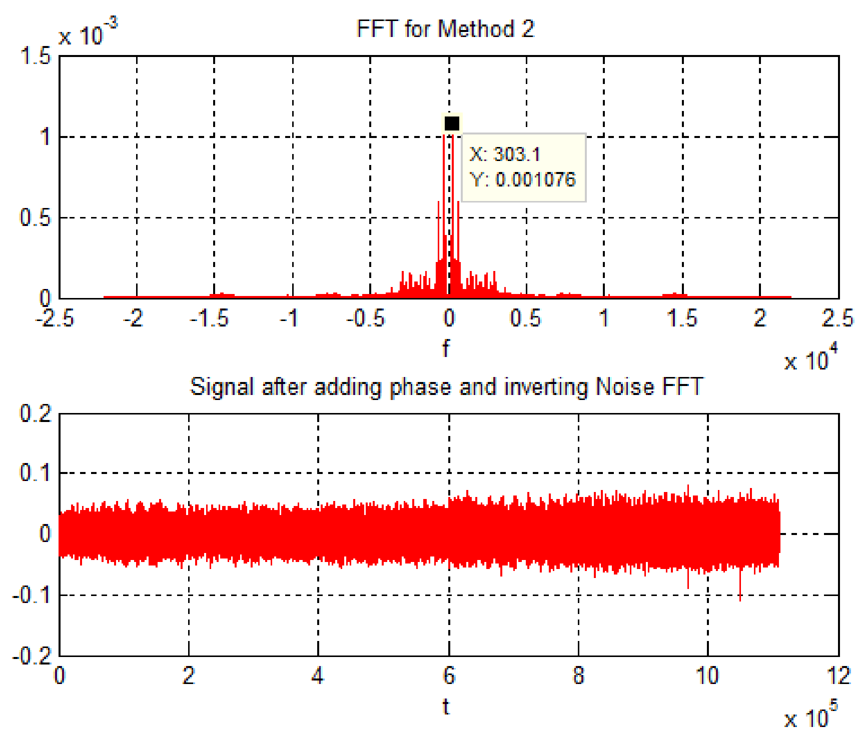

Figure 46: FFT and time domain function for phase cancellation method.

Method two resulted in similar results as method one. The audio signal was still not extracted out cleanly from the noise. The recording distances did not seem to effect the outcome of method 2.

Conclusion:

The project required a lot of FFT analysis of the noise, audio, and the combination of the noise and audio signals. Analysis showed that the noise signals all were in the frequency range of human vocals, thus they interfered with the audio and could not just be filtered. Neither the FFT subtraction nor the phase cancellation techniques were able to remove the noise from the audio signal. This project really made me appreciate the difficulty of removing noise from an audio conversation.